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CLINICAL & BASIC RESEARCH

Heavy Metals in Seafood and Farm Produce from Uyo, Nigeria

Levels and health implications

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المعادن الثقيلة في المأكولات البحرية و النتوجات الزراعية أويو، نيجيريا

المستويات و الآثار الصحية

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abstract: ***Objectives:*** This study aimed to obtain representative data on the levels of heavy metals in seafood and farm produce consumed by the general population in Uyo, Akwa Ibom State, Nigeria, a region known for the exploration and exploitation of crude oil. ***Methods:*** In May 2012, 25 food items, including common types of seafood, cereals, root crops and vegetables, were purchased in Uyo or collected from farmland in the region. Dried samples were ground, digested and centrifuged. Levels of heavy metals (lead, cadmium, nickel, cobalt and chromium) were analysed using an atomic absorption spectrophotometer. Average daily intake and target hazard quotients (THQ) were estimated. ***Results:*** Eight food items (millet, maize, periwinkle, crayfish, stock fish, sabina fish, bonga fish and pumpkin leaf) had THQ values over 1.0 for cadmium, indicating a potential health risk in their consumption. All other heavy metals had THQ values below 1.0, indicating insignificant health risks. The total THQ for the heavy metals ranged from 0.389 to 2.986. There were 14 items with total THQ values greater than 1.0, indicating potential health risks in their consumption. ***Conclusion:*** The regular consumption of certain types of farm produce and seafood available in Uyo, Akwa Ibom State, Nigeria, is likely adding to the body burden of heavy metals among those living in this region.

Keywords: Heavy Metals; Food; Recommended Daily Intake; Risk Assessment; Food Safety Analysis; Nigeria.

الملخص: الهدف: هدفت هذه الدراسة للحصول على معلومات عن تركيزات المعادن الثقيلة في الأطعمة البحرية والمنتجات الزراعية التي يستهلكها عامة السكان في يو بمحافظة أكوا ابيوم في نيجيريا، وهي منطقة تتم فيها استكشاف واستغلال النفط الخام. **الطريقة:** تم في مايو 2012م شراء 25 نوعا من الأطعمة أو جمعها من المزارع في منطقة يو شملت الأنواع الشائعة من الأطعمة البحرية والمحاصيل الجذرية والخضروات. وتم سحن عينات الأطعمة الجافة وهضمها وطردها، ثم قياس تركيزات المعادن الثقيلة (الرصاص والكادميم والنيكل والكوبلت والكروميم) فيها بواسطة جهاز معامل الطيف الضوئي الذري. وتم تقدير متوسط الكمية المستهلكة يوميا وحواصل خطر الهدف (THQ). **النتائج:** وجد أن ثمانية أنواع من الأطعمة (الدخن والذرة الشامية وجراد السمك والسمك المملح (القديد) وسمك سابينا وسمك بونجا ونبات اليقطين) لها THQ أعلى من 1.0 بالنسبة للكادميم، مما يشير إلى احتمالا حدوث آثار خطرة على الصحة عند تناول هذه الأطعمة. وكان الـ THQ بالنسبة لبقية الأطعمة الأخرى أقل من 1.0. وكان الـ THQ الكلي بالنسبة للمعادن الثقيلة يتراوح بين 0.389 و 2.986. وكانت لأربعة عشر من تلك الأطعمة قيم THQ أكثر من 1.0 مما يشير إلى خطر محتمل على الصحة من تناول تلك الأطعمة. **الخلاصة:** إن التناول المنتظم لأنواع معينة من الأطعمة البحرية والمنتجات الزراعية في منطقة يو بنيجيريا قد يزيد من عبء المعادن الثقيلة عند الذين يعيشون في تلك المنطقة.

مفتاح الكلمات: المعادن الثقيلة؛ الأغذية؛الكمية الموصى بها يوميا؛ تقييم المخاطر؛ تحليل سلامة الأغذي؛ نيجيريا.

Advances in Knowledge

- *Heavy metals, particularly lead and cadmium, have been implicated in metabolic syndrome and other chronic diseases which have been increasing in sub-Saharan Africa. Although food, water, air and the soil are known sources of these heavy metals, the exact individual contribution of these is unknown. The present study therefore sought to determine the levels of heavy metals in seafood and farm produce in Uyo, Nigeria.*

Application to Patient Care

- *Determining the health risks of consuming seafood and farm produce from Uyo, Nigeria, is of the utmost importance to public health since the results of this study indicate that these foods likely add to the body burden of heavy metals among individuals residing in this region.*

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The southeastern coastal region of Akwa Ibom State is currently the highest oil and gas producing state in Nigeria. It is characterised by rich marine biodiversity as well as agricultural and crude oil exploration activities. Heavy metals are ubiquitous in the environment, arising from both natural and anthropogenic activities.[1] Humans are exposed to these metals through various pathways.[1]

Seafood is widely consumed as part of the local diet in Nigeria, due in part to its high protein content, low saturated fats and omega fatty acids which are known to contribute to good health.[2] Fish can be very nutritious as they are rich in many vitamins, with a good selection of minerals and all of the essential amino acids in the right proportions.[3] However, fish absorb heavy metals from the surrounding environment depending on a variety of factors, such as the characteristics of a species, the exposure period and concentration of the element, as well as abiotic factors such as temperature, salinity, pH and seasonal changes.[4] Hence, harmful substances like heavy metals released by anthropogenic activities may accumulate in marine organisms; as a result, the consumption of fish contaminated by toxic chemicals may present a risk to human health.

Vegetables constitute an essential dietary component by contributing protein, vitamins, iron, calcium and other nutrients which are usually in short supply;[5,6] furthermore, this component also acts as a buffer for acidic substances produced during digestion. Vegetables, fruit and cereals can accumulate heavy metals, potentially posing a direct threat to human health.[6–8] Plants can absorb heavy metals from contaminated soil or via exposure to polluted air.[9] It has been reported that nearly half of the mean ingestion of lead (Pb), cadmium (Cd) and mercury through food is due to the consumption of plant products.[9] Moreover, some population groups may be more exposed to these heavy metals, e.g. vegetarians, since they consume higher quantities of these types of food within their daily diets.[9]

Risk assessments of the bioaccumulation of heavy metals in various foods are important. This study attempted to obtain representative data on the levels of heavy metals in seafood and farm produce consumed by the general population in Uyo, Akwa Ibom State, Nigeria. Nevertheless, while sometimes the levels of contaminants in food items exceed the legal limits set by various regulatory bodies, they may not always represent a significant risk to human health. For that reason, target hazard quotients (THQs) were estimated in order to evaluate potential hazards to human health. This study also aimed to estimate the dietary intake and THQ of heavy metals via the consumption of selected seafood and farm produce items from Uyo.

Methods

Samples of 25 commonly consumed food crops, vegetables and seafood were either purchased from the metropolis in Uyo or collected from farmlands in the region in May 2012. Only edible parts of the selected food items were used for the analysis. Where purchased, the sources of the food items were authenticated by suppliers in order to ensure they were locally caught or grown in Uyo.

All samples were first washed with deionised water and then oven-dried at 70–80 °C for 24 hours. Dried samples were ground using a pestle and mortar and sieved through a muslin cloth. For each sample, 0.5 g was placed in crucibles. Samples were then placed for ashing in a furnace for four hours at 550 °C. The ash was digested in a solution of perchloric acid and nitric acid (at a volume ratio of 1:4). Following this, samples were left to cool. A final volume of 25 mL was made by adding deionised water. The hydrolysed samples were then well shaken and transferred to a centrifuge tube for centrifugation at a rate of 3,000 x g to remove solid particles. The resulting samples were thoroughly mixed before sub-samples were taken to ensure homogeneity.

The presence of Pb, Cd, nickel (Ni), cobalt (Co) and chromium (Cr) were analysed using an atomic absorption spectrophotometer (model 929 UNICAM, Spectronic Unicam, Cambridge, UK) at wavelengths of 217.0, 228.8, 232.0, 242.5 and 357.9 nm, respectively. The limit of detection for the heavy metals were 0.005 μg/g, with blank values reading as 0.00 μg/g for the metals in deionised water with an electrical conductivity value of <5 μS cm^{-1}. Appropriate quality procedures and precautions were carried out to reduce the risk of contamination and assure the reliability of the results. Double-distilled deionised water was used throughout the study. Glassware was properly cleaned and all reagents were of analytical grade. Blank determinations of reagents were used to correct instrument readings. For validation of the analytical procedure, several samples that had already been analysed were spiked and homogenised with various amounts of standard solutions of the metals.

Daily intake rate (DIR) in g $person^{-1}$ day^{-1} was calculated based on the following formula:[10]

$$DIR = C_{metal} \, x \, D_{food\ intake} / B_{average\ weight}$$

Where C_{metal} is the metal concentration in food in μg

Table 1: Levels of selected heavy metals in farm produce and seafood from Uyo, Nigeria

Food item	Heavy metal levels in µg g^{-1}				
	Pb	Cd	Ni	Co	Cr
Cereals					
Rice	<0.05	0.13	0.84	<0.05	0.41
Wheat	<0.05	0.16	0.41	<0.05	0.42
Soya bean	<0.05	0.07	0.24	<0.05	0.58
Millet	<0.05	0.21	0.39	<0.05	0.43
Maize	<0.05	0.22	0.81	<0.05	0.47
Fruit					
Cucumber	<0.05	<0.05	0.11	<0.05	0.09
Orange	<0.05	<0.05	0.10	<0.05	0.09
Guava	<0.05	<0.05	0.15	<0.05	0.11
Watermelon	<0.05	<0.05	0.14	<0.05	0.12
Pawpaw	<0.05	<0.05	0.13	<0.05	0.09
Root crops					
Potato	<0.05	0.11	0.56	<0.05	0.64
Yam	<0.05	0.14	0.74	<0.05	0.83
Cocoyam	<0.05	0.14	0.83	<0.05	0.84
Sweet potato	<0.05	0.15	0.91	<0.05	0.86
Water yam	<0.05	0.16	0.74	<0.05	0.81
Vegetables					
Pumpkin leaf	0.07	0.35	1.45	0.12	1.08
Water leaf	<0.05	<0.05	0.74	<0.05	0.53
Scent leaf	<0.05	<0.05	0.68	<0.05	0.41
Bitter leaf	<0.05	<0.05	0.75	<0.05	0.38
Editan leaf	<0.05	<0.05	0.69	<0.05	0.39
Seafood					
Periwinkle	0.09	0.34	0.05	0.13	1.07
Crayfish	0.09	0.21	0.11	0.15	1.08
Stockfish	0.09	0.43	1.32	0.07	1.06
Sabina fish	0.08	0.33	1.41	0.11	1.05
Bonga fish	0.08	0.33	1.43	0.14	1.07

Pb = lead; Cd = cadmium; Ni = nickel; Co = cobalt; Cr = chromium.

g^{-1}, $D_{food\ intake}$ is the daily intake of food in kg $person^{-1}$ and $B_{average\ weight}$ is average body weight in kg $person^{-1}$.

Using an adapted method, an average daily consumption of 345 g of rice was assumed.[11] This method was originally calculated by Wang *et al.* in a Chinese population where rice is eaten in different forms, as it is in the Nigerian population.[11] Since the local population of Uyo is predominantly comprised of subsistence farmers who do not have the luxury of variety in their menu, daily consumption of other farm produce and seafood was assumed to be 345 g/person/day and 34.5 g/person/day, respectively.[11,12] Average adult body weight was considered to be 60 kg.[11,12]

Noncarcinogenic risk estimation of heavy metal consumption was determined using THQ values. THQ is a ratio of the determined dose of a pollutant to a reference level considered harmful. THQ values were determined based on the following formula:[10]

$$THQ = EFr \times ED \times FIR \times C / RfD_o \times B_{average\ weight} \times AT_n \times 10^{-3}$$

Where EFr is exposure frequency in 365 days $year^{-1}$, ED is exposure duration in 70 years (equivalent to an average lifetime),[13] FIR is average daily consumption in g $person^{-1}$ day^{-1}, C is concentration of metal in food sample in µg g^{-1}, RfD_o is reference dose in µg g^{-1} day^{-1} and AT_n is average exposure time for noncarcinogens in days. The following reference doses were used: Cr = 1.5 µg g^{-1} day^{-1}, Ni = 2.0×10^{-2} µg g^{-1} day^{-1}, Pb = 4.0×10^{-3} µg g^{-1} day^{-1} and Cd = 1.0×10^{-3} µg g^{-1} day^{-1}.[12]

AT_n was based on the following formula:

$$At_n = EFr \times ED_{total}$$

Where ED_{total} is the total number of exposure years, which was assumed to be 70 years.[13]

A THQ value of >1.0 was considered to indicate that the level of exposure was smaller than the reference dose, implying that daily exposure at this level was unlikely to cause any harmful effects in a human subject during their lifetime. Thus, the exposed population was considered unlikely to experience obvious adverse effects at this level.[11,14] THQs were calculated according to the methodology described by the Environmental Protection Agency (EPA) in the USA.[15] Doses were calculated using the standard assumption for an integrated risk analysis and an average adult body weight of 60 kg.[11,15] In addition, based on EPA guidelines, it was assumed that ingested doses were equal to absorbed contaminant doses.[16,17]

The total THQ of heavy metals for individual food samples was calculated as the sum of the individual THQ of the toxic metals.[12] A reference value for tolerable weekly intakes of heavy metals has been established.[18,19] Therefore, the daily intake of these heavy metals was compared with the provisional tolerable weekly intake (PTWI) and the proposed maximum permissible level.[18,19]

Table 2: Estimated daily intake rates of selected heavy metals through the consumption of farm produce and seafood from Uyo, Nigeria

Food item	Daily intake rate of heavy metals in g person^{-1} day^{-1}				
	Pb	Cd	Ni	Co	Cr
Cereals					
Rice	0.00029	0.00075	0.00483	0.00029	0.00236
Wheat	0.00029	0.00092	0.00236	0.00029	0.00241
Soya bean	0.00029	0.00004	0.00138	0.00029	0.00334
Millet	0.00029	0.00121	0.00225	0.00029	0.00247
Maize	0.00029	0.00127	0.00466	0.00029	0.00270
Fruit					
Cucumber	0.00029	0.00029	0.00063	0.00029	0.00052
Orange	0.00029	0.00029	0.00029	0.00029	0.00052
Guava	0.00029	0.00029	0.00087	0.00029	0.00063
Watermelon	0.00029	0.00029	0.00080	0.00029	0.00069
Pawpaw	0.00029	0.00029	0.00075	0.00029	0.00052
Root crops					
Potato	0.00029	0.00063	0.00322	0.00029	0.00368
Yam	0.00029	0.00080	0.00426	0.00029	0.00477
Cocoyam	0.00029	0.00080	0.00477	0.00029	0.00483
Sweet potato	0.00029	0.00087	0.00524	0.00029	0.00495
Water yam	0.00040	0.00092	0.00426	0.00029	0.00466
Vegetables					
Pumpkin leaf	0.00040	0.00201	0.00895	0.00069	0.00621
Water leaf	0.00029	0.00029	0.00425	0.00029	0.00305
Scent leaf	0.00029	0.00029	0.00391	0.00029	0.00236
Bitter leaf	0.00029	0.00029	0.00431	0.00029	0.00219
Editan leaf	0.00029	0.00029	0.00397	0.00029	0.00225
Seafood					
Periwinkle	0.00005	0.00020	0.00003	0.00007	0.00061
Crayfish	0.00005	0.00012	0.00006	0.00009	0.00062
Stockfish	0.00005	0.00025	0.00008	0.00004	0.00061
Sabina fish	0.00005	0.00019	0.09398	0.00006	0.00060
Bonga fish	0.00005	0.00019	0.00082	0.00008	0.00061

Pb = lead; Cd = cadmium; Ni = nickel; Co = cobalt; Cr = chromium.

Results

The concentrations of heavy metals (Pb, Cd, Ni, Co and Cr) in selected farm produce and seafood from Uyo are shown in Table 1. Periwinkle, crayfish and stockfish had the highest Pb content (0.09 μg g^{-1}), followed by sabina and bonga fish (0.08 μg g^{-1} each) and pumpkin leaf (0.07 μg g^{-1}). All other food items had Pb levels <0.05 μg g^{-1}. Pb ranged from 0.08–0.09 μg g^{-1} in seafood samples and <0.05–0.07 μg g^{-1} in vegetable samples.

Table 3: Permissible intake levels of heavy metals as per Food and Agriculture Organization and World Health Organization recommendations[13,18]

Heavy metal	PTWI in μg kg^{-1} week^{-1}	Daily intake in μg kg^{-1} day^{-1}	Intake for a 60 kg individual in μg day^{-1}
Pb	25.0	5.0	300.0
Ni	1.0	0.2	12.0
Cd	7.0	0.4–2.0	60.0
Cr	0.5	0.1	6.0

PTWI = provisional tolerable weekly intake; Pb = lead; Cd = cadmium; Ni = nickel; Cr = chromium.

Concentrations of Cd ranged from <0.05–0.35 μg g^{-1} in vegetable samples, with the highest levels in pumpkin leaf (0.35 μg g^{-1}). In seafood samples, concentrations ranged from 0.21–0.43 μg g^{-1}. Higher concentrations of Cd were noted in the fish samples, with the highest amount found in stockfish (0.43 μg g^{-1}). Cd concentrations in cereals, fruit and root crops ranged from <0.05–0.22 μg g^{-1}.

Ni levels were highest in pumpkin leaf, with a concentration of 1.45 μg g^{-1}. Concentrations ranged from 0.68–1.45 μg g^{-1} in vegetable samples and 0.05–1.43 μg g^{-1} in seafood samples. Concentrations of Ni in cereals, fruit and root crops ranged from 0.10–0.91 μg g^{-1}.

The highest concentration of Co was recorded in crayfish (0.15 μg g^{-1}). Concentrations ranged from <0.05–0.12 μg g^{-1} in vegetable samples and 0.07–0.15 μg g^{-1} in seafood samples. In root crop, fruit and cereal samples, concentrations of Co were <0.05 μg g^{-1}.

For Cr, crayfish and pumpkin leaf had the highest concentrations (1.08 μg g^{-1} each). Cr content ranged from 0.38–1.08 μg g^{-1} in vegetable samples and 1.05–1.08 μg g^{-1} in seafood samples. Among root crop, fruit and cereal samples, sweet potato had the highest level of Cr (0.86 μg g^{-1}) while cucumber, oranges and pawpaw had the lowest concentration (0.09 μg g^{-1}) each.

As can be seen in Table 2, the daily intake of heavy metals from the consumption of analysed food items showed large variations. Cr levels were found to be above permissible levels in all of the food items. While still at permissible values, crayfish and pumpkin leaf contained the highest levels of Cr (0.00062 and 0.00621 g person^{-1} day^{-1}, respectively). Table 3 shows the permissible intake levels of selected heavy

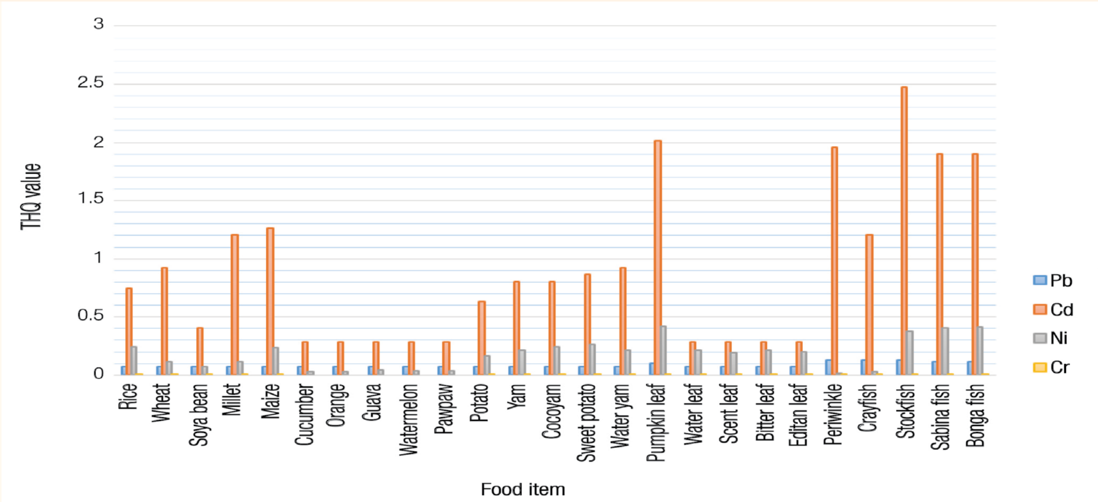

Figure 1: Target hazard quotient values of selected heavy metals via consumption of farm produce and seafood from Uyo, Nigeria.
THQ = target hazard quotient; Pb = lead; Cd = cadmium; Ni = nickel; Cr = chromium.

metals as per recommendations from the Food and Agriculture Organization (FAO) and the World Health Organization (WHO).[13,18]

Figure 1 shows the estimated total THQs caused by consumption of the food items. Estimated THQ values for the selected heavy metals ranged from 0.000–2.473. Total THQ values for the metals ranged from 0.389–2.986. A total of 14 of the food items had total THQ values greater than 1.0, indicating some health risks. For Cd, eight food items, comprising of cereals (millet and maize), vegetables (pumpkin leaf) and seafood (periwinkle, crayfish, stockfish, sabina and bonga fish), had THQ values greater than 1.0, indicating potential health risks. All other metals had total THQ values below 1.0, indicating an insignificant health risk.

Discussion

In order to assess the health risk of any pollutant, it is essential to estimate the level of exposure by quantifying the exposure routes of the pollutant to the target organisms. While there are various possible exposure pathways of pollutants to humans, the food chain is one of the most important. As for many dietary components, the intake of metals can be both beneficial and harmful. For example, many Nigerian families exhibit low levels of dietary calcium due to poverty, which has potentially harmful effects.[20] However, preventative measures should be in place to avoid the surplus ingestion of potentially toxic metals. Many developed countries spend significant resources to avoid excessive metal intake by the general population, from monitoring endogenous metal levels in foods to detecting contamination during food preparation processes.[21,22] Cases of excessive intake of trace metals have been implicated in pathological events and inflammation.[23]

In the current study, Pb levels were observed to be lower than those noted in a similar study by Orisakwe *et al.*, which reported a Pb range of 0.00–61.17 μg g^{-1} in different foodstuffs from southeastern Nigeria.[24] However, like the current study, Pb concentrations were found to be highest in seafood. According to the FAO and WHO, the safe limit for Pb in fruit, root crops and cereals is 0.1 μg g^{-1}, 0.1 μg g^{-1} and 1.00 μg g^{-1}, respectively.[25] Therefore, the food items analysed could be considered to have safe levels of Pb.

A PTWI of 25 μg kg^{-1}, equalling 1,500 μg Pb/week for a 60 kg person, has been established.[18] In Taiwan, Huang *et al.* demonstrated that low-level prenatal exposure to Pb among fetuses can lead to decreased intelligence and delayed cognitive function.[26] Furthermore, a recent Nigeria-based study found that prenatal Pb exposure was significantly associated with crown rump length at birth.[27] Among individuals of reproductive age, exposure to Pb is a public health issue of great concern, since evidence indicates that even low levels of exposure to this metal can affect fetal growth and development.[28] Conditions associated with Pb poisoning (impaired mental and physical development, poor school performance, anaemia, under-nutrition, cardiovascular diseases, metabolic syndrome, infertility, etc.) represent a significant social, financial and health burden on affected individuals and their families and communities.[29] In Nigeria, there are multiple sources of exposure to Pb, including automobiles which burn leaded petrol.[30,31] Despite the introduction of a planned Clean Air Initiative to reduce levels of Pb in Nigerian petrol from 0.74 g/L to 0.15 g/L by 2002, there is as yet no evidence to suggest that the programme has been implemented.[30]

Concentrations of Cd observed in the current study agreed with a similar study in southeastern Nigeria which reported a range of 0.00–0.24 µg g^{-1} of Cd in various items of food.[32] Safe limits of Cd in cereals, fruit and root crops are 0.2 µg g^{-1}, 0.05 µg g^{-1} and 0.1 µg g^{-1}, respectively, according to the European Commisson.[25] In the current study, Cd was below the permissible level in all the food items. The recommended value of Cd is within the range of 7.0 µg kg^{-1} body weight $week^{-1}$ for adults.[19] Considering the accumulative properties and long biological half-life of Cd, a level of 0.4–2.0 µg kg^{-1} body weight day^{-1} has been set as permissible.[33] This equals 60 µg day^{-1} for an individual of 60 kg. Absorption following the oral exposure of Cd likely depends on physiological status, such as age and levels of iron, calcium and zinc stored in the body. There is epidemiological evidence that *in utero* exposure to Cd may have adverse effects on a newborn's health.[34]

Mostly present in the pancreas, Ni plays an important role in the production of insulin and is required in small quantities by the body; a deficiency of Ni can result in liver disorders.[35] However, increased concentrations of Ni can have many adverse effects, namely kidney damage, cancers of the lung and nasal sinus, pneumonitis, chronic bronchitis, allergic reactions and mild skin rashes.[35] Concentrations of Ni in cereals, fruit and root crops in the current study were in line with another study which reported a range of 0.00–3.13 µg g^{-1} among various food items.[24] The recommended daily intake of Ni is approximately 0.2 µg kg^{-1} body weight day^{-1}.[18] Unfortunately, in the current study, Ni levels in the cereals, root crops, vegetables, stockfish, Sabina fish and bonga fish were found to be higher than recommended for all food items.

While the body requires trace amounts of Co, this metal is toxic in elevated concentrations. For diabetic patients, a total of 2.0 µg day^{-1} is required in the form of vitamin B_{12}. High intake of Co can lead to gastrointestinal, vision and heart problems, as well as thyroid damage.[25,36] The Co concentrations of

the studied samples conformed with those reported by Dabeka *et al.* among Canadians (<0.003–0.0759 µg g^{-1}).[37] According to another Nigerian study, normal daily intake of Co is between 2.5–3.0 mg day^{-1}, which is equivalent to 180 mg kg^{-1} body weight day^{-1} for an adult of 60 kg.[38] Poisoning therefore occurs when daily Co intake is greater than this range.

Exposure to Cr can occur through air, water, food or skin contact. In human beings and animals, it is considered an essential metal for carbohydrate and lipid metabolism within a certain concentration (up to 200 µg day^{-1}).[39] However, exceeding this concentration leads to an accumulation and toxicity that can result in hepatitis, gastritis, ulcers and lung cancer.[39] In the current study, cucumber, oranges and pawpaw had the lowest concentration of Cr and were within acceptable limits of 250 µg day^{-1} for adults equivalent to 1,500 µg g^{-1} for an average weight of 60 kg.[40] However the Cr concentration was above the permissible level in all the other tested food items. The recommended value of Cr is 0.5 µg kg^{-1} body weight $week^{-1}$ and 0.1 µg kg^{-1} body weight day^{-1} for adults.[18]

Levels of Pb, Cd, and Ni have been previously investigated in three popular types of seafood in Ondo State, Nigeria (fish, crab and periwinkle), in order to evaluate the ecosystem of this oil-polluted coastal region.[30,41] Increasing levels of Pb, Cd, and Ni could pose a potential threat to the ecology of the area and the health of the local population.[30,41] Using reference doses, estimates of THQs for heavy metals in eight food items analysed in the current study found Cd values of over 1.0, indicating a potential health risk.[14,15] Multiple exposure to heavy metals or pesticides may lead to additive and/or interactive effects according to the risk addition hypothesis.[12,42]

There are several limitations of the current study that should be considered. These include the unavailability of national food diaries and nutrition data in Nigeria and the absence of national standard nutritional limits and guidelines. In humans, the degree of toxicity of heavy metals is dependent on the daily intake.[32] In view of the paucity of food consumption data and the absence of food diaries in Nigeria, the current study assumed a daily consumption of 345 g of rice based on an adaptation of Wang *et al.*'s study of a Chinese population.[11] Rice is a staple food throughout West Africa. Like China, rice is one of the most important cereals in Nigeria and is a staple food for both urban and rural dwellers. In Nigeria, urban consumers have developed a preference for imported rice, mainly due to a perception of superior quality. Most of the rice consumed in Nigeria is imported from China.[12] Uyo is a riverine community with a local population of subsistence farmers; it was therefore assumed that intake of rice would be complemented by farm produce and seafood. Daily ingestion rates of farm produce and seafood were therefore estimated to be 345 g/person/day and 34.5 g/person/day, respectively.[11,12] These assumptions require a cautionary interpretation of the results as they may not give an accurate view of health concerns associated with heavy metal consumption in Nigeria. Further studies are recommended to investigate consumption patterns in this region.

Conclusion

Consumption of certain types of seafood and farm produce is likely to add to the body burden of heavy metals among individuals living in Uyo, Nigeria. Heavy metal analysis of millet, maize, periwinkle, crayfish, stockfish, sabina fish, bonga fish and pumpkin leaf indicated a potential health risk with regards to Cd content. As the excessive ingestion of heavy metals can have severe public health implications, the monitoring of these metals in seafood and farm produce in Nigeria is of the utmost importance.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

References

1. Wilson B, Pyatt FB. Heavy metal dispersion, persistence, and bioaccumulation around an ancient copper mine situated in Anglesey, UK. Ecotoxicol Environ Saf 2007; 66:224–31. doi: 10.1016/j.ecoenv.2006.02.015.
2. Kennedy A, Martinez K, Chuang CC, LaPoint K, McIntosh M. Saturated fatty acid-mediated inflammation and insulin resistance in adipose tissue: Mechanisms of action and implications. J Nutr 2009; 139:1–4. doi: 10.3945/jn.108.098269.
3. Savikko N, Pitkälä KH, Laurila JV, Suominen MH, Tilvis RS, Kautiainen H, et al. Secular trends in the use of vitamins, minerals and fish-oil products in two cohorts of community-dwelling older people in Helsinki: Population-based surveys in 1999 and 2009. J Nutr Health Aging 2014; 18:150–4. doi: 10.1007/s12603-013-0381-4.
4. Ginsberg GL, Toal BF. Quantitative approach for incorporating methylmercury risks and omega-3 fatty acid benefits in developing species-specific fish consumption advice. Environ Health Perspect 2009; 117:267–75. doi: 10.1289/ehp.11368.
5. Islam MS, Ahmed MK, Habibullah-Al-Mamun M. Determination of heavy metals in fish and vegetables in Bangladesh and health implications. Hum Ecol Risk Assess 2015; 21:986–1006. doi: 10.1080/10807039.2014.950172.
6. Umoru PE. Heavy metal content in vegetables from an irrigated farmland in Kaduna metropolis, Nigeria. Int J Adv Res Technol 2013; 2:1–1.
7. Türkdoğan MK, Kilicel F, Kara K, Tuncer I, Uygan I. Heavy metals in soil, vegetables and fruits in the endemic upper gastrointestinal cancer region of Turkey. Environ Toxicol Pharmacol 2003; 13:175–9. doi: 10.1016/S1382-6689(02)00156-4.
8. Damek-Poprawa M, Sawicka-Kapusta K. Damage to the liver, kidney, and testis with reference to burden of heavy metals in yellow-necked mice from areas around steelworks and zinc smelters in Poland. Toxicology 2003; 186:1–10. doi: 10.1016/S0300-483X(02)00595-4.
9. Dorne JL, Fink-Gremmels J. Human and animal health risk assessments of chemicals in the food chain: Comparative aspects and future perspectives. Toxicol Appl Pharmacol 2013; 270:187–95. doi: 10.1016/j.taap.2012.03.013.
10. Singh A, Sharma RK, Agrawal M, Marshall FM. Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India. Trop Ecol 2010; 51:375–87.
11. Wang X, Sato T, Xing B, Tao S. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Sci Total Environ 2005; 350:28–37. doi: 10.1016/j.scitotenv.2004.09.044.
12. Ge KY. The Status of Nutrient and Meal of Chinese in the 1990s. Beijing, China: People's Hygiene Press, 1992. Pp. 415–34.
13. Bennett DH, Kastenberg WE, McKone TE. A multimedia, multiple pathway risk assessment of atrazine: The impact of age differentiated exposure including joint uncertainty and variability. Reliab Eng Syst Saf 1999; 63:185–98. doi: 10.1016/S0951-8320(98)00046-5.
14. Chien CL, Hung TC, Choang KY, Yeh CY, Meng PJ, Shieh MJ, et al. Daily intake of TBT, Cu, Zn, Cd and As for fishermen in Taiwan. Sci Total Environ 2002; 285:177–85. doi: 10.1016/S0048-9697(01)00916-0.
15. United States Environmental Protection Agency. Mid-Atlantic Risk Assessment: Human Health Risk Assessment. From: www.epa.gov/reg3hwmd/risk/human/index.htm Accessed: Oct 2014.
16. United States Environmental Protection Agency. Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish: A guidance manual. From: nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000DGLF.txt Accessed: Oct 2014.
17. Cooper CB, Doyle ME, Kipp K. Risks of consumption of contaminated seafood: The Quincy Bay case study. Environ Health Perspect 1991; 90:133–40.
18. Food and Agriculture Organization/World Health Organization. Evaluation of Certain Food Additives and Contaminants: Forty-first report of the Joint FAO/WHO Expert Committee on Food Additives. From: whqlibdoc.who.int/trs/WHO_TRS_837.pdf Accessed: Oct 2014.
19. Food and Agriculture Organization/World Health Organization. Joint FAO/WHO Expert Committee on Food Additives: Fifty-third meeting: Summary and conclusions. From: ftp://ftp.fao.org/codex/Meetings/CCFAC/ccfac32/JECFA_53.pdf Accessed: Oct 2014.
20. Hu H. Bone lead as a new biologic marker of lead dose: Recent findings and implications for public health. Environ Health Perspect 1998; 106:961–7.
21. European Commission. RASFF - Food and Feed Safety Alerts. From: ec.europa.eu/food/food/rapidalert/index_en.htm Accesssed: Oct 2014.
22. Marvin C, Charlton M, Milne J, Thiessen L, Schachtschneider J, Sardella G,et al. Metals associated with suspended sediments in Lakes Erie and Ontario, 2000-2002. Environ Monit Assess 2007; 130:149–61. doi: 10.1007/s10661-006-9385-4.
23. Naughton DP, Petróczi A. The metal ion theory of ageing: Dietary target hazard quotients beyond radicals. Immun Ageing 2008; 5:3. doi: 10.1186/1742-4933-5-3.
24. Orisakwe OE, Kanayochukwu NJ, Nwadiuto AC, Dike D, Onyinyechi O. Evaluation of potential dietary toxicity of heavy metals of vegetables. J Environ Analytic Toxicol 2012; 2:136. doi: 10.4172/2161-0525.1000136.
25. European Commission. Commission Regulation (EC) No 1881/2006: Setting maximum levels for certain contaminants in food stuff. From: eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32006R1881 Accessed: Oct 2014.
26. Huang PC, Su PH, Chen HY, Huang HB, Tsai JL, Huang HI, et al. Childhood blood lead levels and intellectual development after ban of leaded gasoline in Taiwan: A 9-year prospective study. Environ Int 2012; 40:88–96. doi: 10.1016/j.envint.2011.10.011.
27. Obi E, Orisakwe OE, Okafor C, Igwebe A, Ebenebe J, Afonne OJ, et al. Towards prenatal biomonitoring in eastern Nigeria: Assessing lead levels and anthropometric parameters of newborns. J UOEH 2014; 36:159–70. doi: 10.7888/juoeh.36.159.

28. Xie X, Ding G, Cui C, Chen L, Gao Y, Zhou Y, et al. The effects of low-level prenatal lead exposure on birth outcomes. Environ Pollut 2013; 175:30–4. doi: 10.1016/j.envpol.2012.12.013.

29. United Nations. Millennium Development Goals: 2005 Progress Chart. From: www.un.org/millenniumgoals/pdf/mdg2005progresschart.pdf Accessed: Oct 2014.

30. Orisakwe OE, Blum JL, Sujak S, Zelikoff JT. Metal pollution in Nigeria: A biomonitoring update. J Health Pollut 2014; 4:40–52.

31. Nriagu J, Afeiche M, Linder A, Arowolo T, Ana G, Sridhar MK, et al. Lead poisoning associated with malaria in children of urban areas of Nigeria. Int J Hyg Environ Health 2008; 211:591–605. doi: 10.1016/j.ijheh.2008.05.001.

32. Orisakwe OE, Nduka JK, Amadi CN, Dike DO, Bede O. Heavy metals health risk assessment for population via consumption of food crops and fruits in Owerri, South Eastern, Nigeria. Chem Cent J 2012; 6:77. doi: 10.1186/1752-153X-6-77.

33. Bellinger D, Bolger M, Goyer R, Barraj L, Baines J. WHO Food Additives Series 46: Cadmium. From: www.inchem.org/documents/jecfa/jecmono/v46je11.htm Accessed:Oct 2014.

34. Lin CM, Doyle P, Wang D, Hwang YH, Chen PC. Does prenatal cadmium exposure affect fetal and child growth? Occup Environ Med 2011; 68:641–6. doi: 10.1136/oem.2010.059758.

35. Khan SA, Khan L, Hussain I, Shah H Akhtar N. Comparative assessment of heavy metals in Euphorbia helioscopia L. Pak J Weed Sci Res 2008; 14:91–100.

36. Kumar U, Singh DN. Electronic waste: Concerns and hazardous threats. Int J Curr Eng Technol 2014; 4:801–11.

37. Dabeka RW, McKenzie AD. Survey of lead, cadmium, fluoride, nickel, and cobalt in food composites and estimation of dietary intakes of these elements by Canadians in 1986-1988. J AOAC Int 1995; 78:897–909.

38. Agency for Toxic Substances and Disease Registry (ATSDR), Public Health Service, US Department of Health and Human Services. Toxicological Profile for Cobalt. From: www.atsdr.cdc.gov/toxprofiles/tp.asp?id=373&tid=64 Accessed:Oct 2014.

39. Parveen Z, Khuhro MI, Rafiq N. Market basket survey for lead, cadmium, copper, chromium, nickel, and zinc in fruits and vegetables. Bull Environ Contam Toxicol 2003; 71:1260–4. doi: 10.1007/s00128-003-8640-4.

40. European Food Safety Authority. Scientific Opinion on the Safety of Trivalent Chromium as a Nutrient Added for Nutritional Purposes to Foodstuffs for Particular Nutritional Uses and Foods intended for the General Population (Including Food Supplements). From: www.efsa.europa.eu/en/search/doc/1882.pdf Accessed:Oct 2014.

41. Ololade IA, Lajide L, Olumekun VO, Ololade OO, Ejelonu BC. Influence of diffuse and chronic metal pollution in water and sediments on edible seafoods within Ondo oil-polluted coastal region, Nigeria. J Environ Sci Health A Tox Hazard Subst Environ Eng 2011; 46:898–908. doi: 10.1080/10934529.2011.580208.

42. Amirah MN, Afiza AS, Faizal WIW, Nurliyana MH, Laili S. Human health risk assessment of metal contamination through consumption of fish. J Environ Pollut Human Health 2013; 1:1–5. doi: 10.12691/jephh-1-1-1.