POLLUTION INDICES AND HEALTH RISK ASSESSMENT OF HEAVY METALS IN RICE FROM GASHUA, YOBE STATE.

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KEYWORDS

Parboiled rice, Heavy metals, MP-AES, Hazard quotient, ILCR

ABSTRACT

Heavy metal contamination in food crops, particularly rice, poses significant health risks due to widespread consumption. Gashua, Yobe State, Nigeria, is a key agricultural area where rice cultivation may be influenced by environmental pollution. However, few studies have quantified the health risks of heavy metal contamination in this region and link it to the prevalence of Kidney diseases within the study area. This study addresses these challenges by assessing the levels of Arsenic, Cadmium, Lead, and Chromium in rice and evaluating associated health risks. A simple random sampling technique was used to collect the rice samples. A total of 120 rice samples were collected, 90 paddy rice from four farms and 30 parboiled rice from Gashua Market. The samples were digested and analyzed using Micro plasma atomic emission spectrometry (MP-AES). The data generated was subjected to a one-way analysis of variance. The result of the study revealed a significant ($P<0.05$) difference in heavy metals concentration across all samples. Parboiled Samples from Gashua market exhibited the highest Arsenic concentration at (0.383mg/kg) greatly surpassing WHO/USEPA acceptable limits. Cadmium (0.0242mg/kg) also exceeded the permissible limit of 0.001mg/kg. Lead concentration from all locations superseded the recommended limit especially from Gashua market at 0.102mg/kg exceeding the limit of 0.0035mg/kg. Hazard quotient (HQ) values indicated children are at low risk at location Gashua South (GS) 0.8266 thou not exceeding the threshold of 1, Gashua Market 0.5984, and Gashua North 0.5398 were all below the threshold of 1 however in adults, the value of Chromium at Gashua Market (2.162) was above the threshold and poses a significant health risk. The hazard index (HI) for both adults and children were greater than one 1 mainly contributed because of the high concentration of As in GMK (0.5984), As in GS (0.8266), and Cr in GMK (2.162) which also signifies potential health risk. The Incremental lifetime cancer risk (ILCR) showed a heightened risk of cancer from long-term exposure. In conclusion, rice grown and sold in Gashua poses potential health risks due to heavy metal contamination. Continuous monitoring by regulators (NAFDAC), in-depth research, public health interventions, and stricter regulatory enforcement are necessary to mitigate these risks.

Introduction.

The world's third-largest crop is rice and it plays a significant role in human nutrition (Proshad et al., 2019). Rice cultivation however is known for heavy metal accumulation in its grain (Zhao et al., 2010). Because of anthropogenic activities, the concentration of heavy metals in the soil is increasing gradually (Bakshi and Abhilash, 2020). The increase is attributed to various human activities such as inappropriate dumping of waste in textile industries, metal mining, tanneries, paper industries and the release of untreated industrial effluents in water bodies which further leach and accumulate in soil (Fayiga and Saha, 2016; Rai et al., 2019). Human activities can also cause heavy metal contamination through applications of fertilizers containing metals, animal manures, and untreated sewage sludge which can result in high concentrations of heavy metals in agricultural soils. (WHO, 1993). Other major anthropogenic sources of toxic metal contamination in the environment include Industrial discharge, application of agrochemicals, and mining (Kamani et al., 2018).

Human exposure to toxic metals can occur either through inhalation of polluted air or diet however exposure through diet is one of the commonest ways through which toxic elements get into the human body. (Deng et al., 2019). Grains are major diets that provide carbohydrates and other nutrients to human beings however they may at the same time contain toxic metals which the human body can easily be exposed to via ingestion as rice is known to easily accumulate more metals than other cereals. (Khanam et al., 2020). Scholarly findings have shown Paddy rice containing Cadmium and lead concentrations above acceptable limits are not safe for consumption by humans since they can cause a lot if illness like kidney dysfunction, bone pain, and lung cancer when consumed in large quantities over time. (Eske 2020; Genchi et al., 2020; TatahMentan et al., 2020; Hasan et al., 2022). Heavy metals such as Arsenic are harmful and have been linked to different types of cancers in humans (Majumder and Banik, 2019; Oberoi et al., 2019; Arcella et al., 2021).

Heavy metals are d-block elements on the periodic table; they have high density and specific gravity and they are considered harmful even at a lower concentration level, examples are (As), Lead (Pb), Cadmium (Cd), Platinum (Pt), Palladium (Pd), Manganese (Mn), Mercury (Hg), Silver (Ag), Zinc (Zn), Copper (Cu), Nickel (Ni), Iron (Fe) and Chromium (Cr); Some of the human and natural sources of these metals in the environment include industrial waste, automotive exhaust, industrial discharge, rock wheathering and mining. Heavy metals are nonbiodegradable and can easily be accumulated in living organisms (Manavi et al., 2019). In recent times heavy metals like Pb, Mn, Hg, and Cd have attracted a lot of attention because of their widespread exposure (Khalef et al., 2022). The objectives of the research are to assess the extent of heavy metal pollution in paddy and parboiled rice and carry out a health risk assessment.

Materials and methods:

Brief description of the study area.

The town Gashua in Bade Local Government area of Yobe State is located between latitude 120 52' 05 N and 120 87'11 N and longitude 110 57'26 E and 110 02'47 E. Among the towns in Bade, Gashua is one of the largest having an area of 3,336 square kilometers and a population of 139,804 as of the 2006 census; male was 73,709 and female 66,095. (Census , 2006). Gashua town lies in the plain region of the savannah and the town has a fertile soil which supports the cultivation of Rice, Millet, Groundnut, Guinea corn, and Sorghum. The vast land within the LGA supports the rearing of animals. Among the cereals cultivated within Gashua, Rice is one of the major grains cultivated because of the river that passes through the town (Oladimeji, 2001). The climate is characterized by high amount of temperature and low annual rainfall towards the northern region (Kimmage,2012). Rainfall ranges between 400 mm and 800 mm with an annual mean rainfall of 750 mm. The Mean annual temperature is usually around 39^{O} C and the mean monthly value range is between 27^{O} C in the coolest month of December to January and 32^{O} C in the hottest month of April to May. The major river that flows in Gashua and the adjoining area is the River Komadugu Yobe (Kimmage, 2012).

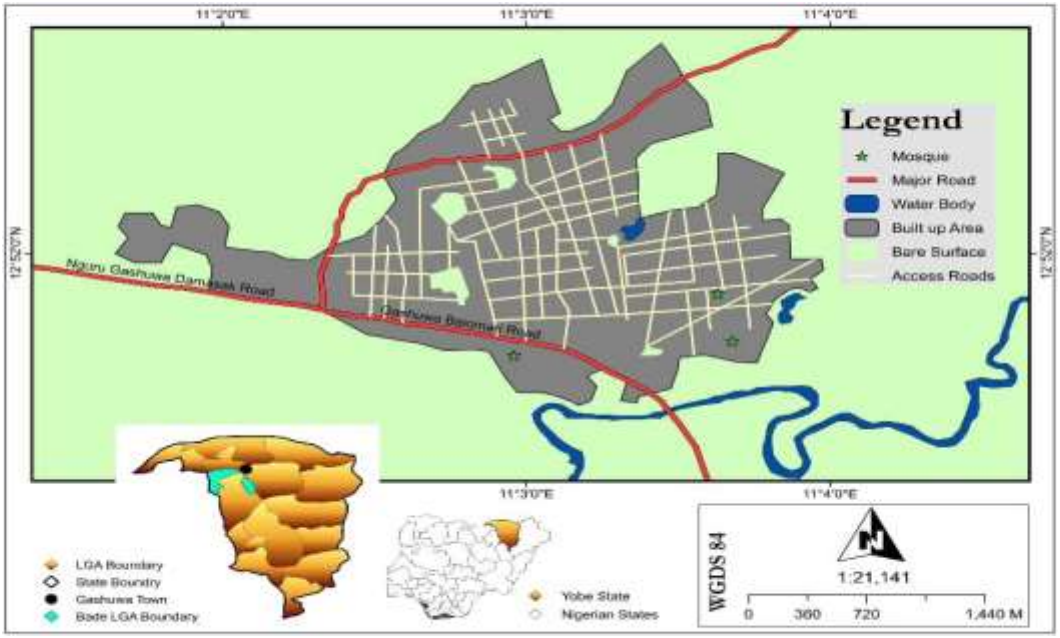

Figure 1: Map of the study area (Bade LGA)
(Source: Adopted and Modified from the Political Map of Yobe State, 2019) (Saleh & Ahmed,2019)

Sample Size and Collection of Sample

Sampling paddy rice at the farm
The rice samples were collected after harvest between 29th November 2022 to 26th December 2022. Simple random Sampling (Systematic sampling) was used in collecting rice samples at the various farms. Sampling units were created in a range of 20/20 ft to make at least 300 units. Numbers were assigned to all the elements within the population (1-300). From each of the locations, a sample size of (30) was divided by the population (300), S = n/N,30/300 = 6. Every 6th item was chosen within the sampling unit. The random start was obtained by randomly selecting an integer. (Muhammad, 2017; Flatman and Yfantis, 1984; Mulla and Bhatti, 1997). Thirty (30) samples were then collected within the sampling units, sealed in polyethylene sampling bags, and taken to the laboratory for analysis. Geographical positioning (Longitude & Latitude) of the sampling points was recorded using GPS (Lu et al., 2020).

Sampling parboiled rice at the Market
Simple random sampling was used to collect the parboiled rice samples at the market. A list of ninety (90) parboiled rice sellers from the market was collected at various shades/shops and numbers were assigned to each seller. Using a computer, a random number generator was used to generate a list of random numbers corresponding to the sample size (30). The random numbers were matched to the numbers on the sampling frame. (Muhammad,2017 & Najib, 2015). Thirty (30) samples were then purchased, sealed in polyethylene sampling bags, and taken to the laboratory for analysis. The analysis was carried out at Chemistry Laboratory, Bayero University Kano State, Nigeria.

Sample size
A total of ninety (90) samples of freshly harvested paddy rice samples at four different locations (30 from each farm) and Thirty (30) samples of Parboiled rice from the market were sampled making a gross total of one hundred and twenty (120) samples were collected.

Sample preparation (paddy rice)

The rice samples (Paddy rice) collected from the farm were rinsed with distilled water and deionized water to remove dust and other unwanted materials. The samples were then dried to constant weight in an oven at 60^o C. The Paddy rice was hulled using a laboratory dehuller and then pulverized into fine powder. The powder was sieved to less than 0.15mm, labeled, and stored in plastic bags before analysis.

Sample preparation (parboiled rice)

The parboiled rice samples were rinsed with distilled water and deionized water to remove dust and other unwanted particles. The samples were then dried to constant weight in an oven at 60^o C after which they were pulverized into fine powder and sieved to less than 0.15mm. The powdered Samples were labeled and stored in plastic bags before analysis.

Digestion

Using a weighing balance, two (2) grams of each powdered sample were weighed and transferred into a crucible. The sample was incinerated at 6000^O C in a Carbolite muffle furnace for three (3) hours., 10.0 ml of 6 N HCl was added to the ashed sample and then placed in a water bath and boiled for 10 minutes. The sample was carefully removed, filtered, and transferred into a 100 ml volumetric flask. The filter paper was washed down and the volume was made up to 100 ml using deionized water. Ten (10) milliliters of the digested sample were transferred to the sample container and taken into the MP-AES for analysis. Reading was recorded in ppm (AOAC, 2010).

Analysis using MP-AES (Principles of MP-AES)

The principle of MP-AES (Microwave Plasma-Atomic Emission Spectrometry) is based on the excitation and emission of atoms in a high-temperature plasma generated by microwave energy. MP-AES takes advantage of the high-temperature plasma to atomize and excite the sample and then measures the resulting emission where the emitted photons are collected and separated into their component wavelengths using a spectrometer. A diffraction grating disperses the emitted light and a detector measures the intensity of each wavelength of light to determine the elemental composition of the sample. The method is known for its simplicity, speed, and wide dynamic range providing accurate and precise elemental analysis for a variety of samples. (Ozbek et al., 2019)

Operational procedure

The MP-AES instrument was set up and calibrated according to the manufacturer's guidelines. It was ensured that the correct plasma gas flow rates, sample introduction method, and other parameters were optimized for the analysis. The prepared sample was introduced into the MP-AES instrument for analysis. This was done using nebulization techniques. The plasma was then generated in the MP-AES instrument using microwave energy. This creates a high-temperature ionized gas phase where the sample is atomized and excited. An atomic emission from the excited sample was measured using a spectrometer. The emitted radiation was dispersed into its component wavelengths and detected by a detector. The intensities of the emitted wavelengths were recorded automatically. The recorded emission intensities were compared with calibration standards and the concentration of elements in the sample were determined. Calibration curves or standard addition methods was used for this quantification. The obtained analytical results were analyzed and processed and a report was generated. (Ozbek et al., 2019)

Data analysis

The data generated were subjected to analysis of variance (ANOVA) using Special Package for social sciences (SPSS) 25.0 origin pro 8 Where the analysis indicated significant difference mean which were separated using Duncan's multiple range test (DMRT).

Ethical consideration

All responsible individuals were met in person. The Chairman of Bade local government area, the Emir of Bade LGA, the Divisional police officer of Gashua town, the Ward Head, and the Rice farmers were met on 29th September and 30th September 2022. The purpose of the study was duly explained and they all acknowledged the consent letter. Permission was outrightly granted by all the parties to proceed with the research.

F1G II (Gashua GN location).

FIG III (Gashua SW location)

FIG IV (Gashua GS location).

FIG V (Gashua SE location)

Determination of Health Risk Index (HRI)

The Hazard quotient (Noncarcinogenic risk) was determined by employing the equation below,
HQ=DIM/RfD…………………….. (i)

Where RfD is the reference oral dose (mg/kg/day) using specific values provided by the United States Environmental Protection Agency (USEPA) for various concentrations in mg kg-1/day as 0.003, 0.001, 0.0035 and 0.003 for As, Cd, Pb, and Cr (the United States Environmental Protection Agency, 2020, Gerba,2019).

The Daily Intake of Metals (DIM) was computed using the below equation. For a single substance Noncancer risks are expressed in terms of a hazard quotient (HQ) and for multiple substance it is expressed as hazard index (HI). (Gerba,2019) . Harzard quotient less than one HQ < 1 indicates no significant risk or significant toxicity and hazard quotient greater than one HQ >1 could represent a potential risk. (Gerba,2019).

DIM = concentration of metal x Daily Food intake /Average body weight……………. (ii)

The calculation factored in an average adult body weight of 65 kg and a children weight of 32 kg in Nigeria, alongside an average rice consumption of 0.15 kg day^{-1} per capita for adult and 0.075mgkg^{-1} for children. (USEPA, 2021). The HRI value exceeding 1 is deemed unsafe for human health (USEPA,2020).

The human health index investigated in rice samples grown and obtained from different locations of Gashua town with the parboiled rice sample obtained from the Gashua market of Bade Local government of Yobe State was shown in Table II. It was determined by applying the equation from. HQ = DIM/RFD. The HQ was used to assess whether the intake of the contaminant through rice consumption is within acceptable levels or if it poses a potential health risk.

Carcinogenic risk

The carcinogenic risk is the possibility of developing cancer through the intake of carcinogenic heavy metals in the rice samples. This was estimated using the Incremental lifetime cancer risk (ILCR) equation below. (USEPA,2014; Gerba, 2019).

ILCR = CDI X CSF………………………….. (iii)

Where CDI is a chronic daily intake of the heavy metal (carcinogen), mg/kg bw/day which represents the lifetime average daily dose of exposure to the chemical carcinogen, CSF represent the cancer slope factor which denotes the risk produced by a lifetime average dose of 1 mg/kg bw/day and it is contaminant specific. CDI was calculated using the equation below.

$$CDI = \frac{EDI \times EF \times ED}{AT} \quad \ldots\ldots\ldots\ldots\ldots \quad (v)$$

EF is exposure frequency (days/year), according to USEPA 365 days/year, ED is the exposure duration (years), (Gerba, 2019; USEPA, 2005). According to the World Bank, the life expectancy of an adult Nigerian is 54 years (World Bank,2014). AT is average time- the period over which exposure is averaged (days). For carcinogens, the average time is 25,550 days (365 days/year x 54 years) based on the lifetime exposure of 54 years. Cancer risk of 1×10^{-4} to 1×10^{-6} are considered acceptable (USEPA,2014) which indicates a probability of 1 in 10,000 individuals and 1 in 1,000,000 chances of individuals developing cancer during a lifetime.

Hazard Index (HI)

The hazard index (HI), represent potential risk from the mixture of chemical elements, the sum of all hazard quotient is the HI and was calculated for the rice samples using the equation below.

$$HI = \Sigma\ HQ \ldots\ldots\ldots\ldots\ldots\ v$$

If the HI < 1, chronic risks are assumed unlikely to happen, while non-cancer risks are likely, if HQ ≥ 1 chronic risk are likely.

Results and discussion

Table I :- Concentration of heavy metals in Rice samples from all the sample sites.

	Heavy metals Concentrations in ppm			
Locations	**As**	**Cd**	**Pb**	**Cr**
GMK	0.3830[a] ±0.2451	0.0242[b] ±0.0088	0.1020[d] ±0.0467	0.2810[c] ±0.2183
GN	0.0610 [b] ±0.0524	0.0283[b] ±0.010	0.1877[a] ±0.0634	0.3455[a] ±0.3007
GS	0.0690[b] ±0.0711	0.0330[a] ±0.014	0.0907[e] ±0.0415	0.2850[b] ±0.2071
SE	0.0597[b] ±0.0440	0.0262[b] ±0.0133	0.1667[b] ±0.0547	0.2815[c] ±0.2462

SW	0.0697[b] ±0.0422	0.0265[b] ±0.0127	0.1533[c] ±0.0585	0.2567[d] ±0.2344
Minimum value	0.01	0.00	0.01	0.00
Maximum value	0.31	0.06	0.31	1.23
WHO/USEPA	0.003	0.001	0.0035	0.003

[a, b,]Means within each column with different superscripts are significantly different at $P \leq 0.05$ GMK= Gashua Market, GN= Gashua North, GS= Gashua South, SE= South East, SW= South West, WHO= World Health Organization, USEPA= United State Environmental protection Agency.

Table II:- The Hazard quotient values (HQ) of heavy metals in rice sample for both Children and adults.

	Children			
Locations	As	Cd	Pb	Cr
GMK	0.5984	0.1134	0.1366	0.4391
GN	0.0953	0.1327	0.2514	0.5398
GS	0.8266	0.1538	0.1215	0.4453
SE	0.0922	0.1223	0.2233	0.4398
SW	0.1089	0.1242	0.2053	0.4011
	Adults			
GMK	0.2946	0.0558	0.0673	2.162
GN	0.0469	0.0653	0.1238	0.2658
GS	0.4069	0.0754	0.0598	0.2192
SE	0.0454	0.0605	0.1099	0.2165
SW	0.0536	0.0612	0.1011	0.0197
RFD * ppm/day)	3.0×10^{-3}	1.0×10^{-3}	3.5×10^{-3}	3.0×10^{-3}

- Please note that the specific RfD values and guidelines for contaminants can vary depending on the contaminant in question and the regulatory standards of the region.
- Average body weight for adult was taken as 65 and for children 32 (NBC,2020)

Table III:- The Human Incremental Lifetime cancer risk (ILCR) index for rice sample measured at five different sample sites

	Children			
Locations	**As**	**Cd**	**Pb**	**Cr**
GMK	$4.30\text{x}10^{-2}$	$1.81\text{x}10^{-4}$	$7.65\text{x}10^{-4}$	$1.05\text{x}10^{-2}$
GN	$6.86\text{x}10^{-3}$	$2.12\text{x}10^{-4}$	$1.40\text{x}10^{-3}$	$1.29\text{x}10^{-2}$
GS	$1.16\text{x}10^{-3}$	$2.47\text{x}10^{-4}$	$6.80\text{x}10^{-4}$	$1.06\text{x}10^{-2}$
SE	$6.71\text{x}10^{-3}$	$1.96\text{x}10^{-4}$	$1.25\text{x}10^{-3}$	$1.05\text{x}10^{-2}$
SW	$1.17\text{x}10^{-2}$	$1.98\text{x}10^{-4}$	$1.14\text{x}10^{-3}$	$9.62\text{x}10^{-3}$
Adults				
GMK	$8.61\text{x}10^{-3}$	$3.65\text{x}10^{-4}$	$1.53\text{x}10^{-3}$	$2.10\text{x}10^{-2}$
GN	$1.37\text{x}10^{-2}$	$4.24\text{x}10^{-4}$	$2.81\text{x}10^{-3}$	$2.91\text{x}10^{-2}$
GS	$1{,}53\text{x}10^{-2}$	$4.95\text{x}10^{-4}$	$1.36\text{x}10^{-3}$	$2.13\text{x}10^{-2}$
SE	$1.34\text{x}10^{-2}$	$3.93\text{x}10^{-4}$	$2.50\text{x}10^{-3}$	$2.11\text{x}10^{-2}$
SW	$1.56\text{x}10^{-2}$	$3.97\text{x}10^{-4}$	$2.29\text{x}10^{-3}$	$1.92\text{x}10^{-2}$
ILCR	$\mathbf{10^{-6}\text{-}10^{-4}}$	$\mathbf{10^{-6}\text{-}10^{-4}}$	$\mathbf{10^{-6}\text{-}10^{-4}}$	$\mathbf{10^{-6}\text{-}10^{-4}}$

USEPA 2022 Standard limit As 1.5mg/kg/dy Cd 0.1mg/kg/dy Pb 0.1mg/kg/dy Cr 0.5mg/kg/dy

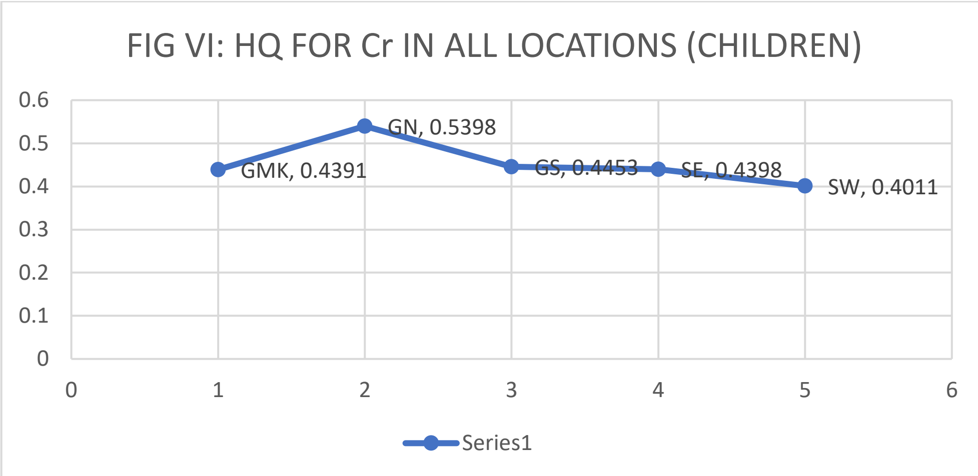

FIG VI: HQ for Cr (In all Locations)

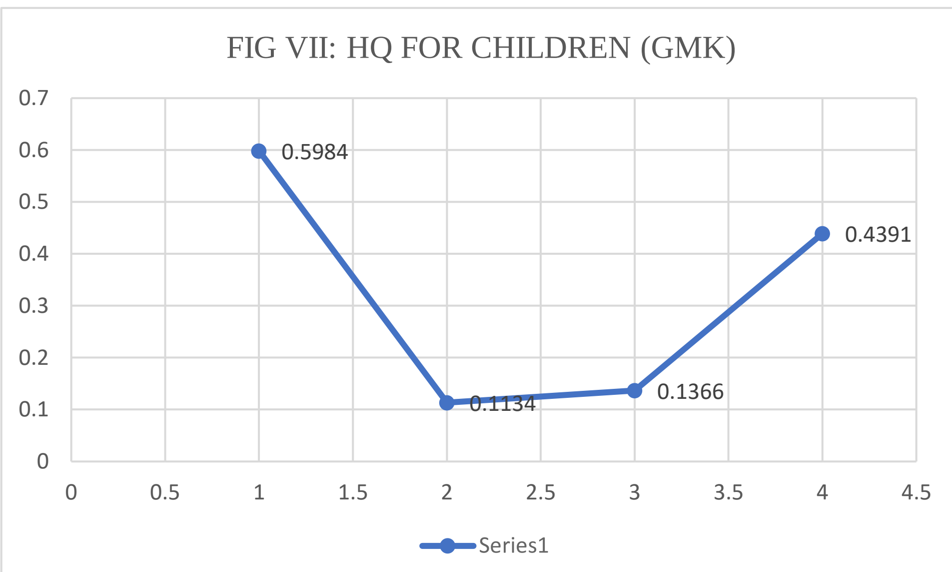

FIG VII: HQ for Children (GMK) As,Cd, Pb,Cr

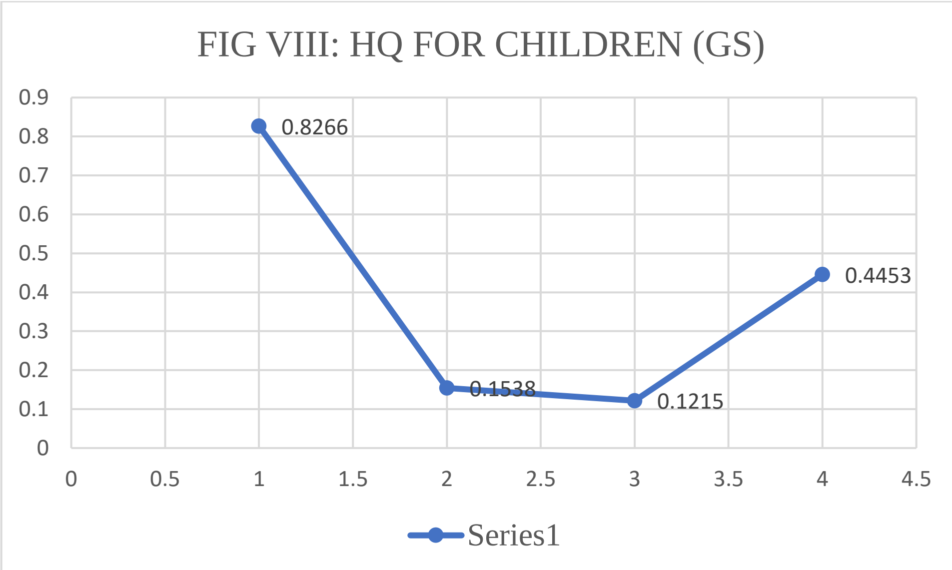

FIG VIII: HQ for Children (GS) As,Cd, Pb,Cr

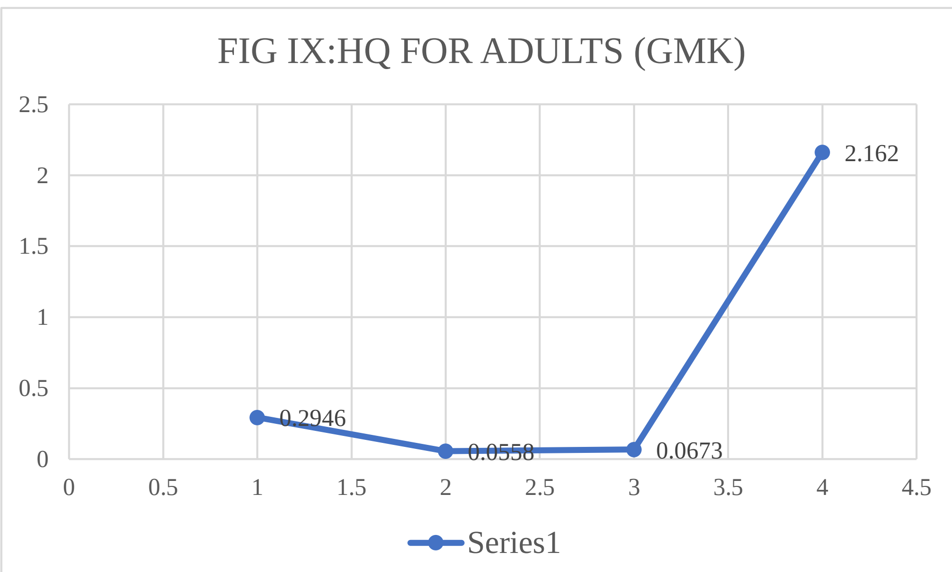

FIG IX: HQ for Adults (GMK) As,Cd, Pb,Cr

DISCUSSION

Rice samples from all the study sites were evaluated for the extent of metal pollution. The mean concentration of Arsenic in the rice samples vary across locations with samples from location GMK (parboiled rice) which showed a highest concentration of (0.3830 mg/kg) and SE having the lowest concentration of (0.0597mg/kg) as shown in Table 1.

The standard deviations showed the variability in Arsenic levels within all the sampled locations. The high level of Arsenic in the parboiled rice sample from the Gashua market (GMK) as shown in Table I may be due to the use of contaminated water, accumulation of Arsenic in the rice Husk, or use of pesticides which are usually reduced during cooking, and helps to reduce the overall intake of Arsenic (Gunduz and Akman, 2013). The study area has been shown to contain high heavy metals above WHO permissible limits in their drinking water. (Amshi et al., 2019). Long time exposure to heavy metals like Arsenic has been linked to various health hazards like skin lesions, cancers, cardiovascular diseases, and developmental problems in children (Al-Saleh, and Abduljabbar, 2017). The outcome of the current study agrees with the scholarly work of Watson & Gustavi, (2022) who showed 2% of unpolished rice samples had Arsenic concentration above WHO safety limit; they depicted the range of contamination from 4.85- 269.4kg-1 with an average of 88.4µg/kg-1 which undoubtedly shows much higher concentration; moreover the results also agrees with the outcome of Yalwa et al., (2023) where they showed high levels of Arsenic in rice samples analyzed from Damashewa, Jigawa state. The present study however did not align with the outcome of the result of Jarjes and Darwesh, (2023), especially on Arsenic concentration in parboiled rice which differs significantly; in their research, they showed Soaking is effective in reducing the concentration of heavy metals in rice. Despite parboiling of rice in the current study the level of Arsenic (As) from GMK sample was considerably higher GMK: 0.383 mg/kg than the WHO/USEPA limit of 0.003 mg/kg. Concentrations of Arsenic from the other locations Gashua North (GN), Gashua South (GS), Gashua East (SE), and Gashua South West (SW) Values (0.061mg/kg, 0.0690mg/kg, 0.0597mg/kg, 0.0697mg/kg) all exceed the acceptable limit. The practice of fossil fuel burning around the market can easily release Arsenic contents into the surrounding air which can easily contaminate the parboiled rice; the presence of Agrochemical shops around the Gashua market can equally be a source where metals can easily be transported through the air or through dust particles and contaminate the rice. (Khan et al., 2018). This has been shown in the work of Abdullaziz et al., (2022) where they estimated the Hazard index (HI) of heavy metals in ambient air and showed very high noncarcinogenic risk, while surface dust suggests no risk. They showed the cumulative ILCR values for Cr, Cd, As, Pb, and Ni indicated a possible risk of cancer via inhalation. Other anthropogenic sources where heavy metals can contaminate the environment are through automobile exhaust which can easily release lead, smelting can release Arsenic, and other insecticides which also release Arsenic respectively (Ugulu et al., 2021). Khan et al., (2021) opined the presence of heavy metals within the environment can lead to several adverse effect and can easily contaminate the soil; this has been a cause for concern because heavy metals don’t decompose easily and can get into humans through the food chain by either air or water.

Cadmium (Cd) concentrations were present across all the locations with GS showing the highest concentration (0.0330 mg/kg) and GMK having the lowest concentration (0.0242mg/kg). Standard deviations are relatively small indicating more uniformity in Cadmium levels within locations. The concentration of Cd in the parboiled rice is lower compared to the level of As. When Cd is inhaled it can result in kidney diseases while its toxicity also contributes to nerve and bone disorders in humans (Khan et al., 2020 and Tariq et al., 2021). Contrary to the current study Nader et al., (2016) and Ahmad and Qadir (2023) in their study did not detect Cadmium in rice samples likewise the Studies conducted by Juliet &

Ndago (2023) at Wukari. Chalestori et al., (2016) however in their study showed higher concentrations of heavy metals, Cd, As, and Pb in Iranian rice. The results agree with the work of Ijeoma et al., (2020) and Ijeoma et al., (2021) where they showed lower concentrations of Cd and other heavy metals in some imported and indigenous rice brands sold within Abuja, Nigeria. The work of Waribo et al., (2023) also showed a lower concentration of Cd in their study. Shahriar et al., (2023) in their study showed much higher values for Cd (1.13 mg/kg) which is greater than the WHO acceptable limit. Cadmium Concentration revealed as 0.0242mg/kg in GMK was very high exceeding the limit of 0.001mg/kg while GN, GS, SE, and SW ranging from 0.0262 to 0.033 mg/kg were all above the permissible limit.

Lead concentrations showed more variation with GN having the highest level (0.1877mg/kg) and GS having the lowest value of (0.0907mg/kg). Standard deviation values were moderately high suggesting some variability within locations. The high heavy metal variability across different locations suggests the influence of environmental factors and agricultural practices (Huo et al., 2016). The result agrees with the work of Wahyuningsih, (2023) where their analysis for both local and imported rice samples in Semarang showed Pb values ranging from 0.561-0.456 mg/kg in the Indonesia sample and 0.307 mg/kg in the United States sample which all exceeded Indonesia recommended level. Shahriar et al., (2023) in their study showed a higher value for Pb (6.87 mg/kg) which is greater than the WHO acceptable limit. The current result agrees with the work of Juliet and Ndago (2023) at Wukari where they detected Pb levels in rice samples ranging from 0.024mg/kg to 0.12mg/kg which they attributed to the residual effect of agrochemicals. The results also agree with the work of Yalwa et al., (2023) who showed a high level of Pb in rice from Damashewa, Jigawa state. Chyad et al., (2022) equally showed higher levels of Pb with values ranging from 1.805-4.776 mg/kg respectively.

From the current study Lead concentration from all five locations superseded the recommended level especially for the parboiled sample from GMK with 0.102mg/kg and from a sample from GN with a concentration level of 0.1877mg/kg exceeding the limit of 0.0035mg/kg which were significantly higher than the recommended limit. Lead levels are of serious concern, especially in GN locations where the concentration is markedly high suggesting a potential acute risk to public health. Possible sources of Lead contamination may originate from occupational settings such as battery workers, smelters, absorption of Lead from water, or other environmental sources (Al- Saleh, and Abduljabbar, 2017; Khan et al., 2021; Ugulu et al., 2021). Crops tainted with these metals may pose significant health risks to individuals potentially leading to severe ailments (Saleem et al., 2020). Myriad of studies support the carcinogenic properties of heavy metals contributing to conditions like blood, bone, heart, and kidney diseases (Hashem et al., 2020 and Javed et al., 2020).

Chromium concentration in location GN (0.3455 mg/kg) is highest and lowest in SW (0.2567 mg/kg) all above the acceptable limit of 0.003mg/kg set by WHO/USEPA. The Highest concentration was recorded in GN (0.3455mg/kg) which agrees with the result of Wahyuningsih, (2023) where they showed a higher concentration of Cr ranging from 241-0.723mg/kg. Shahriar et al. (2023) in their studies equally showed a higher value for Cr (0.43 mg/kg) which is greater than the WHO acceptable limit of 0.003mg/kg. The result however disagrees with the result of Ahmad and Qadir (2023), who showed lower levels of Cr likewise the outcome of Waribo et al., (2023) and also Juliet and Ndago (2023) in their study at Wukari did not detect Cr in rice samples. A comparison against WHO/USEPA standards for heavy metals in food products (Arsenic: 0.003 mg/kg, Cadmium: 0.001 mg/kg, Lead: 0.0035 mg/kg, Chromium: 0.003 mg/kg) highlights that metal concentrations in most locations far exceed the recommended limits. This suggests potential health risks associated with consuming rice from these areas (Tariq et al., 2021). The high concentration of Chromium levels in all locations especially in GN indicates a significant health hazard. These heavy metals persist in the environment inducing severe health hazards for both humans and animals primarily because of their enduring presence and inherent toxicity (Zaheer et al., 2020). Contamination with these metals can induce various health hazards such as cancer, mutations, teratogenicity, disruption of hormones, irritation of the skin and eyes, liver damage, tremors, decreased fertility, effects on the central nervous system, kidneys, headaches, nausea, dizziness, poisoning leading to coma, endocrine disruption, respiratory illnesses, convulsions, abdominal pain, and loss of muscle coordination (Roya and Ali, 2017; Rehman et al., 2019; Ugulu, et al., 2019). Research in Perak, Malaysia by Agatha et al., (2023) showed high levels of As, Cd, and Cr in rice due to historical mining activities presenting a significant health risk. Similarly, a study by Parvez, (2022) showed higher concentrations of Arsenic and Cadmium levels in rice exceeding WHO/USEPA acceptable limits.

HEALTH RISK ASSESSMENT

The Health risk calculation showed potential for health risk due to the presence of As, Cd, Pb, and Cr in analyzed samples (Table II). Calculation of hazard quotient (HQ) of As in children ranged from 0.0922 in SE to 0.8266 in GS as well as 0.0454 in SE to 0.0469 for adults in GN site respectively. For Cadmium (Cd) in children, the concentrations were 0.1223 in SE, 0.1242 in SW, 0.1327 in GN, and 0.1538 in GS which where all higher than the concentration of 0.1134 in the parboiled rice sample obtained from Gashua Market while adults concentration for Cadmium ranged from a value of 0.0605 in SE locations to 0.0754 in GS, this concentration values are higher than the reference dose in part per millions per day and also higher than the concentrations investigated in parboiled rice obtained from GMK respectively (Table II). Adult's concentration for Lead is between 0.0598 in sample from GS which is less of concentration when compared with values recorded for the samples in SW as 0.1011, SE as 0.1099 and 0.1238 in GN while the rate of investigated Lead concentration from rice sample for children varies as 0.1215 in GS, 0.2053 in SW, 0.2233 in SE and 0.2514 in GN (Fig II). This simply signifies that all locations have HQ values for Lead below 1 in children. Chromium presents a stark contrast with the HQ exceeding 1 in GMK for adults (2.162) indicating an unsafe level of exposure and a serious noncarcinogenic risk (Fig IX); this aligned with the studies conducted by Guo et al (2022) where they showed noncarcinogenic risk index of heavy metals for adult at 3.558 and that for children at 6.014 which were all greater than 1. The other locations in the present study have HQ values below one (1) which is considered safe. In children the HQ observed for chromium at GN was (0.5398); which is a warning sign indicating a prospective significant risk to children within these locations (Fig VI).

The hazard quotient (HQ) indicated that Arsenic content in children was high for GMK (0.5984) as shown in (Fig VII) and GS (0.8266) as shown in (Fig VII) thou not above one (1) but still presented an alarming sign indicating unsafe levels and a potential health risk for children consuming rice from these locations. The values for GN, SE, and SW were all below 1 suggesting lower risk levels. The HQ values for Arsenic were equally all below 1 for adults indicating a lower health risk compared to children. However, GMK and GS still show the highest values of 0.2946 and 0.4069 respectively which warrants attention. Studies have linked prolonged or long-term exposure to heavy metals with adverse health effects in multiple organ systems like the stomach, kidneys, liver, and coronary heart disease and diabetes (Saleem, et al., 2019); (Ugulu, et al., 2021). The present study aligned with the scholarly work of Sibuar et al., (2022) where they quantitatively analyzed heavy metal in rice and evaluated the human health risk assessment of heavy metals in paddy plants collected from Perak, Malaysia. They presented their results for HQ for the heavy metals by adults and children in descending order of As>Cr>Cu>Pb>Cd. The HQ for As was the highest and exceeded 1 thou in the present study As range was 0.8266 which was closer to the threshold. They presented their range as 2.08 to 3.33 and 2.197 to 3.530 for both adults and children respectively which suggested As poses potential noncarcinogenic risks. Their result showed the combined Hazard index (HI) value for all the five studied heavy metals was above 1 indicating a potential non-carcinogenic risk to human health, this aligned with the current study where the HI for both Adult and children were above 1 at 5.571 and 4.5107 respectively. the HI value from their study can likely be explained mainly by the As contamination, as its HQ value for As accounted for a huge proportion of the HI; in contrast Cr contributed to the high HI in Adult for the current study with 2.162 and As at different locations contributed to the high HI in children with 0.8266, 0.5984 and in chromium with 0.5398 (Table II). The HQ values for Cadmium in children are all below 1, with GS having the highest value at 0.1538. These values suggest a concern for long-term exposure especially in GS. Similar to children, the HQ values for cadmium in adults were all below 1 but present in all locations with GS having the highest at 0.0754 indicating potential concerns for long-term health effects. Research carried out by Shakerian et al., (2012) and Afzal et al., (2020) recorded higher levels of Cd and Zn and lower levels of Cu compared to current findings of this study. Cadmium exposure can cause kidney dysfunction and bone demineralization, and Lead exposure in children can result in cognitive impairments and developmental delays, while in adults, it causes hypertension and kidney damage (Shrestha and Kazama, 2016; Ihedioha, 2021; Sibuar et al., 2022; Sun, 2023).

The present study also agrees with the outcome of Yin et al., (2023) where they assessed heavy metal content and consumption risk of some selected paddy fields in Malaysia. They showed HQ values of Cd exposure for adults were below 1 (HQ <1) except for the HQ values in other locations which were more than 1. The presence of Cd could cause potential non-carcinogenic health risks such as cardiovascular disease, kidney dysfunction, and severe bone pain (Nishijo 2017; Rahimzadeh et al., 2017; Zulkafflee et al., 2019).

Neisi et al., (2023) in their study also showed contrary results to the present study where they showed the non-carcinogenic risk value associated with heavy metals in adults and kids were below 1 for both HQ and HI although the current study recorded HI greater than 1. Their result showed As has the highest HQ values for kids, measuring 0.0127 for Tarom rice. The maximum HI values for kids were associated with As, measuring 0.0137, 0.0048, and 0.0016 for Tarom rice and radish respectively. The highest HQ for adults was associated with As values ranging 0.0059, 0.0017, and 0.0028 for Tarom rice and radish respectively. The results of Jarjees and Darwesh (2024) also aligned with the current study where they showed HQ were found to be below 1, except for As which exceeded the threshold. They showed the values for Carcinogenic risk for all genders ranged from 2.03×10^{-6} to 9.08×10^{-3}.

In the current study, all locations have HQ values for Lead below 1 for both children and adults with the highest being GN at 0.2514 for children and GN (0.1238) for adults although below the threshold. This suggests a potential risk that should be monitored especially since children are more susceptible to lead exposure and the cumulative effects of lead (Fan et al., 2017); (Amir et al., 2019); (Saleem et al., 2020).

The HQ for chromium is relatively higher in GN (0.5398) and also elevated in GMK, GS, SE, and SW indicating a significant risk to children in these locations while chromium (Cr) presents a stark contrast with the HI exceeding 1 in GMK for adults (2.162) indicating an unsafe level of exposure and a serious NonCarcinogenic risk. The other locations have HQ values below 1, suggesting a lower risk (Saleem et al., 2020). The high level of chromium in the sample investigated for adults from GMK may be a result of soil contamination and water contamination during parboiling (Table 2), this contamination could result from industrial activities, waste disposal, or the use of certain fertilizers or pesticides containing chromium which could potentially affect the local environment including nearby water sources or other crops leading to a broader ecological impact (Qian et al., 2010); (Ugulu et al., 2021). Elevated levels of chromium, particularly hexavalent chromium (a toxic form) can pose health risks if consumed regularly. It may cause stomach upset, allergic reactions, or even lead to more severe conditions (Ugulu et al., 2019; Zaheer et al., 2020; Saleem et al., 2020).

INCREMENTAL LIFETIME CANCER RISK (ILCR)

In the context of evaluating the risk of carcinogens, the ILCR was computed to gauge the likelihood of a person getting cancer throughout their lifetime. For instance, a cancer risk of 10^{-4} signifies a probability of one in 10,000 individuals developing cancer (Ma et al., 2017). According to Ma et al., (2017) and Cao et al., (2015), the risk levels within the range of 1.0×10^{-6} to 1.0×10^{-4} are considered acceptable.

Table III shows the incremental lifetime cancer risk (ILCR) of heavy metals in rice for children and adults across the five locations: GMK, GN, GS, SE, and SW. For children, the concentration range were, in GN for As (6.86×10^{-3}), SE for As (6.71×10^{-3}), GS for Lead (6.80×10^{-4}), GMK for Lead (7.65×10^{-4}) and SW for Cr (9.62×10^{-3}). Significant concentrations at other locations were observed in GMK for Cr (1.05×10^{-2}), SE for Pb (1.25×10^{-3}), and GS for As (1.16×10^{-3}). In terms of the carcinogenic risk in children, Pb in GS and GMK are considered safe while As in GN & SE, Cr in SW & GMK, Pb in SE and As in GS all were not within the threshold value of 10^{-4} & 10^{-6}.

For adults, the concentrations recorded for different locations were, in GMK for As (8.61×10^{-3}), GS for Cd (4.95×10^{-4}), GN for Pb (2.81×10^{-3}), and in GN for Cr (2.91×10^{-2}). Other concentrations observed were, in GMK for As (1.34×10^{-2}), GMK for Cd (3.65×10^{-4}), GS for Pb (1.36×10^{-3}), and SW for Cr (1.92×10^{-2}). Only Cd in GS & GMK were within the threshold, all the other location exceeds the threshold value.

From the results, the ILCR assessment of heavy metals in rice from GMK, GN, GS, SE, and SW shows significant variations in the heavy metals for both children and adults. These variations were influenced by local environmental conditions, agricultural practices, and industrial activities or factors specific to each location (Kohzadi et al., 2019); (Zhang, 2020); (Nnorom and Osibanjo 2022).

Agricultural practices, such as the use of phosphate fertilizers, are linked to elevated Cd levels, the elevated As levels in GN (6.86×10^{-3}) for children and GMK (8.61×10^{-3}) for adults could be due to Arsenic-containing pesticides (Abdulaziz et al., 2022); (Parvez, 2022); and (Sibuar et al., 2022). Shahriar et al., (2023) in their study showed the values of Pb in rice were 0.1×10^{-6} to 1.1×10^{-6} for adults and 0.1×10^{-6} to 1.2×10^{-6} for children; Cr were 0.3×10^{-6} to 2.1×10^{-6} for adults and 0.3×10^{-6} to 2.4×10^{-6} for children; and Cd were 0.33×10^{-4} to 2.19×10^{-4} for adults and 0.38×10^{-4} to 2.48×10^{-6} for children. Their results showed values for Pb and Cr were all within the threshold contrary to the current study. A study by Neisi et al., (2024), where they evaluated the carcinogenic risk caused by heavy metal exposure in children and adults, showed both groups' accumulated lifetime Cancer risk and ILCRs were lower than (1×10^{-6}). Environmental contamination from industrial activities such as electroplating and tanning can be linked to the high Cr levels in SW (9.62×10^{-3} for children), which indicates a possibility of cancer in a lifetime of 1 in 1000. Additionally, mining activities may contribute to the level of (Pb) concentrations in GMK 7.65×10^{-4} and GS 6.80×10^{-4} indicating a very risk of 1 in 10,000 (Vardhan et al., 2019); (Gao, 2021). Contaminated irrigation water is equally a significant factor in the accumulation of heavy metals in crops, affecting all locations. (Soltan et al., 2020); (Rehman et al., 2021); (Agatha et al., 2023). Chronic exposure to Arsenic can lead to skin lesions, cardiovascular diseases, and increased risks of skin, lung, and bladder cancers. (Sall et al., 2020; Ihedioha, 2021 & (Vaezi, 2024).

The current study agrees with the scholarly reviews of Yin et al., (2023), where they showed values of Cd in some locations, namely; Tanjung Karang, Selangor (7.48×10^{-4}), Kota Marudu, Sabah (4.15×10^{-4}) and Ranau Valley, Sabah (1.25×10^{-3}) ,they indicated that among every 10,000 adult individuals in Tanjung Karang (Selangor), Kota Marudu (Sabah), and Ranau Valley (Sabah), there is a probability of 4 to 13 individuals who may develop carcinogenic related health risks caused by Cd exposure, such as lung, pancreas, and breast cancers, over a period of 74 years (Rahimzadeh et al., 2017; Genchi et al., 2020; Tatah Mentan et al., 2020). Intake of Cd-contaminated rice may pose a risk of contracting the itai-itai disease. During the 1950s, ingesting rice contaminated with cadmium led to (itai-itai disease) which impacted humans' well-being. (Nishijo, 2017). The disease complications of Itai-itai are associated with osteomalacia and severe bone pain and disorder, as well as renal tubular failure (Shi et al., 2020). Chromium exposure, particularly to hexavalent chromium, leads to respiratory problems, skin irritation, and lung cancer risks. (Shrestha and Kazama, 2016); (Zhaoyong et al., 2019); (Bashir et al., 2024). The current study agrees with the work of Yin et al. (2023), where they showed all adult's life cancer risk values of Pb exposure were below 1×10^{-4} (LCR $<1 \times 10^{-4}$) except for the LCR value of Pb in Sabak Bernam, Selangor (1.16×10^{-4}). In the current study, the lead value in GMK for children is 7.65×10^{-4} while in adults from all locations they ranged at 10^{-3}. This indicates that among every 10,000 adult individuals in Sabak Bernam, Selangor, there is a probability of 1 individual who may develop carcinogenic-related health risks caused by Pb exposure, such as brain, stomach, and lung cancers over 74 years (Rai et al., 2019) while in Nigeria the probability is 54 years.

Conclusion:

This study highlights the significant risks posed by heavy metal contamination in rice cultivated and sold in Gashua, Yobe State. The elevated levels of Arsenic, Cadmium, Lead, and Chromium detected, particularly in parboiled rice from the Gashua market, exceed permissible limits established by WHO/USEPA, raising serious public health concerns. Chromium levels in adults were especially concerning, presenting non-carcinogenic risks (HQ > 1), while Arsenic concentrations posed potential long-term cancer risks. These findings underscore the urgent need for continuous environmental monitoring and stricter regulatory controls to mitigate exposure to these toxic elements.

Given the widespread reliance on rice as a dietary staple in Nigeria, these results also call for public health interventions, including consumer education and the promotion of alternative food sources in affected regions. Future studies should explore the sources of contamination, remediation strategies, and broader implications for food safety in other rice-producing areas. Regulatory agencies, such as NAFDAC and NESREA, should intensify their efforts to monitor and regulate the presence of heavy metals in agricultural products, ensuring that the safety and well-being of the population are protected.

Recommendations:

The presence of elevated metal levels in rice poses significant health risks demanding immediate action to avert further exposure therefore, the following were recommended:-

1. Regulatory agencies like National Agency for Food and Drug Administration and Control (NAFDAC) should incorporate & intensify the monitoring of heavy metals in unregistered rice sold within open market as this will give the agency a clear picture of the extent of contamination of rice in order to make informed decisions and advised the government appropriately.

2. National Environmental Standard and Regulations Enforcement Agency (NESREA) should intensify regulation and strict control of untreated waste disposal into streams and river leading to irrigation canals and safe chemical usage in agriculture.
3. Regulatory agencies should encourage and advocate the adoption of remediation techniques like phytoremediation and the use of metal-tolerant crops by rice farmers.
4. Standard for water use in parboiling should be developed by regulatory agencies.
5. The Government should intensify public enlightenment about health risks associated with consuming contaminated rice and promote dietary diversity to reduce dependence on tainted food sources.
6. Relevant research, healthcare institutions and Agencies like (NAFDAC) should be encourage and empowered to keep a database on Agrochemical use and incidents of heavy metal contamination in Nigeria as this will help in developing an appropriate response in a timely manner to reduce the adverse impact associated with Agrochemical use in the country.

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