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Health risk assessment of heavy metal contamination for abattoir meat quality in Enugu, Nigeria

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Abstract
Background: The study investigated negative consequences of heavy metal (HM) contamination in meat for humans, particularly in the liver, kidney, and lean meat of beef, mutton, caprine, and chicken from a major abattoir in Enugu Metropolis, to recent poisoning and current hygiene levels.
Methods: Local animal species were studied using an analytically validated wet digestion method to determine Cr, Pb, Cu, Fe, Ni, Co, Mn, Cd, and Zn using Perkin Elmer Analyst 700 Atomic Absorption Spectrophotometer-Gemini BV.
Results: The levels of HMs ranged from 0.00 to 0.04 ± 0.04 mg/kg Cr; 0.03 to 1.60 ± 1.2 mg/kg Cu; 0.44 to 1.66 ± 0.30 mg/kg Fe; 0.00 to 0.31 ± 0.01 mg/kg Ni; 0.00 to 0.27 ± 0.06 mg/kg Co; 0.00 to 0.11 ± 0.01 mg/kg Mn; 0.00 to 0.05 ± 0.00 mg/kg Cd, and 0.00 to 0.08 ± 0.03 mg/kg Zn. Cr was undetectable in the liver, while Pb was not detected in other samples. The HM variations in the liver, kidney, and meat were statistically significant ($P < 0.05$), except for Cu, Cd, Cr, and Fe. The target hazard quotient was > 1 for adults and children, except for Pb and Zn. Cancer risk was primarily associated with Ni > Cr and higher in children than in adults.
Conclusion: The findings highlighted the need for regular monitoring of abattoirs by authorities due to contamination arising from anthropogenic sources of heavy metals and heavy metal speciation data in various animal products and diets, and determined aggregate exposures. The study also provided data for monitoring abattoirs' public health, food authorities, and policymakers at local, national, and international levels.
Keywords: Beef, Goat meats, Lamb meats, Risk analysis, Toxicity
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Introduction

Health risk assessment is crucial because it enables the determination of the quality of meat as influenced by heavy metal pollution in areas such as the Middle East and Africa, where pollution and industrialization result in the accumulation of metals in animals (1-3). Heavy metals such as lead (Pb), cadmium (Cd), and chromium (Cr) can accumulate in animal tissues, posing serious health risks upon consumption. Chronic exposure may cause neurological damage and increase cancer risk. Health risk assessments help identify hazardous levels, set safe consumption limits, and support regulations to protect public health (2,4,5). Comparing contamination levels with the international safety standards helps authorities take measures to minimize exposure and guarantee meat safety. Food contamination can occur at one point or another in the food chain, from the producer to the consumer (1). Food can also become dangerous by taking on certain toxic compounds in the preparation process or storage practices (2), including pathogenic bacteria, owing to incorrect handling, processing, and contact with contaminated food (3). These foodborne infections are the leading causes of illnesses and death in the long run (1). Meat and meat products contribute to most human nutrition needs, including protein, vitamins, and fats (4). However, concerns about the composite parts in meat products have been raised (5). Research conducted in Kuwait abattoirs showed that all the HMs in meat samples were above the MAL set by international food regulatory bodies except Cr (6). The research carried out in Kurdistan, Iran, revealed that most of the analyzed meats exceeded the MAL for all the HMs except Cu (7). A similar study conducted in Zhejiang, China, found the average concentrations of As, Cd, Cr, Cu, and Pb in beef were 0.018, 0.002, 0.061, 0.0038, and 0.061 mg/kg of wet weight (8).

Literature indicates that Pb enters the body through inhalation or ingestion, disrupting multiple organs, while Co enters the food chain via fertilizers, reaching animals and affecting lung, heart, and thyroid function (9). Ni interferes with respiratory, circulatory, and neurological systems. Cr VI is a known carcinogen that has a severe impact on human health. It is mainly food-borne, water-borne, or workplace-borne. Cr VI is known to be a potent carcinogen to humans, and the IARC categorizes it in group 1 (10,11). The main cancer risk associated with Cr VI is lung cancer, which is mostly due to inhalation. Consumption of Cr VI through meat or water also has the potential to cause gastrointestinal cancers, particularly stomach cancer. The cumulative effects of Cr in food or water are known to induce DNA damage, oxidative stress, and carcinogenicity, which constitute a major health risk in contaminated environments (12,13). Iron (Fe) is necessary for the body but toxic if taken in large amounts, and may lead to liver cancer due to liver damage, though it is not a carcinogen. Copper (Cu) is essential for biological processes; however, high concentrations can be toxic to the liver and kidneys with no indication of carcinogenicity. Zinc (Zn) is essential for immune health and is not a carcinogen; while fluctuations in levels may be problematic, there is no direct link between zinc and cancer. Manganese (Mn) is essential for enzymes and toxic at high doses; however, it does not have carcinogenic effects (12,13). Therefore, meat products need to be regularly monitored. A study in Uganda found that average Ni concentrations posed a cancer risk, which was significantly higher in children than in adults (10). Likewise, *P* values of Pb concentrations in broiler liver, breast, and thigh muscles in Pakistan were higher than those of Mn concentrations (11). Foodborne diseases from chemical contamination can vary from mild gastroenteritis to severe liver, kidney, and brain issues. Due to their harmful effects, food poisoning can spread rapidly like an epidemic (12). The presence of metals in meat is a menace to human health and quality of life. Yet, the studies that attempt to associate the toxicity of HMs with risk are still insufficient. The lack of data is a problem for meat safety, especially for the vulnerable groups that lack protection from adverse standards.

Food contamination with HMs (Pb, Cd, Fe, Cr, Cu, Ni, Co, and Zn) is a serious public health issue in developing countries like Nigeria (13). For instance, the edible meat feedlots and the water used in the diet and growth of the animals provided HMs in the meat (14). Heavy metal contamination has recently been found in the liver, meat, gizzards, borehole water, soil, diets, and droppings in Akwa Ibom, Nigeria (15). The abattoirs investigated in Nigeria are likely to slaughter emaciated animals, risking the sale of heavy metal-contaminated meat for human consumption due to inadequate inspections (16). Sewage pollution and leaching of inorganic fertilizers into water sources are considered sources of environmental pollution that enhance the level of heavy metals in food (17). This is worsened by human activities, improper chemical use, and poor industrial waste management, all of which damage the abattoir ecosystem (18,19). A national newspaper has recently reported poor hygiene levels in abattoirs and urged the government to clamp down on violators (20). This indicates a trend of rising heavy metal (HM) contamination in meat products across the continent. Additionally, data on HM levels in developing countries are scarce, hindering policymakers' ability to implement effective consumer protections. Immediate dissemination of this crucial information is vital for public safety. Moreover, there are few studies on HM contamination in meat products, with none conducted in the research area (14,21–24). Recent studies on food poisoning (25) and HM contamination (26) are alarming and require action. This study assessed the level of HM accumulation in the liver, kidney, and lean meat of beef, mutton, goat, and chicken procured from Ogbete Market Slaughterhouse in Enugu Metropolis. It also evaluated the potential harm of these pollutants to the health of the general population. The study will therefore contribute to the understanding of toxic element accumulation in abattoir animals and assist in solving this public health problem.

Materials and Methods

Sampling

The study area was selected based on its cattle, goat, sheep, and chicken-keeping culture, as well as the presence of multiple butcheries capable of slaughtering and preparing over a hundred farm animals per day. Figure 1 depicts the geo-referenced coordinates of Latitude 6.43416 and Longitude 7.48293 with the plus code CFQQ + 34F Enugu.

Fresh samples of lean meat, livers, and kidneys from beef, mutton, caprine, and chicken were obtained at the Ogbete Main Market Slaughterhouse in Enugu, Nigeria. The edible portions, such as the liver, kidney, and lean meat, were chosen at random twice every year. The cow, sheep, goat, and chicken samples were taken between June and December of 2019-2021. Because the best of local breeds is reserved for Sallah in around May-August and Christmas in December, all samples were transferred in clean plastic bags and refrigerated at -20°C for examination in the laboratory. During transportation to the laboratory, the meat samples were kept on ice in an enclosed cooler container at 4°C. The meat(s) chunks (1 kg) were deboned and skinned, sliced into pieces, and minced with a meat mincer (Moulinex-HV8, Paris, France) before being stored in the refrigerator at -20°C for 7 days. Local animal species used were: caged chickens (18-month-old broilers), female sheep and goats (2-3 years old) that were cramped in cages, and a leashed cow (5-year-old). The

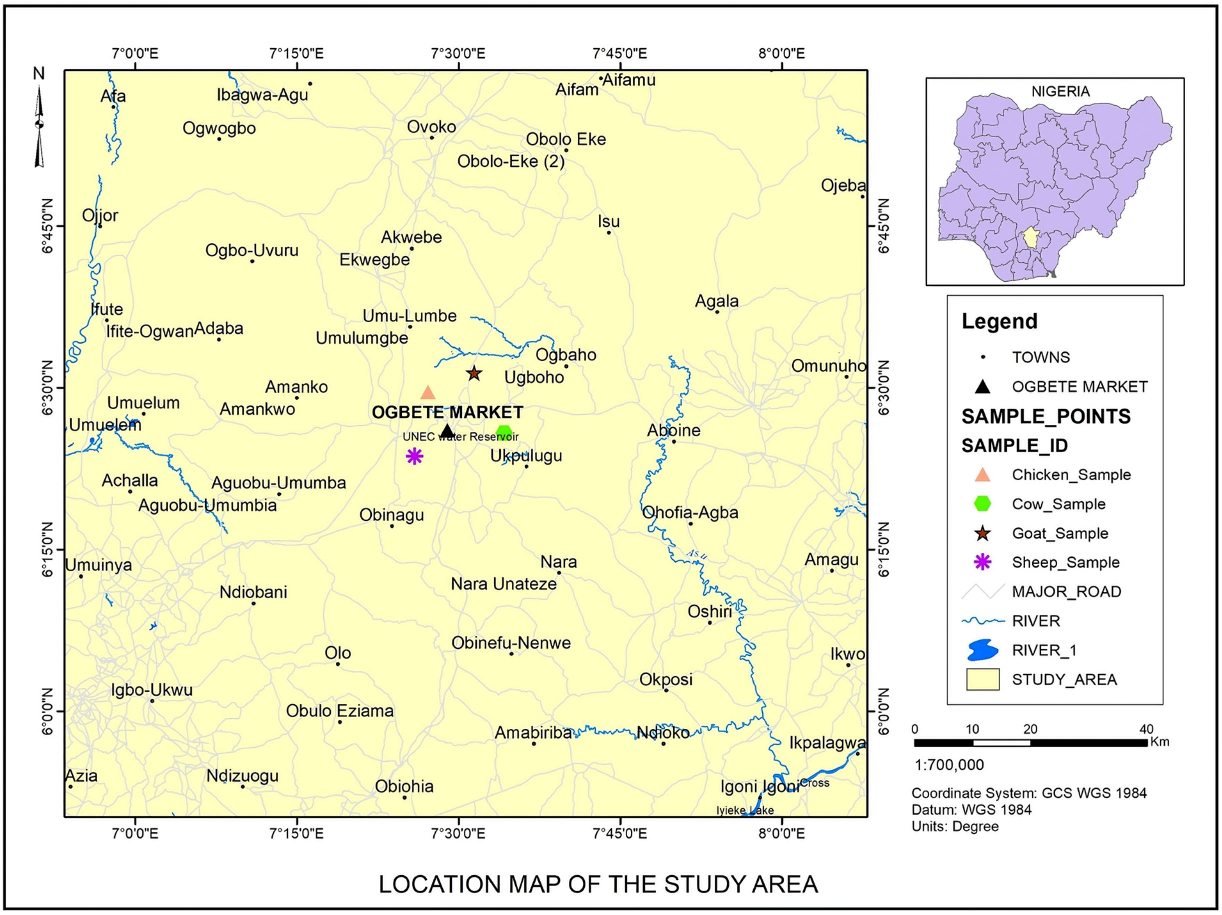

Figure 1. Map of study location. (a) Map of Nigeria, (b) Map of geopolitical zone, (c) Ogbete market

live animal weights were not measured because average height and plumpness, as determined by owners through visual inspection, were sufficient for maturity. The average temperature in the area was 29-33°C, while the average monthly humidity ranged from 78% to 89%.

Preparation and Analysis

Using the wet digestion method, the collected samples were decomposed for the determination of heavy metals. Samples were cut into very small fragments using a stainless-steel dissection instrument. A weighed 1 g of representative meat from each sample was washed with distilled water and transferred into 50 mL beakers. Measured 15 mL of aqua regia (1 part of HNO_3 (65%) to 3 parts of HCl (35%) was added to each sample. Afterwards, samples were heated in a water bath at 100°C until brown fumes were given off. After cooling, H_2O_2 (30%) was added dropwise into each beaker to obtain a clear solution. Then, the content of the beaker was filtered into a 100 mL volumetric flask and made up to the mark with distilled water. Using a modified analytical procedure based on (27), processed samples were analyzed for Cr, Pb, Cu, Fe, Ni, Co, Mn, Cd, and Zn using a Perkin Elmer Analyst 700 Atomic Absorption Spectrophotometer-Gemini BV. Linear calibrations are presented in Table 1, and blank samples were tested for quality assurance validation.

Method Validation

The analytical procedures were validated by analyzing relevant certified reference materials (CRM) with the identical digestion and analytical methodologies. The CRM (Table 1) was obtained from the Association of Official Agricultural Chemists (AOAC) International and in coherence with the National Agency for Food, Drug Administration, and Control NAFDAC Guidelines for Food Hygienic Practices (NGFHP: Reference No.: FSAN-GDL-008-01) in Nigeria. Quantitative findings (no more than 10% of the certified value) were obtained for CRM-specific items. Limits of detection (LODs) were set at three times the standard deviation of 10 sets of blank measurements. The LODs for Cr, Pb, Cu, Fe, Ni, Co, Mn, Cd, and Zn were 0.003, 0.001, 0.002, 0.002, 0.0004, 0.004, 0.005, 0.001, and 0.003 mg/kg, respectively.

Statistics

Data were analyzed using the IBM-SPSS 20.0 statistical package application. Data are presented as mean and standard deviation. These calculations are based on triplicate readings. The data were analyzed using One-way ANOVA ($P < 0.05$) to see if metal levels differed substantially between animals.

Risk Assessment

To calculate the estimated daily intake (EDI), total hazard quotient (THQ), chronic daily intake (CDI), and incremental lifetime cancer risk (ILCR), Eqs 1 to 4 were used as shown.

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

$$THQ = \frac{CDI}{RFD} \quad (2)$$

$$CDI = \frac{EDI \times EF_R \times ED_{TOT}}{AT} \quad (3)$$

$$ILCR = CDI \times CSF \quad (4)$$

Where *C* stands for concentration of HMs, *IR* for ingestion rate at 120 g and 60 g for adults and children per day, respectively, and *BW* for body weight at 60.7 and 20.5 kg for adults and children, respectively, compared to the WHO recommendations. The hazard index and target hazard quotient (THQ), CDI, EDI, reference dose (RfD) for each hazard, and the cancer slope factors (CSF) were used according to (22,26,28). The recommended ingestion rate and body weight by the WHO provide significant changes in muscle mass with age, particularly in older persons, which could be detected in short-term balance studies. These limitations underscore the challenges of determining protein/carbohydrate intake requirements for all adults and children, as well as favorably impacting the adaptive response to acute and chronic health effects.

Results

Figure 1 shows the map of the study location and sample collection with their legends. Table 1 displays the study's results, including the instrumental calibration used to determine Cr, Pb, Cu, Fe, Ni, Co, Mn, Cd, and Zn, and their comparative evaluation with the WHO/FAO standards is presented in Table 2. The correlation coefficient (R^2) indicated that the instrument was calibrated and the method validated. The R^2 for Cd^{2+} was the best in terms of accuracy and precision, with a value of 1, while the R^2 for Co was the lowest at 0.899. Table 3 also revealed the concentration of pollutants in mg/kg. Cr and Pb were not found in their different livers, but Zn, Cu, Fe, Ni, Co, Mn, and Cd were present at various concentrations. In the kidney, only Pb was not detected, and the other trace metals were found at various concentration levels. The amounts of trace metals in the meat were consistent with kidney concentration levels, indicating that extended ingestion of meats, particularly the kidney and lean meat sections, can cause systemic diseases (29). Figures 2 and 3 depict the levels of daily absorbed dose of each heavy metal in different types of animal meat samples from beef, goat, sheep, and chicken. The persistently elevated levels of Fe and Cu demonstrated that both are widespread trace metals in the abattoir, which is consistent with previous findings of potentially harmful health consequences in meat (30). The WHO/FAO provisional weekly/daily tolerable intake is shown in Table 4.

Table 1. Instrumental linear calibration for analyzed heavy metals (HMs)

HMs	v (nm)	Slope	Intercept	R2
Cr	359.9	0.0129	0.0386	0.991
Pb	217.0	0.0115	0.0336	0.998
Cu	324.9	0.0428	0.2304	0.954
Fe	248.3	0.0186	0.0608	0.924
Ni	323.0	0.0212	0.0724	0.972
Co	240.7	0.0199	0.0664	0.899
Cd	228.8	0.0539	0.4150	1.00
Zn	213.9	0.0537	0.4102	0.926
Mn	279.5	0.0312	0.0525	0.947

Discussion

Levels of Heavy Metals (HMs)

The HM FAO/WHO values compared to the present study data varied significantly, except for cadmium in all meat parts. Table 3(a) shows the concentrations of HMs in the liver of beef, caprine, mutton, and chicken. The poisonous Cr and Pb were not discovered in the animal livers, indicating that the liver was capable of detoxifying itself of these two compounds via bio-metabolism but was connected with the other elements. In contrast to another study, Pb and Cr were identified in sheep meat and offal samples, indicating the existence of polluted feed, feedstocks, and drinking water sources (6). Other studies suggest anthropogenic sources (21,22).

The highest Fe and Cu levels were found in chicken and beef livers, at 1.66 and 1.60 mg/kg, respectively. Ni values

Table 2. The FAO/WHO maximum permissible values of HM in meats and safe limits

Metals	Maximum Permissible Level (mg/kg)	Kidney (µg/kg/bw/day)	Liver (µg/kg/bw/day)
Cr	0.05	na	na
Pb	0.1	0.5 mg/kg	0.5 mg/kg
Cu	0.05-0.5	Na	na
Fe	0.01	na	na
Ni	na	na	na
Co	na	na	na
Mn	na	na	na
Cd	0.5	1.0 mg/kg	0.5 mg/kg
Zn	0.3-1.0	Na	na

Source: (Ref: 8,31); na: not available.

Table 3. Heavy metal concentrations in liver, kidney, and meat samples

2a.	Liver of Beef, Goat, sheep, and Chicken								
Sample mg/kg	**Cr**	**Pb**	**Cu**	**Fe**	**Ni**	**Co**	**Mn**	**Cd**	**Zn**
Beef	0.00	0.00	1.60±1.2	0.87±0.15	0.31±0.01	0.03±0.01	0.11±0.01	0.03±0.01	0.00
Goat	0.00	0.00	0.63±0.21	1.32±0.07	0.11±0.01	0.06±0.01	0.11±0.00	0.03±0.02	0.03±0.03
Sheep	0.00	0.00	1.03±0.32	0.94±0.25	0.22±0.02	0.01±0.00	0.06±0.01	0.02±0.01	0.02±0.02
Chicken	0.00	0.00	0.20±0.26	1.66±0.30	0.31±0.01	0.00	0.10±0.02	0.00	0.08±0.03
2b.	***Kidneys* of Beef, Goat, Sheep, and Chicken**								
Sample	**Cr**	**Pb**	**Cu**	**Fe**	**Ni**	**Co**	**Mn**	**Cd**	**Zn**
Beef	0.02±0.02	0.00	0.50±0.35	0.70±0.17	0.00	0.00	0.08±0.01	0.03±0.00	0.00
Goat	0.02±0.02	0.00	0.33±0.29	0.83±0.20	0.02±0.01	0.02±0.01	0.04±0.01	0.05±0.00	0.01±0.01
Sheep	0.01±0.01	0.00	0.83±0.35	0.80±0.08	0.16±0.01	0.03±0.01	0.00	0.02±0.01	0.00
Chicken	0.03±0.01	0.00	0.30±0.26	0.46±0.16	0.00	0.00	0.04±0.01	0.00	0.04±0.03
2c.	***Lean Meat of Beef*, Goat, Sheep, and Chicken**								
Sample	**Cr**	**Pb**	**Cu**	**Fe**	**Ni**	**Co**	**Mn**	**Cd**	**Zn**
Beef	0.04±0.04	0.00	0.00	1.01±0.10	0.00	0.04±0.01	0.06±0.01	0.02±0.01	0.01±0.02
Goat	0.00	0.00	0.17±0.15	0.44±0.10	0.05±0.01	0.00	0.00	0.01±0.00	0.00
Sheep	0.01±0.02	0.00	0.03±0.06	0.54±0.15	0.15±0.01	0.27±0.06	0.00	0.00	0.05±0.02
Chicken	0.00	0.00	0.23±0.41	0.50±0.29	0.00	0.02±0.01	0.07±0.01	0.00	0.02±0.01

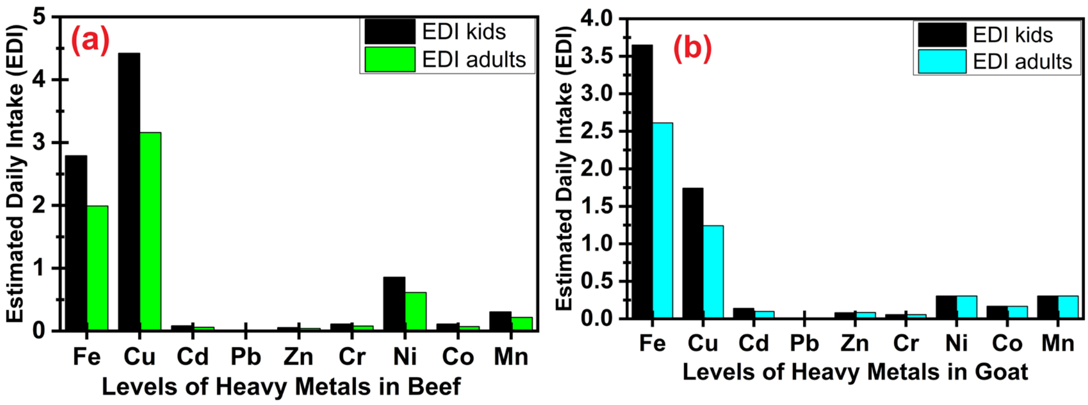

Figure 2. Heavy metal concentrations in liver, kidney, and meat samples of beef and goat

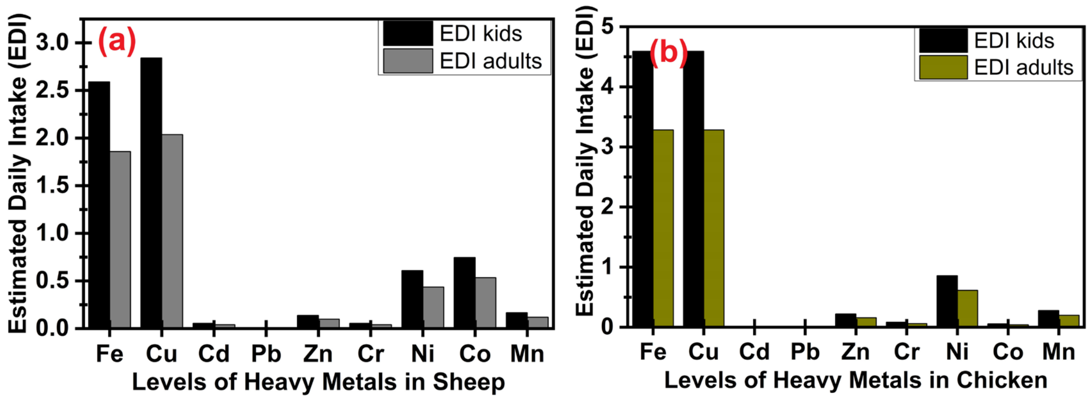

Figure 3. Heavy metal concentrations in liver, kidney, and meat samples of sheep and Chicken

greater than 0.01 and lower than 0.31 mg/kg were higher than Co, Mn, Cd, and Zn values, but lower than Cu and Fe values. The conclusion correlated with a study that linked consumption of such HMs to cytotoxicity and systemic diseases (32). The data from the present study were compared with the results from a separate investigation on toxic metal contamination in goat carcasses processed for human consumption in Southeastern Nigeria. The mean concentrations of lead (Pb) in that study were 0.48±0.38, 0.45±0.24, and 0.82±0.39 mg/kg, while cadmium (Cd)

Table 4. The provisional daily or weekly intake recommendations for heavy metals, along with their effects.

Metal	Provisional intake	Description of effects
Cr	35 µg/day (men) 25 µg/day (women)	Essential for insulin function; deficiencies can lead to glucose intolerance.
Pb	No safe limit	Toxicity can cause developmental issues, neurological damage, and kidney dysfunction.
Cu	900 µg/day	Essential for iron metabolism and nervous system function; excess can lead to toxicity (liver damage).
Fe	8 mg/day (men) 18 mg/day (women)	Essential for oxygen transport; deficiencies can lead to anemia; excess can cause toxicity (organ damage).
Ni	1-3 µg/day	Potential role in enzymes; deficiency effects are not well characterized. Excess can cause allergic reactions.
Co	2.4 µg/day	Essential for vitamin B12 synthesis; deficiency can lead to anemia and neurological issues.
Mn	2.3 mg/day (men) 1.8 mg/day (women)	Essential for bone formation and metabolism; excess can lead to neurological disorders (manganese).
Cd	0.5 µg/kg body weight (weekly)	Toxicity can cause kidney damage and bone fragility; no safe level for long-term exposure.
Zn	11 mg/day (men) 8 mg/day (women)	Essential for immune function, wound healing; excess can cause nausea, immune dysfunction.

Source (Ref: 8,31).

levels were 0.06 ± 0.32, 0.02 ± 0.00, and 0.02 ± 0.00 mg/kg in kidney, liver, and muscle tissues, respectively. These concentrations were significantly higher than those observed in the present study (33).

Table 3(b) shows the determined HM levels in the kidneys of beef, caprine, mutton, and chicken. Similarly, the Pb metal was not discovered in any of the animal kidneys, unlike Cr, which had values ranging from 0.01 ± 0.01 to 0.03 ± 0.01 mg/kg, suggesting a route to non-occupational human exposure to Cr through diet (34). As previously stated, Cu and Fe concentrations in the kidneys were much greater than those in the other metals, ranging from 0.20 to 0.83 mg/kg. The concentration of the other metals was less than 0.16 mg/kg. This showed higher levels of Fe and Cu in relation to forages, feeds, and soils (6), but does not resemble values consumed in the wild; therefore, it is not a major health threat to consumers (35). Furthermore, consistent low-dose exposure binds selectively to specific macromolecules and poses consequences such as poisoning, anxiety, weariness, and even a drop in the intelligence quotient in youngsters.

Table 3(c) presents the levels of heavy metals (HMs) in lean meat from beef, goat (caprine), mutton, and chicken. Chromium (Cr) was detected at concentrations of up to 0.04 mg/kg, which is below the FAO/WHO permissible limit (0.05 mg/kg). This suggests that there is no significant Cr contamination from sources such as drinking water, feed, or the meat pathways, including the liver, kidney, and lean meat. Fe and Cu were also abundant in the lean meat and other portions of the animals studied. Except for the 0.27 mg/kg concentration of Co discovered in sheep (mutton), there was little evidence of Co, Mn, Cd, and Zn. As a result, bioaccumulation of Co, Mn, Cd, and Zn was generally modest, indicating a similar pathway for these low concentrations to bind to reactive oxygen species, weakening antioxidant defense and oxidative stress (33,36). Similar studies on heavy metals in commercial chicken meats found in southern Nigeria showed that the mean heavy metals ranged from 0.001 ± 0.001 mg/kg (Cr) to 2.094 ± 0.001 mg/kg (Zn) and varied significantly ($P < 0.05$) with Warri samples (58.9%) yielding the highest level, followed by Benin City (26.8%), Ado-Ekiti (10.2%), and Akure (4.2%) samples (37).

Statistical Variations and Mechanism

The lean meat of beef contained the highest level of Cr (0.04 mg/kg), while animal livers contained the least one (0.00 mg/kg). The Pb concentration in the caprine liver peaked at 0.23 mg/kg, whereas the chicken meat had the lowest concentration at 0.1 mg/kg. Both Cr and Pb exhibited no significant differences ($P > 0.05$). The chicken liver had the highest level of copper (1.44 ± 0.06 mg/kg), while the chicken meat contained the least one (0.1 mg/g). Fe and Cu levels in liver, kidney, and meat organs varied significantly ($P < 0.05$) across the tested samples. The highest Fe concentration was found in chicken liver (1.66 ± 0.30 mg/kg), whereas mutton had the lowest one at 0.44 mg/kg. The chicken liver had the highest level of Ni (0.31 mg/kg), whereas the caprine meat contained the least one (0.1 mg/kg). The highest Mn content was 0.11 mg/kg in chicken liver, while the lowest one was 0.45 mg/kg in beef flesh. Mn showed statistical variation < 0.05, but Ni had no statistical variation > 0.05. The mutton kidney had the highest Cd levels (0.05 mg/kg), whereas the chicken meat had the lowest one (0.01 mg/kg). Zn concentration was the highest in chicken liver (0.08 mg/kg), and the lowest in beef (0.00 mg/kg). There were no substantial differences between Cd and Zn ($P < 0.05$).

HM bioaccumulation activity has the potential to affect a range of human organs. They influence biological processes such as growth, cell division, proliferation, and repair by interacting with certain macromolecules or proteins (18,33). In this regard, Pb's interaction with aminolevulinic acid dehydratase demonstrates how it can also bind to reactive oxygen species, impairing the antioxidant defense mechanism. These essential organs and glands, including the liver, kidney, heart, brain, and bone, are impacted by the accumulation and disruption of their activities (18,38). The HMs may transport key nutritional minerals away from their original place, disrupting their biological function. Several HMs, such as Cr, Cd, and Pb, have the potential to cause cancer via oxidative stress and DNA damage. They begin their actions by interacting with biological substances, losing one or more electrons in the process, and forming a reactive cation with the ability to attack macromolecular nucleophiles, causing both short- and long-term effects. Thus, the EDI, THQ, and ILCR were calculated to determine the toxicity, non-carcinogenicity, and carcinogenic potential (33,38).

Health Risk and Cancer Assessment

The results of the present study were compared with those of two similar studies conducted in Nigeria, referenced by (30) and (39). The levels of Pb and Cd observed in this study were comparable to those reported by (22) and (39) for beef sold at Gwagwalada Market, Abuja, and fish from Kado Market. However, the concentrations of Zn, Fe, and Mn in the present study were significantly higher than those reported in these studies. Additionally, when compared to a study from Kuwait (6), our findings exceeded the levels of heavy metals (HMs) in sheep meat and offal. In contrast, a comparison with the flesh and internal organs of broiler chickens in Pakistan (11,40) showed similar levels of HMs. Consequently, various methodologies have been proposed to assess the potential health risks posed by the consumption of food contaminated with hazardous heavy metals. Based on the data on food toxicity in Nigeria, the WHO standards, and the Standard Organization of Nigeria (SON) approved limits on the estimated daily intake of beef, mutton, caprine, and chicken meat were computed and depicted in Figures 2 and 3 using the mean values (8,10,41). The recommended references (RfDs) were based on similar reports from previous studies. The calculated daily exposure values for this investigation were lower.

The World Health Organization (WHO) provides recommended provisional guidelines for the daily allowance of essential metals such as iron (Fe), copper (Cu), and zinc (Zn), which are required for biological functions. In children, Fe, Cu, and Zn are 6, 1, and 7 mg/kg for all consumption, including food and supplements, while adult males and females have 8/18, 0.9/1.0, and 11/8 mg/kg, respectively. The data were compared with the WHO guidelines for adults, as shown in Table 2, and with the WHO/FAO provisional weekly/daily tolerable intake as shown in Table 4 (PWTI), and all of the calculated EDI were lower than the WHO/FAO/PTWI. The WHO maximum tolerable Cd limit of 0.49 mg/kg was lower than the calculated EDI in all of the samples tested. The WHO MAL value for Co at 0.25 mg/kg was exceeded in mutton ingested by both kids and adults by 0.746 and 0.533, respectively, whereas Mn was judged non-essential and non-toxic. To assess the health risks associated with these metals, the targeted hazard quotient (THQ) was developed. All THQs in beef, goat, sheep, and chicken were greater than one for both adults and children, except for Pb and Zn, and have been similarly observed in another state/region (15). As a result, it was regarded as having moderate to high risk, with probable unfavorable health effects. A study on metal contamination in soil, plants, feed, and food within the Niger Delta region of Nigeria identified a clustering of As, Cd, and V associated with various types of meat, including chicken, goat, and cow. The highest loadings were observed for V and Zn, specifically linked to soil and meat (goat and cow) samples, which were distinct from those of As and Cd. Additionally, Cd and V exhibited different pollution patterns. Pb intake through meat and fish consumption for both adults and children was significantly higher than the tolerable limits established by the international regulatory bodies. These findings highlight the complexity of metal pollution within the feed-to-food chain and its potential implications for human health in Nigeria (42).

The non-cancer risk was modeled by applying the standard formula used for the target hazard quotient except for Pb and Zn, which showed no carcinogenic risk. The metals tested were greater than 1 for both children and adults. The simulated cancer risk was nonexistent in Pb and Cd, but present in Ni > Cr for all adults and children (especially children) who consume beef, mutton, caprine, and chicken. As a result, there is a carcinogenic risk in the meat of animals in the examined area, possibly indicating a broader concern across the majority of abattoirs and a potential threat if left unregulated. In addition, a systematic review on the methods, pollution levels, and policy implications of heavy metal contamination in soils, water, and food in Nigeria from 2000 to 2019 revealed that concentrations of heavy metals in food crops, meat, and milk consistently surpassed the WHO/FAO safety thresholds across all urban areas studied. The findings underscore the widespread contamination of key food sources, including plant-based crops, livestock (meat), and dairy products, posing significant risks to public health (43). However, according to another study (44), the general limitations of EDI, CDI, THQ, and ILCR are that risk is assumed to be from a specific source rather than being estimated from aggregate exposures. The use of THQ and ILCR does not indicate specific effects on target organs; hence, it may not correspond to real-life exposure scenarios. Therefore, for comparative purposes, further studies can adopt emerging proposals for calculating aggregate exposures, as the consensus among regulatory toxicologists regarding dietary estimations has not yet been established.

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Competing interests

The authors have no competing interests to declare.

Ethical issues

FUTO/PRODA/DIR/FOOD/Abattoir/177-023.

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