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Research article

Risk assessment and origin of metals in chicken meat and its organs from a commercial poultry farm in Akwa Ibom state, Nigeria

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A R T I C L E I N F O

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A B S T R A C T

Contamination of chicken with metals is on the increase, despite its known attendant health risks to human consumers. The study aimed to evaluate the concentration of some metals in various organs of chicken, their sources, and the health risks they pose to human consumers. Samples of liver, meat, gizzard, borehole water, soil, diets, and droppings were investigated for the presence of some metals (Cr, Co, Mn, Zn, Al, As, Cd, Ni, and Hg), and their sources using principal component analysis (PCA). In addition, health risk assessment was manually computed using estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI), and carcinogenic risk (CR) parameters. Cr, Mn, Co, and Zn accumulated more in the liver, while Cd and Ni were only observed in the gizzard. The starter diet recorded higher levels of all the metals compared to the grower and finisher diets except for As. All the metals were detected in the poultry surrounding soil and the drinking water of the birds except for Hg. Furthermore, PCA implicated the soil, water, and diets of the birds as the sources of these metals. The THQ, HI, and CR due to the dietary intake of the gizzard indicate a risk of cancer in children and adults. There is a need to ensure that the identified sources of these metals (soil, water, and diets) are routinely monitored to ensure compliance with safety guidelines.

1. Introduction

Metals occur naturally in various environments where they are stable and non-biodegradable [1]. Despite their natural occurrence, anthropogenic activities have been shown to amplify their concentrations in various environments [2–4]. From these environments, these heavy metals can find their way into the human food chain [3,4]. Of particular concern is the fact that heavy metal contamination is widespread in commonly consumed human foods such as chicken and its by-products including eggs [5–9]. Their wide

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consumption is in part due to the fact that they are very rich in dietary protein, vitamins, minerals, low in fat and cholesterol contents and are high in energy [10–14]. Other reasons include its high affordability and availability, easy digestibility, and public (cultural and religious) acceptance as meat [14]. In Nigeria and most developing countries, chicken meat is largely sourced from poultry farms, where they are reared in commercial quantities for profit [15].

Rearing poultry for profit does not require much training, but just the required start-up capital, space (land), shelter, the presence of formulated or commercially available feed, and a drinking water source for the birds. Most commercial farmers sink their boreholes as national or state-distributed potable water is not readily available. Also, for ease of use, most commercial poultry farms rely on commercial feeds for their birds. Drinking water, feed, environment, and litter contaminants have been implicated as the major routes for heavy metals in poultry [16,17]. To boost the health and growth of birds, the feeds of broilers are usually supplemented with iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), iodine (I), and arsenic (As) [13]. These minerals help maintain their immune systems, aid metabolism, and catalyse other bodily functions [18]. However, in concentrations higher than required in the body, these minerals are excreted as droppings, which could impact the environment negatively [19]. In addition to being used as supplements, mineral pollution in poultry feed seems inevitable, as it can arise from raw materials, supplements, concentrates, and or equipment used in the production of the feed [20]. Despite these concerns, across Nigeria, there is no enforceable regulation or periodic checks on meat, feeds, or water for contaminants such as heavy metals that presents with a number of public health challenges to consumers.

Despite the nutrients contained in poultry meat and its products, when contaminated, they can pose a serious health risk to consumers [18]. Several studies around the world have revealed heavy metal contaminations in the tissues and organs of chicken meat [5–9]. At concentrations higher than normal, these metals have the tendency to bioaccumulate and become magnified in the tissues and organs of these birds, posing serious health hazards to other animals and humans that ingest these metals while consuming them [21]. Severe acute and chronic adverse effects may originate from human exposure to heavy metals [22], such as peripheral nervous systems, hypertension, and damage to the gastrointestinal tract, reproductive anomalies, and nephropathy [23].

With the heavy reliance of humans on potentially contaminated chicken meat that can arise via drinking water, feed, environment, and even their litters [16,17] for dietary protein need, there is a potential risk to consumers [14,21–23]. The health hazards inherent in the contaminated meat informed the study. There are limited studies on the possible sources or routes of heavy metal contamination in chicken meat around the world [16,17]. An understanding of the sources can inform regulatory legislation to safeguard the health of consumers. To the best of our knowledge, the health risk of ingesting metals via the dietary intake of chicken reared in southern Nigeria is yet to be investigated nor the sources of the contaminants known. In addition to establishing the possible source of heavy metal

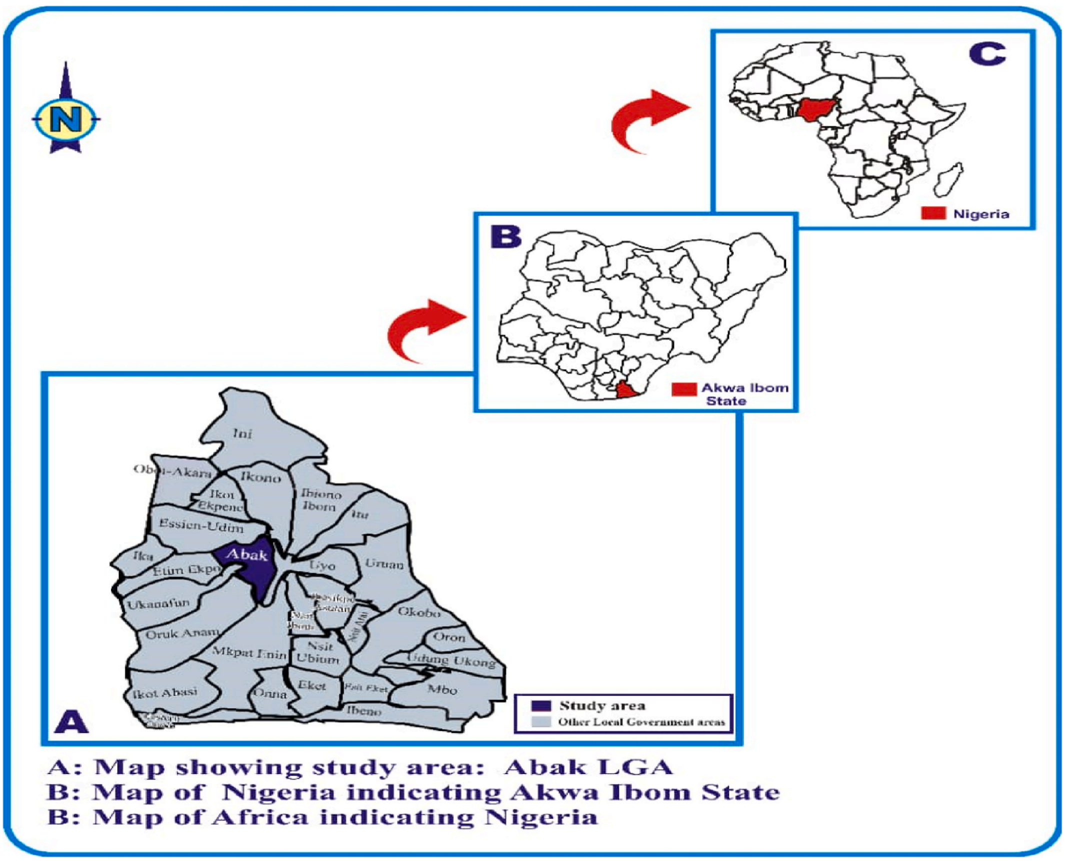

Fig. 1. Map of the study area.

contamination in the broiler meat, the health risk parameters were also utilised to predict the possible health threat of ingesting these metals following the consumption of broilers from the poultry farm under study. Health risk parameters have been successfully used to evaluate the health risks of consuming food contaminated with heavy metals [24–29]. The study evaluated the following: 1) the levels of the metals in the liver, meat, gizzard, and diets of chicken from Abak; 2) the concentrations of these metals in water source, soil, and droppings; 3) origin of heavy metals in liver, meat, and gizzards of chicken from Abak; and 4) chemical health risk of consuming these metals from the dietary intake of liver, meat, and gizzards of chicken from the studied poultry.

2. Materials and methods

2.1. Study area

Abak is a local government area (LGA) located within the south-west region of Akwa Ibom State, Nigeria. It is surrounded by several other LGAs, and these are Ikono, Essien Udim, Etim Ekpo, Ukanafun, Uyo, and Oruk Anam to the north, north-west, west, east, and south, respectively. Abak is 18 km by road from the state capital, Uyo, and has a total land mass of 304 square kilometers (Fig. 1). Geographically, Abak is located between latitude 4° 58′ 56.50″ N and longitude 7° 47′ 21.19″ E [30]. Abak is popularly known for its agricultural exploits and has the presence of several small scale agro-based and agro-allied industries [30]. Abak is blessed with numerous cultural heritages that includes the Ekpe and Ekpo cultural plays. Majority of its indigenes are christians. More so, the LGA abound with privately driven hospitality set-ups like hotels, parks, and gardens. The most common crops cultivated are oil palm, cassava, and diverse vegetables [30]. Abak has an abundance of commercial poultry farms and one of the main dietary protein sources of the inhabitants is chicken.

2.2. Description of the poultry farm

The poultry farm is located in the Abak LGA of Akwa Ibom State, Nigeria. The farm has been in existence for the past 10 years and produces layers, eggs, and broiler chicken on a commercial scale. These produce from the farm are consumed in Abak, Uyo, Etim Ekpo, Ikot Ekpene, and neighbouring states. Typically, the sales of the produce peaks during festive periods such as christmas and easter. Annually, the farm sells over 2000 birds to its numerous consumers. The farm sits on a land mass that measures over 100 m by 100 m. Occasionally, the birds are allowed to roam and eat available food in the surroundings within the fenced poultry farm. The farm gets its water supply from a privately sunk borehole (depth of 64 m) within the farm.

2.3. Purchase of chicks by the poultry farm

Following informed consent from the management of the farm, a total of 220 (mean weight 38.50 ± 5.60 g) day-old chicks were purchased and transported to the farm, where they were reared separately for two months (8 weeks) to maturity. Daily, they were fed twice with commercially purchased feed from Abak and Uyo LGAs as needed. From the stock of 220 birds, only 200 reached full maturity (mean weight 1.85 ± 2.98 kg) from which samples of liver, meat, and gizzards for the study were collected.

2.4. Nutritional composition of chicken feeds

The starter diet contained crude protein (CP), cysteine and methionine (CM), Calcium (Ca), and available phosphorus (AP) in varying amounts (22.5, 0.95, 1.25, 2.00, and 0.52 %, respectively for CP, CM, Ca and AP). For the grower broiler diet, these were present as 20.0, 0.90, 1.25, 0.92 and 0.45 % respectively while for the finisher's diet, they were 18.0, 0.75, 1.20, 0.85 and 0.45 %, respectively for CP, CM, Ca and AP, respectively.

2.5. Collection of samples

From the collected mature birds (n = 100), samples of the liver, meat, and gizzards of the chicken were taken after they were slaughtered. Also, the diet samples (n = 5) fed to the chicken were equally collected into a sampling container. One litre (1 L) of water (n = 5) was collected from the borehole sunk within the poultry farm into a pre-treated 1 L sampling bottle. The droppings of the birds (n = 50) were collected and then made into five (n = 5) composite samples. Similarly, soil samples collected in triplicates from five different locations at 0–15 cm depth into sterile container sample bottles were also made into five composite samples. All samples were collected over a period of three months (June–August 2022). The liver, meat, and gizzard samples were preserved in ice at 4°C until analysed. Prior to the collection of samples, 10 % nitric acid was added and the mixture rinsed with Milli-Q water (MQW), dried in fume hood, and then wrapped with an aluminum foil. The samples were now transported for metal analysis.

2.6. Chemical analysis of samples

2.6.1. Chemical analysis of liver, meat, gizzards, droppings, and feeds of chicken

The sample were first allowed to assume the laboratory temperature (25 ± 2 °C). The samples were then washed again with the MQW, and dried using a sterile Petri dishes at 60°C for 72 h in a sterilised hot air oven [31]. Thereafter, 2 g of the samples were mixed with 5 mL of nitric acid and 15 mL of hydrochloric acid. Samples were then heated at 105°C for 2–3 h using a heating block to enable complete digestion. The digest was allowed to cool, filtered using a Whatman filter paper (Ashless no. 42), and then diluted to 50 mL with deionized water.

The concentrations of chromium (Cr), cobalt (Co), manganese (Mn), zinc (Zn), aluminum (Al), arsenic (As), cadmium (Cd), nickel (Ni), and mercury (Hg) were estimated (mg/kg) in the samples using inductively coupled plasma-atomic emission spectrometry (ICPAES). The working standards for all metals were prepared using 1000 mg/L of their calibration standard. The preparations were done by adding 0.2 % of HNO_3 (for Cd) or 15 % of nitric acid (for other metals) to MQW in a vol/vol serial dilution using a glass volumetric flask. The equipment (ICPAES) was then calibrated using the prepared working standard, and the metals quantified using the calibration curve technique. Subsequently, the curves were derived by plotting the standard solutions against their respective absorbance measurements. The quality of the analytical method and the instrument were determined by comparing the obtained results with the certified reference material of dogfish muscle (DORM-2: National Research Council, Canada) for liver, meat, and gizzards of chicken, droppings, and feeds while for soil, SRM-2710 was used. A total of four (4) samples weighing between 0.2 and 0.3 g were digested. The calibration curve plot was used to determine the calibration curve data [32]. The obtained LODs were 0.015 (Cr), 0.13 (Co), 0.120 (Mn), 1.231 (Zn), 0.032 (Al), 0.020 (Cd), 0.050 (Ni), 0.002 (Hg), and 0.013 (As) mg/kg. The recovered capacities (RC) varied from 91 to 108 %, and had a regression coefficient (R^2) that ranged from 0.87 to 0.98.

2.6.2. *Chemical analysis of the water source*

The ice-preserved water sample was first made to attain the laboratory temperature. Prior to the analysis, the water sample was filtered using a 0.45 μm membrane filter, and then 6 mL of the filtrate was used to make an aliquot of 25 mL for each sample [33]. The concentrations of chromium (Cr), cobalt (Co), manganese (Mn), zinc (Zn), aluminum (Al), arsenic (As), cadmium (Cd), nickel (Ni), and mercury (Hg) were measured (mg/L) in the samples using the ICPAES (Yobin Yvon JY-24 model). The metals were quantified using the calibration curve technique, and the working standards were prepared using the standards of NF IN ISO 15587–2 (2002, AFNOR, France). The working standards for all metals were prepared using 1000 mg/L and MQW in a vol/vol serial dilution. The obtained calibration curve was obtained by plotting the concentrations of the standards against their respective absorbance readings. Method accuracy was tested via comparison of the estimated metal concentrations with those of the reference material for the water sample (SRM 1643e). Thereafter, the RC and R^2 were computed as previously reported [33]. The limits of detection were 0.02 (Cr), 0.012 (Co), 0.120 (Mn), 0.15 (Zn), 0.025 (Al), 0.021 (As), 0.011 (Cd), and 0.02 (Ni) mg/L. The RC ranged from 89.6 to 107.5 % while the R^2 ranged from 0.90 to 0.97.

2.7. *Health risk assessment from the dietary intake of chicken liver, gizzard, and meat*

2.7.1. *Estimated daily intake (EDI) of the metals*

The EDI (mg/kg/day) was used to predict the daily intake of the studied metals from various organs of the chicken, and this was done as previously reported [25] as shown in equation below:

$$\text{EDI} = \frac{Heavymetalslevel \times Chickendailyintake}{Averageweightofhumans}$$

The estimated average weights for adults and children were 60 kg (adults: ≥18 years) and 30 kg (children: 0–17 years); while their respective average daily intake of chicken were 60.95 kg/person/day for adults and 45.59 kg/person/day for children, respectively [34,35].

2.7.2. *Target hazard quotient (THQ) of the metals*

This was manually computed as previously reported previously [25] as shown below:

$$\text{THQ} = \frac{Heavymetalslevel \times Chickendailyintake}{RfD \times Averagehumansweight}$$

Where: THQ = target hazard quotient, and RfD = Oral reference dosage (mg/kg/day). Values of THQ = 1 or greater indicate a potential risk to consumers. The RfD values were 0.001 (Cd), 1.5 (Cr), 0.02 (Ni), 0.3 (Zn), 0.14 (Mn), 0.0005 (Hg), 1.0 (Al), 0.03 (Co), and 0.0003 (As) [35,36].

2.7.3. *Hazard index (HI) of the metals*

HI denotes the combined threat of the ingestion of metals via the dietary intake of chicken. Where computed HI is greater than 1, it indicates a potential risk to human consumers. It was estimated as reported previously [25] as shown below:

$$\text{HI} = \sum \text{THQ of the various metals}$$

2.7.4. *Carcinogenic risk (CR) from the ingestion of the metals*

CR estimation provides a measure of the possibility of developing cancer over a 70-year lifespan. It was determined as previously reported [29] as shown below:

$$CR = EDI \times CaSF$$

Where CR = carcinogenic risk.

EDI = estimated daily intake.

CaSF = carcinogenic slope factor.

The cancer slope factors of Cd, Cr, Ni, As, and Zn were 0.38, 0.5, 1.7, 1.5, and 0 mg/kg/day, respectively [35,36]. Values greater than 10^{-4} indicates carcinogenic risk.

2.8. Statistical analysis

Estimated metal concentrations in the liver, meat, gizzard, diet, and droppings of chicken, as well as those of water sources and soil, were analysed using descriptive statistics (bar charts, mean, standard deviation, and ranges). Furthermore, they were subjected to a one-way analysis of variance (ANOVA) using the OriginPro 2020 software (Originlab, USA) with significance level set at 0.05 or 95 %. Principal component analysis (PCA) was utilised to unravel the potential sources of the heavy metals in the liver, meat, and gizzard of the chicken obtained from the poultry farm.

3. Results and discussion

3.1. Heavy metals concentration in the liver, meat, and gizzard of chicken

The summary of the concentrations of the estimated metals in the various parts of the chicken from the poultry farm is shown in Table 1 (see Supplementary Tables 1–3 for raw data). The values of Cr, Co, Mn, and Zn were highest in the liver, while those of Cd and Ni were highest in the gizzard of the chicken. The concentrations of Cr, Mn, and Zn varied significantly ($p < 0.05$) between the liver, meat, and gizzard of the chicken. Furthermore, the concentrations of Cr, Co, and Mn in the liver were 10.6, 19.8, and 4.05 times, respectively, the FAO/WHO allowable limits in food. For the chicken meat, the concentrations of Cr and Mn in the meat were 2.6 and 1.33 times higher than the FAO/WHO acceptable limits for food. Similarly, the concentrations of Cr, Mn, Cd, and Ni in the gizzard were 9.5, 1.15, 11.0, and 2.43 times, respectively, higher than the limits of FAO/WHO.

Globally, the liver, meat, and gizzard of chicken are important sources of animal protein, energy, vitamins, and minerals for humans [10–13]. Thus, we investigated the concentration of potentially toxic metals in various chicken parts and their sources. These metals have the ability to accumulate and biomagnify in the meat tissues and organs, potentially resulting in health issues for animals and humans [14]. Our findings showed significant differences in the concentrations of Cr, Co, Mn, and Zn within the liver, meat, and gizzard of the sampled chicken, with the liver recording the highest while the meat recorded the least concentration of all examined metals. Overall, Cr, Mn, Co, and Zn accumulated more in the liver of the chicken because its primary function is to detoxify heavy metals from the chicken by producing metallothioneines (metals-binding proteins), thereby binding more Cr, Mn, Co, and Zn to the liver [38]. The gizzard accumulated more Cr, Mn, and Zn than the meat because the gizzard receives the food first and degrade it, potentially allowing the bioaccumulation of Cr, Mn, and Zn. The meat recorded the lowest concentrations of Cr, Mn, and Zn because of its low levels of binding proteins [38]. In the gizzard, only Cd and Ni were recorded, and this could be because the gizzard's main function is to breakdown ingested food particles and, in the process, does not allow much bioaccumulation. On the other hand, Al, As, Cd, Ni, and Hg were not detected in the meat and liver of the chicken, and this could be due to the metals not forming or enhancing the formation of metallothioneines [38].

The liver and meat gave levels of Zn that were higher than those reported earlier in poultry meat [14]. Also, the present study recorded lower levels of Cr, Co (liver only), Mn, and Zn in the liver and meat of the chicken compared to the findings of Korish and Attia [20] but higher concentrations of Cr, Mn, and Zn in meat than the findings of Ogbomida et al. [2] for their study on accumulation patterns of metals in the liver of chicken from Benin City (Nigeria). Additionally, the mean concentrations of Cr, Mn, and Zn in the meat of chicken in our study were higher than those reported by Ogu and Akinnibosun [39] for the study on heavy metals in commercial chicken meat in southern Nigeria. Chromium concentration in the meat of chicken was lower than the findings of Naseri et al. [40] in their study on heavy metals in the muscle of hens sold in eastern Iran. In the same vein, the concentrations of Cr and Ni in the gizzard of the chicken in our study were lower, while that of Cd was higher than those reported by Naseri et al. [40]. The concentrations of Cr, Cd,

Table 1
The concentrations of metals in the various parts of the broiler.

Metals (mg/kg)	Liver of broiler	Meat of broiler	Gizzard of broiler	FAO/WHO [37]
Cr	**1.06** ± 0.19[a] (0.87–1.24)	**0.26** ± 0.44[b] (BDL – 0.78)	**0.95** ± 0.18[c] (0.77–1.12)	0.1
Co	**1.19** ± 0.19 (0.98–1.36)	BDL	BDL	0.06
Mn	**1.62** ± 0.48[a] (1.08–2.01)	**0.53** ± 0.12[b] (0.45–0.67)	**0.46** ± 0.11[c] (0.36–0.58)	0.4
Zn	40.63 ± 4.61[a] (36.54–45.58)	4.57 ± 1.06[b] (3.45–5.56)	3.74 ± 0.67[c] (2.98–4.20)	60
Al	BDL	BDL	BDL	0.001
As	BDL	BDL	BDL	0.01
Cd	BDL	BDL	**0.54** ± 0.09 (0.45–0.64)	0.05
Ni	BDL	BDL	**0.17** ± 0.29 (BDL – 0.51)	0.07
Hg	BDL	BDL	BDL	0.5

Values represent mean ± standard deviation; ranges in parenthesis; BDL – below detectable limits; Bold values are unsafe.
Values with different superscripts between liver, meat and gizzard showed significantly different ($p < 0.05$).

and Ni in the gizzard were higher than those of Okoye et al. [41]. Finally, the concentrations of Cr, Zn, and Ni in the gizzard of chicken for the present study were lower, while those of Mn and Cd were higher than those reported earlier in chicken gizzard [42]. The discrepancies in the levels of metals in the various parts of the chicken in our study and other studies could be due to the differences in the quality and concentration of metals in the drinking water and feed given to the chicken and the soil around the poultry, since these are the potential sources of metal exposure in poultry [16,17]. Similarly, the variations in the levels of the metals between the highlighted studies could be due to differences in the bioavailability rates of the metals in the soil, poultry methods, types of feed given, pollution status of the farm and its environs [4], study periods, geographical areas, and study durations.

The levels of Cr, Co, and Mn in the liver were 10.6, 19.8, and 4.05 times higher than the limit set by FAO/WHO. Similarly, the concentrations of Cr and Mn in the chicken meat were 2.6 and 1.33, and the concentrations of Cr, Mn, Cd, and Ni in the gizzard were 9.5, 1.15, 11.0, and 2.43 times higher than the limit set by FAO/WHO. This denotes that the liver, meat, and gizzards of the chicken are unsafe for human consumption. This is worrisome because heavy metals have the potential to cause health issues in humans even at low concentrations [2,14]. It has been reported that severe acute and chronic adverse effects may originate from human exposure to heavy metals [22], including peripheral nervous systems, hypertension, and damage to the gastrointestinal tract, reproductive anomalies, and nephropathy [23]. Unsafe exposure to Cr and Co from the consumption of liver, meat, and gizzard could lead to nose irritation, nose ulcers, organ damage, and even cancer [43]. Mn poisoning is linked to hallucinations, Parkinson disease, and bronchitis [43], while Cd is linked to growth and learning impairments and cancer [43]. Finally, Ni ingested at toxic concentrations from the dietary intake of chicken (liver, meat, and gizzard) has been implicated in various adverse effects, which include but are not limited to dermatitis [43]. Zn is a very essential element; however, it could be toxic when ingested at an unsafe level, potentially resulting in health issues for humans. In addition to the unsafe levels of Zn recorded in the liver, meat, and gizzards in this study, there is a possibility that its concentration could build up in human tissues over the years to toxic levels that could cause adverse effects such as nausea, vomiting, epigastric pain, lethargy, and fatigue [43].

3.2. Metals concentration in the diets

Diet is a well-known route of metallic exposure in poultry [16,17]. Mineral pollution in animal feeds is inevitable, as it could arise from an impacted poultry environment, supplements and concentrates, or equipment used during the manufacture of the feed [20]. With the possibility of chicken ingesting heavy metals as contaminants from diets and the impending health implications thereafter, we also investigated the heavy metal concentration in the diets fed to the chicken. The metal levels in the broiler's diet are presented in Table 2 (raw data presented in the Supplementary Table 4). Among the examined metals, Hg was not observed in the diets of chicken. The starter diet recorded higher levels of the metals compared to the grower and finisher diets. The concentration of heavy metals between diets varied insignificantly ($p < 0.05$) between the starter, grower, and finisher diets. The levels of metals in all the diet types were lower than the toxic levels set aside by the National Research Council (NRC) for nutrient requirements in poultry (Table 2).

In the present study, the concentration of heavy metals in the starter diets was higher than that of the grower and finisher diets. The higher values recorded for the starter diets could be due to the higher proportion of components added to the diet to boost the rapid growth of the chicks. Nonetheless, the variations in the heavy metal concentrations between the different diets were insignificant and could be traced to the differences in production procedures and handling of the different feeds after production, quality of supplements and concentrates, and equipment used in the manufacturing of the feeds [20]. The mean concentrations of Cr, Mn, and As in all feed types (starter, grower, and finisher) were lower, while those of Zn, Cd, and Ni were higher than the findings of Korish and Attia [20] for a study on the heavy metal concentrations in chicken diets from Saudi Arabia. Similarly, the concentrations of Cr, Zn, and As in all feeds examined in our study were lower, while that of Ni was higher than the report of Haque et al. [45] in poultry diets from the Dhaka area of Bangladesh. Bukar and Said [46] recorded higher concentrations of Co and Mn and lower concentrations of Cr, Zn, Cd, and Ni compared to our findings. The observed differences in the metal concentrations in our study and others could be due to the differences in the procedures and handling methods of the feed during and after production, the quality of supplements and concentrates, the equipment used in the manufacturing of the feed [20], differences in food sources or raw materials used and the environment [20,47].

The three diets contained heavy metals, thus confirming that diets given to chicken can easily be contaminated due to various food sources and the environment they are sourced from. This corroborated the observations of Baykov et al. [47]. Despite recording metals

Table 2
Concentration of metals in diets of broilers.

Metals (mg/kg)	Starter	Grower	Finisher	Toxic level set by NRC (1994)
Cr	2.52 ± 0.45^a (2.05–3.07)	2.41 ± 0.37^b (2.01–3.00)	2.22 ± 0.89^c (2.05–3.07)	10–300
Co	0.71 ± 0.46 (BDL – 1.25)	0.68 ± 0.05 (0.61–0.75)	0.66 ± 0.44 (BDL – 1.25)	100–200
Mn	17.07 ± 1.74 (15.02–18.90)	16.19 ± 1.30 (14.58–17.80)	16.15 ± 1.49 (14.32–17.92)	4000–4800
Zn	56.99 ± 8.86 (44.80–69.78)	55.93 ± 8.64 (43.66–68.08)	55.91 ± 10.37 (42.32–66.19)	500–4000
Al	0.33 ± 0.40 (BDL – 0.98)	0.31 ± 0.38 (BDL – 0.96)	0.31 ± 0.41 (BDL – 0.94)	500–3000
As	1.40 ± 0.31 (0.97–1.78)	1.37 ± 0.27 (0.95–1.70)	1.40 ± 0.50 (0.95–1.80)	100
Cd	2.14 ± 0.48 (1.56–2.89)	2.12 ± 0.46 (1.54–2.83)	2.10 ± 0.45 (1.54–2.77)	12–40
Ni	3.69 ± 0.49 (2.98–4.35)	3.52 ± 0.60 (2.64–4.21)	3.48 ± 0.88 (2.33–4.81)	300–500
Hg	BDL	BDL	BDL	–

Key: ± = plus or minus; ( ) = parenthesis; BDL = below detectable limit; Different superscripts between the different diets varies significantly different ($p < 0.05$) between each diet type.

in the diets, their concentrations were still within the safe levels prescribed by the NRC for nutrient requirements for poultry. Nonetheless, heavy metals could still build up in the tissues of the chicken feeding on these diets to unsafe levels over time, thereby causing health issues for end consumers such as humans. To this end, it is very necessary to ensure that the diets fed to the chicken are free from heavy metals. This will in turn prevent the sales of metal contaminated chicken to the public, as this can pose health risks to humans [2,18].

3.3. Concentration of the various metals in water source

Fig. 2 shows the levels of the metals in the water source of the birds. Again, Hg was not detected in the water samples. The concentrations of Cr, Co, Mn, Al, As, Cd, and Ni were 65.0, 2030.0, 14.83, 24.2, 127.0, 323.33, and 17.43 times, respectively, and higher than the WHO acceptable limits for drinking water (Fig. 2) (See Supplementary Table 5 for raw data).

The importance of providing quality drinking water in a poultry farm cannot be overemphasised. This is because water has been established as a major route of metal contamination in poultry and beyond [4,29]. The quality of the drinking water on a poultry farm can be influenced by the socioeconomic activities taking place around the farm. According to Simone et al. [3] and Gall et al. [4], metals may occur naturally in the environment, and in some other instances, the heavy metal pollution is anthropogenically driven [4]. In this study, varying concentrations of different metals were recorded in the water source within the poultry farm. These metals could potentially have originated from the extensive fertiliser and pesticide applications taking place in farm lands within the poultry farm, which may have infiltrated into the groundwater over time, thereby contaminating it [4].

In a study carried out by Haque et al. [45] on heavy metal concentrations in water sources from a poultry farm in Dhaka (Bangladesh), higher concentrations of Zn, As, and Ni were recorded compared to the present study. Furthermore, Joseph et al. [29], from a study on the concentration of metals in borehole water from Ikot Abasi LGA in Akwa Ibom State, Nigeria, recorded lower concentrations of Cr, Cd, and Ni in the water compared to the present study. The concentrations of Cr, Co, Mn, As, Cd, and Ni in the poultry farm's water source were higher than those of Joseph et al. [28] for a study on the water quality of boreholes in Ikot Ada Udo (Nigeria). Finally, Asare-Donkor et al. [49] reported lower concentrations of Cr, Co, Mn, Zn, Al, As, Cd, and Ni in water compared to our findings. The discrepancies in the concentrations of metals in water between the present study and other studies compared could be due to the differences in the level of anthropogenic activities [4], depth of boreholes, closeness to contaminants, and other factors enumerated by Joseph et al. [29].

Furthermore, in a study carried out by Gall et al. [4], it was reported that the quality of water from poultry farms is influenced by the anthropogenic activities around them. This was obvious from the unsafe levels of metals seen in the water source from the poultry farm in our study. In our study, the concentrations of Cr, Co, Mn, Al, As, Cd, and Ni were 65.0, 2030.0, 14.83, 24.2, 127.0, 323.33, and 17.43 times, respectively, above the drinking water level set by WHO. This denotes that the extensive fertiliser and pesticide application taking place in farm lands within close proximity to the poultry farm introduced contaminants into the soil, which infiltrated into the groundwater. This potentially contaminated the water source and made it unsafe for the chicken, thus posing a health risk to humans consuming the chicken. It is well documented that at toxic levels, metals and other contaminants can bioaccumulate in meat causing health hazards to animals and humans consumers [14]. Furthermore, severe acute and chronic adverse effects may originate from human exposure to metals [22], including peripheral nervous systems, hypertension, and damage to the gastrointestinal tract, reproductive anomalies, and nephropathy [23]. Unsafe exposure to Cr, Mn, Cd, Ni, and Zn has been linked to health defects in humans. Zn is a very essential element; however, it could still become toxic when ingested at unsafe levels, potentially resulting in health issues for humans as outlined previously [43].

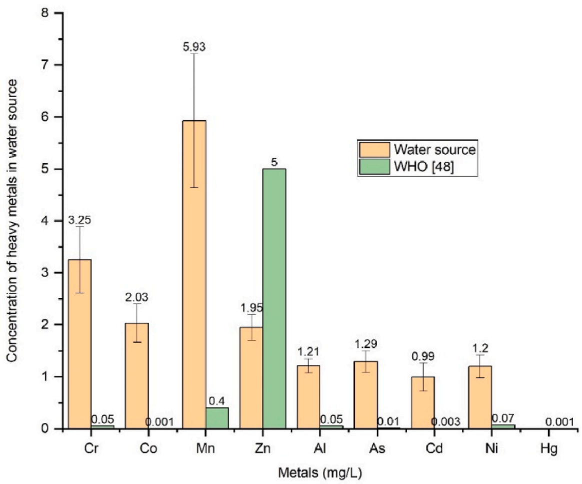

Fig. 2. Concentration of heavy metals in water source compared to WHO [48].

3.4. Metal concentration in the soil from the poultry farm

Fig. 3 shows the level of analysed metals in the soil samples obtained from the poultry farm. Again, Hg was not detected. The concentrations of Cr, As, and Cd were 36.2, 12.7, and 1.67 times, respectively, above the WHO [43] acceptable limits for soil (Fig. 3) (See Supplementary Table 5 for raw data).

In most cases, poultry birds are allowed to roam and eat any available food particles from the earth within the perimeter of the poultry farm. To this end, the possibility of these chicken ingesting contaminated food and soil is very high. In some earlier studies, feed, environment, and litter contaminants were implicated as the major sources of heavy metal exposure in poultry [16,17]. The extensive application fertiliser and pesticide practiced within and around the farm, and the practice of allowing the birds to eat freely from the earth increases the possibility of ingesting contaminated food and soil during the course of feeding [4]. This could result in the heavy metal contamination of the chicken sold to consumers that presents with potential health hazards to animals and humans [2,14]. The concentrations of Cr, Co, Zn, and Ni in the soil from the poultry farm were lower, while the Cr concentration was higher than the findings of Arroyo et al. [50] for a study on the heavy metal concentration in soil from poultry manure. Furthermore, the mean concentration of Mn, Zn, As, and Cd in the soil was higher than that of Ogunwale et al. [51] for an assessment on the metals distribution in the poultry farm surface soil of Osun State (Nigeria). Similarly, the mean concentration of Zn, As, and Cd in the soil from the poultry farm was lower than the findings of Ogunwale et al. [52] for a study on the mobility of heavy metals in soil from some poultry farms in Osun State (Nigeria). The observed difference in our study and compared studies could be due to the factors already mentioned [4].

From our study, it was observed that the concentrations of Cr, As, and Cd were 36.2, 12.7, and 1.67 times, respectively, above the WHO acceptable limits for soil. This denotes that the extensive fertiliser and pesticide application practice may have raised the concentrations of the aforementioned metals to levels that are unsafe for chicken and subsequently human consumption [4]. It is well documented that severe acute and chronic adverse effects may originate from human exposure to heavy metals [22], including peripheral nervous systems, hypertension, and damage to the gastrointestinal track, reproductive anomalies, and nephropathy [23]. Toxic levels of Cr and Cd have been linked to various adverse effects [43]. Poisoning from As could cause cancer of the skin, lungs, bladder, and kidneys [43]. Although the concentrations of Co, Mn, Zn, Al, and Ni in the soil samples from the poultry farm were within safe levels, over time they could bioaccumulate with the continuous release of contaminants from farmland activities into the environment. To this end, to prevent the distribution of contaminated chicken to the public, it is therefore pertinent to avoid the release of any form of contamination from anthropogenic activities into environments close to poultry farms, and the practice of allowing the birds to eat freely from the earth.

3.5. Metals concentration in the chicken droppings

The concentration of heavy metals in the droppings of chicken from the Abak poultry farm is shown in Table 3. Mercury was not detected in the droppings throughout the study. The concentration of Cd in the droppings was 1.53 times above the European Commission's acceptable limits for compost and organic manure (Table 3) (see Supplementary Table 5 raw data).

According to Eton et al. [19], minerals exceeding the levels required by animals are excreted as manure, which could impact the environment negatively. With the discouraging toxic effects of utilising fertilisers to boost the nutrient composition of soils for cultivation, a bulk of farmers have reverted to the application of animal droppings as manure. To this end, it is therefore vital that uncontaminated droppings are used for this purpose; otherwise, they could still constitute danger to humans over time [2,14]. The mean concentrations of Cr, Mn, Zn, Al, and Ni recorded in droppings in the present study were lower, while that of Cd was higher than the findings of Korish and Attia [20] for the study on metal concentrations in litters of chicken in Saudi Arabia. Furthermore, studies

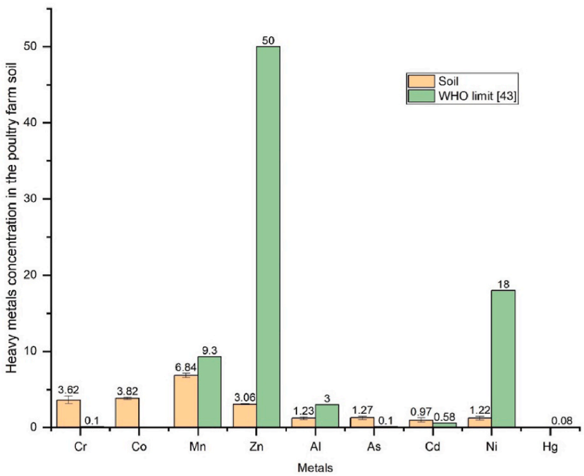

Fig. 3. Concentration of heavy metals in soil samples around the poultry farm compared to WHO [43].

Table 3
The concentration of metals in the droppings of broilers from the poultry farm.

Metals (mg/L)	Broiler dropping	European commission for compost/organic manure [53]
Cr	0.92 ± 0.06 (0.86–1.02)	100
Co	0.40 ± 0.35 (BDL – 0.65)	–
Mn	2.49 ± 0.83 (1.98–3.45)	–
Zn	60.56 ± 17.12 (45.56–79.20)	400
Al	0.54 ± 0.49 (BDL – 0.98)	–
As	BDL	41
Cd	**2.29** ± 0.94 (1.28–3.14)	1.5
Ni	2.49 ± 0.53 (1.98–3.04)	30
Hg	BDL	–

Key: ± = plus or minus; () = ranges; BDL = below detectable limits; Bold values are unsafe.

from Kucharski and Bialecka [54] for heavy metals in poultry litter and Ding et al. [55] for heavy metal concentration in animal droppings in China recorded higher concentrations of Cr, Zn, Cd, and Ni compared to the chicken droppings of the present study. The differences in the levels of the studied metals in the droppings in our study and the other studies compared could be a result of the difference in the bioavailability of the metals, the intensity of anthropogenic activities around the poultry farm, the quality of diets and water given to the chicken, the study periods, geographical areas, and study durations [4].

In addition, the observed concentration of Cd in the droppings was 1.53 times above the European Commission's acceptable limits for compost and organic manure. This reveals that the droppings produced from the poultry farm contain unsafe levels of Cd. The Cd contamination possibly resulted from the water source and diets given to the chicken, contaminated soil they eat from often, the fertiliser and pesticide application practice within the poultry farm, and other anthropogenic activities. When these contaminated droppings are applied to farmlands to boost the availability of nutrients, there is a high tendency that the observed toxic Cd levels will be absorbed into the tissues of the cultivated plants and human consumers, leading to adverse effects [43]. Despite the safe levels of Cr, Co, Mn, Zn, Al, and Ni recorded for droppings in the present study, they could still build up over time and contaminate farmlands.

3.6. *Source of metals in the various samples*

Table 4 shows the results of the PCA analysis done to reveal the origin of metals in the samples. The principal component 1 (PC 1) returned high positive loading values for Mn (0.99), Zn (0.81), Cr (0.86), Co (0.98), and Al (0.92) in the water source.

Table 4
Loading plots of principal component analysis (PCA) for water source, soil, diet, and chicken meat.

	Principal component 1	Principal component 2
Cr-W	0.86	0.07
Co-W	0.98	0.22
Mn-W	0.99	0.04
Zn-W	0.81	0.33
Al-W	0.92	−0.40
As-W	−0.09	0.99
Cd-W	−0.07	−0.99
Ni-W	−0.09	−0.99
Cr-S	0.97	−0.61
Co-S	0.87	0.97
Mn-S	0.99	0.02
Zn-S	0.86	−0.57
Al-S	0.92	−0.40
As-S	−0.08	0.99
Cd-S	−0.06	−0.99
Ni-S	−0.09	−0.99
Cr-D	0.99	0.28
Co-D	0.97	0.26
Mn-D	−0.31	−0.95
Zn-D	0.94	0.50
As-D	−0.79	0.52
Cd-D	−0.96	−0.27
Ni-D	−0.04	0.99
Cr-M	0.99	−0.04
Mn-M	0.89	0.08
Zn-M	0.93	0.37
Total variance	**76.73 %**	**23.27 %**

Key: Cr-W = chromium in water, Cr-S = chromium in soil, Cr-D = chromium in diet, Cr-M = chromium in chicken meat.

Also, high positive loading values for Cr (0.99), Co (0.97), and Zn (0.94) in diets, high positive loading values for Cr (0.97), Mn (0.99), Co (0.97), Zn (0.86), and Al (0.92) in soil, and high positive loading values for Mn (0.89), Cr (0.99), and Zn (0.93) in meat resulted in a total variance of 76.73 %. PC 2 revealed high positive loading values for As (0.99) in water source, high positive loading values for Co (0.97) and As (0.99) in soil, and high loading values for Ni (0.99) in diets, resulting in a total variance of 23.27 % (Table 4). Furthermore, in the PCA plot, Cr-S, Cr-W, Cr-D, and Cr-M formed a cluster; Mn-W, Mn-S, and Mn-M formed the second cluster; and Zn-M, Zn-W, and Zn-D formed the third cluster.

The origin of metals in the muscles of the chicken in the poultry farm under study was traced by evaluating the relationships between the heavy metals in chicken muscles and water source, soil, and diets using PCA. Studies have proven that heavy metals within the tissues of the chicken originate from their water source, diet, and soil [16,17]. Similar observations were recorded for this study. Our PC1 gave high positive loading values for Mn, Zn, Cr, Co, and Al in water source, for Cr, Co, and Zn in diets, for Cr, Mn, Co, Zn, and Al in soil, and for Mn, Cr, and Zn in meat, amounting to 76.73 %. According to Joseph et al. (2022), a total variation value above 60 % denotes an anthropogenic source. This implies that the Mn, Zn, Cr, Co, and Al in the water, Cr, Co, and Zn in diets, Cr, Mn, Co, Zn, and Al in soil, and Mn, Cr, and Zn in the chicken meat originated from the pesticides and fertiliser applications in the farmlands within the proximity of the poultry and other man-made activities. On the other hand, PC 2 returned high positive loading values for As in water sources, for Co and As in soil, and for Ni in diets, resulting in a total variance of 43.27 %, denoting the natural sources for each contaminant.

As revealed by the PCA plot, several clusters were formed. First, Cr-S, Cr-W, Cr-D, and Cr-M formed a cluster while Mn-W, Mn-S, and Mn-M formed the second cluster. The third cluster was formed by Zn-M, Zn-W, and Zn-D. This denotes that the Cr concentration in the chicken meat originated collectively from the soil, water, and diets while Mn in the chicken meat was introduced from the water and soil, On the other hand, Zn in the meat was introduced from water and diets. This stresses the importance of ensuring that uncontaminated diets and water are made available for the chicken. Furthermore, the environment should be kept free from anthropogenic activities that could contaminate the soil within the poultry farm.

3.7. *Health risk assessment from the ingestion of metals*

3.7.1. *Estimated daily intake (EDI)*

Table 5 shows the EDI from the ingestion of the various metals from the liver, meat, and gizzard of the chicken. For liver, Zn returned the highest EDI in children and adults with values, of 1.35×10^{-1} and 1.02×10^{-1} mg/kg/day, respectively. For meat, Zn had the highest EDI in children (1.52×10^{-2} mg/kg/day) while Mn had the highest EDI in adults (5.89×10^{-2} mg/kg/day). Similarly, in the gizzard, Zn had the highest EDI in children and adults with values of 1.25×10^{-2} and 9.35×10^{-3} mg/kg/day, respectively. The EDI due to the ingestion of each metal from the consumption of liver, meat, and gizzard of the chicken from Abak were higher in children. The EDI due to the ingestion of Cd from the consumption of gizzard by children and adults were 1.82×10^{-3} and 1.38×10^{-3} mg/kg/day, respectively and were above the reference oral dose.

3.7.2. *Target hazard quotient (THQ) and hazard index (HI)*

Table 6 shows the result of the manually computed THQ and HI of ingesting metals from the dietary intake of liver, meat, and gizzard. For liver, Zn had the highest THQ in children (4.51×10^{-1}) and adults (3.39×10^{-1}). For meat, Zn had the highest THQ in children (5.08×10^{-2}) and adults (3.81×10^{-2}). For gizzard, Cd had the highest THQ in children ($1.83 \times 10^{\circ}$) and adults ($1.38 \times 10^{\circ}$). The THQ of each heavy metal from the consumption of the liver, meat, and gizzard of the chicken from Abak were higher in children. The THQ due to the ingestion of Cd in children ($1.83 \times 10^{\circ}$) and adult ($1.38 \times 10^{\circ}$) were higher than the safety value of 1. The HI value of ingesting the metals from the gizzard in children and adults were both greater than one with values of $1.92 \times 10^{\circ}$ and $1.44 \times 10^{\circ}$, respectively. Furthermore, the HI for all the metals from consumption of the liver, meat, and gizzard were higher in children.

3.7.3. *Carcinogenic risk (CR)*

Table 7 shows the result of the carcinogenic risk of ingesting the various metals through consumption of liver, meat, and gizzard of chicken from the Abak poultry farm. For gizzard, Cr had the highest CR value from consuming the gizzard by children (1.59×10^{-3})

Table 5
Estimated daily intake (EDI) of heavy metals from the dietary intake of liver, meat, and gizzard of the broilers from Abak, Akwa Ibom State.

Metals (mg/kg/day)	Liver		Meat		Gizzard		Rfd value
	Ch	Ad	Ch	Ad	Ch	Ad	
Cr	3.53×10^{-3}	2.65×10^{-3}	8.67×10^{-4}	6.50×10^{-4}	3.17×10^{-3}	2.38×10^{-3}	1.5
Co	3.97×10^{-3}	2.98×10^{-3}	–	–	–	–	0.03
Mn	5.40×10^{-3}	4.05×10^{-3}	1.77×10^{-3}	5.89×10^{-2}	1.53×10^{-3}	1.15×10^{-3}	0.14
Zn	1.35×10^{-1}	1.02×10^{-1}	1.52×10^{-2}	1.14×10^{-2}	1.25×10^{-2}	9.35×10^{-3}	0.3
Al	–	–	–	–	–	–	1.0
As	–	–	–	–	–	–	0.0003
Cd	–	–	–	–	**1.83×10^{-3}**	**1.38×10^{-3}**	0.001
Ni	–	–	–	–	5.67×10^{-4}	4.25×10^{-4}	0.02
Hg	–	–	–	–	–	–	0.0005

Key: Ad = Adult; Ch = Children; Bold EDI values are unsafe.

Table 6
Target hazard quotient (THQ) of heavy metals from the dietary intake of liver, meat, and gizzard of the broilers from Abak, Akwa Ibom State.

Metals	Liver		Meat		Gizzard	
	Ch	Ad	Ch	Ad	Ch	Ad
Cr	2.36×10^{-3}	1.77×10^{-3}	5.78×10^{-4}	4.33×10^{-4}	2.11×10^{-3}	1.58×10^{-3}
Co	1.32×10^{-1}	9.92×10^{-2}	–	–	–	–
Mn	3.86×10^{-2}	2.89×10^{-2}	1.26×10^{-2}	9.46×10^{-3}	1.64×10^{-2}	8.21×10^{-3}
Zn	4.51×10^{-1}	3.39×10^{-1}	5.08×10^{-2}	3.81×10^{-2}	4.16×10^{-2}	3.12×10^{-2}
Al	–	–	–	–	–	–
As	–	–	–	–	–	–
Cd	–	–	–	–	**1.83×10^{0}**	**1.38×10^{0}**
Ni	–	–	–	–	2.83×10^{-2}	2.13×10^{-2}
Hg	–	–	–	–	–	–
HI	6.24×10^{-1}	4.69×10^{-1}	6.39×10^{-1}	4.79×10^{-2}	$1.92 \times 10^{\circ}$	$1.44 \times 10^{\circ}$

Key: Ad = Adult; Ch = Children; Bold THQ values are unsafe.

and adults (1.19×10^{-3}). The CR values due to the consumption of liver, meat, and gizzard of chicken were higher in children. The CR value due the ingestion of Cr by children and adult from the consumption of liver, meat, and gizzard, and the CR value due to the ingestion of Cd and Ni by children and adult from the consumption of gizzard were greater than the safe value of 10^{-4} (Table 7).

In the present study, we further utilised the health risk assessment model to predict the potential health dangers associated with the ingestion of heavy metals from the dietary intake of chicken over time. For liver and gizzard, Zn returned the highest EDI in children and adults. In chicken meat, Zn returned the highest EDI in children, while Mn had the highest EDI in adults. This makes Zn the most ingested metal by adults and children from the dietary intake of liver and gizzard. Also, Zn was the most ingested by children, and Mn was the most ingested by adults from the consumption of chicken meat from poultry. In all these, Zn and Mn did not indicate any potential danger from the consumption of the liver, gizzard, and meat due to their high Rfd values of 0.3 and 0.14 mg/kg/day, respectively. Furthermore, the EDI due to the ingestion of each metal from the consumption of liver, meat, and gizzard of the chicken from Abak was higher in children, which conforms to the findings of Joseph et al. [29]. Children recorded higher EDI values because they are more vulnerable to metallic exposures due to their rapid growth rates and poorly developed immune systems [29]. The EDI due to the ingestion of Cd in children and adults from the consumption of gizzards was above the reference oral dose (Rfd) value of 0.001. This denotes that the consumption of gizzards will expose adults and children to Cd poisoning and has been implicated in various adverse health effects [43].

In adults and children, Zn had the highest THQ from the dietary intake of liver and meat, while Cd returned the highest THQ from the consumption of gizzard. This makes Zn and Cd the major non-carcinogenic sources. Furthermore, this denotes that the consumption of the liver, meat, and gizzard will make children and adults vulnerable to Zn and Cd poisoning. Similar to the observations for EDI, the THQ, HI, and CR values from the ingestion of each metal from the consumption of liver, meat, and gizzard of the chicken in our study were equally higher in children, thereby making them more vulnerable to the metal exposure. This was also in consonance with the findings of Joseph et al. [29]. Children are more vulnerable because their immune system is not fully developed compared to that of adults [29]. In adults and children, the THQ values due to the ingestion of Cd and the HI from the collective ingestion of heavy metals due to the dietary intake of gizzard were greater than 1. This implies that the children and adults consuming the gizzards of the chicken from the poultry farm in Abak will be exposed to Cd poisoning, with its health implications already established. In adults and children, Cr returned the highest CR value from the consumption of gizzard, denoting that Cr was the major source of cancer risk. The CR value due to the ingestion of Cr by children and adults from the consumption of liver, meat, and gizzard of chicken and the CR value due to the ingestion of Cd and Ni by children and adults from the consumption of gizzard were greater than the safe value of 10^{-4}. This indicates that the ingestion of Cr from the consumption of liver, meat, and gizzard, and the ingestion of Cd and Ni from the consumption of gizzard, could cause cancer in children and adults over time.

4. Conclusion

Our findings indicate that Cr, Mn, Co, and Zn accumulated more in the liver, although Cd and Ni were only recorded in the gizzard.

Table 7
Carcinogenic risk (CR) of heavy metals from the dietary intake of liver, meat, and gizzard of the broilers from Abak, Akwa Ibom State.

Metals	Liver		Meat		Gizzard	
	Ch	Ad	Ch	Ad	Ch	Ad
Cr	**1.77×10^{-3}**	**1.33×10^{-3}**	**4.34×10^{-4}**	**3.25×10^{-4}**	**1.59×10^{-3}**	**1.19×10^{-3}**
Zn	0	0	0	0	0	0
As	–	–	–	–	–	–
Cd	–	–	–	–	**6.95×10^{-4}**	**5.24×10^{-4}**
Ni	–	–	–	–	**9.64×10^{-4}**	**7.23×10^{-4}**

Note: Bold CR values are unsafe.

The starter diet recorded higher concentrations of heavy metals compared to other diets. Levels of Cr, Co, and Mn (in the liver), Cr and Mn (in the meat), and Cr, Mn, Cd, and Ni (in the gizzard) were unsafe. Similarly, unsafe levels of Cr, Co, Mn, Al, As, Cd, and Ni were observed in their water source. Their droppings contained above safe levels of Cd and are unsuitable to be used as manure. According to PCA analysis, the observed levels of Mn, Zn, Cr, Co, and Al in their drinking water, Cr, Co, and Zn in diets, Cr, Mn, Co, Zn, and Al in soil, and Mn, Cr, and Zn levels in the chicken meat originated from the applications of pesticides and fertilisers and other anthropogenic activities within and around the poultry farm. The study further affirms that poultry birds can be contaminated by water, diets, and the environment. The PCA analysis further showed that Cr in the chicken meat originated collectively from the soil, water, and diets while Mn in the chicken meat was introduced from the water and soil, and Zn in the meat introduced from water and diets. The EDI revealed that Zn was the most ingested metal by adults and children from the dietary intake of liver and gizzard, and Mn was the most ingested by adults from the consumption of chicken meat from the poultry under study. As revealed by the findings, children are more susceptible to the metallic exposure from the consumption of liver, meat, and gizzard. The EDI, THQ, and HI due to the dietary intake of gizzard by adults and children indicate potential Cd poisoning. Zn and Cd are the major non-carcinogenic sources, while Cr is the major carcinogenic source. The ingestion of Cr from the intake of liver, meat, and gizzard, and Cd and Ni from the intake of gizzard, could cause cancer in children and adults over time. More similar studies should be carried out around the world to ensure that chicken of good quality is distributed to preserve the health of consumers.

Limitation of the study

The present study had some limitations. First, the number of metals analysed in the various tissues and organs of the chicken was nine ($n = 9$). Second, only one hundred ($n = 100$) samples of the gizzard, meant and liver were analysed. Third, only one poultry farm was studied and this was because its management was easily accessible. The first two limitations were largely driven by limited resources. Fourth, only one LGA was studied out of the thirty (30) in Akwa Ibom State.

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Data availability

Data generated in this study are all in the manuscript and supplementary data.

Ethical approval

Ethical approval was obtained from the ethical committee of Arthur Jarvis University (No. AJU/RC/2022/30). All the procedures and protocols were performed in compliance with the environmental health (2015) ethical guidelines.

CRediT authorship contribution statement

Uwem Okon Edet: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Akaninyene Joseph:** Writing – original draft, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dokwo Bassey:** Formal analysis, Conceptualization. **Itoro Nyong Bassey:** Writing – original draft, Methodology, Investigation, Funding acquisition. **Glory P. Bebia:** Resources, Methodology, Funding acquisition. **Elizabeth Mbim:** Writing – original draft, Investigation, Funding acquisition. **Agbor Yeneochia Ogar:** Writing – original draft, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e36941.

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