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Arsenic and toxic metals in meat and fish consumed in Niger delta, Nigeria: Employing the margin of exposure approach in human health risk assessment

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ABSTRACT

This study provides information on the health risk of As, Cd, Hg, Pb and V exposure from Nigerian foods consumption (fish, cow, goat and chicken meat) in different age-groups (children, adolescent, adult, senior) and six areas of Niger Delta, Nigeria (Choba, Khana, Eleme, TransAmadi, Uyo, and Yenogoa). The health risk assessment was performed by estimating the weekly or monthly intake of metals from foods and Margin of Exposure (MOE) approach by using established benchmark dose levels (BMDLs). Regarding As, cow and chicken meat products contributed to As exposure intake especially in children resulting in values higher than $BMDL_{0.1}$ for cancer risk in TransAmadi and Uyo areas. Cadmium exposure was due to cow, chicken and goat meat ingestion mostly in adolescent above the tolerable monthly intake limit in TransAmadi and Uyo areas. Concerning Hg and V, the exposure from Nigerian food did not constitute a potential health hazard. Lead exposure in children were above or close to $BMDL_{0.1}$ for developmental neurotoxicity by ingestion of cow and goat meat in all the Nigerian areas. In adult and senior the Pb dietary exposure were above the $BMDL_{10}$ providing a low to negligible risk for kidney effects. The potential concern for health effects in Niger Delta population needs further efforts to decrease As, Cd and Pb dietary exposure especially for children and adolescent, who are more vulnerable to adverse life events.

1. Introduction

Diet represents the most relevant source of majority of metals for non-occupationally exposed populations. The relevance of metals in human health and disease is well documented. Arsenic is classified as a Group 1 human carcinogen by the World Health Organization – International Agency for Research on Cancer (IARC, 2004). The toxicities associated with chronic ingestion of inorganic arsenic (As) in humans include skin lesions, cancer, developmental toxicity, cardiovascular diseases, derangement in glucose metabolism, and diabetes. Cadmium (Cd) is a naturally occurring, poorly excreted divalent element classified as non-essential toxic metal which can bioaccumulate in humans (ATSDR, 2012). Although inhalation and dermal contact are known routes of exposure, dietary Cd is the most significant source of exposure in humans through meat and offal (Darwish et al., 2008). Cadmium is a Group I carcinogen according to IARC and causes multi-organ toxicity namely hepato-renal toxicity, developmental neurotoxicity, cardiovascular toxicity, osteomalacia, deficiencies of essential trace elements (IARC, 1993). Lead (Pb) is a class 2A carcinogen (IARC, 2006). In adults, Pb-induced neuro-toxicity manifests as both sensory and motor impairments. Lead has also been implicated in both male and female infertility including miscarriages, cardiovascular diseases, anemia, irritability, osteoarthritis, headaches, constipation, weight loss, joint pain, and muscle weakness. Mercury (Hg) is a ubiquitous environmental pollutant. It is common resident in atmospheric deposition with the primary organic form methylmercury found in the food chain from

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where microbial action converts it to inorganic Hg (Zupo et al., 2019). Exposure to methylmercury may lead to learning and behavioral deficits, cardiovascular diseases, and reproductive impairments (Morgano et al., 2011; Chen et al., 2020; Santos-Lima et al., 2020; Yao et al., 2020). Vanadium (V) has epidemiological evidence of genotoxicity (Altamirano-Lozano et al., 2014).

Among several contaminants, metals are the most persistent because they are not biodegradable (Okoye et al., 2021). This imply that they may bioaccumulate in the food chain and pose a threat to human health. In addition, since malnutrition is a principal cause of death in sub-Sahara Africa, the assurance of food safety of the sub-Sahara Africa's natural resources is of immense importance and a periodical estimation of metals' dietary intake and of consequent health risks through comparison with tolerable levels, is needed to evaluate the long-term risk for public health. In health risk assessment, the expression "tolerable" is used because it describes permissibility rather than acceptability for the intake of contaminants associated with the consumption of foods. Many metals are not removed rapidly from the human body, and hence provisional tolerable weekly intake (PTWI) and/or provisional tolerable monthly intake (PTMI) are provided by JECFA and EFSA, as first step in assessing of dietary exposure to metals (Morgano et al., 2011). As second step, the margin of exposure (MOE) is used to characterize the health risk associated to metals dietary exposure and evaluate efficacy of the actual risk management actions.

Metals pollution of sediments, farmlands (where animals graze), groundwater and seawater is a major public health concern in Niger Delta area of Nigeria (Okogbue et al., 2017; Igwe et al., 2021). The dietary intake assessment of metals in different age groups of the Niger Delta showed Pb intake trough meat and fish consumption for both adults and children exceeded the tolerable limits set by EFSA that may adversely impact the health of Niger Delta population (Okoye et al., 2021). In view of the above evidences, this study explored the characterization of health risks associated to the dietary intake of metals in Nigerian children, adolescent, adult and senior population by using i) the ratio between estimated weekly intake (EWI) or estimated monthly intake (EMI) and the PTWI or PTMI, provided by international food authorities, in order to describe the potentially harmful exposure associate to commonly food Nigerian products; ii) the MOE calculation as useful tool to support risk managers in defining possible actions required to keep metals exposure as low as possible and the improvement of public health and hygiene in Nigeria.

2. Materials and methods

2.1. Study area

Briefly, Niger Delta, Nigeria is the third largest mangrove forest and the second largest delta in the world and falls within the central coastlands of southern Nigeria, with over seven million of inhabitants in the 70,000 square kilometer (Okoye et al., 2021).

2.2. Sample collection, treatment and analysis

Cow meat and goat meat (muscle and liver for both), chicken meat and fish, like flat head catfish (*Pylodictis olivaris*), mud fish (*Clarias anguillaris*), bonga shad (*Ethmalosa fimbriata*) and smoked catfish (*Clarias gariepinus*) were purchased in triplicates from markets, sales points and abattoirs at six areas (Choba, Khana, Trans Amadi, Eleme, Uyo and Yenagoa) of Niger Delta in January 2018 and were packaged in glass petri dishes, and kept frozen in the laboratory for 72–96 h before analyses. Pre-treatment of samples and quantification methods by GBC Sense AA 800G high-resolution continuum source Atomic Absorption Spectrometer (SE-710690), coupled to graphite furnace (Cambridge CB5 8BZ, United Kingdom), were described in earlier publication (Okoye et al., 2021).

2.3. Quality control

According to the methodology developed in Okoye et al. (2021), the instrument was recalibrated after every ten runs and the analytical procedure was checked using spike recovery method (SRM). High purity multi-cathode lamp (1000 mg/kg) from Cambridge CB5 8BZ (UK) was used to obtain the calibration curves for each metal. The multi element calibration curves were verified with a multi-element certified material of 1000 mg/kg (Cambridge CB5 8BZ, UK). The percentages of recovery varied between 94.5 and 100%. The relative standard deviation between replicate analyses was less than 4%. The limits of detection (LoD) were 0.001 mg/kg for As, Cd, Hg and V and 0.01 mg/kg for Pb, while the limits of quantification (LoQ) were 0.0033 mg/kg for As, Cd, Hg and V and 0.033 mg/kg for Pb (Okoye et al., 2021).

2.4. Dietary exposure and risk assessment

The EWI for As, Hg, Pb, and V and the EMI for Cd through meat and fish consumption in different age-groups (children, adolescent, adult, senior) were assessed by using concentration data obtained in Nigeria Delta region (Okoye et al., 2021). The EWI ad EMI as μg/kg/bw were calculated using the following equations (Agusa et al., 2007):

$$EWI_{ijk} = \frac{IR_{jk} \times P_{ij} \times 7}{BW_k}$$

$$EMI_{ijk} = \frac{IR_{jk} \times P_{ij} \times 30}{BW_k}$$

where, EWI_{ijk} and EMI_{ijk} is the weekly and monthly intake of metal i, for age group, through consumption of food category j (meat or fish); IR_{jk} is food category j ingestion rate for population k; Pij is the metal i level in food for category j; BW_k is the body weight for age group k. The following age ranges and body weights were used: children, aged 4–9 years, 24 kg; adolescents, aged 10–19 years, 54.5 kg; adults, aged 20–65 years, 70 kg; seniors, aged >65 years, 62.5 kg (Llobet et al., 2003).

The PTWI and PTMI percentages were assessed for each metal as:

$$\%PTWI = \frac{EWI}{PTWI} \times 100$$

According to the safety protection principle of risk assessment, the total As and Hg exposure data were compared with the tolerable weekly limit set for the inorganic As (15 μg/kg bw) and inorganic Hg (4 μg/kg/bw) (EFSA, 2009; WHO, 2010). The PTMI of 25 μg/kg/bw for Cd and a reference dose (RfD) of 7 μg/kg bw for V were used (FAO/WHO, 2010; USEPA, 2004). No tolerable safe level for Pb is currently available. The older PTWI at 25 μg/kg/bw by WHO was withdrawn because it was based only on dietary exposure, thus, it was no longer be considered health protective since other sources of exposure should be taken into account for Pb toxicity (FAO/WHO, 2011). In any case, a comparison of Pb exposure data with the older PTWI was carried out in order to give an overall indication of the potential exposure arising from commonly foods consumed by Nigerian population. Moreover, the health risk characterization for As and Pb exposure was explored also through the exposure boundary MOE method and calculated as the ratio between the benchmark dose lower one-sided confidence limit (BMDL) and the estimated daily intake (EDI) to the same metal.

$$MOE = \frac{BMDL}{EDI}$$

As a rule, the lower the MOE, the larger the risk for humans. A MOE value less than 1 represent a potential concern for human health (EFSA, 2005). The $BMDL_{01}$ of 0.3 μg/kg per day of inorganic As for cancers of the lung, skin and bladder, as well as skin lesions (EFSA, 2009), while the $BMDL_{10}$ of 0.63 μg/kg per day of Pb for kidney damage in adult and the $BMDL_{01}$ of 0.50 μg/kg per day of Pb for developmental neurotoxicity in children were used (EFSA, 2010).

3. Results and discussion

3.1. Dietary exposure estimation

Tables 1–6 report the PTWI% of metals from meat and fish consumption in children, adolescent, adult and senior living in 6 different Nigerian areas (Choba, Khana, TransAmadi, Eleme, Uyo, and Yenogoa). In Choba area, a limited exposure to As from foods was observed only in children and in particular from the ingestion of fish, cow meat and goat meat with percentages of 0.48%, 0.33% and 0.99% of As PTWI, respectively. Regarding Cd, cow liver and cow muscle intake contributed significantly to PTMIs of the metal in adolescent (liver 16% and muscle 24%) and senior (liver 12% and muscle 20%). These values corresponded to an EDI through cow meat of ca. 0.20 μg Cd/kg bw in both age groups. Moreover, chicken gizzard consumption accounted for 20% and 24% of Cd PTMI (i.e., 0.17 and 0.20 μg Cd/kg bw per day) in adolescent and senior, respectively. Concerning Pb, the highest PTWIs were observed in children respect to the other age classes, and principally the cow liver (13% corresponding to 0.47 μg/kg bw per day) and cow muscle (10% corresponding to 0.36 μg/kg bw per day) contributed to the dietary Pb intake. In addition, goat liver, goat muscle and chicken gizzard with percentages ranging from 4.2% to 13% also contributed to the Pb intake in children. High Pb exposure in Nigerian children and adult population was recently associated to consumption of goat carcasses, with values (ranged 0.54–0.98 mg/kg per day for children and 0.27–0.49 mg/kg per day for adult) much higher than those reported in the current study (Njoga et al., 2021). Concerning Khana, the As PTWI in children was mainly due from ingestion of cow liver (1.5%), goat liver (0.7%) and chicken gizzard (1.5%). The intakes of Cd in adolescent and senior derived from cow liver and muscle (12–24%), goat liver and muscle (8–20%) as well chicken gizzard (16–20%) consumption. The Pb PTWIs were ascribed to consumption of cow meat (children: 8.4–18%; senior: 4.3–32%) followed by goat meat (children: 5.3–12%; senior: 2.0–4.8%) and chicken meat (children: 5.1–18%; senior: 1.9–6.8%). Fish intake contributed less than meat to Pb PTWIs in children (3.5–5.6%) and senior (1.3–2.6%). The highest exposure level of Pb was observed by the consumption of a typical Nigerian food called kilishi that is a spicy and dried form of suya in the senior population (32% of PTWI and EDI of 1.15 μg/kg bw). Other evidences suggested spices and processed meat samples as relevant sources of further toxic substances like Pb (Rather et al., 2017). In TransAmadi area, cow and chicken meat samples provided the highest contribution to As PTWIs in children and in particular beef suya accounted for an exposure level of 16.5 μg/kg bw per week which was above the tolerable value of 15 μg/kg bw reported by EFSA (EFSA, 2009a). For this reason the high-consuming population of this food may need to pay attention to this exposure. Other commonly ingested Nigerian foods as chicken suya (39.9% of PTWI and EDI of 0.86 μg/kg bw) and fried meat (27.6% of PTWI and EDI of 0.59 μg As/kg bw) significantly contributed to As exposure levels in children. Similarly, in the Brazilian children population significant contribution to As dietary exposure due to chicken (0.22 μg/kg bw per day) and beef intake (0.11 μg/kg bw per day) was estimated (Azevedo et al., 2018). To the opposite, in Bangladesh children the As EDI from chicken (0.087 μg/kg bw) and beef (0.084 μg/kg bw) was limited suggesting the presence of other dietary products (e.g., vegetables and water intake) as main sources of As exposure (Ahmed et al., 2016). In China and US population, the As content in chicken and the correspondent contribution to its dietary exposure was associated to As-based drugs deliberately used in poultry production (Hu et al., 2018; Nigra et al., 2017). In adolescent, the same foods played an important role in monthly Cd dietary exposure, namely fried meat (130 μg/kg bw), chicken suya (74 μg/kg bw), and beef suya (28 μg/kg bw), indicating Cd intakes from these foods well above the tolerable monthly values (25 μg/kg bw). According to our findings, Cd exposure through meat intake (e.g., chicken, cow, goat and sheep) exceeded the guidance level of adult and children population living in northern and south-eastern Nigeria (Orisakwe et al., 2017; Njoga et al., 2021). The Pb intakes revealed, as in the other areas, the ingestion of cow and goat meat as main sources of Pb exposure, with PTWI percentages ranged between 3.0 and 7.7% in children and 1.8–3.6% in senior. In Eleme area, As exposure was not significantly associated to any kind of foods in all age categories. Whist, Cd intake in adolescent was associated to the consumption of cow liver and chicken gizzard with a contribution of 12% to PTMIs for both foods, corresponding to an EDI of 0.10 μg/kg bw. Regarding Pb PTWIs, cow liver and goat liver contributed significantly to the metal intake in children (20% and 13%, respectively) and less in senior (6.70% and 5.3%, respectively). Thus, as

Table 1
Percentage of the provisional tolerable weekly or monthly intake (PTWI% or PTMI%) of metals and metalloids from meat and fish consumption in age-groups (Children aged 4–9 ys; Adolescent aged 10–19 ys; Adults aged 20–65 ys; Senior aged >65 ys) living in Choba, Niger-Delta, Nigeria.

Food products	As PTWI%				Cd PTMI%				Hg PTWI%				Pb PTWI%				V PTWI%			
	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR
Flat head catfish	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	0.02	0.69	0.77	0.00	0.00	0.00	0.00
Mud fish	0.00	0.00	0.00	0.00	0.06	4.00	0.02	4.00	0.00	0.00	0.00	0.00	3.48	0.04	1.19	1.33	0.01	0.00	0.01	0.00
Bonga shad	0.05	0.00	0.00	0.00	0.01	4.00	0.02	4.00	0.00	0.00	0.00	0.00	3.61	0.04	1.24	1.38	0.06	0.00	0.02	0.00
Smoked catfish	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.54	0.04	1.22	1.36	0.06	0.00	0.02	0.00
Cow liver	0.99	0.00	0.09	0.00	0.06	24.0	0.08	20.0	0.10	0.00	0.00	0.00	13.1	0.14	4.48	5.01	0.05	0.00	0.01	0.00
Cow muscle	0.19	0.00	0.05	0.00	0.16	16.0	0.05	12.0	0.08	0.00	0.00	0.00	10.0	0.11	3.43	3.84	0.04	0.00	0.01	0.00
Beef Suya	0.09	0.00	0.05	0.00	0.01	0.00	0.00	0.0	0.03	0.00	0.00	0.00	4.26	0.05	1.46	1.64	0.00	0.00	0.00	0.00
Fried meat	0.09	0.00	0.07	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	2.36	0.03	0.81	0.90	0.01	0.00	0.01	0.00
Kilishi	0.05	0.00	0.00	0.00	0.05	4.00	0.02	4.00	0.02	0.00	0.00	0.00	4.01	0.04	1.38	1.54	0.01	0.00	0.00	0.00
Goat liver (N)	0.33	0.00	0.05	0.00	0.05	4.00	0.02	4.00	0.00	0.00	0.00	0.00	6.38	0.07	2.19	2.45	0.01	0.00	0.00	0.00
Goat muscle (N)	0.29	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.01	0.04	1.38	1.54	0.01	0.00	0.00	0.00
Goat liver (H)	0.10	0.00	0.10	0.00	0.12	12.0	0.04	12.0	0.10	0.00	0.00	0.00	8.34	0.09	2.86	3.20	0.08	0.00	0.03	0.00
Goat muscle (H)	0.14	0.00	0.05	0.00	0.08	8.00	0.03	8.00	0.00	0.00	0.03	0.00	4.19	0.07	2.26	2.53	0.06	0.00	0.02	0.00
Goat pepper soup	0.00	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.08	0.00	0.00	0.00	1.68	0.02	0.58	0.64	0.01	0.00	0.00	0.00
Chicken Suya	0.14	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.08	0.00	0.01	0.00	5.70	0.01	1.96	2.19	0.01	0.00	0.00	0.00
Chicken muscle (N)	0.14	0.00	0.05	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	5.34	0.06	1.83	2.05	0.01	0.00	0.00	0.00
Chicken gizzard (N)	0.09	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00	5.90	0.07	2.02	2.27	0.00	0.00	0.00	0.00
Chicken muscle (B)	0.09	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00	5.41	0.06	1.86	2.08	0.01	0.00	0.00	0.00
Chicken gizzard (B)	0.99	0.00	0.09	0.00	0.06	24.0	0.08	20.00	0.10	0.00	0.01	0.00	13.1	0.14	4.48	5.01	0.05	0.00	0.01	0.00

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria)
B: Broiler
CH= children, ADOL= adolescent, AD= adult, SNR= senior

Table 2
Percentage of the provisional tolerable weekly or monthly intake (PTWI% or PTMI%) of metals and metalloids from meat and fish consumption in age-groups (Children aged 4–9 ys; Adolescent aged 10–19 ys; Adults aged 20–65 ys; Senior aged >65 ys) living in Khana, Niger-Delta, Nigeria.

Food products	As PTWI%				Cd PTMI%				Hg PTWI%				Pb PTWI%				V PTWI%			
	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR
Flat head catfish	0.14	0.00	0.05	0.00	0.03	4.00	0.01	4.00	0.00	0.00	0.00	0.00	3.87	0.00	1.33	1.48	0.03	0.01	0.01	0.00
Mud fish	0.10	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.62	0.01	1.93	2.16	0.00	0.00	0.00	0.00
Bonga shad	0.00	0.00	0.00	0.00	0.06	8.00	0.02	8.00	0.00	0.00	0.00	0.00	3.51	0.00	1.20	1.34	0.04	0.01	0.01	0.00
Smoked catfish	0.19	0.00	0.05	0.00	0.07	8.00	0.02	8.00	0.00	0.00	0.00	0.00	4.38	0.00	2.32	2.60	0.02	0.00	0.01	0.00
Cow liver	1.47	0.00	0.19	0.00	0.18	20.0	0.06	16.0	0.03	0.00	0.00	0.00	17.6	0.01	6.03	6.76	0.05	0.00	0.21	0.00
Cow muscle	0.33	0.00	0.14	0.00	0.14	16.0	0.05	12.0	0.03	0.00	0.00	0.00	14.8	0.01	5.07	5.68	0.03	0.00	0.01	0.00
Beef Suya	0.14	0.00	0.05	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.3	0.00	3.86	4.32	0.02	0.00	0.07	0.00
Fried meat	0.00	0.00	0.00	0.00	0.02	0.00	0.08	0.00	0.00	0.00	0.00	0.00	12.6	0.01	4.32	4.48	0.01	0.00	0.01	0.00
Kilishi	0.05	0.00	0.00	0.00	0.28	4.00	0.01	4.00	0.02	0.00	0.00	0.00	8.4	0.00	2.88	32.3	0.01	0.00	0.00	0.00
Goat liver (N)	0.38	0.00	0.14	0.00	0.19	20.0	0.06	16.0	0.05	0.00	0.00	0.00	6.30	0.00	2.16	2.41	0.01	0.00	0.01	0.00
Goat muscle (N)	0.19	0.00	0.05	0.00	0.11	12.0	0.04	8.00	0.07	0.00	0.03	0.00	6.05	0.00	2.07	2.32	0.01	0.00	0.01	0.00
Goat liver (H)	0.67	0.00	0.24	0.00	0.12	12.0	0.04	12.0	0.10	0.00	0.03	0.00	6.77	0.00	2.32	2.60	0.03	0.00	0.01	0.00
Goat muscle (H)	0.38	0.00	0.14	0.00	0.07	8.00	0.03	8.00	0.05	0.00	0.02	0.00	5.29	0.00	1.86	2.04	0.03	0.00	0.07	0.00
Goat pepper soup	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.5	0.00	4.28	4.79	0.01	0.00	0.01	0.00
Chicken Suya	0.09	0.00	0.05	0.00	0.01	0.00	0.00	0.00	0.05	0.00	0.03	0.00	11.3	0.00	3.86	4.32	0.01	0.00	0.00	0.00
Chicken muscle (N)	0.05	0.00	0.00	0.00	0.08	0.00	0.04	0.00	0.02	0.00	0.00	0.00	5.06	0.00	1.73	1.94	0.01	0.00	0.00	0.00
Chicken gizzard (N)	0.00	0.00	0.00	0.00	0.08	0.00	0.04	0.00	0.07	0.00	0.02	0.00	6.96	0.00	2.38	2.66	0.01	0.00	0.00	0.00
Chicken muscle (B)	0.04	0.00	0.00	0.00	0.05	4.00	0.02	4.00	0.00	0.00	0.00	0.00	8.41	0.00	2.88	3.23	0.07	0.00	0.00	0.00
Chicken gizzard (B)	1.47	0.00	0.19	0.00	0.18	20.00	0.06	16.00	0.02	0.00	0.00	0.00	17.6	0.00	6.03	6.76	0.05	0.00	0.21	0.00

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria)
B: Broiler
CH= children, ADOL= adolescent, AD= adult, SNR= senior

Table 3
Percentage of the provisional tolerable weekly or monthly intake (PTWI% or PTMI%) of metals and metalloids from meat and fish consumption in age-groups (Children aged 4–9 ys; Adolescent aged 10–19 ys; Adults aged 20–65 ys; Senior aged >65 ys) living in TransAmadi, Niger-Delta, Nigeria.

Food products	As PTWI%				Cd PTMI%				Hg PTWI%				Pb PTWI%				V PTWI%			
	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR
Flat head catfish	0.05	0.00	0.00	0.02	0.02	4.00	0.01	0.02	0.00	0.00	0.00	0.00	3.14	0.04	1.08	2.34	0.01	0.00	0.00	0.00
Mud fish	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.31	0.03	0.79	2.57	0.00	0.00	0.00	0.00
Bonga shad	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	4.31	0.05	1.48	1.38	0.00	0.00	0.00	0.00
Smoked catfish	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00	0.00	0.00	2.84	0.03	0.98	0.46	0.00	0.00	0.00	0.00
Cow liver	0.10	0.01	0.05	0.03	0.12	12.0	0.04	0.14	0.03	0.00	0.00	0.00	6.81	0.08	2.34	2.70	0.01	0.00	0.00	0.00
Cow muscle	0.05	0.00	0.00	0.00	0.16	16.0	0.05	0.03	0.00	0.00	0.00	0.00	5.64	0.06	1.93	2.70	0.01	0.00	0.00	0.00
Beef Suya	109.7	0.01	37.6	0.01	1.07	112	0.37	0.37	0.25	0.00	0.08	0.05	4.40	0.05	1.51	1.84	1.88	0.01	0.64	0.00
Fried meat	27.6	0.02	9.48	0.02	5.60	520.0	1.74	1.36	0.63	0.00	0.23	0.00	4.89	0.05	1.68	2.72	0.28	0.00	0.09	0.00
Kilishi	0.33	0.00	0.10	0.03	0.01	0.00	0.00	0.34	0.03	0.00	0.00	0.00	4.35	0.05	1.49	2.72	0.06	0.00	0.02	0.00
Goat liver (N)	0.05	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	7.70	0.08	2.46	1.20	0.01	0.00	0.00	0.00
Goat muscle (N)	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.18	0.05	1.43	2.77	0.01	0.00	0.00	0.00
Goat liver (H)	0.05	0.00	0.00	0.02	0.09	8.00	0.03	0.03	0.03	0.00	0.00	0.00	6.58	0.07	2.26	3.25	0.00	0.00	0.00	0.00
Goat muscle (H)	0.05	0.00	0.00	0.01	0.16	16.0	0.06	0.03	0.03	0.00	0.00	0.00	2.90	0.03	0.99	2.55	0.00	0.00	0.00	0.00
Goat pepper soup	6.67	0.01	2.29	0.11	0.13	12.0	0.04	0.34	0.10	0.00	0.03	0.00	6.12	0.07	2.10	3.61	0.56	0.00	0.19	0.00
Chicken Suya	39.9	0.00	13.7	0.03	2.87	296.0	0.98	0.83	0.13	0.00	0.05	0.00	5.77	0.06	1.98	0.86	0.65	0.00	0.22	0.00
Chicken muscle (N)	0.52	0.00	0.19	0.04	0.04	4.00	0.01	0.01	0.03	0.00	0.00	0.00	5.36	0.06	1.84	2.06	0.18	0.00	0.06	0.00
Chicken gizzard (N)	0.05	0.00	0.00	0.02	0.04	4.00	0.01	0.02	0.03	0.00	0.00	0.00	4.40	0.05	1.51	1.57	0.08	0.00	0.01	0.00
Chicken muscle (B)	0.10	0.00	0.05	0.21	0.12	4.00	0.05	0.02	0.03	0.00	0.00	0.00	6.81	0.03	2.84	3.08	0.01	0.00	0.23	0.00
Chicken gizzard (B)	0.05	0.00	0.10	0.22	0.16	12.00	0.12	0.04	0.00	0.00	0.03	0.00	5.64	0.08	6.81	2.70	0.01	0.00	0.01	0.00

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria)
B: Broiler
CH= children, ADOL= adolescent, AD= adult, SNR= senior

for Cd, an important source of Pb exposure was the consumption of cow liver and chicken gizzard in children (20% for both foods, corresponding to 0.71 μg Pb/kg per day). These data indicated a potential risk of exposure to Cd in adolescent and Pb in children through animal products and especially by offal consumption. Thus, the behaviour of eating meat offal like liver and gizzard should be highly minimized across several communities in Africa since such organs were found to accumulate the highest amounts of metals (Alao et al., 2018; Hashemi, 2018). These findings reflected the higher accumulation of Cd and Pb in liver than in other animal organs previously reported in Italy (Forte et al., 2007). The high Cd accumulation was also found in several meat samples from the Nigerian market (Ihedioha et al., 2012), as well the higher exposure from goat liver than goat muscle (Orisakwe et al., 2017). Similarly in China, higher Cd accumulation in chicken offals (liver, gizzard, heart, and kidney) compared to muscles (Hu et al., 2018). Regarding Uyo area, As exposure in children derived from consumption of kilishi (52% PTWI), fried cow meat (37% PTWI), chicken muscle (12% PTWI) and chicken gizzard (8.7% PTWI). In adults, beef suya (12% PTWI), chicken suya (9.0%), fried cow meat (6.9% PTWI) and chicken muscle (4.1%) contributed to As intake. The Cd intake in adolescent (69 μg/kg bw) and senior (60 μg/kg bw) through chicken suya consumption exceeded the tolerable monthly intake of 25 μg/kg bw established by WHO. In both

Table 4
Percentage of the provisional tolerable weekly or monthly intake (PTWI% or PTMI%) of metals and metalloids from meat and fish consumption in age-groups (Children aged 4–9 ys; Adolescent aged 10–19 ys; Adults aged 20–65 ys; Senior aged >65 ys) living in Eleme, Niger-Delta, Nigeria.

Food products	As PTWI%				Cd PTMI%				Hg PTWI%				Pb PTWI%				V PTWI%			
	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR
Flat head catfish	0.33	0.02	0.14	0.11	0.06	4.00	0.02	0.40	0.02	0.00	0.03	0.02	4.01	0.04	1.38	2.34	0.01	0.00	0.01	0.02
Mud fish	0.00	0.00	0.00	0.00	0.02	4.00	0.01	0.01	0.02	0.00	0.03	0.04	3.67	0.04	1.26	2.57	0.00	0.00	0.00	0.01
Bonga shad	0.05	0.00	0.14	0.24	0.06	8.00	0.02	1.80	0.00	0.00	0.00	0.04	6.11	0.07	2.10	2.38	0.02	0.00	0.01	0.02
Smoked catfish	0.14	0.00	0.05	0.04	0.05	4.00	0.02	0.80	0.00	0.00	0.00	0.03	5.82	0.06	1.99	1.46	0.02	0.00	0.01	0.00
Cow liver	0.28	0.00	0.10	0.09	0.12	12.00	0.04	0.16	0.10	0.00	0.03	0.05	19.93	0.22	6.83	6.70	0.08	0.00	0.93	1.00
Cow muscle	0.38	0.00	0.14	0.40	0.08	8.00	0.03	0.12	0.02	0.00	0.00	0.01	17.45	0.19	5.98	5.70	0.07	0.00	0.02	0.03
Beef Suya	0.14	0.00	0.05	0.12	0.01	0.00	0.00	0.10	0.00	0.00	0.00	0.05	8.46	0.09	2.90	2.84	0.01	0.00	0.00	0.01
Fried meat	0.05	0.00	0.00	0.03	0.06	4.00	0.00	0.01	0.00	0.00	0.00	0.01	12.52	0.14	4.29	4.72	0.01	0.00	0.00	0.01
Kilishi	0.10	0.00	0.05	0.01	0.05	4.00	0.00	0.04	0.05	0.00	0.00	0.03	10.31	0.10	3.54	5.72	0.09	0.00	0.03	0.02
Goat liver (N)	0.19	0.00	0.10	0.54	0.07	8.00	0.02	0.26	0.00	0.00	0.00	0.02	9.91	0.11	3.39	4.20	0.55	0.00	0.19	0.10
Goat muscle (N)	0.29	0.00	0.10	0.02	0.45	8.00	0.15	0.80	0.03	0.00	0.00	0.02	8.92	0.10	3.06	3.77	0.51	0.00	0.18	0.12
Goat liver (H)	0.10	0.00	0.05	0.01	0.01	0.00	0.00	0.12	0.03	0.00	0.00	0.01	13.2	0.15	4.54	5.25	0.03	0.00	0.01	0.01
Goat muscle (H)	0.00	0.00	0.00	0.02	0.02	4.00	0.01	0.80	0.00	0.00	0.00	0.01	9.63	0.11	3.30	4.55	0.06	0.00	0.01	0.02
Goat pepper soup	0.38	0.00	0.01	0.01	0.03	4.00	0.01	0.00	0.00	0.00	0.00	0.21	12.5	0.14	4.28	4.68	0.51	0.00	0.18	0.13
Chicken Suya	0.05	0.00	0.00	0.21	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.02	11.68	0.13	4.00	0.86	0.07	0.00	0.03	0.90
Chicken muscle (N)	0.05	0.00	0.00	0.13	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.02	4.40	0.05	1.51	2.06	0.01	0.00	0.00	0.02
Chicken gizzard (N)	0.05	0.00	0.00	0.14	0.00	0.00	0.00	0.04	0.03	0.00	0.00	0.01	6.27	0.07	2.15	3.58	0.04	0.00	0.01	0.00
Chicken muscle (B)	0.14	0.00	0.05	0.04	0.04	4.00	0.00	0.20	0.03	0. 000	0.00	0.12	4.90	0.05	1.68	5.08	0.01	0.00	0.00	0.01
Chicken gizzard (B)	0.29	0.00	0.10	0.01	0.12	12.00	0.00	0.16	0.10	0.00	0.00	0.02	19.93	0.22	6.83	7.70	0.08	0.00	0.93	0.01

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria)
B: Broiler
CH= children, ADOL= adolescent, AD= adult, SNR= senior

Table 5
Percentage of the provisional tolerable weekly or monthly intake (PTWI% or PTMI%) of metals and metalloids from meat and fish consumption in age-groups (Children aged 4–9 ys; Adolescent aged 10–19 ys; Adults aged 20–65 ys; Senior aged >65 ys) living in Uyo, Niger-Delta, Nigeria.

Food products	As PTWI%				Cd PTMI%				Hg PTWI%				Pb PTWI%				V PTWI%			
	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR
Flat head catfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	2.88	0.03	0.92	1.03	0.01	0.00	0.00	0.00
Mud fish	0.05	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.42	0.02	0.67	0.75	0.00	0.00	0.00	0.00
Bonga shad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	10.5	0.06	1.84	2.06	0.01	0.00	0.01	0.00
Smoked catfish	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.00	0.00	4.64	0.05	1.48	1.66	0.01	0.00	0.01	0.00
Cow liver	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.02	0.00	0.00	0.00	14.1	0.14	4.51	5.05	0.01	0.00	0.00	0.00
Cow muscle	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.00	38.5	0.12	3.66	4.10	0.01	0.00	0.01	0.00
Beef Suya	4.95	0.00	11.9	0.03	0.25	24.0	0.08	24.0	0.38	0.00	0.00	0.00	3.70	0.01	0.27	0.31	0.08	0.00	1.14	0.00
Fried meat	37.3	0.00	6.91	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.76	0.03	1.07	1.20	0.00	0.00	0.01	0.00
Kilishi	51.8	0.00	6.86	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.5	0.06	1.97	2.20	0.01	0.00	0.01	0.00
Goat liver (N)	0.05	0.00	0.00	0.00	0.01	8.00	0.03	8.00	0.03	0.00	0.00	0.00	17.2	0.01	2.96	3.31	0.02	0.00	0.29	0.00
Goat muscle (N)	0.05	0.00	0.00	0.00	0.01	4.00	0.01	4.00	0.03	0.00	0.00	0.00	13.3	0.07	2.29	2.56	0.01	0.00	0.00	0.00
Goat liver (H)	0.10	0.00	0.00	0.00	0.00	4.00	0.01	4.00	0.00	0.00	0.00	0.00	21.2	0.12	3.90	4.37	0.00	0.00	0.00	0.00
Goat muscle (H)	0.01	0.00	0.00	0.00	0.00	4.00	0.01	4.00	0.00	0.00	0.00	0.00	16.0	0.10	3.02	3.38	0.00	0.00	0.01	0.00
Goat pepper soup	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.83	0.03	1.07	1.21	0.00	0.00	0.01	0.00
Chicken Suya	6.38	0.00	9.05	0.02	2.68	276	0.92	240	0.00	0.00	0.00	0.00	1.59	0.01	0.22	0.24	0.66	0.00	0.97	0.00
Chicken muscle (N)	2.28	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	18.5	0.04	1.51	1.69	0.00	0.00	0.01	0.00
Chicken gizzard (N)	8.71	0.00	3.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	4.56	0.05	1.46	1.63	0.01	0.00	0.01	0.00
Chicken muscle (B)	11.95	0.00	4.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.43	0.05	1.74	1.90	0.00	0.00	0.00	0.00
Chicken gizzard (B)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	14.1	0.14	4.51	5.05	0.01	0.00	0.00	0.00

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria)
B: Broiler
CH= children, ADOL= adolescent, AD= adult, SNR= senior

adolescent and senior, also beef suya and goat liver contributed to Cd dietary exposure corroborating data on the enrichment of Cd in different kinds of meat purchased in Nigeria (Orisakwe et al., 2017). Lead dietary exposure data in children showed the highest exposure from cow muscle (38% PTWI), followed by goat liver (21% PTWI) and chicken muscle (18% PTWI). In Yenogoa, like in other cities, a limited As exposure through fish (maximum of 0.95% PTWI) was observed only in children. Therefore in all of the Nigerian areas, fish had a minimal contribution to As exposure. A previous study showed that inorganic As accounted for 2–4% of the total As in aquatic products (JEFCA, 2011). Whilst in China, more than half of total As exposure derived by fish products and their derivatives (Wang et al., 2020). Monthly Cd intake in adolescent and senior was associated to fish, cow and goat meat. Fish consumption accounted up to 32% in adolescent and 28% in senior that corresponded to a daily exposure of 0.27 and 0.23 μg/kg, respectively. In a previous study, fish and shellfish consumption marginally influenced Cd exposure in Niger-Delta population (Ihedioha et al., 2016). Cadmium exposure from cow muscle ingestion accounted for 20% (0.17 μg Cd/kg per day) in adolescent and 16% (i.e., 0.13 μg Cd/kg per day) in senior population. Similarly to other areas, goat liver contributed for 32% in adolescent (0.27 μg/kg per day) and 28% in senior (0.13 μg/kg per day) to dietary Cd exposure. Regarding Pb exposure, goat meat, chicken meat, cow

Table 6
Percentage of the provisional tolerable weekly or monthly intake (PTWI% or PTMI%) of metals and metalloids from meat and fish consumption in age-groups (Children aged 4–9 ys; Adolescent aged 10–19 ys; Adults aged 20–65 ys; Senior aged >65 ys) living in Yenagoa, Niger-Delta, Nigeria.

Food products	As PTWI%				Cd PTMI%				Hg PTWI%				Pb PTWI%				V PTWI%			
	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR	CH	ADOL	AD	SNR
Flat head catfish	0.95	0.00	0.33	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.08	0.07	2.09	2.34	0.04	0.00	0.01	0.00
Mud fish	0.67	0.00	0.24	0.00	0.16	16.0	0.05	12.0	0.03	0.00	0.00	0.00	11.9	0.13	4.08	4.57	0.00	0.00	0.00	0.00
Bonga shad	0.29	0.00	0.08	0.00	0.30	32.0	0.14	28.0	0.05	0.00	0.02	0.00	6.21	0.07	2.13	2.38	0.16	0.00	0.06	0.00
Smoked catfish	0.00	0.00	0.00	0.00	0.22	24.0	0.07	20.0	0.00	0.00	0.00	0.00	3.79	0.04	1.30	1.46	0.14	0.00	0.04	0.00
Cow liver	4.71	0.00	1.62	0.00	0.09	8.00	0.03	8.00	0.05	0.00	0.03	0.00	7.04	0.08	2.41	2.70	0.03	0.00	0.01	0.00
Cow muscle	2.91	0.00	1.00	0.00	0.20	20.0	0.07	16.0	0.05	0.00	0.03	0.00	4.42	0.05	1.52	1.70	0.24	0.00	0.08	0.00
Beef Suya	0.76	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.03	0.05	4.79	0.05	1.64	1.84	0.02	0.00	0.01	0.00
Fried meat	1.52	0.00	0.52	0.00	0.04	4.00	0.01	12.0	0.08	0.00	0.02	0.00	7.09	0.08	2.43	2.72	0.04	0.00	0.09	0.00
Kilishi	1.10	0.00	0.38	0.00	0.01	0.00	0.00	0.00	0.08	0.00	0.03	0.00	7.10	0.08	2.43	2.72	0.16	0.00	0.06	0.00
Goat liver (N)	0.81	0.00	0.29	0.00	0.06	8.00	0.02	4.00	0.15	0.00	0.05	0.00	8.58	0.09	2.93	3.20	0.06	0.00	0.02	0.00
Goat muscle (N)	0.38	0.00	0.14	0.00	0.13	12.0	0.04	12.0	0.05	0.00	0.03	0.00	9.81	0.11	3.36	3.77	0.12	0.00	0.04	0.00
Goat liver (H)	0.38	0.00	0.14	0.00	0.32	32.0	0.19	28.0	0.00	0.00	0.00	0.00	8.47	0.09	2.90	3.25	0.24	0.00	0.08	0.00
Goat muscle (H)	0.33	0.00	0.09	0.00	0.13	12.0	0.04	12.0	0.03	0.00	0.00	0.00	11.8	0.13	4.06	4.55	0.21	0.00	0.07	0.00
Goat pepper soup	0.38	0.00	0.14	0.00	0.02	0.00	0.00	0.00	0.03	0.00	0.00	0.00	9.40	0.10	3.22	3.68	0.06	0.00	0.21	0.00
Chicken Suya	0.95	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.03	0.00	2.24	0.02	0.77	0.86	0.02	0.00	0.01	0.00
Chicken muscle (N)	0.62	0.00	0.24	0.00	0.03	4.00	0.08	0.00	0.05	0.00	0.03	0.00	5.36	0.06	1.84	2.06	0.19	0.00	0.06	0.00
Chicken gizzard (N)	0.48	0.00	0.19	0.00	0.01	0.00	0.00	0.00	0.05	0.01	0.02	0.00	9.31	0.10	3.19	3.58	0.02	0.00	0.01	0.00
Chicken muscle (B)	1.14	0.00	0.38	0.00	0.02	4.00	0.01	0.00	0.08	0.00	0.03	0.00	13.2	0.15	4.53	5.08	0.01	0.00	0.01	0.00
Chicken gizzard (B)	4.71	0.00	1.62	0.00	0.09	8.00	0.03	8.00	0.05	0.00	0.03	0.00	7.04	0.08	2.41	2.70	0.03	0.00	0.01	0.00

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria)
B: Broiler. CH= children, ADOL= adolescent, AD= adult, SNR= senior

meat and in some extend also fish were the main contributing foods to the daily intake of the metal, with maximum PTWIs in children coming from chicken muscle and goat muscle (13% and 12%). In addition, in all the studied Nigerian areas, food products considered did not constitute a possible source of Hg and V exposure and data never exceed the tolerable intake of 4 μg Hg/kg per day set by EFSA and the RfD of 7 μg V/kg per day set by EPA. The results obtained for Hg dietary exposure from beef were much lower than those reported in Catalonia (Spain) (González et al. (2019) and in Korea (Kwon et al., 2009). In the case of V, exposure data was more than hundred-fold lower than the dose (ca. 200 μg/kg bw per day) at which possible adverse health effect may occur, as well lower than the estimated range of daily intake of V (10–20 μg/day) from normal food (EFSA, 2004).

3.2. *Risk assessment by MOE approach*

The MOE approach was applied only for the metals and for the aged classes that showed significant or appreciable dietary exposure assessment. For this reason, MOE values were calculated for As in children and adult and for Pb in children, adult and senior by using the BMDLs set by EFSA (Tables 7 and 8). Regarding As, exposure data by cow and chicken meat were higher than the As $BMDL_{01}$ of 0.3 μg/kg bw day associated to a 1% increased risk of developing lung cancer (EFSA, 2009) in Trans-Amadi and Uyo areas and the resultant MOE values were lower than 1.

Table 7
MOEs for As derived for Nigerian adults and children based on benchmark doses of 0.3 μg/kg bw per day set by EFSA (EFSA, 2009).

Food categories	Food products	Choba		Khana		TransAmadi		Eleme		Uyo		Yenogoa	
		CH	AD	CH	AD	CH	AD	CH	AD	CH	AD	CH	AD
fish	Flat head catfish	29.4	-	97.2	280	280.0	-	42.4	100	-	-	14.7	42.4
	Mud fish	-	-	140	280	-	-	-	-	291.7	-	20.9	58.8
	Bonga shad	292	-	-	-	-	-	280	100	-	-	49.0	175
	Smoked catfish	292	-	73.7	280	-	-	97.9	280	-		-	-
cow meat	Cow liver	14.1	156	9.52	73.7	140	280	50.0	147	-	-	2.97	8.64
	Cow muscle	73.3	280	42.4	100	280	-	36.8	100	-	-	4.81	14.0
	Beef Suya	156	280	100	280	0.13	0.37	100	280	2.83	1.18	18.4	58.3
	Fried meat	156	200	-	-	0.51	1.48	280	-	0.38	2.03	9.21	26.9
	Kilishi	280	-	292	-	42.4	147	140	280	0.27	2.04	12.8	36.8
goat meat	Goat liver (N)	42.0	280	36.8	100	280	-	73.7	140	292	-	17.3	49.0
	Goat muscle (N)	49.0	147	73.7	280	-	-	48.3	140	292	-	36.7	97.9
	Goat liver (H)	147	147	20.9	58.3	280	-	140	292	147	-	36.7	100
	Goat muscle (H)	100	280	36.8	100	292	-	-	-	2800	-	42.4	156
	Goat pepper soup	-	280	280	-	2.10	6.12	36.7	1400	2800	-	36.8	97.9
chicken meat	Chicken Suya	100	-	156	280	0.35	1.02	280	-	2.19	1.55	14.7	42.4
	Chicken muscle (N)	100	280	292	-	26.9	73.3	280	-	6.14	18.4	22.6	58.8
	Chicken gizzard (N)	156	280	-	-	292	-	280	-	1.61	4.67	29.2	73.7
	Chicken muscle (B)	156	280	350	-	140	292	100	280	1.17	3.42	12.3	36.8
	Chicken gizzard (B)	14.1	156	9.52	73.3	280	147	48.3	140	-	-	2.97	8.64

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria)
B: Broiler
-: not significant

CH= children, AD= adult

Table 8
MOEs for Pb derived for Nigerian children adults and senior based on benchmark doses of 0.5 μg/kg bw per day for children and 0.63 μg/kg bw per day for adult set by EFSA (EFSA, 2010).

Food categories	Food products	Choba			Khana			Transamadi			Eleme			Uyo			Yenogoa		
		CH	AD	SNR	CH	AD	SNR	CH	AD	SNR	CH	AD	SNR	CH	AD	SNR	CH	AD	SNR
fish	Flat head catfish	13.8	25.5	22.8	3.62	13.3	11.9	4.46	16.4	7.54	3.49	12.8	7.54	4.86	19.1	17.1	2.30	8.44	7.54
	Mud fish	4.02	14.8	13.3	2.49	9.14	8.17	6.06	22.3	6.86	3.81	14.0	6.86	1.66	26.25	23.5	1.18	4.32	3.86
	Bonga shad	3.88	14.2	12.8	3.99	14.7	13.2	3.25	12.0	12.8	2.29	8.42	7.41	1.33	9.59	8.56	2.25	8.27	7.41
	Smoked catfish	3.95	14.5	13.0	3.20	7.60	6.78	4.93	18.1	38.3	2.41	8.86	12.1	3.02	11.9	10.6	3.69	13.6	12.1
cow meat	Cow liver	1.07	3.94	3.52	0.80	2.93	2.61	2.06	7.55	6.53	0.70	2.58	2.63	1.00	3.91	3.49	1.99	7.32	6.53
	Cow muscle	1.40	5.14	4.59	0.95	3.48	3.11	2.48	9.13	6.53	0.80	2.95	3.09	0.36	4.81	4.30	3.17	11.6	10.4
	Beef Suya	3.29	12.1	10.8	1.24	4.57	4.08	3.18	11.7	9.59	1.65	6.08	6.21	3.78	65.3	57.3	2.92	10.8	9.59
	Fried meat	5.93	21.8	19.6	1.11	4.08	3.94	2.86	10.5	6.49	1.12	4.11	3.74	1.43	16.5	14.70	1.97	7.26	6.49
	Kilishi	3.49	12.8	11.5	1.67	6.13	0.55	3.22	11.8	6.49	1.36	4.98	3.08	1.12	8.95	8.02	1.97	7.26	6.49
goat meat	Goat liver (N)	2.19	8.06	7.20	2.22	8.17	7.32	1.82	7.17	14.7	1.41	5.20	4.20	0.81	5.97	5.33	1.63	6.02	5.51
	Goat muscle (N)	3.49	12.8	11.5	2.31	8.52	7.60	3.35	12.3	6.37	1.57	5.76	4.68	1.05	7.70	6.89	1.43	5.25	4.68
	Goat liver (H)	1.68	6.17	5.51	2.07	7.60	6.78	2.13	7.82	5.43	1.06	3.89	3.36	0.66	4.52	4.04	1.65	6.07	5.43
	Goat muscle (H)	3.34	7.81	6.97	2.65	9.48	8.66	4.83	17.8	6.92	1.45	5.35	3.88	0.88	5.84	5.22	1.19	4.34	3.88
	Goat pepper soup	8.33	30.4	27.6	1.12	4.13	3.68	2.29	8.42	4.89	1.12	4.12	3.77	1.42	16.5	14.6	1.49	5.48	4.79
chicken meat	Chicken Suya	2.46	9.00	8.05	1.24	4.57	4.08	2.43	8.91	20.5	1.20	4.41	20.5	8.82	81.7	73.5	6.25	22.9	20.5
	Chicken muscle (N)	2.62	9.64	8.60	2.77	10.2	9.09	2.61	9.61	8.56	3.18	11.7	8.56	0.76	11.7	10.4	2.61	9.59	8.56
	Chicken gizzard (N)	2.37	8.73	7.77	2.01	7.41	6.63	3.18	11.7	11.2	2.23	8.20	4.93	3.07	12.1	10.8	1.50	5.53	4.93
	Chicken muscle (B)	2.59	9.48	8.48	1.66	6.13	5.46	2.06	6.20	5.73	2.86	10.5	3.47	2.58	10.2	9.28	1.06	3.89	3.47
	Chicken gizzard (B)	1.07	3.94	3.52	0.80	2.93	2.61	2.48	2.59	6.53	0.70	2.58	2.29	1.00	3.91	3.49	1.99	7.31	6.53

N: Native (specie originating from the Niger Delta, Nigeria)
H: Hausa (specie originating from Hausa tribe (northern Nigeria) and reared in Niger Delta, Nigeria), B: Broiler
CH= children, AD= adult, SNR= senior

In particular in TransAmadi, children MOE ranged 0.13–0.51 through different kind of meat (beef suya, fried cow meat and chicken suya), and in adult the lowest MOE value (0.37) was found for beef suya ingestion. In Uyo, children showed MOE between 0.27 and 0.38 again for cow meat consumption. In both TransAmadi and Uyo areas, there were also MOE values close to 1 (ranged 1.02–1.61) for adult population by consumption of cow and chicken meat (fried meat, chicken gizzard, chicken suya and chicken muscle), suggesting that the possibility of a risk to specific meat samples cannot be excluded. In the other areas, MOE values in children ranged 14–291 in Choba, 9.5–350 in Khana, 37–280 in Eleme and 3–49 in Yenogoa, and in adult in the intervals of 147–280 in Choba, 58–280 in Khana, 100–1400 in Eleme, and 8.9–175 in Yenogoa. Nevertheless, some studies suggested that the increase in cancer risk among adults might derived from the exposure during childhood (IARC 2012); therefore, the constant monitoring of As levels in foods and risk assessment studies are necessary for the improvement of public health, especially in developing countries like Nigeria. The MOE values of Pb for children were below or close to 1 with the consumption of cow and goat meat products collected in the investigated areas, and thus the dietary exposure to Pb was higher or close to the $BMDL_{01}$ for developmental neurotoxicity (0.50 μg/kg bw per day) in children. The lowest MOE was found in Khana, Eleme and Uyo areas, with range 0.36–0.95 for cow liver and cow muscle ingestion and 0.66–0.88 for goat liver and goat muscle consumption. In Khana and Eleme, also chicken gizzard (MOE of 0.80 and 0.70, respectively) seem to be involved in potential health concern by food intake. In this view, it has been estimated that 400 to 500 children died of acute Pb poisoning due to ingestion of food contaminated with Pb-contained soil and dust in Nigeria (Tirima et al., 2018). Regarding the other age groups, a similar risk was generally found in senior and adult population, although in senior the ingestion of kilishi (MOE of 0.55 in Khana area) resulted in Pb exposure higher than $BMDL_{10}$ value for effects on kidney (i.e., 0.63 μg/kg bw per day). Taken together the Nigerian areas, the MOE was higher than 1 for Pb by consumption of cow meat (2.5–65.3 and 2.6–57.3 in adult and senior), goat meat (3.89–30.4 and 3.36–27.6 in adult and senior), and chicken meat (2.59–81.7 in adult and 2.29–73.5 in senior). It has been reported that a MOE of Pb of 10 or greater is considered sufficient to ensure no appreciable risk of a clinically significant effect on kidney and at MOEs >1 the risk can be considered very low. With regard to effects on neurodevelopment in children, for MOE greater than 1 the risk is likely to be low, although risk of adverse effects could not be dismissed (EFSA, 2010). Therefore, MOE data of the present study are indicative that, at current levels of Pb exposure, the risk of clinically important effects on kidneys in adult and senior was low to negligible. To the opposite, the potential concern for effects on neurodevelopment in children needs further efforts to decrease Pb exposure for this vulnerable population.

4. Conclusions

Meat and meat offal (liver and gizzard) consumption may add toxic As, Cd and Pb metals to the body burden of Niger Delta population, mainly for children and senior population groups. Whilst, the exposure to Hg and V from Nigerian foods did not constitute a potential health hazard. Since malnutrition is a principal cause of death in sub-Sahara Africa, assurance of food safety of the sub-Sahara Africa's natural resources is of immense importance. Meat is a significant natural food sources, then, monitoring of metals in such food should be mandatory in Nigeria, as well as in animal feeds and pastures or by using native Nigerian wild and farmed animals as sentinel species to identify and evaluate environmental stressors.

Risk communication and data sharing also remain hampered since results are not publicly available. Hitherto, very limited research has been published on the human effects of metals contamination through meat consumption in sub-Saharan Africa. This lack of knowledge and information transfer has led to large knowledge deficits for scientists, consumers and industry as a whole. It is therefore suggested that all data (food, feed, and environment) collected be made publicly available.

CRediT authorship contribution statement

Esther Amaka Okoye: PhD student, sampling and bench work. **Beatrice Bocca:** Formal analysis, Writing – review & editing. **Flavia Ruggieri:** Formal analysis, Writing – review & editing. **Anthonett N. Ezejiofor:** Supervision, of PhD candidate. **Ify L. Nwaogazie:** Supervision, of PhD candidate. **Chiara Frazzoli:** Formal analysis, Writing – review & editing. **Orish E. Orisakwe:** Conceptualization, Writing – review & editing.

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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