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Distribution of trace metals in oven-dried, roadside broiler meats and related health implications on the consumers

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Abstract

Poultry-related foods are used mainly as one of the major sources of protein for human however; foods contaminated with toxic metals could have adverse health problems on the consumers. Trace metals loads in water, feeds, oven-dried, and roadside broiler meats from poultry farms in Uyo Metropolis were examined using atomic absorption spectrophotometer. The mean concentrations of chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) were within their safe limits however; the mean concentrations of cadmium (Cd) and iron (Fe) were higher than their limits. Mean concentrations of all the metals were within their recommended limits except Cr. The concentrations of Cu and Pb were higher than their acceptable limits in oven-dried meats, while Cr, Cu, and Pb in roadside meats were above their limits. The tolerable daily intake rates (TDI) of Cd and Cr for the children class via the consumption of oven-dried meats were above their oral reference doses (RfDs). Whereas, the TDI of Cd and Cr via the consumption of roadside broiler meats were higher than their RfD values. The non-carcinogenic risks of the metals for children and adult classes through the consumption oven-dried and roadside broiler meats were higher than one. However, the children class was more vulnerable to the non-carcinogenic risks. The values of total cancer risk (TCR) for the oven-dried and roadside meats for the children and adults were higher than their acceptable limits. The principal component factor analysis (PCA) identified the sources of trace metals in poultry-related products and foods examined.

Keywords: Poultry farms; Oven-dried broiler meats; Roadside broiler meats; Health risks; Trace metals; Nigeria

1. Introduction

The act of raising birds commercially for the meat and eggs is gradually becoming one the lucrative businesses globally. Poultry meat is widely consumed due to its high protein and vitamins contents needed for the proper functioning of the human body, [1]. However, the activities within the poultry farms and the processing of meats harvested from these farms introduce contaminants into the meats, [2]. The major sources of toxic substances in poultry farms are poultry feeds, drinking water, and the environment, [3-5]. The processing of poultry meats can also contaminate the meat, [6]. A contaminated poultry farm has the potentials of negatively affecting the air, soil, and water environments, [7, 8]. According to Abdullahi *et al.* [9] metals are natural components of the environment however; their natural levels are not hazardous. They are ubiquitous and persist in the environment hence; the control techniques are very complex, [10, 11]. The existence of metals at concentrations higher than their recommended limits is highly hazardous to human health. Poultry farming is one of the channels through which metals are transferred into human body, [12]. These metals have the potential of causing adverse health problems in human body, [13]. Consequently, the environment should be appropriately managed to avoid unnecessary accumulation of metals.

Elevated levels of toxic metals in poultry feeds and drinking water from poultry farms have been documented by Amitaye and Okwagi [14], Idrissa *et al.* [15] and Oladeji *et al.* [16]. Significant concentrations of toxic metals have also

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been recorded for broiler meats, [17, 18]. Reports have shown that, roadside foods have higher concentrations of toxic metals than foods processed at homes, [19-21].Consequently, poultry-related foods should be properly assessed to ascertain their suitability for human consumption.

Despite the available literature on the metal loads in broiler meat and the associated problems in other parts of the globe, information on this aspect within the study area is scarce. Consequently, this research work was carried out to ascertain the distribution channels of trace metals in raw and roasted broiler meats sold in Uyo. The work also aimed at assessing the effects of these metals on the consumers of these meats. The actual sources of these metals in poultry-related foods and products will be established using multivariate analysis. Information gathered will be useful to both the poultry farmers, consumers of broiler meat and policy makers within and beyond the study area.

2. Materials and Methods

2.1. Study Area

Uyo local government area is the capital of Akwa Ibom State in the South-South Area of Nigeria where crude oil activities are at the peak. The metropolis within Uyo is situated between latitude 04° 59! N and Longitude 07° 57! E. Uyo has the wet (April-November) and dry (December-March) as its outstanding seasons. Based on the ongoing crude oil activities in the zone, human population is high and poultry-related foods are highly consumed. The mean yearly temperature and rainfall range from 25 to 29°C and 2000 and 3000 mm, respectively. Poultry farming is one of the main sources of income for the farmers within the area. The consumption of poultry-related foods harvested in Uyo is both within and outside the state. Consequently, the assessment of poultry-related foods is a necessary tool to forestall human health problems associated with the food contamination within and outside the area.

2.2. Sample Collection, Treatment, and Digestion

The starter, grower, finisher, and layer feeds were obtained randomly from poultry farms in Uyo local government area and mixed together to form a composite sample for each farm, [22]. These samples were mixed together, dried for three weeks, and homogenized using pestle, and mortar. The samples were later filtered and stored in clean containers for digestion. One gram of the feed from each location was mixed with Aqua regia (20 mL) in a conical flask. The mixture was placed on a hot plate until the solution was clear. The conical flask was then cooled and filtered using Whatman No. 1 Filter paper into a 50mL volumetric flask and made to mark with distilled water. The filtrates obtained were preserved in sample containers for the analysis of trace metals, [23].

Water samples used as drinking water for the birds in the poultry farms examined were collected directly from the taps into clean polyethylene bottles. Before the collection of water samples, these containers were rinsed twice with water to be sampled. The concentrations of trace metals in the samples were maintained by the addition of 1 mL Conc. HNO_3 on site. Samples collected were preserved at 4 °C before the analysis of trace metals was done, [24, 25].

Matured broilers (*Gallus gallus domesticus)* obtained from the studied farms were slaughtered using stainless steel knife then their organs and muscles harvested. These organs and muscles harvested were washed with distilled water and cut into pieces using stainless steel knife, then merged together based on the farm. These organs and muscles obtained were divided into two parts; one part was treated and dried in an oven while the other part was roasted by the roadsides. One part of the samples was kept in an oven at a temperature of 105°C for two hours. The other parts of the samples were roasted by the roadsides until they were properly dried. Two grams of the dried samples (both the oven dried and roadside) were digested with a mixture of 1 mL $HClO_4$ and 5 mL Conc. HNO_3 on a hot plate until colourless solutions were obtained. The volume of digestion flasks were increased to 50 mL with distilled water. Filtration of the mixtures into clean polyethylene bottles was later performed with Whatman No. 42 Filter Paper. The separate filtrates obtained were stored at 4 °C before metal analysis, [5, 26].

2.3. Appraisal of Health Risks

The evaluation of health risks associated with exposure to trace metals through the raw and roasted broiler meats was done using tolerable daily intake rate (TDI). The non-carcinogenic risks were evaluated using target hazard quotient (THQ), and hazard index (HI), [27, 28]. While the carcinogenic health hazards were estimated based on the incremental lifetime cancer risk (ILCR) and total cancer risk (TCR), [29, 30].

2.3.1. Tolerable daily intake (TDI) rate of trace metals

The TDI of trace metals via the consumption of oven-dried and roadside broiler meats from the studied farms by the children and adult categories was estimated using Equation (1).

$$TDI = \frac{MC \times IR}{BW} \quad (1)$$

MC is the concentration of individual trace metal in the oven-dried and roadside broiler meats, IR indicates the ingestion rate, and BW is the body weight. In this study, the IR for a child is 0.114 kg and 0.227 kg for an adult. The body weight for a child is 24 kg and 70 kg for an adult, [31, 32].

2.3.2. Target hazard quotient (THQ) of trace metals

The THQ of trace metals through the consumption of raw and roasted broiler meats from the poultry farms investigated was computed using Equation (2).

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

Where TDI denotes the tolerable daily intake rate of trace metal calculated in Equation 1, RfD is the recommended oral reference dose of the metals. The RfD values for Cd, Cr, Cu, Fe, Pb, and Zn used is this work are 1.00E-03, 3.00E-03, 4.00E-02, 7.00E-01, 4.00E-03, and 3.00E-01 $mgkg^{-1}day^{-1}$, respectively, [31].

2.3.3. Hazard index (HI) of trace metals

The HI of trace metal through the consumption of oven-dried and roadside broiler meats from the studied farms by the young and old was computed using Equation (3).

$$HI = \Sigma THQ = THQCd + THQCr + THQCu + THQFe + THPb + THQZn \quad (3)$$

Where ΣTHQ denotes the summation of target hazard index for Cd, Cr, Cu, Fe, Pb, and Zn.

2.3.4. Incremental lifetime cancer risk (ILCR) of cancer-causing metals

`The ILCR for Cd, Cr, and Pb through the consumption of oven-dried and roadside broiler meats from the studied farms by the children and adult classes was calculated with Equation (4) below.

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

Where CSF represents the cancer slope factor of the metals and TDI is the tolerable daily intake rate of the carcinogens. The CSF for Cd, Cr, and Pb are 3.80E-01, 5.00E-01, and 8.50E-03 $mgkg^{-1}day^{-1}$, respectively, [33].

2.3.5. Total cancer risks (TCR) of the carcinogens

The TCR of Cd, Cr, and Pb via the consumption of oven-dried and roadside broiler meats from the studied farms by the young and old people was estimated using Equation (5).

$$TCR = \Sigma ILCR = ILCRCd + ILCRCr + ILCRPb \quad (5)$$

Where ΣILCR is the sum of the incremental lifetime cancer risk for Cd, Cr, and Pb. The different classes of TCR are 1.0E-01-1.0E-03 is the very high cancer risk class, 1.0E-04 belongs to the high cancer risk class, 1.0E-05 is in the medium cancer risk class, 1.0E-06 belongs to the low cancer risk class, and TCR less than 1.0E-06 belongs to the negligible cancer risk class, [34].

2.4. Data Analysis

Results obtained from this research were subjected to statistical treatments using IBM SPSS Statistic version 29.0.2.0 (20) Software. The average, maximum, minimum, and standard deviation data were achieved using the software. The principal component analysis (PCA) was performed on the six trace metals with Varimax Factor analysis. The results of PCA considered values from 0.622 and higher as being relevant for the study.

3. Results and discussion

3.1. Results of Trace metals in water, feeds, oven-dried, and roadside broiler meats from the studied farms

The results of trace metals in poultry feeds, water, oven-dried, and roasted meats are shown in Table 1.

Table 1 Concentrations of Trace metals in Poultry feeds, water, oven-dried, and roasted meats

Samples	Conc./ Parameters	Cd	Cr	Cu	Fe	Pb	Zn
Water	MIN	0.015	0.011	0.887	2.862	0.002	0.872
	MAX	0.024	0.018	1.130	3.621	0.004	1.127
	MEAN	0.019	0.015	1.007	3.322	0.003	0.967
	SD	0.004	0.003	0.101	0.324	0.001	0.112
	MPL	0.003	0.05	2.00	2.00	0.01	3.00
Feeds	MIN	0.153	0.048	1.085	45.852	0.068	1.766
	MAX	0.204	0.055	1.207	50.357	0.082	2.053
	MEAN	0.180	0.051	1.159	47.528	0.075	1.899
	SD	0.021	0.003	0.052	1.964	0.006	0.118
	MPL	1.00	0.01	8.00	80.00	5.00	40.00
Oven-dried Meat	MIN	0.248	0.725	2.851	19.746	0.186	2.984
	MAX	0.317	0.902	3.706	24.962	0.235	3.725
	MEAN	0.275	0.815	3.363	22.200	0.207	3.476
	SD	0.030	0.082	0.392	2.175	0.021	0.338
	MPL	0.50	1.00	0.40	180.00	0.10	150.00
Roadside Meat	MIN	0.386	0.886	5.482	36.267	0.513	5.092
	MAX	0.470	1.274	7.014	43.174	0.728	7.109
	MEAN	0.433	1.072	6.406	39.973	0.631	6.458
	SD	0.040	0.176	0.685	3.062	0.093	0.927
	MPL	0.50	1.00	0.40	180.00	0.10	20.00

MIN = Minimum; MAX = Maximum; SD = Standard deviation; MPL = Maximum permissible limit

Results of trace metals in water utilized in the different poultry farms examined are in Table 1. Concentrations of Cd varied from 0.015 to 0.024 mgL^{-1} in the water used for the breeding of birds in the studied farms. Results of trace metals in water utilized in the different poultry farms examined are in Table 1. Concentrations of Cd varied from 0.015 to 0.024 mgL^{-1} in the groundwater used for the management of birds in the studied farms. The concentrations of Cd reported is lower than 0.09 – 0.75 mgL^{-1} but higher than 0.00 – 0.004 mgL^{-1} obtained by Sayed and Omar [35] and Hussein *et al.* [36], respectively. However, the mean concentration of Cd obtained 0.019±0.004 mgL^{-1} is higher than the recommended 0.003 mgL^{-1} by WHO [37]. Consequently, water sources at the various poultry farms investigated could be routes through which Cd may contaminate broilers harvested from the studied farms and subsequently the consumers.

Cr in water samples examined ranged from 0.011 to 0.018 mgL^{-1}. The range reported for Cr is lower than 0.002 – 0.044 mgL^{-1} obtained by Idrissa *et al.* [15] in water used for poultry farms. The average concentration of Cr obtained (0.015±0.003 mgL^{-1}) is also less than the recommended 0.05 mgL^{-1} by WHO [37]. Hence, water sources used in the studied poultry farms may not be a source of Cr toxicity and the associated health problems to the birds and the consumers. Conversely, the levels of Cr supplied from the water sources used in these farms could be beneficial to the birds as reported by Farag *et al.* [38] and Youssef *et al.* [39].

The levels of Cu in water samples assessed ranged between 0.887 and 1.130 mgL^{-1}. This range is consistent with 0.976 – 1.018 mgL^{-1} but higher than 0.00 – 0.024 mgL^{-1} reported by Etuk *et al.* [40] and Idrissa *et al.* [15]. However, the average value of Cu recorded (1.007±0.101 mgL^{-1}) is lower than 2.00 mgL^{-1} recommended by WHO [37]. Hence, as an essential element, water sources examined were deficient of Cu and may have negative effects on the birds in farms assessed and their consumers, [41, 42].

Concentrations of Fe in water samples from the studied farms varied from 2.862 to 3.621 mgL^{-1} (Table 1). The obtained range is higher than 0.06 – 0.11 mgL^{-1} reported by Reda *et al.* [43], but lower than 0.00 – 15.955 mgL^{-1} obtained by Idrissa *et al.* [15] in water utilized in poultry farms. The mean value obtained 3.322±0.324 mgL^{-1} is higher than the 2.00 mgL^{-1}recommended by WHO [37]. The high levels of Fe reported may not have adverse implications on the broilers and their consumers since the metal is an essential element, [44]. However, bioaccumulation of Fe in broilers should be avoided to forestall consequences reported by Pavone *et al.* [45].

Pb in the water samples from poultry farms investigated ranged from 0.002 to 0.004 mgL^{-1}. This is lower than 0.00 – 0.05 mgL^{-1} obtained by Hussein *et al.* [36] in water used in poultry farms. The average value of Pb indicated in Table 1 (0.003±0.001 mgL^{-1}) is higher than 0.001 mgL^{-1} recommended for potable water by WHO [37]. Consequently, the utilization of water from the studied in these poultry farms may result in harmful effects on the birds and the consumers [46-48]. Thus, water treatment should be carried on these water sources to reduce or eliminate their high Pb content and avoid related effects.

Results in Table 1 indicate the range and mean value of Zn as 0.872 – 1.127 mgL^{-1} and 0.967±0.112 mgL^{-1}. The obtained range is higher than 0.00 – 0.352 mgL^{-1} reported by Idrissa *et al.* [15]. However, the mean value obtained is lower than 3.00 mgL^{-1} recommended for water by WHO [37]. Accordingly, the water sources for these poultry farms are deficient of Zn needed for proper functioning of the birds and consumers, [49, 50]. Hence, the Zn should be supplemented in the feeds supplied to birds in these farms for proper growth

The results of trace metals in poultry feeds assessed are shown in Table 1. Cd varied between 0.153 and 0.204 $mgkg^{-1}$ with an average value of 0.180±0.021 $mgkg^{-1}$. This range is lower than 0.00 – 0.83 $mgkg^{-1}$and 1.296 – 1.362 $mgkg^{-1}$ reported by Morshed *et al.* [51] and Islam *et al.* [52], respectively. However, the range reported is higher than 0.028 - 0.094 $mgkg^{-1}$ obtained by Amitaye and Okwagi, [14] in similar work. The mean value of Cd obtained is lower than the recommended limit of 1.00 $mgkg^{-1}$ by FAO/WHO [53]. Hence, the concentrations of Cd recorded in the studied poultry feeds may not pose instant serious problems to the birds.

The range and mean concentration of Cr in the studied poultry feeds were 0.048 – 0.055 $mgkg^{-1}$ and 0.051±0.003 $mgkg^{-1}$, respectively. The range obtained is lower than that reported by 0.402 – 7.884 $mgkg^{-1}$ and 2.07 – 4.33 $mgkg^{-1}$ reported by Islam *et al.* [54] and Korish & Attia [17]. However, the mean concentration obtained is higher the permissible limit (0.01 $mgkg^{-1}$) by FAO/WHO [53]. The reported high levels of Cr in poultry feeds can have adverse effects on the birds and their consumers, [55, 56].

The levels of Cu in poultry feeds investigated ranged from 1.085 to 1.207 $mgkg^{-1}$ with a mean concentration of 1.159±0.052 $mgkg^{-1}$. The obtained range is consistent with 0.04 – 1.21 $mgkg^{-1}$ recorded by Suleiman *et al.* [57]. The reported range is lower than 15.58 – 30.66 $mgkg^{-1}$, but higher than 0.00 – 0.29 $mgkg^{-1}$ reported in poultry feeds by Igwemmar *et al.* [23] and Lyambee *et al.* [58], correspondingly. The mean value obtained is lower than the recommended limit of 8.00 $mgkg^{-1}$ by FAO/WHO [53]. The low levels of Cu content in the studied feeds can affect the growth of birds in farms examined negatively, [59]. Hence, these feeds should as a matter on necessity be supplemented with Cu to encourage proper growth of the birds.

Fe in the studied feeds varied between 45. 852 and 50.357 mgkg-1 with an average value of 47.528±1.964 $mgkg^{-1}$. This range is lower than 164.81 – 283.09 $mgkg^{-1}$ however; higher than 8.70 – 38.36 $mgkg^{-1}$ obtained in poultry feeds by Igwemmar *et al.* [23] (2022) and Iqbal *et al.* [60], correspondingly. Nevertheless, the mean value is lower than the recommended limit of 80.0 $mgkg^{-1}$ by FAO/WHO [53]. Hence, the reported levels of Fe are essential for the birds and their consumers, [44, 61].

Concentrations of Pb in the feeds ranged from 0.068 to 0.082 $mgkg^{-1}$ with a mean value of 0.075±0.006 $mgkg^{-1}$. The range reported is inconsistent with 0.68 – 5.46 mgkg-1 and 0.27 – 0.80 mgkg-1 obtained by Raghavan *et al.* [62] and Oladeji *et al.* [16], respectively. The average concentration of Pb is also lower than 5.00 $mgkg^{-1}$ recommended by FAO/WHO [53] hence; the birds examined may not manifest any symptom of Pb toxicity immediately but bioaccumulation overtime should be avoided. Bioaccumulation of Pb can eventually have negative effects on the broilers and their consumers, [48, 63].

The studied poultry feeds had concentrations of Zn ranging from 1.766 to 2.053 $mgkg^{-1}$ with an average value of 1.899±0.118 $mgkg^{-1}$. The range reported is consistent with 1.934 to 2.140 $mgkg^{-1}$ but lower than 30.2 – 39.2 $mgkg^{-1}$ obtained by Etuk *et al.* [40] and Korish & Attia [17]. The mean value obtained is far less than 40.0 mgkg-1 recommended for feeds by FAO/WHO [53]. Consequently, deficiency symptoms of the metal might manifest in birds within the studied poultry farms, [64, 65]. Hence, Zn ought to be introduced into these feeds as supplement to support the birds and their consumers.

The concentrations of trace metals in the oven-dried and roadside broiler meats are indicated in Table 1. The concentrations of Cd varied as follows: 0.248–0.317 $mgkg^{-1}$ and 0.386-0.470 $mgkg^{-1}$in the oven-dried and roadside broiler meats, respectively. These ranges are lower than 0.16-0.65 $mgkg^{-1}$obtained by Chowdhury and Alam [66], but higher than 0.004- 0.09 $mgkg^{-1}$reported by Kia *et al*. [67] in similar studies. The mean values obtained for the raw and roasted broiler meats were 0.275±0.030 $mgkg^{-1}$ and 0.433±0.040 $mgkg^{-1}$, respectively. However, both mean values are within the recommended safe limit of 0.50 $mgkg^{-1}$ by FAO/WHO [53] .

Cr in the studied oven-dried and roadside broiler meats ranged from 0.725 to 0.902 $mgkg^{-1}$ and 0.886 to 1.274 $mgkg^{-1}$, respectively. These values are lower than the 0.161-2.215 $mgkg^{-1}$ reported in broiler meat by Kamaly & Sharkawy [7]. However, the mean value (0.815±0.082 $mgkg^{-1}$) obtained in the oven-dried is lower than the recommended safe limit of 1.00 mgkg-1 by FAO/WHO [53]. However, the average value of Cr recorded for the roadside meat (1.072±0.176 $mgkg^{-1}$)is higher than the safe limit. Consequently, the observed Cr levels in the studied broiler meats roasted by the roadside could have unpleasant impacts on the birds and human system, [38, 68].

Cu concentrations in the oven-dried broiler meat ranged between 2.851 and 3.706 mgkg-1 with an average value of 3.363±0.393 $mgkg^{-1}$. While Cu levels in roadside broiler meat varied from 5.482-7.014 $mgkg^{-1}$with a mean value of 6.406±0.685 $mgkg^{-1}$. The ranges reported are higher than 0.23-3.01 $mgkg^{-1}$ and 1.20-4.63 mgkg-1 obtained by Morshdy *et al*. [69] and Enuneku *et al*. [70]. The mean values obtained are higher than the recommended safe limit of 0.40 $mgkg^{-1}$ by FAO/WHO [53]. The high levels of Cu reported in this study may be attributed to the addition of the metal as a supplement in poultry feeds, [59]. The high levels of Cu obtained might have negative effects on the broilers and their consumers over time, [71, 72].

The range of Fe for the oven-dried and roadside broiler meats were 19.746-24.962 $mgkg^{-1}$ and 36.267-43.174 $mgkg^{-1}$, respectively.The levels of Fe obtained in both the oven-dried and roadside broiler meats are lower than the 2.67-160.45 $mgkg^{-1}$ reported by Butt *et al*. [73] in a related work. The mean values 22.200±2.175 $mgkg^{-1}$ and 39.973±3.063 $mgkg^{-1}$obtained in the oven-dried and roadside broiler meats, respectively are lower than the stipulated safe limit of 180.0 $mgkg^{-1}$ by FAO/WHO [53]. The low concentrations of Fe in the studied meats might have affected the birds adversely and can also have impact on the consumers, [44, 74].

Pb in the oven-dried and roadside broiler meats varied from 0.186 to 0.235 $mgkg^{-1}$ and 0.513 to 0.728 $mgkg^{-1}$, respectively. These ranges are lower than 4.50-8.50 $mgkg^{-1}$ obtained by Salamat & Shahbaz [75] however; higher than the 0.005-0.05 $mgkg^{-1}$ reported in broiler meat by Kia *et al*. [67]. The mean values obtained for the oven-dried and roadside broiler meats (0.207± 0.021$mgkg^{-1}$ and 0.631± 0.093 $mgkg^{-1}$) are higher than the recommended safe limit of 0.10 $mgkg^{-1}$ by FAO/WHO [53]. The reported high Pb concentrations may pose adverse health problems on the birds and human body, [46, 76].

The ranges of Zn in the broilers were 2.984-3.725 $mgkg^{-1}$ and 5.092-7.109 $mgkg^{-1}$ for the oven-dried and roadside broiler meats. These ranges are lower than 7.963-31.980 $mgkg^{-1}$ obtained in broiler meats by Kamaly & Sharkawy [7] (2023). The average values 3.476±0.338 $mgkg^{-1}$ and 6.458±0.927 $mgkg^{-1}$ were recorded for Zn in the oven-dried and roadside broiler meats, respectively. The mean values of 3.476±0.338 $mgkg^{-1}$ and 6.458±0.927 $mgkg^{-1}$for the raw and roasted broiler meats are lower than the recommended safe limit (150.0 $mgkg^{-1}$) by FAO/WHO [53]. The concentrations of Zn in the oven-dried and roadside broiler meats may result in deficiency symptoms in the broilers from studied farms and their consumers, [77, 78].

Generally, the concentrations of trace metals in the oven-dried meats were lower than values obtained in roadside broiler meats. This is similar to the results obtained by Adebiyi *et al*. [79] and Kingsley *et al*. [21]. Thus, vehicular emissions are one of the major sources of contaminants in foods sold by the roadsides, [19, 80, 81]. The other sources of metal contaminants in broiler meats roasted by the roadsides may include the cooking utensil used for boiling the raw meats, [82, 83]. The variations in temperature between the oven-dried meats and roadside meats could also be a factor, [84, 85]. The other factor that might influence variations in the concentrations of metals is the wood used for roasting the meats, [86].

3.2. Results of Health risks evaluation

Table 2 Results of tolerable daily intake (TDI), target hazard quotient (THQ), and hazard index (HI) of trace metals

Samples/Parameters	Cd	Cr	Cu	Fe	Pb	Zn
	TDI					
Oven-dried Meat						
Children	1.31E-03	3.87E-03	1.60E-02	1.06E-01	9.83E-04	1.65E-02
Adult	8.92E-04	2.64E-03	1.09E-02	7.20E-02	6.71E-04	5.35E-05
Roadside Meat						
Children	2.06E-03	5.09E-03	3.04E-02	1.90E-01	3.00E-03	3.07E-02
Adult	1.40E-03	3.48E-03	2.08E-02	1.30E-01	2.05E-03	2.09E-02
	THQ					
Oven-dried Meat						
Children	1.31E+0	1.29E+0	4.00E-01	1.50E-01	2.60E-01	6.00E-02
Adult	8.90E-01	8.80E-01	2.70E-01	1.00E-01	1.70E-01	1.78E-04
Roadside Meat						
Children	2.06E+0	1.70E+0	7.60E-1	2.70E-01	7.50E-01	1.00E-01
Adult	1.40E+0	1.16E+0	5.20E-01	1.90E-01	5.10E-01	7.00E-02
	HI					
Oven-dried Meat						
Children	3.47E+0					
Adult	2.31E+0					
Roadside Meat						
Children	5.64E+0					
Adult	3.85E+0					

Results of mean Tolerable daily intake (TDI) rates of trace metals through the exposure to oven-dried broiler meats from farms investigated are indicated in Table 2. The mean TDI values for Cd, Cr, Cu, Fe, Pb and Zn were 1.31E-03, 3.87E-03, 1.60E-02, 1.06E-01, 9.83E-04, and 1.65E-02 $mgkg^{-1}day^{-1}$, respectively for the children category. The average TDI values for the adult category were 8.92E-04, 2.64E-03, 1.09E-02, 7.20E-02, 6.71E-04, and 5.35E-05 $mgkg^{-1}day^{-1}$ for Cd, Cr, Cu, Fe, Pb and Zn, respectively. These results revealed that, the mean TDI values of Cd and Cr for the children category were higher than their recommended oral reference doses (Rfd), while values obtained for Cu, Fe, Pb and Zn were within their limits, [31, 87]. The high value of Cd obtained is similar to the results reported by Darwish and Elsawey [88] and Ebuete *et al*. [89], but inconsistent with the findings by Begum *et al*. [90]. Consequently, consistent exposure to oven-dried broiler meats from the studied farms might cause adverse health problems related to high Cd and Cr in children. However, the values obtained for the adults class for all the metals were within their Rfd limits. Hence, exposure to oven-dried broiler meat from the studied farms may not cause serious health problems to the adult class.

The mean TDI values of trace metals via the consumption of broiler meats roasted by the roadsides within Uyo Metropolis by the children and adult categories are in Table 2. The mean TDI values for the children class were 2.06E-03, 5.09E-03, 3.04E-02, 1.90E-01, 3.00E-03, and 3.07E-02 $mgkg^{-1}day^{-1}$ for Cd, Cr, Cu, Fe, Pb and Zn, respectively. For the adult class, the average TDI values obtained for Cd, Cr, Cu, Fe, Pb and Zn were 1.40E-03, 3.48E-03, 2.08E-02, 1.30E-01, 2.05E-03, and 2.09E-02 $mgkg^{-1}day^{-1}$, respectively (Table 2). Based on the results obtained, the mean TDI values of Cd and Cr for both the children and adult categories were higher than their oral reference dose (Rfd) limits by USEPA [31] and USEPA [87]. Thus, the consumption of broilers from the studied farms roasted by roadsides might cause serious health issues in both the children and adult categories. Nevertheless, the mean TDI values for Cu, Fe, Pb and Zn were within their acceptable limits. The overall results obtained for TDI indicated that, the children class was more vulnerable to health problems associated with exposure to these metals than the adult. This is in agreement with the report by Njoga *et al*. [91] and Ogu & Akinnibosun [92]. It was also observed that, the mean TDI values of trace metals in the roadside broiler meats (roasted) were higher than the raw. Hence, the consumers of roadside broiler meats could be more vulnerable to health problems associated with these metals.

Table 2 shows the results of target hazard quotient (THQ) of trace metals through exposure to both the oven-dried broiler meats and roadside ones from the studied farms. The mean THQ values of trace metals via exposure to oven-dried broiler meats by the children category were 1.31, 1.29, 0.40, 0.5, 0.26, and 0.06 for Cd, Cr, Cu, Fe, Pb and Zn, respectively. For the adult class, the mean THQ values for Cd, Cr, Cu, Fe, Pb and Zn were 0.89, 0.88, 0.27, 0.0, 0.17, and 1.78E-04, respectively. Hence, prolonged exposure to oven-dried broiler meats from the studied farms may result in adverse non-carcinogenic health problems related to high Cd and Cr. The high THQ values obtained for Cd and Cr in this study is consistent with the report by Adebiyi *et al*. [93] however; different from the findings by Hossain *et al*. [5]. More so, as the mean THQ values of the metals for the adult class were less than one, exposure to these broiler meats may not result in adverse non-carcinogenic risks. The mean THQ values of trace metals for the children category via exposure to oven-dried broiler meat were higher than the adult, [66].

The target hazard quotient (THQ) of trace metals for both the children and adult classes via the consumption of roadside broiler meat are shown in Table 2. The mean THQ values of trace metals via the roadside broiler meat for the children class were 2.06, 1.70, 0.76, 0.27, 0.75, and 0.10 for Cd, Cr, Cu, Fe, Pb and Zn, respectively. The mean THQ values of Cd, Cr, Cu, Fe, Pb and Zn for the adult class were 1.40, 1.16, 0.52, 0.19, 0.51, and 0.07, respectively. Hence, the mean THQ values of Cd and Cr were higher than one, while values for Cu, Fe, Pb and Zn were less than one for both classes of consumers. This is similar to the results obtained for the oven-dried broiler however; the values obtained for the roadside broiler meats were higher. Consequently, the consumers of roadside broiler meats from the studied farms might be more exposed to non-carcinogenic risks, and the children were more susceptible. The higher mean THQ values reported for trace metals in the roasted broiler meats could be attributed to the impacts of vehicular emissions, [26, 81]. Thus, the consumption of foods sold by roadsides could be a major source of health problems to the consumers as opined by Negassa *et al*. [94].

Table 2 indicates the mean values of hazard index (HI) of trace metals for the children and adult classes via the consumption of oven-dried broiler meats from studied farms. The average HI values of children and adult classes via exposure to raw broiler meats were 3.47E+0 and 2.31E+0, respectively. Hence, the mean HI values for both children and adult categories were higher than one. This is consistent with the results obtained by Igwemmar and Kakulu, [76] in chicken meats. The HI results reported revealed that, exposure to oven-dried broiler meats from the studied poultry farms could cause harmful non-carcinogenic health problems and children class might be more vulnerable, [67, 95].

Table 3 Results of Incremental lifetime cancer risk (ILCR) and total cancer risk (TCR)

Samples/Parameters	Cd	Cr	Cu	Fe	Pb	Zn	TCR
Oven-dried Meat							
Children	4.98E-04	1.94E-03			8.36E-06		2.45E-03
Adult	3.39E-04	1.32E-03			5.70E-06		1.67E-03
Roadside Broiler Meat							
Children	7.83E-04	2.55E-03			2.55E-05		3.36E-03
Adult	5.32E-04	1.74E-03			1.74E-05		2.29E-03

The results of mean HI values of trace metals via the consumption of broiler meats roasted by the roadsides by the children and adult classes are shown in Table 2. The mean HI values of trace metals via the consumption of roadside broiler meats by the children and adult classes were 5.64E+0 and 3.85E+0, respectively. Consequently, the HI values for the consumers of roadside broiler meats from the studied farms were higher one as reported by Jonah and Essien [96]. The mean HI value for the children class was also higher. Relatively, the mean HI values of trace metals for both classes of consumers were higher through roadside broiler meat than in the oven-dried meat. Hence, the studied roadside broiler meats (roasted) could have higher potentials of causing non-carcinogenic risks in the consumers than the oven-dried meat. Generally, the major contributors to the HI obtained were Cd and Cr as obtained by Onoyima *et al*. [97]. The contributions by the trace metals for both samples and consumers followed a decreasing order of Cd > Cr > Cu > Pb > Fe > Zn.

Human exposure to cancer-causing agents may manifest as cancer overtime as reported by Cao *et al*. [98]. The rate of human exposure to carcinogens via the consumption of broiler meats was evaluated with incremental lifetime cancer risk (ILCR), [99]. The results of mean values of ILCR of metals via the consumption of broiler meats are indicated in Table 3. For the children class, the mean values of metals via the consumption of oven-dried broiler meats were 4.98E-04, 1.94E-03, and 8.36E-06 for Cd, Cr, and Pb, respectively. While the mean ILCR values of the carcinogens through the consumption of oven-dried broiler meats examined by the adult were 3.39E-04, 1.32E-03, and 5.70E-06 for Cd, Cr, and Pb, respectively. The mean ILCR values of Cd and Cr for both categories of consumers belong to the high cancer risk and very high cancer risk categories, [34, 100]. However, the mean ILCR values of Pb for the children and adult classes were in the low cancer risk class. The ILCR values of Pb were also within the acceptable range. The mean ILCR values reported for Cd and Cr were higher than the acceptable range of 1.0E-06 and 1.0E-04 by USEPA [33].

Results of the ILCR of trace metals via the consumption of roadside broiler meat by the children and adult classes are shown in Table 3. The mean ILCR values for exposure to Cd, Cr, and Pb via the consumption of the studied roasted broiler meats were 7.83E-04, 2.55E-03, and 2.55E-05, respectively. The mean ILCR values of Cd, Cr, and Pb via the consumption of roasted chicken by the adult were 5.32E-04, 1.74E-03, and 1.74E-05, respectively. The mean ILCR values of Cd, Cr, and Pb for groups of consumers belong to high, very high, and medium cancer risk classes, respectively, [34]. The mean ILCR values of Cd and Cr for both children and adult were above the acceptable range of 1.0E-06 and 1.0E-04 by USEPA [33]. Nevertheless, the mean ILCR values of Pb were within the acceptable range. The high mean ILCR values of Cd and Cr obtained in this study is similar to the findings by Salihu [27]. Hence, constant exposure to oven-dried and roadside broiler meats from the studied farms could result in cancer risks, [28]. The general ILCR results revealed that, the mean ILCR values for the children class were relatively higher than those of the adult category. This is consistent with the results of ILCR result obtained by Emmanuel *et al*. [101] in their research.

Results of total cancer risk (TCR) of carcinogens via the consumption of oven-dried and roasted broiler meats by children and adult from the studied poultry farms are in Table 3. The TCR values of trace metals via the consumption of oven-dried broiler meats for the children and adult classes were 2.45E-03 and 1.67E-03, respectively. TCR values of metals via the consumption of roasted broiler meats by children and adult were 3.36E-03 and 2.29E-03, respectively. The TCR values obtained for the oven-dried and roadside broiler meats for both categories of consumers were higher the recommended range of 10^{-6} - 10^{-4} by USEPA [33]. This is in agreement with the results obtained by Hasan and Khanam [102] in a study conducted by them. However, the TCR values of trace metals via the consumption of raw and roadside broiler meats were higher the children class than adult as reported by Hossain *et al*. [5]. Consequently, constant exposure to the studied broiler meats could cause cancer in the consumers, [103]. The major contributor to the total TCR reported in this study was Cr as previously reported by Lu *et al*. [104].

3.3. Results of Principal component analysis of trace metals in oven-dried and roadside broiler meats

Table 4 Results of Principal Component analysis (PCA) of Toxic Metals in the studied oven-dried and roadside broiler meats

	POULTRY FEEDS		**WATER**		**OVEN-DREID MEAT**			**ROADSIDE MEAT**	
	F1	F2	F1	F2	F1	F2	F3	F1	F2
Cd	0.956	0.285	0.875	-0.202	-0.455	0.836	-0.306	0.908	0.414
Cr	-0.837	-0.029	0.873	0.486	0.998	-0.054	-0.032	-0.556	0.815
Cu	-0.772	0.636	0.086	-0.884	0.425	0.786	0.449	0.825	0.562
Fe	0.849	-.0301	0.789	-0.089	0.949	0.084	-0.303	-0.629	0.728
Pb	0.970	0.243	0.976	-0.169	0.783	-0.035	0.621	0.881	0.453
Zn	0.223	0.964	0.069	0.915	0.688	-0.072	0.722	0.686	-0.479
Eigen value	3.92	1.56	3.12	1.93	3.37	1.33	1.30	3.46	2.12
% Variance	65.4	26.1	51.9	32.2	56.2	22.2	21.6	57.6	35.2
% Cumulative	65.4	91.5	51.9	84.1	56.2	78.4	100	57.6	92.8

The results of principal component analysis (PCA) of trace metals determined are shown in Table 4. PCA was used to identify the factors with significant influence on the parameters determined in poultry farms examined, [105].The PCA of trace metals in poultry feeds revealed two main factors with Eigen values over one (1) and a total variance of 91.5%. The first factor (F1) had Eigen value of 3.93 and contributed 65.4% for the total variance. F1 showed significant loadings on Cd, Cr, Cu, Fe, and Pb (Table 4). These metals could have been introduced as contaminants during the production of the feeds, [16, 106]. Factor two (F2) had Eigen value of 1.56 and added 26.1% to the total variance. F2 indicated significant loading for Cu and Zn only. This could be caused by the supplements introduced in poultry feeds by the producers, [3, 107].

PCA of water samples obtained from water sources at the different poultry farms investigated showed two main factors with Eigen values higher than 1 and a total variance of significant 84.1%. Factor one (F1) had Eigen value of 3.12, attributed 51.9% of the total variance and showed strong influence on Cd, Cr, Fe, and Pb. This could be the natural and anthropogenic impacts on the water quality supplied to the farms, [108]. The second factor (F2) had Eigen value (1.93) and contributed 32.2% of the total variance. F2 showed strong loadings on Cu and Zn. This could be the influence of mainly natural factor on the water quality as reported by Noulas *et al*. [109].

The results in Table 4 indicate that, PCA of oven-dried meat had three factors with Eigen values greater than 1 with a total variance of 100%. Factor one (F1) with Eigen value of 3.37, had 56.2% of the total variance and strong loadings on Cr, Fe, Pb, and Zn. This might have originated from the feeds and the environment. Factor two (F2) showed Eigen value of 1.33 and contributed 22.2% of the entire variance. F2 showed significant loadings on Cd and Cu which could be from anthropogenic inputs and supplements, [3]. The third factor (F3) had 1.30 as Eigen value and added 21.6% to the total variance. The third factor showed strong loading on Zn and could be as a results of the supplements added to the feeds, [110].

However, the PCA results of broiler meat roasted by roadsides indicated two major factors with Eigen value greater than 1 with a total variance of 92.8%. The first factor (F1) had Eigen value of 3.46 and 57.65% of the total variance with significant loadings on Cd, Cu, Fe, Pb, and Zn. Factor two (F2) had an Eigen value of 2.12 and contributed 35.2% of the total variance. This could be mostly the impact of vehicular emissions and other wastes within the area as reported by Ebong et al. [111] and Kasozi *et al*. [112]. Factor two had strong loadings on Cr and Fe; this might be combination effects of poultry feeds and vehicular emissions, [38, 113, 114].

4. Conclusion

The concentrations of Cd, Cr, Cu, Fe, Pb, and Zn in water, feeds, oven-dried, and roadside broiler meats obtained from poultry farms within Uyo Metropolis, Nigeria were assessed. Concentrations of some of the metals were higher than their recommended safe limits in the samples examined. The daily consumption of the oven-dried and roasted broiler meats may result in adverse health problems associated with high Cr, Cu, and Pb. The study revealed that, the consumption of oven-dried and roadside broiler meats harvested from the studied farm could have non-carcinogenic health problems on the consumers especially children. The consumption of these poultry-related meats could also expose the consumers to severe cancer risks. The sources of these metals in the poultry-related foods and products examined were identified using PCA. The results obtained also affirmed that, food processing techniques have significant effects on the quality of foods produced. The information gathered from this work could assist the poultry farms and serve as a panacea for good health to the consumers of poultry-related foods within Uyo and beyond.

Compliance with ethical standards

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