

Evaluation of Heavy Metals Concentration in Poultry Feeds and Potential Health Risk Assessment

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Received: 21.11.2025 / Accepted: 29.11.2025 / Published: 23.04.2026

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DOI: [10.5281/zenodo.19711097](https://doi.org/10.5281/zenodo.19711097)

Abstract

Original Research Article

This study assessed the potential health hazards linked to the selected heavy metals (Pb, As, Cr, Mn, Cd, Cu, Zn, Ni) in poultry feed. Samples from various batches of the same brand of commercial feed and grains (soybean and corn) were collected from Kara Market in Sokoto. These feeds were used to feed groups of birds—three birds each for the starter and grower feeds, and two birds for the locally prepared feed—over a period of forty days. The feed samples were analyzed using Atomic Absorption Spectroscopy (AAS), with blank analyses conducted for reliability. The research assessed human exposure to heavy metals via three primary routes: oral ingestion, dermal absorption, and inhalation. Children were identified as the most susceptible group, with higher exposure risks compared to adults due to greater intake per body weight, increased hand-to-mouth activity, and underdeveloped detoxification systems. Starter and grower feeds showed elevated risk values, suggesting contamination from feed formulation, while local feed had the highest Total Lifetime Cancer Risk (TLCR) for Cr and Ni, indicating potential unregulated or environmental sources. Health risk assessment values were below 1, indicating no significant current risk, but continuous monitoring of poultry feed is recommended to prevent future overexposure.

Keywords: heavy metals contamination, poultry feed safety, health risk assessment, atomic absorption spectroscopy, human exposure pathways.

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INTRODUCTIONS

The environment faces a major problem of heavy metals pollution, which impacts the environment due to their stability and non-degradability. Despite natural occurrences of these heavy metals, Human activities have been shown to significantly increase their concentrations across different environmental compartments. Ogbomida et al. (2017). From these environments, the toxic metals can be taken up by crops, vegetables, and plants and find their way into the food chain since they are not degradable. When these crops are consumed, the metals will bio-

accumulate in various tissues and organs of animals and humans. Food is the primary source of man's exposure to heavy metals, through food crops cultivated in soils contaminated with heavy metals, or when contaminated water is used as an irrigation source. Ihedioha *et al* (2014) In recent years, poultry-derived products like meat and eggs have emerged as essential global sources of protein, energy, vitamins, and minerals. Their appeal stems from high nutritional value, palatability, affordability, and ability to supply a substantial portion of the recommended daily intake of various



Citation: C. D. Aniobi, I. S. Shabanda, & A. R. Koko (2026). Evaluation of heavy metals concentration in poultry feeds and potential health risk assessment. *Global Academic and Scientific Journal of Multidisciplinary Studies (GASJMS)*, 4(4), 37-57.

trace elements. (Attia *et al.*, 2016; Attia *et al.*, 2020; Bamuwamye *et al.*, 2015; Doyle and Spaulding, 2020; Mertz, 2019). In recent years, Poultry farms have been rapidly increasing in Nigeria as a result of high demand for meat and other poultry products due to the increase in population. In Nigeria, the poultry Business covers a huge percentage of total livestock growth, and broiler meat contributes significantly to the total meat produced (Bukar and Sa'id, 2014). Most populations of Nigerians rely on poultry products to fulfill their protein demand. Therefore, the feeds that broiler and layer chicks are fed with should be able to cover their nutritional requirements. These nutritional requirements include mineral elements, of which heavy metals are significantly integral components. Iron is crucial for preventing deficiencies that could hinder growth and disrupt essential metabolic functions, including oxygen transportation, DNA synthesis, and electron transfer processes. (Wijayanti *et al.*, 2021; Zoroddu *et al.*, 2019). Zinc is necessary for DNA structure dominance and the proper functioning of enzymes. Zinc deficiency can result in poor egg production and hatchability and reduced meat quality in broilers and other poultry species. However, zinc and selenium are vital for strengthening the immune system and feathering (Imran *et al.*, 2014). While promoting the growth of poultry chick Arsenical compounds were historically used in poultry production as growth promoters and for the control of parasitic infections such as coccidiosis; however, their use has been restricted due to toxicity concerns and residue accumulation in food products (Cortinas *et al.*, 2006; Nachman *et al.*, 2013). As the toxic metals gain access to the animals through the food chain, so do the essential elements also, the essential metals assist the human body in maintaining cellular processes, while the toxic ones cause a lot of damage even at minimal concentrations. Ogwok, *et al.* (2014). Metals like Pd, Hg, Cr, As, and Cd are very toxic even in low concentrations. They cause inhibition of several biochemical processes in the human body. However, when present in excessive amounts, these metals become toxic, posing serious health risks and contributing to chronic conditions such as cancer, developmental abnormalities, central nervous system damage, and neurological disorders (Liang

et al., 2019). Many heavy metals tend to accumulate particularly in the liver and kidneys of animals, as these organs function as the body's primary filtering, storage, and detoxification sites. Ogwok, *et al.* (2014). Developmental abnormalities, neurotoxicity effects, and deficits in intelligence quotient in infants, and constipation, colic, and anemia are the major side effects of chronic Pb exposure. Cadmium is also toxic to almost all the systems in the body of an animal. It is virtually absent in the body of humans at birth but tends to accumulate as we age. However, the primary source of cadmium exposure is through food, and its adverse health effects tend to happen in the form of kidney damage, with possibly bone effects and fractures (Thomas *et al.*, 2011). Also, Pb, when ingested by a pregnant woman, can have a teratogenic effect on fetus growth. In the same way, excessive intake of Pb in infants is responsible for decreased biosynthesis of the hormonal metabolite vitamin D, the causative agent for calcium metabolism. Strong accumulation of Pb in the system can affect haeme biosynthesis and erythropoiesis Ogwok, *et al.* (2014). Peripheral neuropathy, peripheral vascular disease, dermal lesions, and skin cancer are the chronic effects of As. Li, *et al.* (2014). Pregnant women and children are prone to the toxicity of toxic metals Liang, *et al.* (2019). Various harmful consequences of heavy metal consumption on humans were examined by Previous researchers and found that the resultant effects often rely on the amount found in an individual. This makes the computation of heavy metal risk factors for consumers expedient. When these metal levels in humans exceed the upper limit established by regulatory standard organizations, there is a risk to human health Abd-Elghany, *et al.* (2017). With regards to the potential harm that eating foods containing heavy metals can cause, it is paramount to frequently monitor the quantity of these metals in commonly consumed foods in order to assess the risk to human health and suggest preventative measures Liang, *et al.* (2019). Poultry feed is a major component in the poultry industry, directly influencing the health, growth, and productivity of birds. It comprises a blend of various ingredients designed to meet the nutritional requirements of poultry at different life stages. The

primary constituents of poultry feed include grains, protein sources, fats, vitamins, minerals, and additives. Poultry feed is formulated to meet the specific nutritional requirements of chickens at various stages of their development. The primary types of chicken feed include starter, grower, and finisher feeds, each designed to support different growth phases and production goals. Previous studies have highlighted the presence of heavy metals in poultry feed, suggesting a strong link between feed and feces contamination. For instance, Sahu and Singh (2008) found that heavy metal contamination in poultry feces was primarily due to

the contaminated feed. However, the extent and nature of this correlation require further investigation to develop comprehensive mitigation strategies. By quantifying the level of heavy metals in poultry feed and evaluating the potential risk to the general public concerning the ingestion of heavy metals bioaccumulating in the tissues of these animals fed with these feeds, this study aims to provide a deeper understanding of the environmental contamination through the acquisition of heavy metal ions during feeding, monitor and minimize the transfer of heavy metals into the food chain through the poultry industry.

STUDY AREA:



Sokoto state is one of the 36 states of Nigeria, situated in the extreme northwest of Nigeria. It has a total land mass of 25,973 km² (10,028 square meters) and is located between, Latitude: 13° 03' 45.68" N and Longitude: 5° 14' 35.59" E, It has boundary with Niger Republic to the north and west for 363 km (226 miles), and Zamfara states to the east, and Kebbi state to the south and west, partly along the Ka River. It has its capital and largest city, Sokoto, located towards the confluence of the Rima River

and Sokoto River. As of 2022, their population was estimated to be more than 6.3 million.

Materials and Methods

Sample collection and identification

Samples of two poultry feed types (Starter and Grower) were randomly collected at 10 g each from different bags of the same brand, and grains (soya bean and corn) for locally prepared feed

were randomly sampled from various bags at Kara Market, Sokoto. The samples were packaged in zip-lock bags and labelled appropriately. These zip-lock bags containing the samples were transported to the Laboratory of Pure and Applied Chemistry at Abdullahi Fodiyo University of Science and Technology, Aliero (AFUSTA), for digestion and analysis.

Sample pretreatment and preparation

The collected poultry feed samples were sundried to remove all moisture. The samples were sundried until the difference between the two weight readings was found to be negligible. After which it was homogenized into a fine powder using a mortar and pestle, then sieved and stored in a well-labeled zip lock bag. 2g of dried prepared samples each was collected using a conical flask. 15ml of concentrated Nitric acid (HNO₃) was added. Digestion was carried out using a hot plate, and stirring was done at 100°C for 2 hours until the solution turned colorless. The Digested samples was allowed to cool, and filtration was carried out using Whatman filter paper (grade 41, pore size 20µm) into a 100ml volumetric flask. The individual filtrate was diluted to the mark with ultrapure deionized water. These were then transferred into prewashed sample bottles for analysis of the heavy metals using an Atomic Absorption Spectrophotometer (AAS). (Igwemmar *et al*, 2022).

Quality Assurance.

The method used for the determination of heavy metal concentration in poultry feed using AAS was validated through Blank analysis, which was conducted to ensure the reliability of heavy metal measurements, confirming the absence of contamination in analytical procedures and validating the accuracy and supporting data integrity.

Sample analysis

The heavy metals determination on each digested sample was analyzed for Pb, Cd, Mn, Cr, Cu, Zn, Ni, and As, using SensAA GBCAvanta version

2.20 Atomic Absorption Spectrophotometer (AAS) calibrated with the standard for each metal under investigation at individual wavelengths 248.3, 283.3, 228.8, 279.4, 357.869, 324.754, 232.003 and 119.3 nm for Pb, Cd, Mn, Cr, Cu, Zn, Ni and As respectively. The presence of heavy metals determination was carried out in the central Laboratory of Usman Danfodiyo University, Sokoto State, Nigeria.

Assessment of Health Risk

Human health risk assessment is a systematic approach used to evaluate the potential adverse impacts on human health resulting from exposure to both carcinogenic and non-carcinogenic contaminants present in environmental samples (USEPA, 2001). The framework, developed by the United States Environmental Protection Agency (USEPA, 2011), encompasses four key steps: hazard identification, exposure assessment, toxicity assessment, and risk characterization. In the present study, physiological and behavioral differences between children and adults were taken into account; therefore, exposure levels and associated health risks were determined separately for each population group.

Risk Identification and Exposure Assessment.

Cr, Pd, As,,Ni, and Cd are among the hazard metals considered to possess both carcinogenic and non-carcinogenic risks. Meanwhile, Cu, Mn, and Zn are heavy metals considered to have only non-carcinogenic risks (IARC, 2012; USEPA, 2011). Therefore, this research considered Cr, Pd, As, Cd, Ni, Mn, Cu, and Zn as the risk factors.

The research investigated potential health risks associated with selected heavy metals, namely lead (Pb), cadmium (Cd), arsenic (As), nickel (Ni), zinc (Zn), chromium (Cr), copper (Cu), and manganese (Mn), present in poultry feed, focusing on their capacity to cause non-carcinogenic and carcinogenic effects upon exposure. Exposure assessment involved estimating the average daily intake (ADI) and, for carcinogenic evaluation, the

lifetime average daily dose (LADD) of these metals through ingestion, inhalation, and dermal contact routes for both children and adults. Key toxicity parameters employed were the reference dose (RfD) for non-carcinogenic effects and the cancer slope

factor (CSF) for carcinogenic potency. All calculations followed the exposure and risk assessment equations recommended by the United States Environmental Protection Agency (USEPA, 1989).

Inhalation of Heavy Metals

$$AD_{inh} = \frac{C_x \times IR \times EF \times ED \times ET}{BW \times AT \times PEF} \dots\dots\dots (1)$$

AD_{inh} represents the average daily intake of heavy metals via inhalation, expressed as the amount of contaminant absorbed per unit body weight per day (mg kg⁻¹ day⁻¹). For carcinogenic risk evaluation, this parameter is termed the lifetime average daily dose (LADD); for non-carcinogenic effects, it is referred to as the average daily dose (ADD) or simply ADI. The key variables include:

- C_x: concentration of the heavy metal in the exposure medium (mg kg⁻¹)
- IR: inhalation rate (m³ day⁻¹)

- EF: exposure frequency (days year⁻¹)
 - ED: exposure duration (years)
 - BW: body weight (kg)
 - PEF: particle emission factor (m³ kg⁻¹)
 - ET: daily exposure time (h day⁻¹)
 - AT: averaging time
- For carcinogenic risk, AT is fixed at 25,550 days (equivalent to 70 years × 365 days/year). For non-carcinogenic risk, AT equals ED × 365 days/year.

Ingestion of Heavy Metals

$$AD_{ing} = \frac{C_x \times IR \times EF \times ED \times CF}{BW \times AT} \dots\dots\dots [2]$$

AD_{ing} is the average of daily intake of the heavy metals ingested, that is the amount of contaminants (mg/kg.day); C_x is the concentration in the media of concern (mg kg⁻¹), IR is the ingestion in mg/day,

EF is the frequency of exposure (days year⁻¹), duration of exposure is ED (years), BW is the weight of the body (kg), AT is the average period in days, and CF is the factor of conversion in kg/mg.

Dermal Contact of Heavy Metals

$$AD_{I\text{derm}} = \frac{C_x \times EF \times AF \times ED \times SA \times ABS \times CF \dots\dots [3]}{BW \times AT}$$

AD_{I_{derm}} is the dermal contact exposure (mg/kg.day); C_x is the concentration in the media of concern (mg kg⁻¹), AF is the soil adherence factor in mg/cm², SA is exposed skin area in cm², ABS is the fraction of the applied dose absorbed on the skin, BW, ED, AT, EF and CF as defined in equation (2).

Toxicity and Hazard Characterization.

In the toxicity evaluation, carcinogenic slope factors and non-carcinogenic reference doses (expressed in mg kg⁻¹ day⁻¹) were sourced from the United States Environmental Protection Agency (USEPA) guidelines (USEPA, 1989, 2011). The toxicity values presented in Table 3.4 were applied, following USEPA protocols, to estimate both carcinogenic and non-carcinogenic health risks for adult and child populations.

Non-carcinogenic Risk Assessment

Non-carcinogenic risks are quantified using the hazard quotient (HQ), a dimensionless indicator that

reflects the likelihood of experiencing adverse health effects. The HQ is calculated by dividing the average daily intake (ADI) by the reference dose (RfD), which represents the chronic oral exposure level in (mg/kg/day) considered safe for a specific heavy metal over a lifetime.

$$HQ = ADI/RfD \dots\dots\dots [4]$$

For n number of heavy metals, the non-carcinogenic effect of the population is the summation of HQs due to different metals known as hazard index (HI).

$$HI = \sum HQ = \sum ADI/RfD \dots\dots\dots [5]$$

When the hazard index (HI) is less than 1, the exposed population is considered unlikely to suffer any noticeable adverse health effects. Conversely, an HI exceeding 1 indicates a potential concern, as it suggests that non-carcinogenic health risks may occur regarding non-carcinogenic effects. The HQ, which is the summation of an average daily index by the reference dose, is the independent variable, while the HI depends on its outcome.

Table 1. Parameters used for health risk Assessment exposure

PARAMETERS	UNIT			REFERENCE
	ADULT	CHILDREN		
Exposure Freq. (EF)	Days/Years	350	350	USEPA(2009)
Exposure Duration (ED)	Years	30	6	DEA 2010
Body Weight	Kg	70	15	DEA (2010)
Inhalation Rate (IR)	M ³ /day	20	10	USEPA(2009)

Ingestion Rate (IR)	Mg/day	100	200	USEPA(2009)
Skin surface area(SA)	Cm ²	5700	2800	USEPA(2001)
Skin Adherence factor(AF)	Mg/ Cm ²	0.07	0.2	USEPA(2009)
Dermal Absorption Factor(ABS)	None	0.001	0.001	DEA (2010)
Particulate Emission factor(PEF)	m ² /Kg	1.36 x 10 ⁹	1.36 x 10 ⁹	DEA (2010)
Conversion Factor (CF)	Kg/mg	10 ⁻⁶	10 ⁻⁶	USEPA(2004)
Average Time (AT)	Days	365 *ED	365 *ED	DEA (2010)

Cancer Risk Assessment

Carcinogenic risk is defined as the probability that an individual may develop cancer during their lifetime as a result of prolonged exposure to these contaminants.

Risk pathway = Σ ADI.CSF.....[6]

The Risk is a unit-less value. ADI in (mg/kg.day) and CSF in (mg/kg.day)⁻¹, these are the average daily intake and the cancer slope factor of heavy metals, respectively. The average daily intake and the cancer slope factor are the independent

variables, while the cancer risk depends on their outcome.

The total lifetime cancer risk was calculated from the input of different heavy metals in all the pathways as follows:

Risk total = Riskinh + Risking + Riskderm... (7)

Where Riskinh, Risking, and Riskderm are the risk contributors in inhalation, ingestion, and dermal pathways.

Table 2. RfDs (reference dose) of heavy metals (mg kg⁻¹ day⁻¹) adopted in this study (USEPA 2012)

Metals	Pb	AS	Cr	Mn	Cd	Cu	Zn	Ni
RfD ing	3.50 × 10 ⁻³	3.00 x 10 ⁻³	3.00 × 10 ⁻³	4.60 × 10 ⁻²	5.0 x 10 ⁻⁴	4.00 × 10 ⁻²	3.00 × 10 ⁻¹	2.00 × 10 ⁻²
RfD inh	3.52 × 10 ⁻³	3.12 x 10 ⁻⁴	2.86 × 10 ⁻⁵	1.43 × 10 ⁻⁵	2.4 x 10 ⁻⁶	4.02 × 10 ⁻²	3.00 × 10 ⁻¹	2.06 × 10 ⁻²
RfD dermal	5.25 × 10 ⁻⁴	3.00 x 10 ⁻³	6.00 × 10 ⁻⁵	1.84 × 10 ⁻³	5.7 x 10 ⁻⁵	1.20 × 10 ⁻²	6.00 × 10 ⁻²	5.40 × 10 ⁻³

Table 3. CPFs (cancer Slope factor) of heavy metals (mg kg⁻¹ day⁻¹) adopted in this study, (USEPA 2012)

	CANCER SLOPE FACTORS		
	Inhalation	Ingestion	Dermal
Pb	4.20 x 10 ⁻²	8.50 x 10 ⁻³	
AS	4.3 x 10 ⁻³	1.5	1.5
Cr	42	0.5	
Mn			
Cd	6.3		
Cu			
Zn			
Ni	0.84	0.84	

RESULT AND DISCUSSION

Table 4. The mean concentration of heavy metals in poultry feeds (mg/kg).(WHO 2011)

METALS	STARTER FEED	GROWER FEED	LOCAL P FEED	WHO LIMIT
Pb	0.05 ± 0.00	0.04 ± 0.00	0.02 ± 0.00	0.1
As	0.04 ± 0.00	0.06 ± 0.01	0.02 ± 0.00	0.01
Cr	0.12 ± 0.00	0.11 ± 0.00	0.04 ± 0.00	0.05
Mn	0.52 ± 0.00	0.15 ± 0.00	0.39 ± 0.00	0.5
Cd	ND	ND	ND	0.01
Cu	0.59 ± 0.00	0.53 ± 0.01	0.22 ± 0.00	20
Zn	3.12 ± 0.09	3.39 ± 0.05	0.80 ± 0.01	50
Ni	0.02 ± 0.00	0.07 ± 0.00	0.04 ± 0.00	0.02

NOTE: ND = Not-detected. Note: WHO = World Health Organization, P= prepared}.

Comparative data of the mean concentrations of heavy metals in poultry feed and faeces with the WHO standard

Table 5. The average daily intake (ADI) values in mg/kg/day of heavy metals obtained from the samples

SAMPLES	ADI ING	CHILDREN		ADULTS		
		ADI INH	ADI DERMAL	ADI ING	ADI INH	ADI DERMAL
STARTER FEED						
Pb	6.39 x 10 ⁻⁷	2.35 x 10 ⁻¹¹	1.79 x 10 ⁻⁹	2.94 X 10 ⁻⁷	1.01 x 10 ⁻¹¹	1.17 x 10 ⁻¹⁰

As	5.11×10^{-7}	1.88×10^{-11}	1.43×10^{-9}	2.35×10^{-8}	8.06×10^{-12}	9.37×10^{-11}
Cr	1.53×10^{-6}	5.64×10^{-11}	4.30×10^{-9}	7.06×10^{-7}	2.42×10^{-11}	2.81×10^{-10}
Mn	6.64×10^{-6}	2.44×10^{-10}	1.86×10^{-8}	3.05×10^{-7}	1.05×10^{-10}	1.22×10^{-9}
Cd	ND	ND	ND	ND	ND	ND
Ni	2.56×10^{-7}	9.40×10^{-12}	7.16×10^{-10}	1.17×10^{-8}	4.03×10^{-12}	4.68×10^{-11}
Zn	3.99×10^{-5}	1.47×10^{-9}	1.12×10^{-7}	1.83×10^{-6}	6.29×10^{-10}	7.31×10^{-9}
Cu	7.4×10^{-6}	2.77×10^{-10}	2.11×10^{-8}	3.46×10^{-7}	1.19×10^{-10}	1.38×10^{-9}
GROWER FEED						
Pb	5.11×10^{-7}	1.88×10^{-11}	1.43×10^{-9}	2.34×10^{-8}	8.05×10^{-12}	9.37×10^{-11}
As	7.67×10^{-7}	2.82×10^{-11}	2.15×10^{-9}	3.35×10^{-8}	1.21×10^{-10}	1.41×10^{-9}
Cr	1.41×10^{-6}	5.17×10^{-11}	3.93×10^{-9}	6.45×10^{-8}	2.22×10^{-11}	2.58×10^{-10}
Mn	1.92×10^{-6}	7.05×10^{-11}	6.31×10^{-12}	8.81×10^{-8}	3.02×10^{-11}	3.51×10^{-10}
Cd	ND	ND	ND	ND	ND	ND
Ni	8.95×10^{-7}	3.29×10^{-11}	2.51×10^{-9}	4.11×10^{-8}	1.41×10^{-11}	1.64×10^{-10}
Zn	4.33×10^{-5}	1.59×10^{-9}	1.21×10^{-7}	1.99×10^{-6}	6.83×10^{-10}	7.94×10^{-9}
Cu	6.78×10^{-6}	2.49×10^{-10}	1.80×10^{-8}	3.11×10^{-7}	1.07×10^{-10}	1.24×10^{-9}
LOCAL PREPARED FEED						
Pb	2.56×10^{-7}	9.40×10^{-12}	7.16×10^{-10}	1.17×10^{-8}	4.03×10^{-12}	4.68×10^{-11}
As	2.56×10^{-7}	9.40×10^{-12}	7.16×10^{-10}	1.17×10^{-8}	4.03×10^{-12}	4.68×10^{-11}
Cr	5.11×10^{-6}	1.88×10^{-11}	1.43×10^{-9}	2.35×10^{-8}	8.06×10^{-12}	9.37×10^{-11}
Mn	4.99×10^{-6}	1.83×10^{-10}	1.39×10^{-8}	2.29×10^{-7}	7.86×10^{-11}	9.14×10^{-10}
Cd	ND	ND	ND	ND	ND	ND
Ni	5.11×10^{-6}	1.88×10^{-11}	1.43×10^{-9}	2.35×10^{-8}	8.06×10^{-12}	9.37×10^{-11}
Zn	1.02×10^{-5}	3.76×10^{-10}	2.86×10^{-8}	4.69×10^{-7}	1.61×10^{-10}	1.87×10^{-9}
Cu	2.81×10^{-6}	1.03×10^{-10}	7.88×10^{-9}	1.29×10^{-7}	4.43×10^{-11}	5.15×10^{-10}

NOTE: ND = Not Detected.

Note: The table contains the calculated average daily intake (ADI) of heavy metals in poultry feed for both children and adults, it provides critical insights into potential health risks associated with exposure through ingestion, inhalation, and dermal contact.

Table 6. Average Daily Intake(ADI) Values in mg/kg/day, Hazard Quotient(HQ) and Hazard Index(HI) for Adults and Children

SAMPLES STARTER FEED	CHILDREN				ADULTS			
	HQING	HQINH	HQDerma CHILDREN	HI CHILDREN	HQING	HQINH	HQDERMA L	HI ADULTS
Pb	1.83×10^{-4}	6.68×10^{-9}	3.41×10^{-6}	1.86×10^{-4}	8.40×10^{-5}	2.87×10^{-9}	2.23×10^{-7}	8.42×10^{-5}
As	1.70×10^{-4}	6.03×10^{-8}	4.77×10^{-7}	1.71×10^{-4}	7.83×10^{-6}	2.58×10^{-8}	3.12×10^{-8}	7.89×10^{-6}
Cr	5.10×10^{-3}	1.97×10^{-6}	7.17×10^{-4}	5.82×10^{-3}	2.35×10^{-4}	8.46×10^{-7}	4.68×10^{-5}	2.82×10^{-4}
Mn	1.44×10^{-4}	1.71×10^{-5}	1.01×10^{-5}	1.71×10^{-4}	6.63×10^{-6}	7.34×10^{-6}	6.63×10^{-7}	1.46×10^{-5}

Cd	ND	ND	ND	ND	ND	ND	ND	ND
Ni	1.28 x 10 ⁻⁵	4.56 x 10 ⁻¹⁰	1.33 x 10 ⁻⁷	1.29 x 10 ⁻⁵	5.85 x 10 ⁻⁷	3.80 x 10 ⁻¹⁰	8.67 x 10 ⁻⁹	5.94 x 10 ⁻⁷
Zn	1.33 x 10 ⁻⁴	1.33 x 10 ⁻²	1.87 x 10 ⁻⁶	1.34 x 10 ⁻²	6.10 x 10 ⁻⁶	2.09 x 10 ⁻⁹	1.21 x 10 ⁻⁷	6.22 x 10 ⁻⁶
Cu	1.85 x 10 ⁻⁴	1.84 x 10 ⁻⁴	1.76 x 10 ⁻⁶	3.71 x 10 ⁻⁴	8.65 x 10 ⁻⁶	2.96 x 10 ⁻⁹	1.15 x 10 ⁻⁷	8.76 x 10 ⁻⁶
GROWER FEED								
Pb	1.46 x 10 ⁻⁴	5.34 x 10 ⁻⁹	2.72 x 10 ⁻⁶	1.49 x 10 ⁻⁴	6.69 x 10 ⁻⁶	2.29 x 10 ⁻⁹	1.78 x 10 ⁻⁶	8.47 x 10 ⁻⁶
As	2.56 x 10 ⁻⁴	9.04 x 10 ⁻⁸	1.31 x 10 ⁻⁶	2.57 x 10 ⁻⁴	1.12 x 10 ⁻⁵	3.88 x 10 ⁻⁷	4.70 x 10 ⁻⁷	0.00 x 10 ⁻⁵
Cr	4.70 x 10 ⁻⁴	1.81 x 10 ⁻⁶	6.55 x 10 ⁻⁵	5.37 x 10 ⁻⁴	2.15 x 10 ⁻⁵	7.76 x 10 ⁻⁷	4.30 x 10 ⁻⁶	0.00 x 10 ⁻⁵
Mn	4.17 x 10 ⁻⁵	4.93 x 10 ⁻⁶	3.43 x 10 ⁻⁹	4.66 x 10 ⁻⁵	1.92 x 10 ⁻⁶	2.11 x 10 ⁻⁵	1.91 x 10 ⁻⁷	0.00 x 10 ⁻⁵
Cd	ND	ND	ND	ND	ND	ND	ND	ND
Ni	4.48 x 10 ⁻⁵	1.50 x 10 ⁻⁹	4.65 x 10 ⁻⁷	4.53 x 10 ⁻⁵	2.01 x 10 ⁻⁶	6.84 x 10 ⁻¹⁰	3.03 x 10 ⁻⁸	2.04 x 10 ⁻⁶
Zn	1.44 x 10 ⁻³	5.30 x 10 ⁻⁹	2.02 x 10 ⁻⁶	1.44 x 10 ⁻³	6.63 x 10 ⁻⁶	2.28 x 10 ⁻⁹	1.32 x 10 ⁻⁷	6.76 x 10 ⁻⁶
Cu	1.60 x 10 ⁻⁴	6.19 x 10 ⁻⁹	1.50 x 10 ⁻⁶	1.62 x 10 ⁻⁴	7.78 x 10 ⁻⁶	2.66 x 10 ⁻⁹	1.03 x 10 ⁻⁷	7.88 x 10 ⁻⁶
LOCALFEED								
Pb	7.31 x 10 ⁻⁵	2.67 x 10 ⁻⁹	1.36 x 10 ⁻⁵	8.67 x 10 ⁻⁵	3.34 x 10 ⁻⁶	1.14 x 10 ⁻⁹	8.914 x 10 ⁻⁸	3.43 x 10 ⁻⁶
As	8.53 x 10 ⁻⁵	3.01 x 10 ⁻⁸	2.39 x 10 ⁻⁷	8.56 x 10 ⁻⁵	3.90 x 10 ⁻⁶	1.29 x 10 ⁻⁸	1.56 x 10 ⁻⁸	3.92 x 10 ⁻⁶
Cr	1.17 x 10 ⁻³	6.57 x 10 ⁻⁷	2.38 x 10 ⁻⁵	1.19 x 10 ⁻³	7.83 x 10 ⁻⁶	2.81 x 10 ⁻⁷	1.56 x 10 ⁻⁶	9.76 x 10 ⁻⁶
Mn	1.08 x 10 ⁻⁴	1.28 x 10 ⁻⁵	7.55 x 10 ⁻⁶	1.28 x 10 ⁻⁴	4.98 x 10 ⁻⁶	5.40 x 10 ⁻⁶	4.97 x 10 ⁻⁷	1.09 x 10 ⁻⁵
Cd	ND	ND	ND	ND	ND	ND	ND	ND
Ni	2.56 x 10 ⁻⁴	9.13 x 10 ⁻¹⁰	2.65 x 10 ⁻⁷	2.56 x 10 ⁻⁴	1.18 x 10 ⁻⁶	4.03 x 10 ⁻¹⁰	1.73 x 10 ⁻⁸	1.19 x 10 ⁻⁶
Zn	3.40 x 10 ⁻⁵	1.25 x 10 ⁻¹⁰	4.77 x 10 ⁻⁷	3.45 x 10 ⁻⁵	1.56 x 10 ⁻⁶	5.37 x 10 ⁻¹⁰	3.12 x 10 ⁻⁸	1.59 x 10 ⁻⁶
Cu	7.02 x 10 ⁻⁵	2.56 x 10 ⁻⁹	6.57 x 10 ⁻⁷	7.09 x 10 ⁻⁵	3.23 x 10 ⁻⁶	1.10 x 10 ⁻⁹	4.29 X 10 ⁻⁸	3.27 X 10 ⁻⁶

NOTE: ND = Not Detected.

Note: The table shows the non-carcinogenic risk assessment for heavy metals in poultry feed and feces as it was evaluated using the hazard quotient (HQ) for individual metals and the hazard index (HI) for combined exposure pathways (ingestion, inhalation, and dermal contact).

Table 7. Lifetime Average Daily Intake(LADI) in mg/kg/day and Hazard Cancer Risk for Adult and Children

	CHILDREN				ADULTS			
	SAMPLES. CRing	CR inhale	CRdermal	CRing	CR inhale	CR dermal	TLCR Children	TLCR Adult
STARTER FEED								
Pb	5.43 X 10 ⁻⁹	9.87 x 10 ⁻¹³		2.40 x 10 ⁻¹⁰	8.56 x 10 ⁻¹⁴		5.43 x 10 ⁻⁹	2.40 x 10 ⁻¹⁰
As	2.10 X 10 ⁻⁹	2.82 x 10 ⁻¹¹	2.15 x 10 ⁻⁹	1.01 x 10 ⁻¹⁰	1.21 x 10 ⁻¹¹	9.83 x 10 ⁻⁹	4.38 x 10 ⁻⁹	1.09 x 10 ⁻⁹
Cr	7.65 X 10 ⁻⁷	2.37 x 10 ⁻⁹		3.53 X 10 ⁻⁷	1.02 x 10 ⁻⁹		7.67 x 10 ⁻⁷	3.53 x 10 ⁻⁷
Ni	2.15 X 10 ⁻⁷	7.90 x 10 ⁻¹²		9.83 X 10 ⁻⁹	3.39 x 10 ⁻¹²		2.15 x 10 ⁻⁷	9.83 x 10 ⁻⁹
GROWER FEED								
Pb	4.34 X 10 ⁻⁹	7.89 x 10 ⁻¹³		1.99 X 10 ⁻¹⁰	3.38 x 10 ⁻¹²		4.34 x 10 ⁻⁹	2.02 x 10 ⁻¹⁰

As	1.15×10^{-6}	1.21×10^{-13}	2.42×10^{-9}	5.02×10^{-8}	5.20×10^{-13}	2.12×10^{-9}	1.15×10^{-6}	5.04×10^{-8}
Cr	7.05×10^{-7}	2.17×10^{-9}		3.23×10^{-8}	9.32×10^{-10}		7.07×10^{-7}	4.16×10^{-9}
Ni	7.52×10^{-7}	2.76×10^{-11}		3.46×10^{-8}	1.18×10^{-11}		7.55×10^{-7}	3.46×10^{-8}
LOCAL FEED								
Pb	2.18×10^{-9}	3.95×10^{-13}		9.96×10^{-11}	1.69×10^{-13}		2.18×10^{-9}	9.98×10^{-11}
As	3.84×10^{-8}	4.04×10^{-14}	1.07×10^{-9}	1.76×10^{-8}	1.73×10^{-14}	7.02×10^{-12}	3.95×10^{-8}	1.76×10^{-8}
Cr	2.56×10^{-6}	7.80×10^{-10}		1.18×10^{-8}	3.39×10^{-10}		2.56×10^{-6}	1.21×10^{-8}
Ni	4.29×10^{-6}	1.57×10^{-11}		1.97×10^{-8}	6.78×10^{-12}		4.29×10^{-6}	1.97×10^{-8}

The table shows the cancer risk assessment conducted in this study, it evaluated the potential carcinogenic health implications associated with the presence of heavy metals Pb, As, Cr, and Ni in poultry feed with separate assessments for children and adults via ingestion, inhalation, and dermal pathways.

The metal contents in the poultry feeds are presented in Table 4. The mean concentration of the heavy metals under study Pb, As, Cr, Mn, Cd, Cu, Zn, and Ni in the Starter feed were found to be 0.05 ± 0.00 , 0.04 ± 0.00 , 0.12 ± 0.00 , 0.52 ± 0.00 , ND, 0.59 ± 0.00 , 3.12 ± 0.09 and 0.02 ± 0.00 respectively while the concentration of the heavy metals on the grower feed was found to be 0.04 ± 0.00 , 0.06 ± 0.01 , 0.11 ± 0.00 , 0.15 ± 0.00 , ND, 0.53 ± 0.01 , 3.39 ± 0.05 , and 0.07 ± 0.00 . whereas in the level of the heavy metals on the locally prepared feed were found to be 0.02 ± 0.00 , 0.02 ± 0.00 , 0.04 ± 0.00 , 0.39 ± 0.00 , ND, 0.22 ± 0.00 , 0.80 ± 0.01 , 0.04 ± 0.00 (ND = Not detected). The highest concentrations of Pb, As, and Cu were found in the starter feed, followed by Cu, which shared the same concentration as in the starter feed. Ni and As have the highest concentration in the grower feed. Overall, Zinc had the highest concentration across all the samples, followed by copper and manganese, while cadmium was not detected in all the samples. The overall concentration of heavy metals across the feeds shows higher values in the commercially prepared feed than in the locally prepared one, in comparison with the proposed standard by WHO, some of the concentration shows higher value than the standard which indicate a health risk to the poultry birds and human beings been the end consumers, hence this study. The high concentrations of this metal in the commercially prepared feeds may be due to the

sources of the raw material used in the preparation of these feeds, which may likely be contaminated.

From Table 4. It is illustrated that in the case of starter feed the heavy metal concentration follows the order: $Zn > Cu > Mn > Cr > Pb > As > Ni > Cd$, while in the case of grower feed the metals concentrations are in the order $Zn > Cu > Mn > Cr > Ni > As > Pb > Cd$. But in the case of locally prepared feed, the concentrations of the metals were found to be in the order $Zn > Mn > Cu > Cr > Ni > As > Pb > Cd$,

The high level of zinc, copper, and manganese in the chicken feeds is not unexpected, for they are essential elements in metabolic activities. For instance, zinc is known to involve in over 300 enzymes and function in many biochemical pathways, its deficiency could result in immunological abnormalities such as growth retardations, hair loss, loss of appetite, night blindness, parakeratosis etc. and it is relatively nontoxic (Attia, 2020). Copper, on the other hand, is also essential for various physiological functions in humans and animals, including enzyme activity and iron metabolism. A deficiency of copper could lead to anemia, weak immune function, neurological issues, and gastrointestinal distress (Xu et al., 2008). However, excessive copper intake can lead to toxicity, causing liver damage, reduced growth performance, and increased mortality rates. Copper toxicity has also been associated with oxidative

stress, which can damage cellular components and impair immune function (Chen et al., 2007).

Manganese, as an essential element, is also required for various physiological functions in the body, such as bone development, brain and nervous system functions, and enzyme cofactor etc. Still, excessive levels can be harmful (Das, 2020).

There is a general unequal concentration of heavy metals in the different chicken feeds under investigation. For instance, Zn, Cu, Mn, Pd, As, Ni, Cr, and Cd, the order of concentration in the samples is Starter feed > Local Feed > Grower Feed (Table 4.). Zinc, Copper, and Manganese were observed in relatively higher concentrations than other heavy metals. The high levels of these metals may be associated with their nutritional function in various chicken tissues. (Okoye et al., 2020).

The heavy metal concentrations in the three poultry feeds samples were compared except for Cadmium, which was not detected across the whole sample, Zn, Mn, and Cu levels were the highest. Generally, the starter feed sample had the highest metal concentrations, whilst the locally prepared feed had the least. The high levels of metals in the starter feed could be attributed to the poor production process, improper packaging and use of contaminated raw materials such as grains (corn, soya beans) and protein source for the toxic metals, while the high level of Zinc, Cu and Mn is as results of their nutritional functional role they play in the body of the poultry birds. Arsenic in the other hand has been used for ages as a coccidiostat during poultry feed production. (Zhong, G, *et al*, 2021).

Several works have been reported on the heavy metal levels in poultry feeds. The mean concentrations of lead in the starter, from this study is 0.05 ± 0.00 mg/kg which is showing higher concentration than the mean concentration of grower, and local prepared feed 0.04 ± 0.00 mg/kg, and 0.02 ± 0.00 mg/kg respectively (Table 4). the higher level of Pb in the feed may be attributed to the use of contaminated raw material, poor processing, or improper packaging of this feed. When comparing the commercially prepared feed and locally prepared feed, the mean concentration of Pb shows a higher value in the commercially

prepared feed than the locally prepared one, indicating that the locally prepared feed is more contaminant-free and highly recommended. The mean concentrations of Pb found in this study were far lower than those published in other research. Rohma, (2014). observed 3.24 ± 3.78 mg/kg, 4.0 ± 3.17 mg/kg, and 3.43 ± 3.12 mg/kg lead in starter, grower, and local feed. Hira and Munir (2021) reported 2.32 ± 8.21 mg/kg starter feed and 1.22 ± 4.64 mg/kg grower feed. Richard and Augustine (2018) reported 1.17 ± 0.071 mg/kg in a poultry feed. A lead concentration of 10 ± 0.00 mg/kg for local broiler feed and 10 ± 0.00 mg/kg layer local feed was obtained by Fabrice De Paul and Tatfo Keutchatang *et al*. (2022). The lead concentrations found in this study were lower than the maximum permissible limits of 0.1mg/kg (FAO/WHO 2001) as well posed no health risk to any individual exposed to these feed and as well as the poultry animal fed with the feed. Exposure to lead and lead chemicals mainly occurs through ingestion of lead-contaminated food and water, dermal absorption, inhalation, and trans placental (endogenous) routes (ATSDR, 2007).

Richard and Augustine (2018) in their studies observed a strong positive relationship between heavy metal concentrations in poultry feed and those detected in chicken feces, concluding that the primary pathway for heavy metal uptake in poultry is through contaminated feed. Lead, a highly toxic element with no established physiological role, raises particular alarm when present at elevated levels in food products. According to the World Health Organization (WHO), there is no safe threshold for lead exposure. Lead contaminates poultry feed mainly via polluted feed components—including grains, fishmeal, and water—as well as through environmental contamination, notably from discarded lead-acid batteries and related waste (Hossain et al., 2023). Cadmium was not detected across all the samples (Table 4). Cadmium is a non-essential element for all biological systems, and any detectable amount in an organism's tissues is regarded as contamination (Rehman et al., 2012). It is essentially undetectable in newborns but gradually builds up throughout life, primarily

concentrating in the liver, kidneys, and gizzard (Akan et al., 2010).

Several studies have reported the mean concentration of cadmium in both poultry feed and feces. Richard and Augustine (2018) reported 0.53 ± 0.001 mg/kg for poultry feed and 0.031 ± 0.005 mg/kg in poultry feces. Diverse environmental sources such as oil, lake sewage, fertilizers, and groundwater are known to contain Cd. The Cd source in chicken feed in Bangladesh comprises contaminated grains, oil seeds, fishmeal, animal by-products, water, and mineral additions Igwemmar et al, (2022).

The concentrations of Nickel in the grower feed 0.07 ± 0.00 mg/kg shows higher concentration than the values of starter and locally prepared feed 0.02 ± 0.00 mg/kg, and 0.04 ± 0.00 mg/kg. (Table 4). The results of Nickel in this present study are far lower than the values observed by Keutchatang et al. (2023). In starter and grower feeds, 22575 ± 35.4 mg/kg, 6942.4 ± 0.1 mg/kg, However, the concentration of nickel reported by Rohma et al. (2014), 4.01 mg/kg, 3.99 mg/kg, and Attia et al (2020). 4.23 mg/kg, 9.85 mg/kg, and 2.18 mg/kg on starter, grower, and finisher poultry feeds also shows higher values than what is obtained in this study. Nickel is one of the naturally abundant metals; apart from that, it enters the environment through the incineration of waste, the combustion of diesel oil, and coal. Nickel (Ni) can cause respiratory problems and is a carcinogen (Anonymous, 2004). The concentrations of Ni on grower feed and locally prepared feed are both higher than the permissible limit of 0.02 mg/kg set by WHO, while starter feed is within the limit. Ni contamination in chicken feed is primarily from industrial processes like electroplating, alloy fabrication, and chemical manufacturing, affecting grains like maize, wheat, soybean, and canola, and infiltrating feed through contaminated water and air (Baj et al., 2023).

Copper concentration in the samples is shown in Table 4. The highest copper concentration was found in the starter feed 0.59 ± 0.00 mg/kg. the results obtained for Cu in this study were lower than the values found in Rohma et al (2014). 3.76 mg/kg, 3.55 mg/kg, and 1.35 mg/kg for starter feed, grower,

and finisher's feed. Copper is an essential element for various enzymes and is mostly stored in the liver and muscle, and is involved in different body functions (NRC, 2020). But an increased Cu dose provokes stomach, nausea, jaundice, diarrhea, and severe colic, while excessive deposition of copper in the liver, eye, and brain is characteristic of Wilson's disease (Attia et al., 2014). While its deficiency can lead to anemia, bone disorders.

All the copper concentrations in the present study were well below the recommended value of 20 mg/kg proposed by WHO, as indicated in Table 4. Cu contamination in poultry feeds can result from various sources, including excessive copper in mineral supplements, by-products like fish meal or meat and bone meal, and grains grown in copper-rich soil (Zhong, G, *et al*, 2021). environmental factors such as contaminated water, soil or the use of copper-based fungicides can also contribute. Additionally, cross-contamination during feed manufacturing or storage in Cu-based containers may increase Cu levels (Korish et al., 2020).

The concentrations of Manganese across the samples of the study are 0.52 ± 0.00 mg/kg, 0.78 ± 0.00 mg/kg, 0.15 ± 0.00 mg/kg, 0.17 ± 0.00 mg/kg, 0.39 ± 0.00 mg/kg, 0.07 ± 0.00 mg/kg. The level of Mn in the samples shows that the concentration of this metal in the starter feed is higher than the concentrations in the grower and locally prepared feed. Higher concentration of Mn has been reported in other studies (Attia et al, 2020). 31.8 mg/kg, 27.3 mg/kg, 32.6 mg/kg for starter, grower, and finishers feed, and Rohma et al (2014). 0.42 mg/kg, 0.63 mg/kg, 0.24 mg/kg for starter, grower, and finisher's feeds. The Mn concentration found in the starter feed is also lower than the value obtained by Imran et al, 0.57 ± 0.2 mg/kg. The study by Igwemmar et al (2022). reported Mn levels of 99.57 ± 15.63 mg/kg, which is way higher than the findings in this study. Manganese is one of the least toxic of all the trace minerals required by animals. It plays an important role in the growth, skeletal development, and reproduction in poultry (Attia et al, 2011). Some of the mean concentration of manganese obtained in this study is slightly higher than the proposed standard 0.50 mg/kg recommended by WHO, as shown in table 4. Mn

concentration in the commercially prepared feed shows higher value than locally prepared one which may likely come from contaminated crops like grains and soybeans which can be caused by mining operations, natural deposits, irrigations and contaminated water, and excessive application of substandard manganese premixes.

Zinc is an essential element, commonly ingested as a nutritional supplement. It acts as a cofactor for several enzymes. Zinc toxicity can occur in both acute and chronic forms. Acute deleterious effects of high zinc intake include nausea, vomiting, loss of appetite, abdominal cramps, diarrhea, and headache (Gary, 1990; Russell et al., 2001). The concentration of zinc was observed across all the samples of study: starter feed, grower feed and local prepared feed, was 3.12 ± 0.09 mg/kg, 3.39 ± 0.05 mg/kg, 0.80 ± 0.01 mg/kg, (Table 4). Zn is the dominant metal across all the samples; the concentrations show higher values in the locally prepared feed, which primarily indicates some level of absorption of these metals in the tissue of the poultry animals. Rohma et al. (2014), reported zinc concentration of 39.8 mg/kg, 46.5 mg/kg, 47.80 mg/kg for starter, grower, and finisher feed. Attia et al. (2020). Reported a zinc concentration of 33.2mg/kg, 30.2mg/kg, 39.2mg/kg for starter, grower, and finisher feed, and 134.8mg/kg, 99.4mg/kg, 112.3mg/kg for starter, grower, and finisher litter of Broiler diet and zinc value of 60.3mg/kg, 49.9mg/kg, and 45.4mg/kg for starter, grower, and finisher feed and 90.6mg/kg, 84.0mg/kg, and 275.3 mg/kg for starter, grower, and finisher litter of Layers hen. Keutchatang et al., (2023). Observed a zinc concentration of 82791 ± 0.2 mg/kg, 51789.4 ± 0.1 mg/kg for broiler and layers feed. The Zn mean concentrations of 3.12 ± 0.09 mg/kg, 3.39 ± 0.05 mg/kg, 0.80 ± 0.01 mg/kg, obtained across all the samples in this study are lower than the 50mg/kg permissible limits set by WHO (2000).

The mean concentrations of Arsenic in all the feed samples were found to be 0.04 ± 0.00 mg/kg, 0.06 ± 0.01 mg/kg, 0.02 ± 0.00 mg/kg. The concentration in the grower feed shows a higher value than the value obtained in the starter and locally prepared feeds, while the commercially prepared feed is slightly

higher than the locally prepared feed. The commercially prepared feed was likely contaminated with As through contaminated grains or fish meal, which depicts a slightly higher concentration than in the locally prepared feed. The highest level of arsenic was found in the grower feed at 0.06 ± 0.01 mg/kg. which is lower than the value reported by Rohma *et al.* (2014), 1.46 ± 0.59 mg/kg, and the lowest value was found to be in the locally prepared feed at 0.02 ± 0.00 mg/kg. Islam *et al.* (2007). Reported a mean concentration of arsenic in the poultry feed sold in Bangladesh to be within the range of 0.7640 -0.0069 mg/kg. While a value of 0.0007 mg/kg, 0.00048mg/kg for a starter and grower waste of a layer's hen was reported by Attia *et al.*, (2013). However, in the comparison with the reference standard established by WHO (2005); arsenic concentration in the study is slightly above the permissible limit of 0.01mg/kg, respectively, as shown in Table 4. which evidently showed that arsenic pollution in the vicinity of the feed ingredient crops was a bit high along with the use of arsenic contaminated fishmeal and supplement like roxarsone, arsenillic acid, nitarsone and carbasone in the poultry feed manufacturing as coccidiostat. (Zhong, G, *et al.*, 2021).

All the levels of chromium observed across all the samples range from 0.12 ± 0.00 mg/kg – 0.04 ± 0.00 mg/kg as shown in Table 4. which was slightly higher than the permissible limit set by WHO, 0.05 mg/kg. The highest concentration of chromium was found in the starter feed at 0.12 ± 0.00 mg/kg, while the local prepared feed had the lowest mean level of chromium, 0.04 ± 0.00 mg/kg. The concentration of chromium observed in this study was lower than the level observed by other researchers. Richard and Augustine. (2018) reported the mean concentration of chromium in poultry feed as 0.529 mg/kg. Islam *et al.* (2016) reported the mean concentration of Cr in poultry feed ranges from 1.03 – 2.26mg/kg. Rohma *et al.* (2014) recorded 3.35 mg/kg, 1.81 mg/kg, and 6.55 mg/kg of chromium in starter, grower, and finisher poultry feed in Kasur District of Pakistan. Also, Hira *et al.* (2023) obtained Cr concentration ranging from 0.61 mg/kg – 10.20 mg/kg from poultry feeds across six farms studied.

The mean concentration of Cr obtained in this study is slightly higher than the permissible limit set by WHO, 0.05mg/kg, as shown in Table 1. Cr is Chromium (Cr) is widely employed in industries such as dye and paint manufacturing, leather tanning, brick production, and metallurgy to impart corrosion resistance and a shiny finish. The extensive use of chemical fertilizers and the practice of irrigating crops with wastewater have further contributed to its environmental dispersion. Consequently, people can be exposed to chromium through inhalation, oral ingestion, and dermal contact. In Bangladesh, tannery sludge, which is rich in protein, has recently been incorporated into poultry feed formulations. Tannery effluents, however, typically contain high levels of chromium, a recognized hazardous pollutant (Attia et al., 2013). The toxicity of chromium depends on its oxidation state. Trivalent chromium Cr(III) is considered an essential micronutrient for humans and is not classified as carcinogenic. Nevertheless, excessive intake of Cr(III) beyond a certain limit can still trigger adverse health effects. In contrast, hexavalent chromium Cr(VI) is highly toxic and poses serious threats to human health, including skin allergies, respiratory and cardiovascular complications, renal and hepatic damage, and an elevated risk of cancer. The relatively high mean chromium concentrations observed in this study are likely attributed to contamination originating from feed ingredient and protein source used in the feed formulation.

5.3 Health Risk Assessment.

The calculated Health Risk Assessment (HRA) values for the factors EDI, THQ, HI, and LTCR were derived from the three exposure pathways (ingestion, inhalation, and dermal) associated with contaminated poultry products. The estimated results were then compared to permissible threshold limits and evaluated to assess the potential health risks they pose.

5.4 Average Daily Intake

The average daily intake (ADI) of heavy metals in poultry feeds for both children and adults provides

critical insights into potential health risks associated with exposure through ingestion, inhalation, and dermal contact. The ADI values for each metal varied across sample types, reflecting differences in feed

composition and metal concentrations. The ADI was calculated using Eqs. (1)- (3), and the results are presented in Table 4.2. The ADI values for Pb ranged from 6.39×10^{-7} mg/kg/day in starter feed (children) to 9.40×10^{-12} mg/kg/day in locally prepared feed (Children). For adults, the ADI values were generally lower, with the highest value observed in starter feed (2.94×10^{-7} mg/kg/day). Although the ADI values for Pb remain relatively low, consistent exposure may still be of concern due to the cumulative toxic nature of lead. The ADI value for As was highest in grower feed for children (7.67×10^{-7} mg/kg/day) and for adults (3.35×10^{-8} mg/kg/day). Cr showed significantly higher ADI values in both children and adults, with the maximum values being 1.41×10^{-6} mg/kg/day in grower feed (children) and 6.45×10^{-8} mg/kg/day in grower feed (adults). Elevated Cr levels suggest potential exposure through contaminated feed components or environmental sources. However, the ADI values for Mn were particularly elevated in starter feed for children (6.64×10^{-6} mg/kg/day) and locally prepared feed for adults (3.05×10^{-7} mg/kg/day). Mn being an essential nutrient, its elevated levels in feed could be as a result of exposure through contaminated feed or excess supplementation.

Ni exhibited relatively lower ADI values across all samples, with the highest being 5.11×10^{-6} mg/kg/day in locally prepared feed (children) and 4.11×10^{-8} mg/kg/day in grower feed (adults). While Ni exposure is less prominent, it is important to monitor cumulative intake due to its carcinogenic potential. Zn in other hand, displayed the highest ADI values overall, particularly in starter feed (3.99×10^{-5} mg/kg/day for children) and grower feed (1.99×10^{-6} mg/kg/day for adults) This trend suggests that Zn may be present in significant quantities in poultry feed, potentially as a feed additive or contaminant.

Cu ADI concentrations were also notable, with 7.40×10^{-6} mg/kg/day in starter feed (children) being the highest observed value. Elevated Cu levels in feeds may result from the excess supplementation of the feed or from contaminated ingredients used in feed formulation or environmental sources. From the children's perspective, the ADI of all the studied metals via the ingestion route showed a higher value than the inhalation and dermal routes. Similarly, the ADIs of the heavy metals are of an order of magnitude higher for the ingestion pathway than inhalation and dermal contact in adults. In comparison to the maximum Tolerable Daily Intake limits for the three exposure routes, the ADI values obtained in Table 4.2 are below the suggested daily intake ranges (*Rfds*) for heavy metals set by WHO/FAO. The ADI values of heavy metals calculated from exposure to these poultry feeds indicate that the average exposure to the samples, as well as the poultry chicken fed with the samples, does not constitute a health risk.

The findings indicated that neither children nor adults faced a significant non-carcinogenic health risk from exposure to these heavy metals. As presented in Table 4.2, oral ingestion accounted for approximately 90% of the total average daily intake (ADI) of the metals in both age groups, confirming that ingestion represents the predominant exposure pathway for children and adults alike. When comparing exposure levels between the two groups, children exhibited higher intake rates than adults, which can likely be explained by their frequent hand-to-mouth behavior and other age-specific dietary patterns.

5.5 Target Hazard Quotient (THQ).

The non-carcinogenic risk assessment for heavy metals in poultry feeds was evaluated using the hazard quotient (HQ) for individual metals and the hazard index (HI) for combined exposure pathways (ingestion, inhalation, and dermal contact). The analysis was conducted separately for children and adults, given their varying susceptibility to metal exposure. The non-carcinogenic risk is usually expressed in terms of hazard quotient (HQ). The results of the non-carcinogenic health risk of heavy metals in Table 4.3 show the calculated Total

Hazard Quotient (*THQ*) for seven heavy metals that are contained in the poultry feed samples under study.

The HQ values for Pb ranged from 1.83×10^{-4} mg/kg/day to 1.46×10^{-4} mg/kg/day in children and 8.40×10^{-5} mg/kg/day to 6.69×10^{-6} mg/kg/day in adults. The highest HI values for Pb in children and adults were observed in starter feed 1.83×10^{-4} mg/kg/day and grower feed 8.42×10^{-5} mg/kg/day, suggesting a potential risk from ingestion exposure, though still below the risk threshold of 1.0.

Arsenic (As) exhibited HQ values ranging from 1.70×10^{-4} mg/kg/day to 8.53×10^{-5} mg/kg/day in children and 7.83×10^{-6} mg/kg/day to 3.90×10^{-6} mg/kg/day in adults. The highest HI values were noted in grower feed, with As being a notable contributor to overall risk, particularly through ingestion exposure. Chromium (Cr) showed elevated HQ values, with the maximum reaching 5.10×10^{-3} mg/kg/day in starter feed (children) and 2.35×10^{-4} mg/kg/day in starter feed (adults). The HI values for Cr were particularly high in local feed, indicating a potential risk from ingestion exposure, and suggesting Cr contamination could be significant in certain feed sources.

The HQ values for Mn ranged from 1.44×10^{-4} mg/kg/day to 1.08×10^{-4} mg/kg/day in children and 2.11×10^{-5} mg/kg/day to 6.63×10^{-6} mg/kg/day in adults. While Mn is a nutritional element, its elevated values in certain feed samples (e.g., local feed) suggest potential overexposure, though still within acceptable risk levels. Nickel (Ni) exhibited relatively lower HQ values, with the highest being 2.56×10^{-4} mg/kg/day in local feed (children) and 1.18×10^{-6} mg/kg/day in local feces (adults). While Ni poses a lower risk than other metals, its presence across multiple feed samples warrants continued monitoring due to its carcinogenic potential.

Zinc (Zn) showed HQ values as high as 1.33×10^{-2} mg/kg/day in starter feed (children) and 6.63×10^{-6} mg/kg/day in grower feed (adults). Although Zn is an essential nutrient, the high HQ values suggest a potential risk from ingestion, particularly in children exposed to starter feed.

Copper (Cu) exhibited HQ values ranging from 2.56×10^{-9} mg/kg/day to 1.85×10^{-4} mg/kg/day in

children and 1.10×10^{-9} mg/kg/day to 8.65×10^{-6} mg/kg/day in adults. The highest HI values were observed in starter feed, indicating a moderate risk of Cu exposure, particularly through ingestion.

Generally, the HQ values of children were considerably higher than that of the adults in all the samples. similar results were reported by Zhang *et al.*, (2021) and Ghahramani *et al.* (2020). The

The bulk of the heavy metals found in the samples had THQ (Target Hazard Quotient) values less than 1 ($HQ > 1$) in both children and adults, suggesting that exposure to these poultry feeds samples as well as chicken fed with these samples, does not present a serious health risk when exposed to just one metal. However, the elevated hazard quotient (HQ) values observed in children compared to adults suggest that children are at greater risk from heavy metal exposure. This heightened susceptibility can be attributed to children's distinct behavioral patterns (such as frequent hand-to-mouth activity) and physiological factors (including higher absorption rates and lower body weight), which collectively make them more vulnerable to the adverse effects of heavy metals than adults. The total target hazard quotients or Hazard index (TTHQ or HI) determined by applying Eq.4, for the samples under study varied between 0.00×10^{-6} mg/kg/day and 9.76×10^{-6} mg/kg/day depending on the specific metals being analyzed. This information may be found in Table 4.3.

The research samples revealed that TTHQ or HI values are below 1, indicating that exposure to these samples under study does not constitute any negative effect.

5.6 Incremental Lifetime Carcinogenic Risk (ILCR).

The cancer risk assessment conducted in this study evaluated the potential carcinogenic health implications associated with the presence of heavy metals Pb, As, Cr, and Ni in poultry feed, with separate assessments for children and adults via ingestion, inhalation, and dermal pathways, as shown in Table 4.4, The values were derived using Eq.5. The estimated cancer risk values ranged from

2.56×10^{-6} for locally prepared feed to 8.56×10^{-14} , for grower feed and were compared against standard thresholds recommended by international bodies such as the United States Environmental Protection Agency (USEPA) and World Health Organization(WHO)., According to USEPA guidelines, a cancer risk value of $<1.0 \times 10^{-6}$ is considered negligible, values between 1.0×10^{-6} and 1.0×10^{-4} are regarded as tolerable, while any value $> 1.0 \times 10^{-4}$ is considered unacceptable and may require regulatory attention or mitigation.

Across all samples, cancer risks from Pb, for both children and adults, were consistently below 1×10^{-6} , with values ranging from 5.43×10^{-9} to 8.56×10^{-14} . This indicates a negligible cancer risk through all exposure routes. Children exhibited slightly higher values than adults, consistent with known higher vulnerability due to lower body weight and higher exposure per unit body mass.

Arsenic, on the other hand, showed higher risk values compared to Pb. The grower feed in children recorded the highest total cancer risk value of 1.15×10^{-6} , just above the negligible threshold. The local feed samples ranged from 1.15×10^{-6} to 4.04×10^{-14} , still within the tolerable range for both groups. In most cases, ingestion was the dominant exposure route, followed by dermal, with inhalation contributing minimally.

This suggests that while the risk is still within acceptable bounds, long-term exposure, especially in children, could lead to bioaccumulation and potential health concerns.

Chromium displayed some of the highest cancer risk values in the assessment; the local feed sample for children had the highest Cr related cancer risk of 2.56×10^{-6} , exceeding the negligible thresholds but still within the acceptable limit. Higher cancer risk value of Cr 6.87×10^{-6} for children and 1.94×10^{-5} for adult, was reported by Hossain *et al.*, (2018).

Cr exposure risks were notably higher in feeds across the board. In both children and adults, ingestion dominated the exposure pathways, though dermal exposure also contributed significantly in some cases.

In the case of Nickel, it showed elevated values in grower feed, 7.52×10^{-7} for children and 3.46×10^{-8} for adults, local feed 4.29×10^{-6} for children, which is above the negligible risk threshold.

In all samples where Ni was detected, the risk remained within the tolerable limit, though its elevated values in local feed for children raise moderate concern.

Cancer risk values were consistently higher in children than in adults, across all metals and exposure routes. This pattern is consistent with established toxicological understanding due to higher intake per body weight. Increased hand-to-mouth activity and underdeveloped detoxification systems.

Starter and grower feeds had more elevated risk values compared to locally prepared feed, indicating that the source contamination is more likely from the commercial feed formulation. and local feed had the highest TLCR for Cr and Ni, suggesting potential contamination from unregulated or environmental sources.

The lifetime cancer risk values calculated for all the investigated heavy metals were consistently higher in children than in adults. This finding demonstrates that children face a greater probability of developing cancer due to heavy metal exposure compared to adults. Similar trends were reported by Zhang *et al.*, (2021)

CONCLUSION

This study assessed the levels of eight heavy metals (Pb, As, Cr, Mn, Cd, Cu, Zn, Ni) in commercial starter and grower poultry feeds, as well as locally prepared feed from Kara Market, Sokoto, Nigeria. It also evaluated the potential non-carcinogenic and carcinogenic health risks to children and adults through ingestion, inhalation, and dermal exposure pathways. Atomic Absorption Spectroscopy (AAS) analysis showed that Cd was not detected in any of the sample, while Zn had the highest mean concentrations across all feed types (3.12 ± 0.09 mg/kg in starter, 3.39 ± 0.05 mg/kg in grower, and 0.80 ± 0.01 mg/kg in local), followed by Cu and Mn, reflecting their essential nutritional roles and

intentional supplementation. Generally, commercial feeds contained higher levels of most metals compared to locally prepared feed, with starter feed showing the highest levels for Pb (0.05 mg/kg), Cu (0.59 mg/kg), Mn (0.52 mg/kg), and Cr (0.12 mg/kg). Although some concentrations (like Cr, As, Ni in certain feeds) slightly exceeded WHO permissible limits, overall metal levels were lower than those reported in many previous studies from Nigeria, Pakistan, and Bangladesh. Health risk assessments indicated that average daily intake (ADI) values were well below WHO/FAO tolerable limits, with ingestion accounting for approximately 90% of exposure. Non-carcinogenic risks, measured by hazard quotients (HQ) and hazard indices (HI), were all below 1 for both children and adults, suggesting no immediate health effects from single or combined metal exposure. Carcinogenic risk estimates, based on total lifetime cancer risk (TLCR) for Pb, As, Cr, and Ni, ranged from 10^{-14} to 10^{-6} , remaining within or below USEPA tolerable limits (10^{-6} to 10^{-4}). However, local feed showed the highest TLCR for Cr (2.56×10^{-6}) and Ni (4.29×10^{-6}) in children. Children consistently faced higher risks than adults due to higher intake relative to body weight, frequent hand-to-mouth behavior, and immature detoxification mechanisms. Risks linked to starter and grower feeds were mainly due to formulation contaminants, while risks from local feed pointed to unregulated environmental sources. These findings confirm that current heavy metal levels in the studied poultry feeds do not pose significant health threats to consumers or poultry. Nonetheless, slight exceedances of permissible limits and the risk of bioaccumulation through the food chain highlight the importance of continued vigilance in an industry vital to Nigeria's protein supply.

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