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Risk Potentials of disease-causing metals in poultry-related foods and products in Uyo, southern Nigeria

Ebong, G. A.,[1*] Okon, A. O.[2] and Anweting, I. B.[1]

[1]Department of Chemistry, University of Uyo, Akwa Ibom State, Nigeria.

[2]Department of Animal and Environmental Biology, University of Uyo, Akwa Ibom State, Nigeria.

**E-mail: g_ebong@yahoo.com*

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Abstract: Poultry-related foods and products serve as sources of protein and organic manure for most farmers however, if they are contaminated by toxic metals the consumers are in danger. This research examined health hazards associated with eggs, meats, and organic wastes from some poultry farms in Uyo, Nigeria. These poultry-related foods and products were obtained from designated poultry farms within the study area, treated, and analyzed for concentrations of Cd, Cr, Ni, and Pb using atomic absorption spectrophotometer. Results obtained indicated that, the mean concentration of Cr in eggs was higher than the acceptable limit. Principal component analysis indentified factors accountable for these toxic metals in the studied poultry-related samples. The mean concentrations of these metals in broiler meats and poultry wastes were within their acceptable limits. The estimated daily intake (EDI) of the metals for children and adults' classes in the entire studied products except broiler meats were within their recommended oral reference doses. The target hazard quotient (THQ) of the metals for both children and adult classes via the exposure to eggs and poultry wastes were less than one. However, the THQ values for Cd, Cr, and Pb via the consumption of broiler meats were higher than one. The mean values of hazard index (HI) of the toxic metal via exposure to the studied eggs and poultry wastes by both classes of the consumers were less than one. The mean HI values of the metals via the consumption of broiler meats were higher than one for both the children and adult classes though; the children class was more vulnerable. The cancer risk (CR) of the metals for children and adult classes were within the acceptable limit but, the values for broiler meat for both classes were higher than one and the children class was also more susceptible.

1. Introduction

Presently, poultry farming is one of the major sources of income in most countries of the world. The eggs, meat, and wastes harvested from poultry farms are useful to human in their respective ways. However, these products harvested from poultry farms are not free of metal contaminants originating from natural and anthropogenic sources (Sobhanardakani *et al*., 2018). The poultry feeds, water, and the environment are the main sources of metal contaminants in poultry-related foods and products (Kodani *et al*., 2022; Lv *et al*., 2023; Zakanova *et al*., 2023). Reports have shown that apart from essential metals, toxic metals are as well introduced into poultry feeds during processing (Adekanmi, 2021; Aljohani, 2023). These toxic metals in poultry feeds are transferred into the meats, eggs, and organic wastes (Abedi *et al*., 2023; Darwish *et al*., 2023). Poultry-related foods and products are widely consumed in most countries of the world including Nigeria as good sources of protein (Adedokun *et al*., 2019). Chicken meat is also consumed intensively due to its outstanding qualities as white meat (Morshdy *et al*., 2022).

Organic wastes from poultry farms are mostly used as organic manure for the cultivation of crops by farmers (Richa *et al*., 2020; Ur Rahman *et al*., 2022). Thus, if these poultry wastes applied in farms are loaded with toxic metals these metals are subsequently transferred to the crops cultivated alongside the essential nutrients (Ebong *et al*., 2022; Etuk *et al*., 2022; Priya *et al*., 2023). Eventually, these toxic metals in poultry farms are transferred to the consumers of chicken meats, eggs, and crops fertilized with poultry wastes (Chen *et al*., 2022; Tindwa and Singh, 2023). The metals have very strong potentials of causing both carcinogenic and non-carcinogenic human health hazards (Abd-Elghany *et al*., 2020; Shi *et al*., 2023; Chowdhury and Alam, 2024). Studies have also shown that, metals can bio-accumulate in the environment and biological systems and manifest themselves later with negative tendencies (Ebong and Ekong, 2015, Balali-Mood *et al*., 2021; Offiong *et al*., 2021).

The accumulation of toxic metals in poultry-related product may results in the contamination and subsequent pollution of both the aquatic and terrestrial environments (Oyewale *et al*., 2019; Gržinić *et al*., 2023). In other words, toxic metals in poultry-related products if improperly managed can cause serious damage to human race (Aljohani, 2023). Nevertheless, much has not been done to investigate the levels of bio-accumulation of toxic metals in poultry-related products. Hence, information on the accumulations of toxic metals in poultry-related products sold in the City of Uyo, Akwa Ibom State is scanty. Literature survey shows that the heavy metals chiefly include Pb, Hg, Cd, Cr, Cu, Zn, Mn, Ni, Ag, etc. are considered most toxic to humans, animals, fishes and environment (Huseen *et al*., 2019; Karim *et al*., 2016; El Hammari *et al*., 2022; Alam *et al*., 2023)

Hence, this study was conducted to evaluate the levels of toxic metals in poultry-related products sold in Uyo and the associated health problems on prolonged exposure to these products by the consumers. The outcome of this research could assist in the proper planning and execution of poultry farming and proper management of poultry-related products available in Uyo. The results of this study will be beneficial to both farmers and the consumers of poultry-related foods and products harvested from farms within the study area.

2. Materials and Method

2.1. Study Area

Uyo is the capital of Akwa Ibom State and it locates within the Niger Delta Region of Nigeria. Uyo Metropolis locates within latitude 04° 59! N and Longitude 07° 57! E. As a State in the Oil producing Area of Nigeria, the population is high. The region locates within the Equatorial rain forest with a land mass of almost 28.48km^2(Udoh and Igbokwe, 2014). Akwa Ibom State has two distinctive seasons namely: Dry and wet. The dry season begins from December and ends in March, while the wet season runs from April to November. The average yearly rainfall varies between 2000 and 3000 mm, while the average yearly temperature varies from 25°C and 29°C (Afangideh *et al*., 2005). Due to the high population within the State, there is high demand and consumption of poultry-related products. Consequently, the quality of poultry-related products sold and consumed within the area has a direct impact on a greater proportion of the inhabitants. The utilization of poultry-related products loaded with toxic metals can have immense consequences on the consumers within and outside the State. Hence, the assessment of these products to ascertain their aptness for human utilization or otherwise is essential.

2.2. Samples Collection, treatment and Digestion

Ten (10) were obtained from each of the poultry farms investigated and transported in plastic bags to the laboratory. In the laboratory, the eggshells were thoroughly washed with distilled water and cracked using sterile spatula, and the content was poured into a clean 100 mL beaker. The egg albumin and yolk were properly homogenized using a clean stirrer. The samples were oven-dried at 80 °C until a constant weight was achieved. The dried samples were ground to powdered form using plastic pestle and mortar. One gram (1 g) of the dried sample placed in a 250 mL digestion tube then 10 mL of Conc. HNO_3 was added. The mixture was heated for 45 mins at 90°C on a hot plate; the temperature was later increased to 150 °C and the mixture was allowed to boil for 8 hours when a clear solution was obtained. The digestion process was continued by adding 5 mL Conc. HNO_3 and the process was completed when the volume of the mixture reduced to 1 mL. During the digestion, the internal wall of the digestion tube was washed down with distilled water and the tube swirled all through the process to avoid loss of sample. On cooling, 5 mL of 1 % HNO_3 was added to the residue. The solution was filtered using Whatman No. 42 filter paper into a 25 mL volumetric flask and made to mark with distilled water (Samad *et al*., 2023).

Six weeks old broilers (*Gallus gallus domesticus*) were purchased from the poultry farms investigated and slaughtered using stainless steel knife. Then the various parts such as heart, liver, muscle, and gizzard were harvested and washed with distilled water. These chicken parts were reduced to smaller sizes with knife and mixed mutually according to the site. Two grams each was weighed and oven-dried at 105 °C for two hours. The dried sample was placed in a digestion flask then a mixture of 1mL Conc. $HClO_4$ and 5mL Conc. HNO_3 was added and digested on a hot plate. The digestion process was continued until a colourless solution was achieved. The volume of the digest in the flask was increased to 50 mL with distilled water. Then the mixture was filtered through Whatman No. 42 filter paper into a clean 50 mL volumetric flask and made to mark with distilled water (Hossain *et al*., 2023).

Poultry wastes were obtained from the studied farms into polyethylene bags, properly labeled and transported to the laboratory. These poultry wastes were oven-dried at a temperature of 105 °C until a constant weight was obtained. Two grams (2 g) of the waste was placed in a flask, a mixture of Conc. HNO_3 and H_2SO_4 (3:1 v/v) was added and digested on a hot plate. The digestion was continued until a clear coloured solution was achieved. The residue was then transferred into a clean 25 mL volumetric flask and made to mark with distilled water (AOAC, 2004; Korish and Attia, 2020). All the filtrates obtained were stored at a temperature of 4°C before analysis with AA Dual atomic absorption spectrophotometer.

2.3. Evaluation of human health risks

The health risks related to constant exposure to toxic metals through the studied eggs, broiler meat, and poultry wastes were appraised using Estimated Daily Intake (EDI) of metals, Target Hazard Quotients (THQ), Hazard Index (HI), and Target Cancer Risk (TCR) as reported by USEPA (2018).

2.3.1. Estimated Daily Intake (EDI) of Toxic Metals

The estimated daily intake of toxic metals via the studied poultry-related products sold in Uyo was determined using Eqn. 1.

$$\text{EDI} = \frac{MCxIR}{BW} \qquad \textbf{Eqn. 1}$$

Where MC represents the concentration of toxic metals in the studied poultry related products, IR is the ingestion rate of the products, and BW is the body weight of the consumers. The values of IR used in this study were for eggs: 0.0065 and 0.0113 kgday^{-1}for the children and adult classes, respectively

(Shaheen *et al*., 2016). For broiler meat IR were 46.59 and 60.95 kgday-1 for children and adult classes, respectively (Patrick-Iwuanyanwu and Chioma, 2016; Etuk *et al*., 2023). IR used for poultry wastes were 2.00E-04 and 1.00E-04 $kgday^{-1}$ for the children and adult classes, respectively (USEPA, 2011). The body weights of the consumers used was 24.0 kg for children and 70.0 kg for the adult class (Ekhator *et al*., 2017). Values of MC were obtained directly from the analysis with AAS.

2.3.2. Determination of Target hazard quotient (THQ)

The target hazard quotient of the toxic metals via exposure to the studied poultry-related products sold in Uyo was evaluated using Eqn. 2.

$$\text{THQ} = \frac{EDI}{RfD} \qquad \textbf{Eqn. 2}$$

Where EDI is the estimated daily intake rate of toxic metals and RfD indicates the recommended oral reference doses of the toxic metals. The values for EDI were calculated with Equation (1), while the values of RfD according to USEPA (2007) are 1.00E-03, 3.00E-03, 2.00E-02, and 4.00E-03 (mg/kg BW/day) for Cd, Cr, Ni, and Pb, respectively.

2.3.3. Estimation of Hazard index (HI)

The hazard index of toxic metals due to exposure to the studied poultry-related products was assessed using Eqn. 3.

$$\text{HI} = \Sigma\text{THQ} = \text{THQCd} + \text{THQCr} + \text{THQNi} + \text{THQPb} \qquad \textbf{Eqn. 3}$$

In Equation 3 above, ΣTHQ represents the sum of all the target hazard quotients of toxic metals for each of the poultry farms examined. THQCd, THQCr, THQNi, and THQPb are the target hazard quotient for Cd, Cr, Ni, and Pb, respectively.

2.3.4. Evaluation of Cancer risk (CR)

Cancer risk is the likelihood of a consumer having cancer or cancer-related ailment during his or her lifetime on earth as a result of exposure to cancer-causing agents. CR of the toxic metals was assessed by the use of Eqn. 4 below.

$$\text{CR} = CSFxEDI \qquad \textbf{Eqn. 4}$$

In the above equation, CSF is the cancer slope factor of the toxic metals and EDI indicates the estimated daily intake rate of the metals. In this research, values of CSF used were 0.38, 0.50, 1.70, and 8.50E-03 ($mgkg^{-1}day^{-1}$) for Cd, Cr, Ni, and Pb, respectively (USEPA, 2010; Onyedikachi *et al*., 2018).

2.4. Data treatment

This research employed IBM SPSS Statistic version 29.0.2.0 (20) Software for the analysis of results obtained. The mean, minimum, maximum, and standard deviation values were obtained by the use of the software. Multivariate analyses such as Principal component analysis and Cluster analysis were carried out with Varimax Factor analysis on the four parameters determined and values below 0.608 were regarded inconsequential. Dendrograms with average linkages were used for the Hierarchical Cluster Analysis.

3.0 Results and discussion

3.1. Concentrations of Toxic metals in poultry-related foods and product

The results for the concentrations of toxic metals in poultry-related foods and products in Uyo are shown in Table 1 below.

Table 1: Results of Toxic metals in poultry-related foods and products

Samples		Cd	Cr	Ni	Pb
	MIN	0.051	0.005	0.001	0.001
	MAX	0.072	0.009	0.002	0.003
EGGS	MEAN	0.061	0.007	0.001	0.002
	SD	0.008	0.002	0.001	0.001
	RL[a]	0.1	0.002	1.65	0.1
	MIN	0.086	0.013	0.001	0.004
	MAX	0.104	0.017	0.003	0.005
BROILER MEAT	MEAN	0.093	0.015	0.002	0.005
	SD	0.007	0.002	0.001	0.001
	RL[b]	0.50	1.00	0.50	0.10
	MIN	0.130	0.019	0.006	0.220
POULTRY WASTES	MAX	0.185	0.025	0.009	0.599
	MEAN	0.158	0.022	0.007	0.448
	SD	0.022	0.002	0.001	0.140
	RL[c]	1.5	2.0	50	120

a = FAO/WHO (2002); b = FAO/WHO, (2011); c = EU (2019).

Results for the concentrations of toxic metals in eggs, broiler meat, and poultry wastes are shown in Table 1. Table 1 indicates that, Cd in eggs from the different poultry farms investigated ranged from 0.051 to 0.072 mgkg^{-1}with average concentration of 0.061±0.008 mgkg^{-1}. The range is lower than 1.190 – 5.000 mgkg^{-1} reported in eggs from poultry farms by Hoseini *et al*. (2023) but higher than 0.000 – 0.024 mgkg^{-1}obtained by Rokanuzzaman *et al*. (2022). However, the mean concentration of Cd obtained (0.061±0.008 mgkg^{-1}) is lower than the limit of 0.1 mgkg^{-1} set up by FAO/WHO (2002). Consequently, the consumers of eggs from poultry farms studied may not have immediate health problems associated with Cd toxicity. But as a highly toxic metal, the level of Cd in eggs from these farms should be evaluated frequently (Okon *et al*., 2023). Cr ranged from 0.005 to 0.009 mgkg^{-1}in eggs from the poultry farmsinvestigated. This range is lower than 0.48 – 8.45 mgkg^{-1}obtained by Aliu *et al*. (2021) however; the range is higher than < 0.005 mgkg-1 reported by Samad *et al*. (2023). The mean value of Cr obtained in the studied eggs (0.007±0.002 mgkg^{-1}) is higher than the stipulated 0.002 mgkg-1 by FAO/WHO (2002). Hence, the consumers of eggs from poultry farms examined may develop health problems including cancer over time as opined by Shin *et al*. (2023) and Ebong *et al*. (2024).

Concentrations of Ni in the studied eggs varied between 0.001 and 0.002 mgkg^{-1}. This is lower than 0.05 – 1.03 mgkg^{-1}obtained in eggs from various poultry farms by Samad *et al*. (2023). The mean concentration of Ni in the studied eggs (0.001±0.001 mgkg^{-1}) is also lower than 1.65 mgkg^{-1} recommended by FAO/WHO (2002). Thus, the consumption of eggs from poultry farms examined may not result in immediate health hazards related to Ni. Pb in eggs from poultry farms evaluated ranged from 0.001 to 0.003 mgkg^{-1}. The reported range of Pb in the studied eggs is below 0.0001 –

0.044 mgkg^{-1} obtained by Rokanuzzaman *et al*. (2022). The mean value of Pb obtained (0.002±0.001 mgkg^{-1}) is lower than the permissible limit of 0.10 mgkg^{-1} by FAO/WHO (2002). Hence, immediate problems associated with Pb toxicity may not be experienced by the consumers of eggs from poultry farms investigated. Though, as a highly toxic metal its accumulation in eggs from the studied farms should be investigated regularly to avoid bioaccumulation and the attendants´ health issues.

The results of toxic metals in broiler meat from poultry farms examined are indicated in Table 1. The results in Table 1 revealed that, concentrations of Cd ranged from 0.086 to 0.104 mgkg^{-1}. This range is consistent with 0.097 – 0.113 mgkg^{-1}obtained by Etuk *et al*. (2023) but higher than 0.004 – 0.010 mgkg-1 reported in broiler meat from different poultry farms by Kia *et al*. (2024). However, the mean concentration of Cd obtained (0.093±0.007 mgkg^{-1}) is lower than the recommended limit of 0.50 mgkg^{-1} by FAO/WHO (2011).

Concentrations of Cr in the studied broiler meat varied between 0.013 and 0.017 mgkg^{-1} (Table 1). The reported range of Cr is consistent with the 0.06 – 0.11 mgkg^{-1} reported by Khan *et al*. (2016) but, lower than 0.161 – 2.215 mgkg^{-1} obtained in chicken meat by Kamaly and Sharkawy, (2023). The mean concentration of Cr in meat samples assessed (0.015±0.002 mgkg^{-1}) is lower than 1.00 mgkg^{-1} stipulated by FAO/WHO (2011). Hence, health consequences associated with exposure to high Cr may not manifest in the consumers of broiler meat from poultry farms assessed. However, bioaccumulation and the related health problems over time should be closely monitored.

Ni in broiler meat harvested from poultry farms investigated varied between 0.001 and 0.003 mgkg^{-1} (Table 1). The reported range is lower than 0.004 – 0.012 mgkg^{-1} obtained in chicken meat by Kia *et al*. (2024). The mean obtained (0.002±0.001 mgkg^{-1}) is far below 0.50 mgkg-1 recommended for poultry meat by FAO/WHO (2011). Thus, the consumption of broiler meat harvested from the studied farms may not pose instant health problems to the consumers.

Table 1 shows that, concentrations of Pb in broiler meat obtained from the studied poultry farms ranged from 0.004 to 0.005 mgkg^{-1}. The range reported is lower than 0.04 – 0.50 mgkg^{-1} recorded in broiler meat by Sher *et al*. (2024). The average value obtained (0.005±0.001 mgkg^{-1}) is below the recommended limit of 0.1 mgkg^{-1} by FAO/WHO (2011). Consequently, the consumption of broilers harvested from the studied farms may not result in health consequences linked to Pb toxicity. However, as a poisonous metal even at low concentration; regular assessment of its presence in the studied farms is recommended to forestall its bioaccumulation and associated problems (Okon *et al*., 2023).

The results of toxic metals in poultry wastes mostly used as organic manure are shown in Table 1. Concentrations of Cd in poultry wastes from the studied farms ranged from 0.130 – 0.185 mgkg^{-1}. The range recorded is lower than 0.031 – 19.0 mgkg-1 reported for Cd in poultry wastes from different poultry farms by Okeke *et al*. (2015). However, the mean concentration of Cd obtained (0.158±0.022 mgkg^{-1}) is lower than the recommended limit of 1.5 mgkg^{-1} by EU (2019). Hence, the utilization of organic wastes from the studied poultry farms as organic manure may not be hazardous to the crops cultivated in the farms however; the trend should be monitored to avert bioaccumulation of metals and related health problems reported by Etuk *et al*. (2022) and Ebong *et al*. (2022).

Cr in poultry wastes obtained from poultry farms examined varied between 0.019 and 0.025 mgkg^{-1}(Table 1). This range is much lower than 2.74 – 151.15mgkg^{-1}obtained in poultry wastes by Gong *et al*. (2019). The average value of Cr in the studied wastes (0.022±0.002mgkg^{-1}) is lower than 2.0mgkg^{-1} stipulated by EU (2019) for organic manures. Hence, the application of poultry wastes from the studied farms as manure may not be detrimental to the crops rather Cr in these wastes might assist in the growth of the crops (Samantaray *et al*., 1998).

Concentrations of Ni ranging from 0.006 to 0.009 mgkg^{-1} was recorded for poultry wastes from the studied poultry farms. The reported range of Ni in poultry wastes is lower than 1.71 – 276.0 mgkg^{-1} obtained by Ravindran *et al*. (2017). The average value of Ni obtained (0.007±0.001 mgkg^{-1}) is less than 50.0 mgkg^{-1} recommended for organic wastes by EU (2019). Thus, the application of the studied poultry wastes as organic manure might be useful for the enzymatic activities of the crops (Chouhan *et al*., 2022; Rakkamma *et al*., 2024).

Table 1 indicates a range and mean concentration of Pb in poultry wastes as 0.220 – 0.599 mgkg^{-1} and 0.448±0.140 mgkg^{-1}, respectively. This range is higher than 0.014 – 0.017 mgkg^{-1} reported in poultry wastes by Okeke *et al*. (2015) however; the range is less than 0.42 – 107.1 mgkg-1 obtained by Ravindran *et al*. (2017). Nevertheless, the mean concentration reported is much lower than 120.0 mgkg^{-1} permissible limit for Pb in organic wastes by EU (2019). Thus, the application of the studied poultry wastes as organic manure might not affect the crops and the consumers. Although, as a toxic metal it can accumulate in soil over time and become toxic to the plants cultivated and invariably the consumers (Ur Rahman *et al*., 2024).

3.2. Principal component analysis (PCA) of toxic metals in the studied samples

The results of PCA of toxic metals in the various poultry-related foods and product examined are shown in Table 2.

Table 2: Results of Principal Component analysis (PCA) of Toxic Metals in the studied poultry-related foods and products

	EGGS		BROILER MEAT	POULTRY WASTES	
	PC1	PC2	PC1	PC1	PC2
Cd	-0.530	0.792	-0.539	0.640	0.754
Cr	0.877	-0.095	0.958	0.892	0.370
Ni	0.623	0.727	0.970	-0.816	0.451
Pb	0.953	0.052	0.884	0.570	-0.781
% Variance	58.7	29.2	2.93	54.9	38.0
Eigenvalue	2.35	1.17	73.2	2.20	1.52

The principal component analysis (PCA) was used to identify variables with common variance and source (Samad *et al*., 2023). Table 2 shows the results of PCA for the different poultry-related products examined. PCA of the studied eggs indicated two factors with Eigen values higher than one (1) and a total variance of 87.9 %. Component 1 had an Eigen value of 2.35, while component had 1.17. The first factor indicated very high positive loadings for Cr, Ni, and Pb, with 58.7% of the total variance. Thus, the accumulation of Cr, Ni, and Pb in the studied might have originated from a common source (Ebong *et al*., 2019; Samad *et al*., 2023). The second factor contributed 29.2% of the total variance with significant loadings for Cd and Ni. Consequently, the other factor could have been the major source for Cd and Ni. Hence, factors 1 and 2 were both sources of Ni in the studied eggs. The factors responsible for the accumulation of these toxic metals in the studied eggs could be feeds and the environment (Kabeer *et al*., 2021; Voica *et al*., 2023). Results of PCA of the studied broiler meat showed one factor with Eigen value of 2.93 and a total variance of 73.2% (Table 2). The factor explained 73.2% of the total variance with strong loadings for Cr, Ni, and Pb hence; the emanated from a familiar source. The factor could basically be poultry feeds as reported by Aljohani, (2023).

PCA results of the studied poultry wastes indicated two major factors responsible for the buildup of toxic metals; these factors contributed a total variance of 92.9% (Table 2). The first factor explained 54.9% of the total variance with strong loadings for Cd, Cr, and Ni. The second factor indicated significant loadings for Cd and Pb with 38.0% of the total variance. The first and second factors could be the feeds and the environment where these farms are operated (Kabeer *et al*., 2021; Voica *et al*., 2023).

3.3. Results of health risks evaluation of toxic metals

The results of health risks evaluation of the effects of toxic metals on human due to exposure to the studied poultry-related foods and product are shown in Table 3.

Table 3: Estimated daily intake (EDI) of toxic metals via the exposure to poultry-related foods and product

	Cd	Cr	Ni	Pb	Cd	Cr	Ni	Pb
				EGGS				
	Children Class				**Adult Class**			
MIN	1.38E-05	1.35E-06	2.71E-07	2.71E-07	8.23E-06	8.07E-07	1.61E-07	1.61E-07
MAX	1.95E-05	2.44E-06	5.42-7	8.13E-07	1.16E-05	1.45E-06	3.23E-07	4.84E-07
MEAN	1.64E-05	1.84E-06	3.79E-07	6.50E-07	9.77E-06	1.10E-06	2.26E-07	3.87E-07
				BROILER MEAT RAW				
	Children Class				**Adult Class**			
MIN	1.67E-01	2.52E-02	2.00E-03	8.00E-03	7.50E-02	1.13E-02	9.00E-03	4.00E-03
MAX	2.02E-01	3.30E-02	6.00E-03	1.00E-02	9.10E-02	1.48E-02	3.00E-03	4.00E-03
MEAN	1.81E-01	2.91E-02	4.40E-03	9.20E-03	8.12E-02	1.31E-02	2.18E-03	4.00E-03
				POULTRY WASTES				
	Children Class				**Adult Class**			
MIN	1.08E-06	1.58E-07	5.00E-08	1.83E-06	1.86E-07	2.71E-08	8.57E-09	3.14E-07
MAX	1.54E-06	2.08E-07	7.80E-08	4.99E-06	2.64E-07	3.57E-08	1.29E-08	8.56E-07
MEAN	1.32E-06	1.87E-07	6.23E-08	3.73E-06	2.26E-07	3.20E-08	1.06E-08	6.40E-07

3.3.1. Estimated Daily Intake (EDI) Rates of Toxic Metals

The results of estimated daily intake rates of toxic metals via the studied poultry products are indicated in Table 3. The EDI results for the exposure of children to toxic metals via the consumption of eggs from the studied farms revealed the following mean values for Cd, Cr, Ni, and Pb: 1.65E-05, 1.84E-06, 3.79E-07, and 6.50E-07 $mgkg^{-1}day^{-1}$, respectively. The results of EDI for the adult class due to exposure via the consumption of eggs indicated 9.77E-06, 1.10E-06, 2.26E-07, and 3.87E-07 $mgkg^{-1}day^{-1}$ for Cd, Cr, Ni, and Pb, respectively. The results obtained revealed that, the valued of EDI reported for both the children and adult classes were within their acceptable oral reference doses (USEPA, 2007; Zheng *et al*., 2020). Consequently, the consumption of eggs from the studied farms may not cause health problems associated with the toxicity of the metals. However, as toxic metals their concentrations in studied poultry-related products should be assessed regularly to avoid bioaccumulation and the related health issues.

Table 3 shows the mean EDI values for the exposure to Cd, Cr, Ni, and Pb through the consumption of broiler meat obtained from the studied farms as 1.81E-01, 2.91E-02, 4.40E-03, and 9.20E-03 for the children and 8.12E-02, 1.31E-02, 2.18E-03, and 4.00E-03 for the adult, respectively. The mean EDI values for Cd, Cr, and Pb for the children were higher than their oral reference doses of 1.00E-03, 3.00E-03, and 4.00E-03 mg/kg-bw/day, respectively (USEPA, 2007; Zheng *et al*., 2020). However, that of Ni was within the acceptable dose of 2.00E-02. For the adult class, the values reported for Cd and Cr were higher than their limits, while those of Ni and Pb were within their limits. Hence, the consumption of broiler meat harvested from the farms examined could result in health problems related to Cd, Cr, and Pb in the children class. While the adult class may experience health issues associated with Cd and Cr toxicity over time (Samad *et al*., 2023).

The mean EDI values of Cd, Cr, Ni, and Pb through the exposure to the wastes from the studied farms were 1.32E-06, 1.87E-07, 6.23E-08, and 3.73E-06 for the children class, and 2.26E-07, 3.20E-08, 1.06E-08, and 6.40E-07, respectively (Table 3). Thus, the exposure to these metals through organic wastes from the studied farms may not have immediate health problems on both the children and adult classes. The results also indicated that, organic wastes from the studied farms could be suitable as organic manure for crop farming.

3.3.2. Results of non-carcinogenic risks of toxic metals

Results obtained of Target hazard quotient (THQ) and hazard index (HI) of toxic metals are summarized in Table 4.

Table 4: Results of Target hazard quotient (THQ) and hazard index (HI) of toxic metals

	Cd	Cr	Ni	Pb	Cd	Cr	Ni	Pb
EGGS								
	Children Class				**Adult Class**			
MIN	1.40E-02	4.50E-04	1.36E-05	6.78E-05	8.23E-03	2.69E-04	8.05E-06	4.03E-05
MAX	2.00E-02	8.13E-04	2.71E-05	2.03E-04	1.16E-02	4.83E-04	1.62E-05	1.21E-04
MEAN	1.65E-02	6.14E-04	1.90E-05	1.63E-04	9.75E-02	3.66E-04	1.13E-05	9.68E-05
HI	1.42E-02 – 2.05E-02 (1.72E-02)				8.64E-03 – 1.19E-02 (1.02E-02)			
BROILER MEAT RAW								
	Children Class				**Adult Class**			
MIN	167.0	8.40	I.00E-01	2.0	75.0	3.77	4.50E-02	1.0
MAX	202.0	11.00	3.50E-01	2.5	91.0	4.93	1.50E-01	1.0
MEAN	180.6	9.71	2.80E-01	2.3	81.2	4.35	1.09E-01	1.0
HI	178.42 – 212.50 (192.62)				80.17 – 95.82 (86.66)			
POULTRY WASTES								
	Children Class				**Adult Class**			
MIN	1.18E-03	5.27E-05	2.50E-06	4.58E-04	1.86E-04	9.03E-06	4.29E-07	7.85E-05
MAX	1.86E-03	6.93E-05	3.90E-06	1.25E-03	2.64E-04	1.19E-05	6.45E-07	2.14E-04
MEAN	1.47E-3	6.22E-05	3.11E-06	9.34E-03	2.26E-04	1.07E-05	5.29E-07	1.60E-04
HI	1.91E-03 – 2.86E-03 (2.47E-03)				3.29E-04 – 4.57E-04 (3.98E-04)			

3.3.2.1. Results of the target hazard quotients (THQ) of toxic metals

The results of target hazard quotients (THQ) of toxic metals via exposure to the studied poultry-related products for children and adult classes are shown in Table 4. Results of the mean values of THQ of toxic metals via the consumption of eggs from the studied farms by children revealed the following: 1.65E-02, 6.14E-04, 1.90E-05, and 1.63E-04 for Cd, Cr, Ni, and Pb, respectively. For the adult class, the mean THQ values for Cd, Cr, Ni, and Pb were 9.75E-02, 3.66E-04, 1.13E-05, and 9.68E-05, respectively. Hence, the mean THQ values of all the metals for both the children and adult classes through the consumption of were below one similar to the results obtained Voica *et al*. (2023). Consequently, the consumption of eggs by both the children and adult classes may not have significant health problems to the consumers (USEPA, 2011).

The mean THQ values of toxic metals due to the consumption of broiler meat for the children class were as follows: 180.6, 9.71, 2.80E-05, and 2.3 for Cd, Cr, Ni, and Pb, respectively. Table 4 indicates the mean THQ values of Cd, Cr, Ni, and Pb for the adult class as 81.2, 4.35, 1.09E-01, and 1.0, respectively. Results obtained revealed that, the mean THQ values of Cd, and Cr, and Pb were higher than one (1) hence; these metals could cause adverse non-carcinogenic risks on the consumers. The results also showed that, the mean THQ values of toxic metals were higher in children than the adult class as reported by Naseri *et al*. (2021). Thus, persistentconsumption of broiler meat from poultry farms investigated could cause harmful health problems and the children class might be more susceptible.

The results of mean THQ values of Cd, Cr, Ni, and Pb caused by exposure to the studied poultry wastes by the children class were 1.47E-3, 6.22E-05, 3.11E-06 and 9.34E-03 (Table 4). For the adult class, the mean THQ values obtained were2.26E-04, 1.07E-05, 5.29E-07, and 1.60E-04 for Cd, Cr, Ni, and Pb, respectively. Thus, the mean THQ values of toxic metals via exposure to the studied poultry wastes by both the children and adult class were less than one (1). Consequently, exposure to these toxic metals through the studied wastes may not cause immediate non-carcinogenic health problems (USEPA, 2011).

3.3.2.2. Results of hazard Index (HI) of toxic metals

The results of hazard index (HI) of toxic metals in the studied poultry-related products are indicated in Table 4. The HI values of toxic metals for the consumption of eggs by children from the various poultry farms assessed varied from 1.42E-02 – 2.05E-02 with an average of 1.72E-02. While the HI values for the adult class ranged from 8.64E-03 – 1.19E-02 with a mean of 1.02E-02. The mean HI values for both the children and adult classes were less than one. Hence, the consumption of eggs from the studied farms may not have adverse health implications on the children and adult classes. However, the mean HI value for the children class was higher than that of the adult thus; the children were more vulnerable to the non-carcinogenic hazards associated with the consumption of the studied eggs (Samad *et al*., 2023).

The HI values for the consumption of broilers from the studied farm by children varied between 178.42 and 212.50 with a mean of 192.62. HI values of toxic metal via the consumption of broiler meat by the adult ranged from 80.17 to 95.82 with an average of 86.66. The mean values obtained were higher than one and was higher in the children class than the adult. This is consistent with the finding by Chowdhury and Alam, (2024) from their study. Consequently, the consumption of broiler meat harvested from the studied farms might have significant non-carcinogenic risks on the consumer and the children class was more susceptible (USEPA, 2011).

The results of hazard index of toxic metals via studied poultry wastes for the children class ranged from 1.91E-03 – 2.86E-03 with an average value of 2.47E-03 (Table 4). Whereas, the HI values of toxic metals through exposure poultry wastes varied between 3.29E-04 and 4.57E-04 with a mean value of 3.98E-04. Thus, the mean HI values of toxic metals via poultry wastes examined for the children and adult classes were below one (1). This is consistent with the results reported by Durowoju *et al*. (2018) in their study. However, the children had higher HI values than the adult class similar to the findings by Munene *et al*. (2023). Accordingly, exposure to these toxic metals by the children and adult via the poultry wastes assessed may not cause adverse non-carcinogenic health hazards (USEPA, 2011). Generally, the entire values of HI for the studied eggs and broiler meat indicated that for the children and adult classes, Cd was the major contributor. This is in agreement with the results obtained for the health risks assessment of toxic metals by Belew *et al*. (2024). However, for the studied poultry wastes Pb and Cd were the major contributors to the children and adult classes respectively.

3.3.2.3. Results of cancer risk (CR) of toxic metals

The results of cancer risks associated with prolonged exposure to toxic metals are shown in Table 5 above. Constant exposure to carcinogens such as Cd, Cr, Ni, and Pb by human could cause cancer (Alsafren *et al*., 2021). The cancer risks of these carcinogens at the different poultry farms examined for the children and adult classes are shown in Table 5. The cancer risks for the consumption of eggs by the children class ranged from 6.52E-06 to 8.55E-06 with a mean value of 7.81E-06. While the CRs for the consumption of eggs by the adult class varied between 3.89E-06 and 5.09E-06 at the various farms with an average value of 4.65E-06. The CR values obtained for the children and adult classes were within the acceptable range of 1.0E-06 and 1.0E-04 by USEPA (2010).

Table 5: Results of Cancer Risk (CR) of toxic metals

		Values of CR	
		Children Class	**Adult Class**
EGGS	MIN	6.52E-06	3.89E-06
	MAX	8.55E-06	5.09E-06
	MEAN	7.81E-06	4.65E-06
BROILER MEAT	MIN	8.46E-02	3.82E-02
	MAX	9.83E-02	4.44E-02
	MEAN	9.15E-02	4.12E-02
POULTRY WASTES	MIN	6.34E-07	1.09E-07
	MAX	8.24E-07	1.41E-07
	MEAN	7.20E-07	1.25E-07

Ranges of CR obtained belong to the low cancer risk class according to USEPA (2012) classifications of cancer risks. Thus, the consumption of eggs from poultry farms investigated by both the children and adult classes may not result in cancer however; higher CR values were reported for the children class as reported by Samad *et al*. (2023).

Cancer risk values obtained for the consumption of broiler meat harvested from the studied farms by the children class varied from 8.46E-02 to 9.83E-02 with average of 9.15E-02 (Table 5). The cancer risks of carcinogens for the consumption of broiler meat by the adult class ranged 3.82E-02 to 4.44E-02 with a mean of 4.12E-02. The CR values reported for the consumption of broiler meat by children and adult classes were higher than the acceptable limit by USEPA (2010). These ranges of cancer risks belong to the very high cancer risk class (USEPA, 2012). Hence, the consumption of broiler meat harvested from the farms examined might result in adverse cancer and cancer-related hazards in the consumers. The reported cancer risks were higher in the children than the adult class as obtained by Kasozi *et al*. (2021).

The cancer risks for the exposure to carcinogens through poultry wastes by the children class varied from 6.34E-07 to 8.24E-07 with a mean value of 7.20E-07 (Table 5). CR values for the exposure to carcinogens by the adult class ranged between 1.09E-07 and 1.41E-07 with an average value of 1.25E-07. The CR values reported for both classes were lower than the acceptable range by USEPA

(2010). These values belong to the negligible cancer risk class based on the USEPA (2012) classifications. Consequently, exposure to poultry wastes from the studied farms either directly or indirectly may not cause significant cancer risk.

4. Conclusion

The research work examined levels of Cd, Cr, Ni, and Pb in eggs, broiler meats, and organic wastes from some poultry farms within Uyo, Akwa Ibom State, Nigeria. Cancer and cancer risks associated with persistent human exposure to these poultry-related products. The sources of these metals in these products were also investigated. Results obtained showed that, the total concentration of all the metals except Cr in eggs were within their recommended standards. Principal component analysis identified poultry feeds as the major source of these toxic metals in the studied farms. The estimated daily intake rate of the metals via the studied eggs and poultry wastes were within their recommended oral reference doses but higher in broiler meat. The non-cancer hazards of the toxic metals linked to exposure to eggs and wastes examined were lower than one but higher than one for broiler meats. Cancer risks of the metals via eggs and poultry wastes were within the acceptable limit but higher in broiler meats. The cancer and non-cancer risks of the metals were higher for children than the adult class. Consequently, broiler meats from farms investigated could cause serious health problems and the children class was more susceptible. The outcome of this research also revealed that, it is necessary to assess poultry-related foods and products to forestall health problems associated with toxic metals in the consumers. More so, it will be beneficial to review the materials used for the production of poultry feeds processing equipment and raw materials to avoid the introduction of harmful metals into the feeds produced.

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