

Heavy Metal Concentrations in Local and Northern Goat Breeds and their Associated Health Risks through Consumption

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Abstract

This study investigated heavy metal concentrations and associated health risks in tissues (kidney, liver, and muscle) of local and northern goat breeds obtained from Oliha and Aduwawa Cattle Markets, Benin City, Edo State, Nigeria. Samples were analyzed using atomic absorption spectrophotometry to determine levels of zinc (Zn), cadmium (Cd), and lead (Pb). Results showed that Zn had the highest concentrations in all tissues, with the muscle of the local breed showing the greatest accumulation (1.4 ± 0.28 mg/kg), while the local breed kidney had the lowest (0.2 ± 0.141). Cd and Pb levels were generally below detectable limits in most tissues, particularly in the northern breed. The measured concentrations of all metals were within permissible limits for human consumption. Health risk assessment revealed target hazard quotient (THQ) values of 0.00694 (local breed) and 0.00361 (northern breed), indicating no non-carcinogenic risk. However, cancer risk (CR) values for Cd (2.04×10^{-5}) and Pb (4.82×10^{-8}) in the local breed were below the recommended threshold (10^{-4}). The presence of heavy metals in local breed suggests potential carcinogenic concern from local goat meat consumption. Overall, meat from both northern and local goats breed posed minimal health risk. However, regular monitoring of heavy metals in livestock and further studies on both indigenous and imported animals is recommended to protect public health and strengthen food safety measures.

Keywords: Heavy Metals, Health Risk, Concentrations, Hazard Quotients, Goat Breed, Cancer Risk, Nigeria.

Introduction

Heavy metals are natural components of the earth's crust. They are persistent and cannot be easily degraded or destroyed. To some extent they enter our bodies through food, drinking water and air. Some heavy metals (e.g., copper, selenium, zinc) are essential to maintain the metabolism of the human body (Nriagu *et al.*, 2019; Ugwu, 2010). However, at higher concentrations they can lead to poisoning. Most of the non-essential heavy metals are carcinogenic, teratogenic and pose severe health problems like organ damage, reduce growth and development, nervous system impairments and oxidative stress (Chadi & Abdulhameed, 2018).

The consumption of meat is of immense benefit as it provides a substantially large amount of essential micronutrients to man. Meat is most important source of protein to millions of people worldwide. It is known to be one of the cheapest sources of protein and other essential nutrients required in human diets. Because of its distinctive taste and desirable chemical composition, goat meat is increasingly consumed in Nigeria. Globally, consumption of goat meat is lower than consumption of beef, but goats undoubtedly serve as a major source of red meat for the people, particularly in developing countries like Nigeria. Heavy metals are naturally present in the environment, their occurrence, however, has gradually been increasing with the increase in industrialization (Enuneku *et al.*, 2025). Accumulation of toxic metals in the environment as a result of pollution by industrial and urban activities has generated global health concerns due to the risks of such chemical ending up in the food chains (Mukhtar *et al.*, 2022a). Heavy metals such as lead, cadmium, Zinc, arsenic, and mercury are pervasive environmental contaminants often found in soil, water, and feed sources. Due to their bio-accumulative nature, these metals can accumulate in the tissues of animals, including goats, through ingestion of contaminated fodder, water or exposure to polluted environments (Demirezen *et al.*, 2006).

Local goat breeds, commonly reared in smallholder farming systems, may be particularly vulnerable to heavy metal exposure due to limited access to uncontaminated grazing areas and inadequate feed management practices. Consequently, there is a pressing need to investigate the extent of heavy metal accumulation in tissues of local goat breeds and assess the associated health risks for consumers. The presence of heavy metals in goat meat poses potential health hazards to consumers upon ingestion. Chronic exposure to heavy metals has been linked to various adverse health effects, including neurological disorders, kidney damage, cardiovascular diseases, and carcinogenicity (Chadi & Abdulhameed, 2018). Vulnerable populations such as pregnant women, infants, and the elderly are at heightened risk due to their increased susceptibility to the toxic effects of heavy metals.

Health risk assessment of heavy metal contamination in local goat breed and northern breed is of great concern for both food safety and human health because of the toxic nature of these metals at relatively minute concentrations. Moreover, the lack of comprehensive monitoring and regulatory measures exacerbates the risk, as consumers may unknowingly be exposed to contaminated goat meat without proper labeling or awareness.

The presence of heavy metals such as cadmium (Cd), lead (Pb), iron (Fe), copper (Cu), and manganese (Mn) in food in developing countries is a significant issue for public health (Nambowa *et al.*, 2024). The contamination of heavy metals in the food chain presents a significant danger because of their poisonous properties, ability to accumulate in organisms, and tendency to increase in concentration as they go up the food chain. Furthermore, the potential risk associated with the presence of heavy metals in meat is a cause for alarm for human health (Abd-Elghany *et al.*, 2020). Heavy metals do not degrade; thus, they persist and accumulate in animal organs and tissues including muscle, liver, and kidney leading to hazardous quantities that are harmful to consumers (Nambowa *et al.*, 2024).

Several studies such as Muktar *et al.*, 2022b; Njoga *et al.*, 2021; Nambowa *et al.*, 2024; Adeoye *et al.*, 2025; Al-Perkhdri *et al.*, 2025 on heavy metal concentrations in goat breed have been documented in different parts of the world. However, there is still a paucity of studies on heavy metals concentrations in goat breed in Benin City, Edo State Nigeria. Thus, this study aims to assess heavy metal concentration and health risks in local goat breeds and northern goat breeds. The following are the objectives of the study:

1. Determination of Zn, Cd, and Pb concentrations in kidney, liver, and muscle of both breeds
2. Comparison of heavy metal concentrations against WHO/FAO permissible limits
3. Evaluate the carcinogenic health risks (EDI, THQ, and cancer risk) associated with the consumption of goat meat contaminated with heavy metals.

Literature Review

Theoretical/Conceptual Framework

This study is anchored on the United States Environmental Protection Agency (USEPA) Human Health Risk Assessment Framework, which serves as both the theoretical and conceptual basis for evaluating the health implications of heavy metal contamination in food. The framework is widely applied in environmental toxicology and food safety studies to assess the risks associated with exposure to contaminants through dietary intake. It provides a systematic approach for determining how environmental pollutants accumulate in food products and the potential health consequences of their consumption.

The theoretical foundation of this framework is based on the dose–response relationship, which posits that the magnitude of adverse health effects is directly related to the level and duration of exposure to a contaminant. In environmental health studies, heavy metals such as cadmium (Cd) and lead (Pb) are recognized as toxic elements that can accumulate in biological tissues and pose significant health risks even at relatively low concentrations when exposure occurs over extended periods. Zinc (Zn), although an essential trace element required for normal metabolic functions, may also become harmful when present in excessive amounts. The dose–response principle therefore explains how exposure to varying concentrations of heavy metals may result in different health outcomes ranging from negligible effects to severe toxicity and cancer.

The USEPA risk assessment paradigm consists of four interrelated stages: hazard identification, dose-response assessment, exposure assessment, and risk characterization. Hazard identification involves determining the presence of contaminants such as Zn, Cd, and Pb in goat tissues. Dose-response assessment evaluates the relationship between contaminant concentration and potential health effects. Exposure assessment estimates the amount of heavy metal ingested by consumers through meat consumption, while risk characterization integrates exposure and toxicity information to determine the likelihood of adverse health outcomes.

Conceptually, this study assumes that environmental contamination arising from anthropogenic activities such as industrial emissions, vehicular traffic, waste disposal,

agricultural practices, and contaminated water or feed sources introduces heavy metals into the ecosystem. Goats grazing or feeding within such environments absorb these metals, which subsequently accumulate in edible tissues including the kidney, liver, and muscle. The degree of accumulation depends on factors such as environmental contamination levels, feeding habits, physiological characteristics of the animals, and the chemical properties of the metals.

Human exposure occurs through the consumption of contaminated goat meat and organs. The number of heavy metals ingested is quantified using the Estimated Daily Intake (EDI) model, which estimates the daily exposure of consumers relative to body weight. The potential non-carcinogenic health effects are evaluated using the Target Hazard Quotient (THQ), where values less than one indicate negligible risk and values greater than one suggest possible adverse health effects. Similarly, the Cancer Risk (CR) model estimates the probability of developing cancer over a lifetime due to exposure to carcinogenic metals such as cadmium and lead. Together, these risk assessment indices provide a comprehensive understanding of the potential health implications of consuming goat meat contaminated with heavy metals.

The framework therefore establishes a logical relationship between environmental contamination, heavy metal accumulation in goat tissues, human dietary exposure, and subsequent health risks. In the context of this study, heavy metal concentrations (Zn, Cd, and Pb) in the kidney, liver, and muscle tissues of local and northern goat breeds represent the independent variables, while the estimated daily intake, target hazard quotient, and cancer risk constitute the dependent variables used to assess consumer health outcomes. The framework guides the investigation by explaining how contaminants move from environmental sources into animal tissues and ultimately affect human health through food consumption.

Sources of Heavy Metals Contamination

Heavy Metals in the Atmosphere

Heavy metals presence in the atmosphere may result from combustion of fossil fuel. They could also emanate from non-exhaust sources like wear and tear of vehicle brakes and tyres, and from a host of other anthropogenic activities (Anake *et al.*, 2017). Metals may exist in form of vapour in the air, thereby increasing the chance of being inhaled by humans.

There have been reports of heavy metals presence in the atmosphere in Northern Nigeria. Mafuyai *et al.* (2014) determined heavy metals (Pb, Cr, Fe, Mn, Cd, Zn, Cu and Ni) in respirable dusts from seven locations within Jos metropolis, Plateau state, over a period of 3 months. Concentrations of Cd, Ni and Mn were found to greatly exceed the WHO recommended limits for the metals in respirable dusts. The study attributed the presence of the metals in the samples to vehicular traffic and wastes incineration in the city (Mafuyai *et al.*, 2014). Ayua *et al.* (2020) also investigated heavy metals in respirable dust and PM around industrial sites in Kano, Kaduna and Jos. Concentrations of Cd, Ni and Pb were found to be above the WHO set standard limits in some of the areas studied. The study reported strong correlation between PM and the heavy metals, thereby confirming that the

contaminants indeed originated from the industrial activities. This finding also gives credence to the use of sampled air-suspended PM for the evaluation of heavy metal levels in air, as reported by most of the studies.

Heavy Metals in Ground Waters, Surface Waters and Aquatic Biota Species

The majority of Nigerian homes depend on underground waters, accessed via hand-dug wells and mechanically drilled borehole facilities for their water supply and only about 10% of Nigerians have access to centrally managed clean pipe-borne water (Idowu *et al.*, 2022). Many rural populations also depend on water abstracted from unprotected surface sources such as streams and rivers. This situation, coupled with poor enforcement of environmental laws, which potentially exposes these water resources to contamination by various industrial and municipal wastes, has formed part of the motivation for many studies investigating levels of heavy metals in water samples. Additionally, unprotected and unmanaged streams and rivers often serve as means of recreation (i.e. swimming) to people in rural Nigeria, with the potential hazard of ingesting waters contaminated with toxic metals.

Denkok *et al.* (2021) determined heavy metals in various water samples, including ground water and factory-packaged sachet water, in Jos, Plateau state. The authors found that the levels of Pb, Cd, Cr, and Cu were higher than their respective WHO allowable limits in drinking water. Adeyemi and Ojekunle (2021) investigated heavy metals concentrations in underground waters (which provide drinking water to people) around industrial estates in Ogun state. High concentrations of Pb, Fe, Ni and Cr were measured in the samples, with the total hazard index (HI) showing high risk across different age groups, and particularly for infants.

On the other hand, Enuneku *et al.* (2018) worked on water samples from boreholes sited close to some dumpsites in Benin city, Nigeria. Based on the metals pollution indices and the estimated daily dosage through drinking, it was established that the levels of metals in the boreholes posed no threat to the health of the people. Afolayan (2018) reported heavy pollution of surface waters in Ibadan with Pb, Cd and Fe, due to the presence of a battery waste dumpsite from which these metals leach to the surface water. Odebunmi *et al.* (2014) worked on various ground and surface water samples from different locations in Osun state, and found that the toxic metals (Pb, Hg, As and Cd) were all higher than WHO permissible limit for drinking water. Because many Nigerian homes harvest rainwater for drinking during the rainy season.

Olabanji and Adeniyi (2005) investigated heavy metals content of rain water, comparing levels in free-fall rain water to those harvested via roof tops. The study found that the metals concentrations were higher in roof-harvested rain water, with the metals content reflecting the metallic composition of the roofing material. However, levels in both water types were within safe limits and were lower than those determined for the neighbouring surface waters, packaged table waters, and vegetation-intercepted rainwater.

Ekere *et al.* (2014) determined levels of As, Cd, Hg, Pb, Cr, Fe and Cu in water samples from streams, lakes/ponds and hand-dug wells in rural parts of South-Eastern Nigeria. The result showed that except for Hg, other showed above the permissible limit of drinking water. The total hazard index of the metals, assessed through human oral water consumption, indicated that the water sources were mostly of high risk.

A number of studies (for example Aiyesanmi *et al.*, 2010; Anani and Olomukoro, 2017; Aduwo and Adeniyi, 2018; Ayeku *et al.*, 2019; and Aigberua *et al.*, 2020) have also reported levels of heavy metals in river sediments, the bottom layer comprising soil, dead and decayed plant and animal materials, onto which metals are significantly adsorbed and may be suspended into the water column.

Heavy Metals in Soils

Soil could be imparted with trace metals through weathering and mineralization of parent rock materials, as well as anthropogenic influences such as industrialization, mining, indiscriminate waste dumping and automobile emissions. Particular areas of soil prone to receiving high concentrations of heavy metals in Nigeria are the waste dumpsites, serving as receptacle for all forms of solid and liquid wastes and are mostly unregulated by authorities.

Aiyesanmi and Idowu (2012) reported high concentrations of heavy metals in soils of three dumpsites in Akure, Southwestern Nigeria. Order of concentration of the metals was the same in the three dumpsite soils and followed the pattern: Cu > Ni > Pb > Zn > Cr > Cd > Co. High concentrations of all the metals were also detected in edible leafy vegetables (*Amaranthus spinosus* and *Talinum triangulae*) found growing around the waste dumpsites. Eze *et al.* (2022) investigated heavy metals levels in four major dumpsites in South-eastern Nigeria and performed an assessment of human health risks associated with metals at the dumpsites. The study revealed that children were at the highest risk of exposure to As, Pb and Ni, with the ingestion exposure pathway being the major contributor to both the cancer and non-cancer risks. Electronic wastes, particularly the cathode and anode of batteries used in many portable devices, contain substantial number of heavy metals and rare earth elements after their useful life (Odegbemi *et al.*, 2021).

Study by Ofudje *et al.* (2014) and Ibe *et al.* (2018) on electronics workshops and electronic wastes dumpsites in Nigeria have demonstrated the release of heavy metals from these materials. Investigation of heavy metals in soil near a battery wastes dumpsite in Ibadan, Oyo State by Afolayan (2018) revealed soil contamination factor above 6.0 for Cd, Pb and Fe, indicating excessive and severe pollution of the soil with the metals. Furthermore, the toxic metals, Cd and Pb, were found at concentrations above 2.80 and 40.0 mg/kg, respectively, in maize plants grown near the battery dumpsite. Accumulation of metals in vegetables growing around dumpsites is a major cause for concern, as unsuspecting individuals may fetch them for consumption or for sales in open markets. Soils in the proximity of industrial sites have also attracted some attention.

Two recent studies (Olatunde *et al.*, 2020; Laniyan and Adewumi, 2020) investigated heavy metals levels of soils around different cement factories in Southwestern Nigeria. Heavy

metals concentrations were higher in the soil samples, compared to the appropriate reference samples analysed in the studies. Considerable pollution and potential ecological risk from Cd, Cr, Ni and Pb were observed by Olatunde *et al.* (2020) for soil samples around Ibese cement factory. In addition to the proximal soil pollution with heavy metals at the Ewekoro factory, Laniyan and Adewumi (2020) detected Cu, Pb, Cr, Co and Ni in vegetables and root crops, at concentrations above international maximum safe limits.

Ogundele *et al.* (2021) worked on soil samples from both active and abandoned artisanal gold mining sites in Ile-Ife, Nigeria. While various metals were detected in the samples, concentration of Pb was particularly high and an assessment of contamination status via geoaccumulation indices revealed that the soils were indeed contaminated with Pb. Floodplain soils (adjacent to rivers) are commonly used in Nigeria for cultivation of food crops and vegetables, due to their alluvial nature and the availability of water for irrigation purposes. A number of recent studies have been focussing on the metals content of floodplain soils, which potentially derive from materials deposited by overflowing rivers, themselves contaminated with toxic trace metals.

Another study by Aiyesanmi *et al.* (2020) determined the speciation of metals in the floodplain of Onukun river, Ondo state. Cu was found to be associated with the soil organic fraction; Pb and Zn exists in reducible fractions, while Cr and Fe are associated with the residual fraction. The findings suggest that Cu, Pb and Zn were mostly contributed by fluvial deposition to the floodplains, whereas Cr and Fe determined in the soils were more of geogenic or lithologic origin. Association of Pb with reducible soil fraction and attribution to anthropogenic activities was also reported by Ebong *et al.* (2019). In relation to agriculture, soil of vegetable farms irrigated with wastewater have showed higher levels of heavy metals, than similar soils with no wastewater applied (Abdu *et al.*, 2011).

Levels of Heavy Metal Accumulation (e.g., Lead, Cadmium, Zinc) in the Tissues (Muscle, Liver, And Kidney) of Local Goat Breeds

Heavy metal contamination in food, particularly meat products, has garnered significant attention due to its potential health implications. The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) set permissible limits for heavy metals in food items, including meat, to ensure consumer safety. Studies have extensively explored the concentrations of heavy metals such as Cadmium (Cd), Lead (Pb), and Zinc (Zn) in goat meat, reflecting the broader concerns about metal toxicity and nutritional deficiencies.

Fat and protein contents and sensory characteristics have been considered as mainly determinants for meat quality in traditional meat market while healthiness of meat should be contemplated as a critical concept in meat and edible offal quality (Lopez-Alonso *et al.*, 2016). Heavy metals are known as chemical contaminants for meat and edible offal. Metals such as lead (Pb), cadmium (Cd) and mercury (Hg) are toxic even at trace levels and play no useful role in human physiology. Trace essential metals like copper (Cu) and zinc (Zn) are required at low concentration in living organisms to ensure normal growth, development and maintenance, and however their deficiency can cause serious health problems or even

death in livestock, although they pose a risk for human health in exposure to values higher than optimal levels (Nriagu *et al.* 2009; Ugwu, 2010). Accumulation of metals in livestock can be passed on to human through the consumption of their products. Cadmium has been classified as certainly carcinogenic to human.

Therefore, it is necessary to monitor heavy metal residues in meat and animal feed in an accurate manner. Various spectrometric techniques such as flame atomic absorption spectrometry, graphite furnace atomic absorption spectrometry, inductively coupled plasma-optical emission spectrometry and inductively coupled plasma-mass spectrometry have been used for evaluating heavy metals in bovine edible tissues (Sedki *et al.*, 2003; Demirezen and Uruc, 2006; Lopez-Alonso *et al.*, 2016). Some clear advantages, including simultaneous measurement capability of multiple metals and very low detection limits have embossed inductively coupled plasma as choice technique for monitoring the levels of toxic metals in food (Nardi *et al.*, 2009).

Meat, liver and kidney are important sources of essential microelements (notably Fe, Cu, Zn and Se) in the human diet but may also carry toxic metals as residues. Establishment of regulations for heavy metals in these organs has become important in many countries.

For instance, maximum residue limits (MRL) of Pb and Cd (mg/g wet weight) have been prescribed as 0.1 and 0.05 in meat, 0.5 and 0.5 in liver and 0.5 and 1 in kidney of bovine by Commission of the European communities (Commission of the European communities, 2006). The Codex Alimentarius Commission has established a limit for Pb in meat and edible offal of bovine that are the same as those prescribed by Commission of the European Communities (Codex Alimentarius Commission, 1996). In the case of Hg, the European Union has no legal limits in meat products.

A study by Oyebanji *et al.* (2020) investigated the levels of Cd, Pb, and Zn in goat meat samples from selected markets in South-western Nigeria. The study found that Zn were detected in all samples investigated, but Cd was undetected in some samples, especially the liver of goats. Also, the general trend in the mean concentration of metals in goat meat was Zn>Pb>Cd and they were all found in concentrations in some samples that were outside the WHO/FAO permissible limits established in 2006. This indicated an unsatisfactory control of environmental contamination and industrial practices that contribute to Cd and Pb levels in meat and their consumption may have implications.

Another investigation by Oladipo *et al.* (2015) examined the level of heavy metals in parts of goats and cattle and found that Cd values were higher than the permissible limits while Pb was within the limits. The study therefore concluded that public health awareness on the risk associated with Cd ingestion and measures to reduce them in meat and meat products should be advocated.

Further studies by Nnadozie *et al.* (2014) which analyzed the level of heavy metals in milk and meat of four species (camel, cow, goat and sheep) in Sokoto revealed that this produce might be safe for consumption as some toxic metals like Pb were not detected in most samples and other metals like Cd and Zn were found within permissible limits thereby corroborating some of these findings. The study highlighted that although Zn was within

the limits, it was quite low raising concern for deficiency as it is an essential mineral needed for normal physiological body processes.

Zinc deficiency, as indicated by low concentrations in goat meat, can have adverse effects on human health. Studies by Singh *et al.* (2018) and Khan *et al.* (2021) have linked Zn deficiency to immune system dysfunction, delayed wound healing, and impaired cognitive development, especially in vulnerable populations such as children and pregnant women. In conclusion, while the concentrations of Cd and Pb in goat meat are within acceptable limits set by WHO/FAO, the persistent deficiency of Zinc underscores the need for comprehensive strategies to address nutritional deficiencies in meat products. Future research should focus on enhancing Zn bioavailability in livestock and exploring dietary interventions to mitigate Zn deficiency in consumers, ensuring both food safety and nutritional adequacy.

Toxic Effects of Heavy Metals

Cadmium (Cd): Cadmium (Cd), although rare, occurs naturally in soil and minerals such as sulfide, sulfate, carbonate, chloride, and hydroxide salts as well as in water. High levels of Cd in water, air, and soil can occur following industrial activities which could be a substantial human exposure to Cd. Moreover, the ingestion of contaminated food will cause major exposure to Cd. Cd exposure may also occur through smoking, which is capable of elevating blood and urine Cd concentrations.

Presence of Cd in contaminated water could disturb the necessary mechanisms in the body, possibly resulting in short-term or long-term disorders (Jiang *et al.* 2015; Richter *et al.* 2017; Cao *et al.*, 2018). Cd is classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans (Group 1) (Kim *et al.*, 2020). Occupational exposure to Cd may occur in alloy, battery, and glass production and in electroplating industries.

Due to the importance of the subject, Cd level in the air is routinely monitored in some countries. Rice, grains, and sea food have been found to be polluted by Cd (Chunhabundit, 2016); nonetheless, after oral intake, a small portion of Cd is absorbed. Tragically, the outbreak of Itai-itai disease in Japan was due to the mass Cd contamination of food and water supplies. The patients suffered from painful degenerative bone disease, kidney failure, and the GI and lungs diseases (Nishijo *et al.*, 2017).

Unlike low GI absorption, Cd is more efficiently taken from the lungs via industrial dust. Acute or chronic inhalation of Cd in industrial areas might lead to renal tubular dysfunction and lung injuries. Cd blood concentration in smokers is almost twice higher than that of nonsmokers. Batárióvá *et al.* (2006) found Cd blood levels of 0.4 against 1.3 µg/L for nonsmokers vs. smokers in adult population (Batárióvá *et al.*, 2006). This seems to be related to the nature of tobacco plants to accumulate relatively high Cd concentrations in tissues especially in the leaves (Proshad *et al.*, 2020).

Lead (Pb): Lead is a harmful environmental pollutant which has high toxic effects to many body organs. Even though Pb can be absorbed from the skin, it is mostly absorbed from respiratory and digestive systems. Pb exposure can induce neurological, respiratory,

urinary, and cardiovascular disorders due to immune-modulation, oxidative, and inflammatory mechanisms. Furthermore, Pb could disturb the balance of the oxidant-antioxidant system and induce inflammatory responses in various organs. Exposure to Pb can produce alteration in physiological functions of the body and is associated with many diseases (Joseph *et al.* 2005; Jacobs *et al.*, 2009; Kianoush *et al.*, 2012).

Pb is highly toxic which has adverse effects on the neurological, biological, and cognitive functions in the bodies. The international level-of-concern for Pb poisoning is 10 µg/dl in the blood (Burki, 2012; Kianoush *et al.*, 2013). Adulteration of opium with Pb has been considered as a threat to human health in recent years.

The Carcinogenicity of Heavy Metals

The mechanism of carcinogenicity of heavy metals is unclear and complicated. Carcinogenicity of some heavy metals is assumed to be due to their bonding to regulatory proteins that are involved in cell cycle regulation, DNA synthesis and repair, and apoptosis (Kim *et al.* 2015). Besides, toxicogenomic investigations highlight the characterization of gene expressions after metal toxicity. Transcription factors such as Activator Protein 1 (AP-1), Nuclear Factor-kappa B (NF-κB), and p53 are targets for Cd and As. As a result, controlling the expression of protective genes failed, leading to uncontrolled cell growth and division (Valko *et al.*, 2005).

A few studies have examined Ras's proteins mutations or increased activation in carcinogenic heavy metals exposure. Ngalame *et al.* (2014) showed overexpression of Ras in human prostate epithelial cells following as exposure. In another study, the elevation of the level of ERK 1/2, as well as transcription factors jun and fos, was observed in vitro by Cd. Cr (VI) also induced overexpression of jun in cultured cells. The mutated Ras protein loses its ability to be inactivated and the kinase cascade is not turned off. Besides, intensified jun and fos or activated ERK 1/2 continues repeatedly the gene expression. Thus, a permanently activated signaling pathway results in continuously activated proliferation, leading to increased tumor formation (Zuo *et al.*, 2012; Ngalame *et al.*, 2014; Ataei *et al.*, 2019). Arsenic is shown to inhibit DNA repair by inhibiting poly ADP-ribose polymerase 1 (PARP-1), a responsible enzyme for DNA break repair processes (Ding *et al.*, 2009).

Resistance to apoptosis due to heavy metals exposure breaks down a basic cell defense. It has been shown that Cd can induce malignant transformation of the prostate epithelial cell line through increased apoptotic resistance. Apoptotic resistance is attributed to the overexpression of Bcl-2 and disruption of a specific pathway of apoptosis known as the JNK pathway (Qu *et al.*, 2007). Altered expression of genes involved in apoptosis and DNA repair is proposed for resistance to apoptosis induced by Cr6+ (Pritchard *et al.*, 2005). Moreover, hexavalent Cr causes DNA damage by inactivation of DNA ligase, DNA polymerase β, and PARP-1. Deficient DNA repair due to Cr leads to chromosome instability which is a key mechanism of Cr6+- induced carcinogenesis (Wise *et al.*, 2018).

Materials and Methods

Study Area

This study was conducted in Benin City, Edo State (6.6342°N, 5.9304°E). Edo state is one of the 36 states of Nigeria with a total land area of 17,802km². Benin City is the capital city of Edo State and it is home to several notable markets that are known for their unique offerings, bustling atmosphere and cultural significance. Two of the markets, Aduwawa and Oliha markets were sampled to provide a representative sample of the local goat population against the northern breed. 'Oliha market is located in Oredo Local Government Area and lies between latitude 6.345°N and longitude 5.609°E while Aduwawa market is located in Ikpoba-Okha Local Government Area and lies between 6.367°N and 5.683°E. These markets were chosen because their proximity to major roads and high-traffic urban areas makes them potential hotspots for heavy metal contamination. Figure 1 shows the map of the study area.

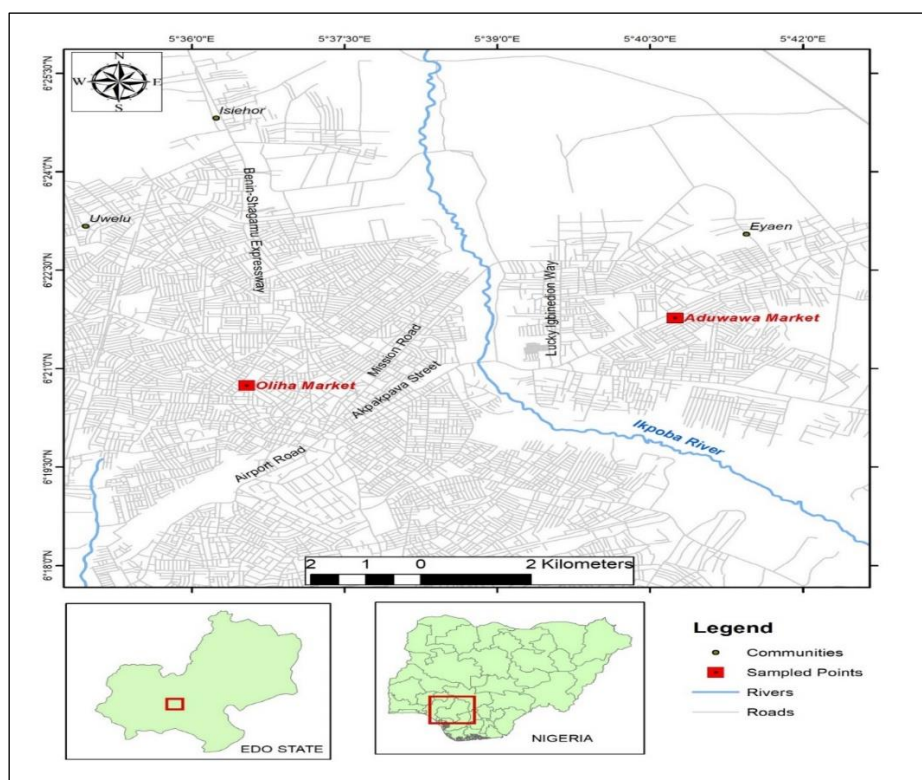


Figure 1: Map of the study area

Sample Collection and Preparation

The organs (kidney, liver, and muscles) of both local and northern bred goat meat was randomly collected after being slaughtered from Aduwawa and Oliha livestock markets in the month of March, 2024. The samples collected were stored in specimen bottles filled with 10% formalin and transported to the laboratory for analysis.

Heavy Metal Analysis

In the laboratory, the organs samples were dried in a crucible for an hour; 10g of each sample (kidney, liver, and muscles) of each breed (local and northern) was introduced into the digestion flask, 20ml of sulfuric acid was added into it and was heated for 30 minutes. It was allowed to flocculate and settled; the flask was heated with high flame. After digestion, hydrogen peroxide was added drop wise until a clear solution, then contents of the flask was filtered into a 50ml volumetric flask and made up to the mark with distilled water. The samples were labeled and thereafter put into plastic containers. The heavy metals concentration and sample digestion were done using the method of Kishore and Machiwa (2003); Likuku *et al.* (2013).

Quality Assurance and Control

The equipment was first calibrated using buck certified atomic absorption standards for the respective heavy metals to obtain calibration curves. Reagent blanks were first run at intervals of every three samples to eliminate equipment drift. All samples were analyzed in duplicates for reproducibility, and to ensure precision and reliability of results.

Statistical Analysis

Results obtained from analysis were evaluated using statistical analysis to characterize the samples. The significant difference in the chemical conditions were tested using parametric analysis of variance (ANOVA).

Human Health Risk Assessment

Risk assessment is the process that evaluates the potential health effects of dietary exposure to a contaminant through one or more exposure pathways. The health risk from consumption of northern breed and local breed meats were analyzed using Target hazard quotient (THQ), and estimated daily intake (EDI).

Estimated daily intake (EDI)

The EDI of Zn, Cd and Pb through consumption of sheep and northern breed meat in the study area were determined using equation 1 presented below:

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

Where, BW is the body weight (kg), C is the concentration of the metal in the tested samples and FIR is the rate of food ingestion rate of meat was estimated at 51g/day (Miller *et al.* 2022). EDI values were expressed as (mg/kg BW/day).

Target hazard quotient (THQ)

THQ is the ratio determined dose of a pollutant to a reference dose level. If the ratio is less than 1, the exposed population is unlikely to experience obvious adverse effects. Target hazard quotient has been recognized as a useful parameter for evaluation of risk associated with the consumption of metal contaminated food.

The THQ was estimated using the U.S. Environmental protection agency (EPA) region III risk-based concentration model table (USEPA, 1995) according to the equation below:

$$THQ = \frac{EDI}{RfD} \quad (2)$$

Cancer risk

The ILCR is defined as the incremental probability of a person developing any type of cancer over a lifetime as a result of exposure to a given daily amount of a carcinogenic element for 70 years (Mohammadi *et al.*, 2019). The following equation is commonly used for the calculation of the life time cancer risk. USEPA 2011 states that 10^{-6} (1 in 1,000,000) to 10^{-4} (1 in 10,000) indicates a range of permissible predicted lifetime risks for carcinogens. Chemicals for which the risk factor falls below 10^{-6} may be eliminated from further consideration as a chemical of concern.

$$\text{Carcinogenic risk} = EDI \times CSF_{ing} \quad (3)$$

Where;

EDI is the estimated daily intake of each heavy metal (mg/kg/day)

CSF_{ing} is the ingestion cancer slope factor (mg/kg/day)⁻¹.

Results

Table 1: Heavy metal concentrations in local and northern breed goat meat

	Zn	Cd	Pb	
Samples	Mean±SD (min-max)	Mean±SD (min-max)	Mean±SD (min-max)	p-value
Local breed kidney	0.2±0.141 (0.1-0.3)	0.005±0.007 (0-0.01)	0.005±0.007 (0-0.01)	p>0.05
Local breed liver	1.25±0.07 (1.2-1.3)	0.005±0.007 (0-0.01)	0.01±0.014 (0-0.02)	p>0.05
Local breed muscle	1.4±0.282 (1.2-1.6)	0±0 (0-0)	0.005±0.007 (0-0.01)	p>0.05
Northern breed kidney	0.8±0.565 (0.4-1.2)	0±0 (0-0)	0±0 (0-0)	p>0.05
Northern breed liver	1.4±0.141 (1.3-1.5)	0±0 (0-0)	0.005±0.007 (0-0.01)	p>0.05
Northern breed muscle	1.25±1.484 (0.2-2.3)	0±0 (0-0)	0±0 (0-0)	p>0.05

Human Health Risk Assessment

Estimated daily intake (EDI)

The EDI of Zn, Cd and Pb through consumption of sheep and northern breed meat in the study area were expressed as (mg/kg BW/day) in Table 2.

Target hazard quotient (THQ)

The oral reference dose for (RfDo) for zinc is 0.3mg/kg/day, cadmium 0.001mg/kg/day and 0.004mg/kg/day for lead were used to achieve the result for target hazard quotient as

shown in table 2. From the calculation the target hazard quotient indicated that there is no non-cancer risk associated with this breed of meat as shown in table 2.

Table 2: Evaluation of target hazard quotient and estimated daily intake

Heavy metal	EDI north	EDI local	THQ north	THQ local
Zn	0.000978	0.000808	0.00326	0.00269
Cd	0.000000	0.00000283	0.000000	0.00283
Pb	0.00000142	0.00000567	0.00035	0.00142
Total			0.00361	0.00694

Cancer risk

The probable cancer risk due to exposure to a specified dose of heavy metal in both local and northern bred goat meat is presented in Table 3.

Table 3: Evaluation of cancer risk

Metals	CR north breed	CR local breed
Cd	0.00000000	2.04×10^{-5}
Pb	1.20×10^{-8}	4.82×10^{-8}

Discussion

The concentrations of heavy metals detected in the organs of both local and northern goat breeds were zinc (Zn), cadmium (Cd), and lead (Pb). Overall, the levels of these metals were within the permissible limits established by the Commission of European Communities (2006). The general trend observed in this study was $Zn > Pb > Cd$, which agrees with the pattern reported by Oyeboji *et al.* (2021). The mean concentration of Zn was highest in the local breed muscle (1.4 ± 0.28 mg/kg), followed by northern breed liver (1.4 ± 0.14 mg/kg), northern breed muscle (1.25 ± 1.48 mg/kg), local breed liver (1.25 ± 0.07 mg/kg), northern breed kidney (0.8 ± 0.56 mg/kg), and lowest in the local breed kidney (0.2 ± 0.141 mg/kg). All recorded values were within acceptable limits and align with the findings of Nnadozie *et al.* (2014), who also reported Zn concentrations in goat meat and milk within safe limits.

Zinc plays critical roles in antioxidant defense, hormone regulation, and cellular metabolism. Although the concentrations in this study fell within permissible ranges, the relatively low levels observed may raise concerns regarding potential Zn deficiency, especially given its importance as an essential micronutrient. Zinc deficiency is associated with hormonal imbalance and impaired reproductive function, whereas excessive Zn intake can result in toxicity, including nausea, vomiting, and impaired sperm production. Thus, continuous monitoring of Zn levels remains important to ensure nutritional adequacy while avoiding toxic exposure.

The findings of this study are consistent with those reported by Lebsir *et al.* (2023), who assessed the concentrations of lead, cadmium, zinc, and copper in goat milk and evaluated their associated health risks in adult consumers. Their study recorded relatively high concentrations of Pb, Cd, and Cu (0.02, 0.0026, and 0.01 mg/kg, respectively), while Zn exhibited a comparatively higher value (3.26 mg/kg). Importantly, the estimated daily

intake (EDI) for all the metals did not exceed the established safety limits. Furthermore, both the target hazard quotient (THQ) for individual metals and the hazard index (HI) for their combined effects were below acceptable thresholds, indicating no significant non-carcinogenic risk to the local population.

The highest Cd mean concentration was found equally in local breed kidney and liver (0.005 ± 0.007) and least in northern breed kidney, liver, muscle and local breed muscle (0 ± 0). This finding is in correlation with the studies done by Oyebanji *et al* (2021) and Nnadozie *et al* (2014). Nnadozie *et al* (2014) results showed that Cd was found in permissible limits while Oyebanji *et al* (2021) revealed that Cd was undetected in some samples. Cd builds up in the kidneys over time and can cause kidney disease and fragile bones. Excess Cd in the body can also lead to cancer as well as affect the central nervous system and impair proper development of a child's brain. This finding is also in agreement to the findings of Adetunji *et al.*, (2014) on Lead and cadmium levels in cattle muscle and edible tissues collected from a slaughter slab in Nigeria. Food Additives and Contaminants; observed higher concentration of cadmium in liver of goat than other tissues and organs. This may be as a result of liver being an organ of detoxification of toxic substances such as heavy metals, lead from blood and other tissue may be mobilized and taken to the liver through circulation for detoxification to take place. Cadmium is toxic to virtually every system in the animal body. It is almost absent in the human body at birth, however, accumulated with age. Cadmium accumulated in the kidney and liver over a long time have been reported by McLaughlin *et al.* (2009). Cadmium interacts with a number of minerals mainly Zn, Fe, Cu, and Se due to chemical similarities and competition for binding stage. It is also reported that Cadmium can affect Ca, P and bone metabolism in both industrial and people exposed to Cadmium in general environment. From the result of these study, the concentration of cadmium (Cd) content in all the samples studied were found to be within the permissible limit of 0.005 mg/kg set.

Also, the study of Ngoja *et al*, (2021) revealed that Excessive Cd level in the body can cause hepatotoxicity, osteoporosis, teratogenicity, neurotoxicity and immunosuppression due to apoptosis induction in normal human mononuclear cells. The Cd metal has been implicated in the pathogenesis and pathophysiology of type-2 diabetes mellitus. Induction of oxidative stress seems to be the major mechanism for the onset of deleterious health effects associated with Cd.

Lead (Pb) concentrations were highest in the local breed liver (0.01 ± 0.014 mg/kg), followed by the local breed kidney and muscle and the northern breed liver (0.005 ± 0.007 mg/kg), while Pb was undetected in the northern breed kidney and muscle. These findings align with Oladipo *et al.* (2015), who also reported Pb levels within permissible limits. Although the concentrations observed in this study were low, Pb remains a critical toxicant associated with hypertension, cardiovascular and renal damage, and adverse pregnancy outcomes.

Studies by Muktar *et al.* (2022) and Abdel-Salam *et al.* (2013) similarly reported higher Pb accumulation in goat kidneys and livers, showing these organs as key sites of heavy metal deposition and important indicators of environmental contamination. This is consistent

with the physiological roles of the liver and kidney in metal detoxification and excretion (Parekhan *et al.*, 2014). Lebsir *et al.* (2023) further reported that estimated daily intake (EDI) values for Pb, along with Cd, Cu, and Zn, remained below threshold limits, with the trend $Zn > Pb > Cu > Cd$. This suggests minimal non-carcinogenic risk from dietary exposure to these metals.

Conclusion

This study showed that heavy metal concentrations in the northern goat breed were generally higher than in the local breed, although all values remained within permissible limits. These findings indicate low but notable environmental contamination. While the meat is considered safe, the detected carcinogenic risk in the local breed highlights the need for continuous monitoring. It is essential to prevent toxic metal exposure while ensuring adequate levels of essential minerals necessary for normal physiological functions. Regular monitoring of heavy metals in livestock and further studies on both indigenous and imported animals is recommended to protect public health and strengthen food safety measures.

Conflict of Interest Disclosure

The authors declare that no known conflict of interest or personal relationships that could have influence the work reported in this paper

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