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ASSESSMENT OF HUMAN HEALTH RISK BASED ON ANALYSIS OF POTENTIALLY TOXIC ELEMENTS IN AFRICAN FOODS SOLD IN THE UK MARKET

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ABSTRACT: *Toxic elements (TEs), arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) were determined in African foods sold in the UK and consumed by African communities. The average concentrations (µg/g) of As, Cd, Hg, and Pb in agricultural products, fishery products, spices, and non-food additives were as follows: As (0.1, 15.4, 0.13, and 2.3); Cd (0.6, 0.3, 0.1, and 0.03); Hg (not detected, 0.07, 0.1, and not detected); and Pb (0.3, 0.12, 0.15, and 3.8), respectively. Hazard quotient (HQ) calculations showed that Prawn, Kaun, and Calabash samples exceeded safety thresholds for As, while only Calabash exceeded safety thresholds for Pb. Regarding Incremental Lifetime Cancer Risk (ILCR), 16%, 4%, and 2% of the total analyzed samples (n = 152) exceeded the guideline value for Pb, As, and Cd, respectively. In conclusion, this study highlights the presence of toxic elements in certain African foods that may pose significant long-term health risks.*

KEYWORDS: Toxic elements; Africa; Foods; Health; ICP-MS; HQ; ILCR.

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INTRODUCTION

The presence of toxic elements (TEs) such as arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb) in food poses significant public health risks. The World Health Organization (WHO) has classified these elements as harmful to human health. Contamination can arise from both geogenic sources and various anthropogenic activities, including mining, industrial processes, agricultural practices, improper waste management, and the use of fertilizers, herbicides, and pesticides. The toxicity of these elements is linked to both carcinogenic and non-carcinogenic effects, including kidney damage, behavioral and developmental disorders, and neurological issues, particularly in children (Onakpa et al., 2018). For example, a study in Nigeria by Anakwue et al. (2021) found that heavy metals (As, Cd, Cu, Hg, and Pb) in rice exceeded the FAO/WHO permissible limits and may contribute to hypertension in consumers. Similarly, Okoye et al. (2022) reported that heavy metals (As, Cd, Hg, Pb, and V) in meat and fish products from the Niger Delta region of Nigeria increased the toxic burden in consumers across all age groups, posing serious health risks. A review by Anyimah-Ackah et al. (2019) highlighted the risks of TEs in cocoa beans and cocoa-based foods, emphasizing gaps in knowledge and the need for further research. The review concluded that food processing plays a critical role in either concentrating or diluting these toxic elements. Notably, it found that children are more vulnerable than adults to the effects of exposure and recommended further risk assessments based on age and bioavailability. Nuapia et al. (2018) assessed TEs in raw foods such as beef, beans, cabbage, and fish from markets in Kinshasa and Johannesburg. They concluded that these foods may pose health risks, as the combined Target Hazard Quotients (THQs) exceeded One for all samples in both cities. In another study, Adelusi et al. (2024) investigated the regional variations in trace element concentrations (As, Cd, Cu, Zn, Pb, and Cr) in dairy cattle feed across the Limpopo and Free State provinces of South Africa. Although the detected levels were within WHO/FAO safety limits, significant regional differences suggested a need for continuous monitoring. The study emphasized the importance of ongoing surveillance and control strategies to reduce heavy metals exposure in livestock and prevent contamination of dairy products and the broader food chain.

The following paragraphs will show a summary of different studies regarding As, Cd, Hg and Pb, respectively.

Arsenic can be transferred to the human food chain through geogenic and anthropogenic activities. The effect of transferring arsenic to food was investigated by Clair-Caliot et al. (2021), who showed that different cooking methods have an impact on transferring arsenic to foods. They demonstrated that cooked food with contaminated water in steam had levels up to 18 times lower than food cooked by the boiling method. Also, the same study suggested that leafy vegetables and root vegetables should be avoided when cultivated in water with an arsenic concentration higher than 100 µg/L. Arsenic in rice was not extensively investigated in Africa compared to many studies worldwide. A review by Mlangeni et al. (2023) showed that African rice contained lower arsenic levels compared to other world regions. The review demonstrated that the low soil pH has an effect on mobilizing the toxic element arsenic, attributed to an increase in its concentration in rice. Moreover, the toxic effect of arsenic in foods varies between different ethnic groups. A study by Brima et al. (2006) showed different total arsenic levels in human urine, hair, and nails between African and Caucasian individuals living in the same city, Leicester, UK. African groups had lower urinary arsenic levels and higher nail arsenic levels compared to Caucasians. This suggests the Africans are accumulating arsenic in

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their protein and excreting lower amounts of arsenic in their urine. The pattern of arsenic species in urine was also completely different, showing higher percentages of dimethylarsinic acid (DMA) and a lower percentage of arsenobetaine (AB) in the African group compared to the Caucasian group, where DMA is more toxic than AB. Their study concluded that methylation pathways in both ethnic groups are different, either due to genetic or dietary factors.

Cadmium (Cd) is a toxic element known to cause kidney damage. It was among the heavy metals (Cd, Pb, Cu, Mn, Fe, and Zn) investigated in cocoa beans collected from farmers in selected cocoa-growing towns in the Ashanti and Western regions of Ghana. The average concentration of cadmium was reported to be 54µg/Kg and it was considered safe for consumption (Nnuro et al., 2018). Eating non-food is known as geophagy; such a practice of eating clay is common in Africa, especially among pregnant women. Geophagy poses serious health risks due to the presence of toxic elements, including cadmium in the clay, despite the presence of essential elements (Nkansah et al., 2016). Hazard Quotient (HQ) and cancer risk calculations indicated that consumers of clay may be at risk of cancer, as the levels of some TEs exceeded the Provisional Maximum Tolerable Daily Intake (PMTDI) set by WHO/FAO. While Cd and Hg were below detection limits in most samples, As and Pb exceeded the PMTDI in all samples. A study by Moyo et al. (2020) examined Cd and other heavy metals in fruit, vegetable, and soil samples in South Africa. The study concluded that the levels of Cd and other metals exceeded FAO/WHO recommended standards in all sample types. In Kenya, foods grown near gold mines, including maize, potatoes, mangoes, fish, and cabbage, were analyzed for Cd, Pb, Zn, and Ni (Ngure et al., 2020). The aim was to assess health risks for miners and nearby communities. The results showed that all foods exceeded the maximum allowable concentrations of toxic elements. Maize, followed by cabbage and potatoes, had the highest concentrations, indicating a significant potential for toxic exposure in the Migori gold mining villages. In Nigeria, Adimula et al. (2019) analyzed 114 snack foods in Ibadan for eight heavy metals (Cd, Co, Cr, Cu, Fe, Ni, and Pb). The results showed that Cd exposure exceeded the PMTDI in the low-income group, while the middle- and high-income groups were within safe limits.

Mercury has two forms: organic (methylmercury (MeHg) and inorganic (Hg), both of which cause neurotoxicity. Human mercury exposure can occur through various pathways, including the inhalation of elemental mercury vapor and the consumption of contaminated food. Artisanal and small-scale gold mining (ASGM) activities are also one of the main sources of mercury exposure. In ASGM, miners and individuals living near mining sites are at risk (Lebel et al., 1998; Chen et al., 2005; Zahir et al., 2005; Risher et al., 1999). A review of mercury contamination in Lake Victoria, shared by Kenya, Tanzania, and Uganda, found that Nile perch exceeded the WHO guideline of 200 µg/kg for total mercury. Different activities, such as biomass burning and soil erosion, were considered as other sources contributing to the increased level of mercury in Lake Victoria (Campbell et al., 2003). Therefore, the study suggested the use of improved technologies to reduce occupational exposure in mining areas. In Lake Tanganyika, several fish species consumed by locals, such as Bathybates spp., Mastacembelus cunningtoni, and Clarias theodorae, contained mercury levels that exceeded the WHO guideline of 200 µg/kg (wet weight). Other species, including Lates microlepis and Polypterus congicus, surpassed the international market limit of 500 µg/kg. Therefore, very strict monitoring for the fish sourced from Lake Tanganyika should be considered (Campbell et al., 2008). A spatiotemporal study by Diop and Amara (2016) along the Senegalese coast

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reported no clear seasonal trends in mercury concentrations in marine biota but noted spatial differences, with higher concentrations near areas of intense human activity. Another study carried out in South Africa showed that mercury levels in different fish species exceeded recommended safety limits. Therefore, it is suggested that the consumption of these species (shortfin mako, soupfin shark, smoothhound shark, and yellowfin tuna) should be avoided (Bosch, 2025). In the Okavango Delta, Botswana, a study by Black et al. (2011) of 27 fish species found low mercury levels, ranging from 19 µg/kg in non-piscivorous fish to 59 µg/kg in piscivorous fish (wet weight). The study suggested a better understanding of the biogeochemical cycling of mercury to manage the health risks.

Lead (Pb) exposure is a cause of different diseases affecting neurophysiological development, especially in children. Even low levels of Pb have diverse effects on children's brains, due to the accumulative character of Pb, and children absorb more Pb through the gastrointestinal tract than adults. Therefore, children are more sensitive to the Pb toxic effect (Canfield et al., 2003; Koller et al., 2004; Lee et al., 2006; Ahamed & Siddiqui, 2007). Lead exposure is a public health concern in South Africa despite the removal of Pb from petrol in 2006. Therefore, more restricted regulations must be applied to Pb-based paints (Mathee, 2014). A study in Tanzania showed some vegetables grown near polluted sites contained Pb levels that exceeded WHO and FAO safety limits, which was considered a health risk for such vegetables' consumers (Bahemuka & Mubofu, 1999). A study in Tanzania showed rice consumption is considered a source of Pb exposure (Simon et al., 2016). A study in Kampala, Uganda, by Mghweno et al. (2008), found that Pb concentrations in maize, beans, and peas exceeded WHO guidelines, posing a significant exposure risk to consumers. In Zambia, Kříbek et al. (2014) assessed heavy metal levels (As, Pb, Co, Cu, Zn) in cassava and found that metal concentrations were significantly higher in cassava leaves compared to the tubers, except for arsenic. Bread was researched in a study in eastern Nigeria, by Emeje et al. (2010), and found traces of Pb, which suggests that consumption of bread in the area of the study is considered a source of Pb exposure.

To the best of our knowledge, this is the first study to investigate TEs (As, Cd, Hg, and Pb) in African foods available for sale in the UK and those commonly consumed by African populations. The primary aims of the research were to assess the levels of these contaminants in a variety of food items and to evaluate potential exposure risks for African consumers. Additionally, the Hazard Quotient (HQ) and Incremental Lifetime Cancer Risk (ILCR) value each of these toxic elements. These assessments are crucial, as even low concentrations of these elements can pose serious health risks due to their toxicity and potential for bioaccumulation.

MATERIALS AND METHODS

Sample Collection and Preparation.

Different types of African food samples, originally from African countries, were collected from special African shops (supermarkets and retailers mainly focused on selling African foods) in Leicester city, and London, UK (2023 to 2024). In total, 76 sample types were collected in duplicates (n = 152). Sample types were divided into 4 categories as follows: (A)- Agricultural products (legumes, nuts, seeds, Leaves, fruit, and tuber crops), (B)- Fishery products (Fish, and prawns), (C)- Processed foods (different spices), and (D)- non-food additives (Kaun (potash)

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and Calabash). All these four categories are presented in Table 1, with more details, including common/local names, scientific names, and land of origin. Some samples were already powder; the other samples were ground by a coffee grinder. All samples were digested as detailed in the following section.

Digestion Method

In the digestion process a 0.3g of a powdered dried food sample was mixed with 8 mL of conc. HNO_{33} (65%) and 2mL of H_2O_2 (30%), and the mixture was digested by using a MARS 6 (CEM) microwave. The following steps were performed as follows: 1- Ramp for 5 min (1000 watts) at 190°C. 2- Hold step for 40 min (1000 watts) at 190°C. 3- Cooling time: 1 hour. The digested sample was made up to 25 ml with deionized water.

Analysis method by Using ICP-MS

Four toxic elements (As, Cd, Hg, and Pb) were measured in all collected African food samples (n = 81 in duplicates, in total n = 162). The measurement was by Inductively Coupled Plasma Mass Spectrometry (ICP-MS), Agilent 7900 ICP-MS. The samples were analyzed in triplicate (n = 3). Operating conditions for the Agilent 7900 ICP-MS were as follows: Rf power:1550 W; Plasma Gas: 15.02 L/min; Carrier Gas: 1.03 L/min; Aux Gas: 0.9 L/min; Nebulizer pump: 0.1 rps; Integration time: 0.1 s; Sampling period: 0.311 s; Acquisition time: 22.74 s; Cell gas: He; Sampling depth: 8 mm.

Analytical Method and Chemicals

A multi-Element Standard Solution VIII (100 mg/L) from Merck KGaA (Darmstadt, Germany), which included As, Cd and Pb, and a separate stock solution, mercury (Hg) at 1 g/L (Sigma-Aldrich, USA), were included in the final stock solution to prepare daily fresh working standards. Calibration standards for toxic elements were prepared at concentrations of 5, 10, 20, 40, and 80 µg/L by using 1%HNO_3.

The internal standard was prepared from the mixture of stock solutions (1,000 mg/L) of rhodium (Rh) and germanium (Ge), which were obtained from Sigma-Aldrich Chemie (Steinheim, Germany). Fresh calibration standards for analysis were prepared daily by diluting stock solutions in 1% HNO_3. Rh and Ge were used at a concentration of 20 µg/L.

Quality Control

Continuing calibration verification (CCV) was also used for a quality control (QC) test for each batch. It was performed by measuring 40µg/L of a mixed standard of all measured toxic elements. The QCs were measured four times (n = 4) within each batch, after each 20 samples, to trace the TES. The QCs' recoveries in one batch were as follows: As (98.35%), Cd (101.07%), Hg (107.30%), and Pb (94.48%).

The daily performance of the ICP-MS in terms of sensitivity and background signals was checked by using a tuning Solution for ICP-MS. Li, Mg, Y, Ce, Tl and Co, Agilent. The tuning solution contained 1 µg/L for each element in 2% HNO_3.

A helium (He) gas was used, and detection limits (DLs) and Background Equivalent Concentration (BEC) for all measured elements were calculated by Agilent's ICP-MS

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MassHunter 4.2 version C.01.02 Workstation Software. DLs and BECs were as follows (μg/L): As (0.07 and 0.03), Cd (0.04 and 0.02), Hg (0.08 and 0.04), and Pb (0.07 and 0.25).

Limit of Quantification (LOQ) was calculated with the following equation: LOQ = 3.33*DL. DLs and LOQs were as follows (μg/L): As (0.07 and 0.23), Cd (0.04 and 0.13) , Hg (0.08 and 0.27), and Pb (0.07 and 0.23).

Quality Assurance (QA)

The accuracy of the measurement was determined by measuring Strawberry leaves (LGC-7162). The values for certified (mg/Kg) and measured (mg/Kg) in the Strawberry leaves-LGC-7162 were as follows: As (0.28±0.07; 0.23±0.02), Cd (0.17±0.04; 0.13±0.01), Hg (0.027±0.006; 0.032±0.005), and Pb (1.8±0.4; 2.2±0.7). Furthermore, spiked samples were used for QA, before digestion. For the major elements, 50 mg/L of each element was spiked in a sample and the recoveries were as follows: As (86.9%), Cd (93.5%), Hg (110.5%), and Pb (95.5%).

Statistical Analysis

A descriptive statistic and t-test were performed by using Excel; the significant differences ($p < 0.05$) were used for the evaluation of the calculated values.

RESULTS AND DISCUSSION

Four categories and their subcategories—agricultural products (legumes, nuts, seeds, leaves, fruit, and tuber crops), fishery products (fish and prawns), processed food (different spices), and non-food additives (Kaun (potash) & Calabash)—are shown in Table 2. The following parameters regarding the TEs (As, Cd, Hg, Pb) are as follows: frequency of detection (%), average concentration (µg/g) in dry weight, and range of concentrations (µg/g) of thirteen subcategories are included in Table 2. The subcategories are as follows: Leaves (N = 22), Tuber-Plant (N = 8), Legume (N = 14), Seed (N = 36), Fruit (N = 24), Spices (N = 22), Fish (N = 24), Prawn (N = 4), Gum (N = 2), Kaun (Potash) (N = 2), Calabash (N = 2), and Chuna (N = 2). The Hazard Quotients (HQs) of As, Cd, Hg and Pb are presented in Figure 1. Hazard quotients (HQ) and Incremental lifetime cancer risk (ILCR) were calculated by using equations explained by Pepper et al. (2012).

$$HQ = EDI/RfD \quad (1)$$

Where:

EDI: (mg/kg bw/day) is estimated daily intake; we based our calculations on 100 g of each food type and body weight of 70 Kg.

RfD: This is the reference dose (mg/kg/day) reported by JECFA (2010, 2011) [35-36].

The Provisional Tolerable Weekly Intake (PTWI) and Provisional Maximum Tolerable Daily Intake (PMTDI) values for toxic elements (As, Cd, Hg, and Pb) and the calculated Estimated Daily Intake (EDI) or PMTDI are shown in Table 3. Among the elements assessed, only arsenic

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(As) and lead (Pb) exceeded their respective reference values. For arsenic, the calculated PMTDI values were 1.7, 1.72, 3.05, and 2.65 times the reference PMTDI for Prawn, chuna, calabash, and kaun, respectively. It is noteworthy that prawns also exceeded the reference value by 1.7 times, even when only 10% of the total arsenic content was considered as inorganic arsenic, the most toxic form. The PMTDIs of the Pb were 3.59 and 3.87 folds of the reference PMTDI for calabash and chuna, respectively. These results indicate a significant potential health risk from long-term consumption of Prawn, chuna, calabash, and kaun.

Figure 1 shows HQs for As, Cd, Hg and Pb for all analyzed African food samples and food additives. In figure 1, Arsenic is higher than >1 among additive foods (Kaun and Calabash), for fishery products 90% of total As was considered as organic arsenic, which is non-toxic, still higher than >1. Only the HQ of Calabash was higher than 1 for Pb. By combining the HQs of the four elements (As, Cd, Hg, and Pb) for each analyzed sample, the total hazard quotients (THQs) were higher than 1 for only five sample types: fish, prawn, kaun, calabash, and chuna (1.01, 2.44, 3.48, 7.74, and 1.11, respectively).

Table 4 shows ILCR for As, Cd and Pb in all analyzed African food samples. They were calculated based on the following equation:

ILCR = (C×IR×EF×ED×CSF×ATILCR)/(BW/AT) (2)

Where:

ILCR = Incremental Lifetime Cancer Risk (unitless).

C = Concentration of the toxic element in food (mg/kg or μg/kg)

IR = Ingestion rate (kg/day).

EF = Exposure frequency (days/year).

ED = Exposure duration (years).

CSF = Cancer slope factor $(mg/kg\text{-}day)^{-1}$ (provided by regulatory agencies such as the EPA).

BW = Body weight (kg) (typically 70 kg for adults).

AT = Averaging time (days) for carcinogens; lifetime is often assumed as 70 years or 25,550 days.

We consider the following interpretation in our study: where ILCR$<10^{-6}$, the risk is negligible; $\leq 10^{-4}$, the risk is in an acceptable range; and ≥ $\geq 10^{-4}$, the risk is high and requires mitigation.

Higher values than 10^{-4} of the ILCR were shown in Table 4 for six sample types (kaun, calabash, chuna, fish, seeds, and prawns). For Cd, only three sample types (leaves, fish, and prawns). For Pb 14%all sample types had an ILCR ≥ 10^{-4}. This indicates that consumers of all analysed samples where Pb detected could be at risk of cancer from lifetime exposure to Pb. The consumers of the following six sample types: kaun, calabash, chuna, fish, seeds, and prawns are at risk of cancer from lifetime exposure to As. Moreover, the consumers of only three sample types: leaves, fish, and prawns are at risk of cancer from lifetime exposure to Cd.

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Food categories and previous studies compared with our study:

Agricultural products:

In Ethiopia, an industrial zone in Dukem, concentrations of TEs (Cr, Cd, and Pb) were investigated in vegetables by Bahiru et al. (2019). Their results showed concentrations of Cr, Cd, and Pb in vegetables ranged from 2.90 -- 3.77 mg/kg, 2.20 -- 3.68 mg/kg, and 4.60 -- 5.50 mg/kg, respectively. They concluded that these results exceeded WHO and FAO safety limits. Another study from South Africa, Limpopo Province, investigated the accumulation of heavy metals in fruits and vegetables, which was performed by Moyo et al. (2020). Their results showed the Cd level in fruits and vegetables ranged from 0.23 to 2.94 mg/kg (dry weight basis). The study found that Cd concentrations in both fruits and vegetables exceeded FAO/WHO safety limits, which are considered potential health risks to humans. Moreover, leafy vegetables were shown to be the highest accumulators. This contradicts our study, where Cd ranged from 0.12-0.2 mg/kg in leafy samples, which is far lower than their results and does not exceed the guideline values.

The effectiveness of food processing was also investigated in a trial to remove TEs from foods by Adjei-Mensah et al., 2021. Different types of food processing were investigated, such as boiling, frying, and roasting. Their results showed unprocessed samples had higher levels of TEs than processed samples, with boiling and frying being the most effective in reducing the TE levels in processed samples, while roasting was the least effective. However, lead (Pb) levels in both unprocessed and processed yam samples were higher than in other food crops across other locations of their study. Our study on cassava, plantain, and yam samples found low levels (µg/g) of toxic elements, including As (0.03, 0.01, 0.02), Cd (0.06, 0.53, <LOD), Hg (<LOD, 0.06, <LOD), and Pb (0.19, 0.01, 0.01). None of these elements exceeded the guideline values. This may be due to controlled food processing and a clean cultivation environment in the analyzed samples.

Table 2 shows only Pb was detected in the tuber plant and legume; this also could indicate controlled food systems such as harvesting, packaging, and distribution. This is plausible, because most staple foods in Africa are considered tuber plants. Seed samples contained all toxic elements, with Pb being the highest among the detected TEs.

Fishery products:

Table 2 shows fish with all four toxic elements detected, while prawns contained only As, Cd, and Pb, with no Hg detected. Prawns showed higher levels of As and Cd than fish samples, while fish samples showed higher levels of Hg and Pb than prawn samples. As is very well known, higher levels of As in fishery products were mainly organo-arsenic, which is considered non-toxic. Therefore, in our results for calculating HQ and ILCR, 10% of the total As in fishery products was considered as inorganic arsenic and is toxic based on the literature (Tanamal et al., 2021), which considered that in the range between 5% and 20% inorganic As. These will remain assumptions, and the future speciation studies will estimate the inorganic arsenic in African fishery products.

A study evaluated toxic elements in raw foods, including fish from open markets in South Africa and Congo, by Nuapia et al. (2018). Their results showed that concentrations of the measured elements varied significantly, often exceeding the maximum acceptable limits set by

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the Joint FAO/WHO Expert Committee on Food. All detected element levels were higher in South African samples than those from Congo, except for Al. The combined Target Hazard Quotients (THQ) for all samples exceeded 1, indicating a potential health risk for local consumers. Compared to our study, the THQs for the four TEs is 1.01 in fish products, which also indicates a health risk for consumers. These findings, along with the literature findings, suggested that long-term consumption of African fishery foods may pose health risks to consumers. Levels of TEs were investigated in three fish species: *Tilapia zillii, Clarias gariepinus, and Oreochromis niloticus* from Nigeria by Abdulrahman et al. (2018). Their findings showed that all three species contained Pb, but no Cd was detected. However, in our study, both Pb and Cd were detected in some analyzed fish samples, with a higher detection percentage for Pb than Cd. In another study, aquaculture food species were investigated by Mok et al. (2012). Their study concluded that As-level discrepancies in the investigated samples were due to variations in aquaculture systems, while Hg and Pb levels were attributed to human activities. Their estimated daily intake (EDI) values for Malaysians were 3.713 (As), 0.115 (Cd), 0.211 (Hg), and 0.738 (Pb) µg/kg body weight per day. None of these values exceeded JECFA guidelines, indicating no immediate health risks for consumers. The calculated EDI values for African fish products in our study were 25.67 (As), 0.53 (Cd), 0.12 (Hg), and 0.2 (Pb) µg/kg body weight per day. Our study shows EDIs for As and Cd higher than their values, while Hg and Pb were lower than their results. The HQs for all the TEs in our study are less than 1, as shown in Figure 1.

Spices:

Levels of TEs As, Cd, and Pb were evaluated in different spices commonly used in South Africa by Oladeji et al. (2023). They reported concentrations (mg/kg) ranging from ND-0.12, ND-0.029, and 2.51 for As, Cd, and Pb, respectively. All concentrations were within the WHO limits. The authors concluded that consumption of such analyzed spice may not pose health risks associated with As, Cd, and Pb. In comparison with our results in different spices imported from Africa and on sale in the UK, the concentrations (mg/kg) ranges were as follows: As: 0.05–0.20, Cd: ND – 0.10, Hg: ND – 0.10, and Pb: 0.05–0.40. Our results are consistent with their findings, supporting the conclusion that consumption of the analyzed spices is unlikely to pose a health risk, based on our calculated Hazard Quotient (HQ) and Incremental Lifetime Cancer Risk (ILCR) values (Fig. 1 and Table 4). Concentrations of TEs (As, Cd, Hg, Pb) in culinary spices and herbs were demonstrated in a review by Alawadhi et al. (2024). Fifty peer-reviewed studies from Asia, Africa, Europe, and the Americas were included in the review. The authors showed that heavy metal levels varied significantly by region, spice type, and agricultural practices from region to region. Levels of Pb were higher in spices from Pakistan, while Cd and Pb were higher in spices from Bahrain, and both exceeded the WHO permissible limits. Levels of Pb exceeded the safety threshold (cancer risk, CR > 10^{-4}) in some spices from Turkey, Egypt, Pakistan, and Ethiopia. In comparison to our study, our results showed HQ < 1 for TEs (As, Cd, Hg, and Pb) in all analyzed species (Fig. 1). Spices contained all four toxic elements (As, Cd, Hg, and Pb) at low levels, but their HQ and ILCR values remained within permissible limits (Table 4). Only Pb ILCR values > 10^{-4}, which may expose consumers to cancer from lifetime exposure to Pb (Table 4).

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Non-foods (additives):

Figure 1 and Table 4 show HQ and ILCR values exceeded guideline limits for calabash, kaun, and chuna regarding As, Cd, and Pb. Therefore, the consumption of calabash, kaun, and chuna should be avoided, as they may cause potential health risks.

Levels of heavy metals, including Pb, were assessed in Kaun obtained from Gashua Potash Market in Yobe State, Nigeria, by Adamu and Baffa (2023). Their findings showed that all investigated heavy metals exceeded the permissible limits, except for Pb and Zn. Their findings agree with our results for Pb, which showed a HQ< 1 for Kaun (Fig. 1). Calabash obtained from Kenya was also investigated for heavy metals, including Cd and Pb, by Abrahams et al. (2013). Their results showed that Pb concentration was 37 mg/kg and ranged from 20 to 43 mg/kg. The results of Pb in calabash in our study are lower than their results, as follows: with a mean of 11 mg/kg and a range of 10.9–11.1 mg/kg (Table 2). However, the calculated ILCR for Pb is $>10^{-4}$. While Abrahams et al. (2013) did not calculate the ILCR for Pb in their study, it would likely exceed recommended safety thresholds, aligning with the findings of our study. Therefore, due to the elevated Pb content and associated health risks, particularly long-term exposure, the consumption of Calabash should be avoided. Toxic elements (As, Cd, and Pb) were assessed in China by Al-Ramalli et al. (2011). Their results showed the mean concentrations of As, Cd, and Pb in China were 3.47 mg/kg, 0.13 mg/kg, and 1.56 mg/kg, respectively. Our results are lower than their results, which are as follows: As (0.27), Cd (0.08), and Pb (2.03) mg/kg, except for Pb. However, in terms of health risk, the ILCR values in our study for As and Cd were below the permissible limit, whereas the ILCR for Pb exceeded the acceptable threshold. In summary, both studies align in indicating that long-term consumption of China may pose significant health risks, particularly due to elevated Pb levels. The high ILCR associated with Pb exposure suggests a potential risk of cancer, supporting the need for public health awareness and regulations.

Different gum samples, including *Commiphora myrrha, Ferula assa-foetida, Boswellia sacra, and Acacia seyal*, were investigated for elements, including toxic elements, by Alshwyeh et al. (2024). They reported average concentrations (mg/Kg) for Cd and Pb in Gum Arabic (Acacia seyal), 0.03 and 0.17, respectively. In comparison to our results, only Pb was detected with a mean concentration of 0.37 mg/Kg. The calculated HQ<1 for Pb (Fig. 1), while the calculated ILCR > in our study was 10^{-4} for Pb (Table 4). Both studies conclude that long-term or excessive consumption of these gums could pose health risks due to the cumulative effects of toxic metal exposure. This shows our findings align closely with theirs.

A comparison between our findings and those of multiple studies conducted across African countries reveals that certain African foods are contaminated with toxic elements. This contamination poses serious health risks, making long-term consumption unsafe, as it may lead to diseases that affect human health and well-being. Notably, 15% of all the analysed samples in this study exceeded the guideline values.

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CONCLUSIONS

This study has concluded that some African foods contain concentrations exceeding the recommended permissible limits for HQ and ILCR. Especially additive foods, the Kaun, Calabash, and Chuna. The ILCR values of Pb exceeded the permissible limits in 15% of all analysed samples. The consumption of Kaun, Calabash, Chuna, fish, seeds, and prawns will put consumers at risk of cancer from lifetime exposure to As. Moreover, only leaves, fish, and prawns will put consumers at risk of cancer from lifetime exposure to Cd. The presence of TEs in foods and non-food additives may be attributed to various factors, including the environment in which they are cultivated or the processing stages, such as harvesting, storage, and drying. Additionally, many processed foods, such as spices, may become contaminated due to being handled in mills that do not adhere to proper hygiene standards. Therefore, we recommend conducting further studies on African foods and non-food additives to identify sources and types of contamination and explore ways to mitigate them. We also emphasize the importance of implementing strict laws and regulations to ensure compliance with health and safety standards at all stages of food production, given the potential health risks associated with consuming contaminated foods over extended periods.

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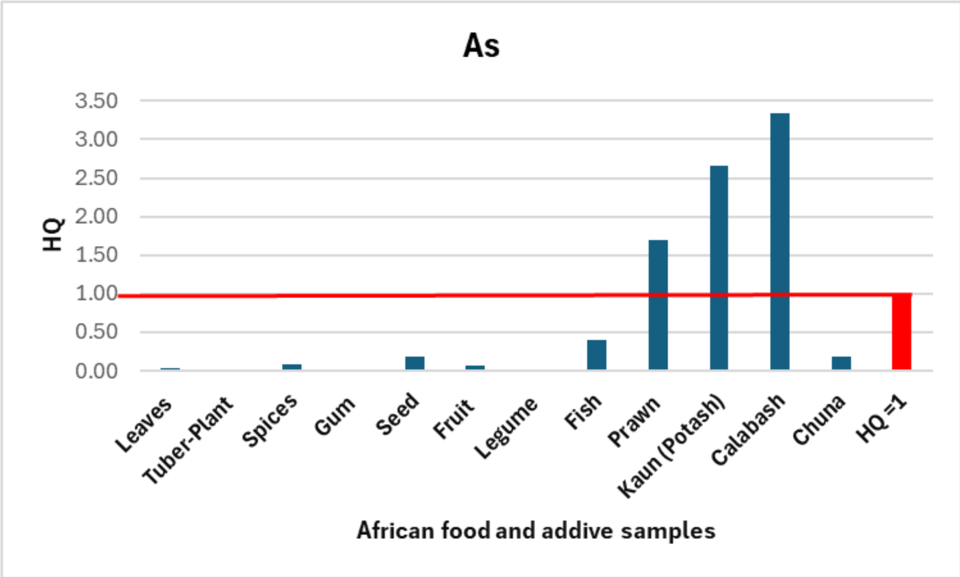
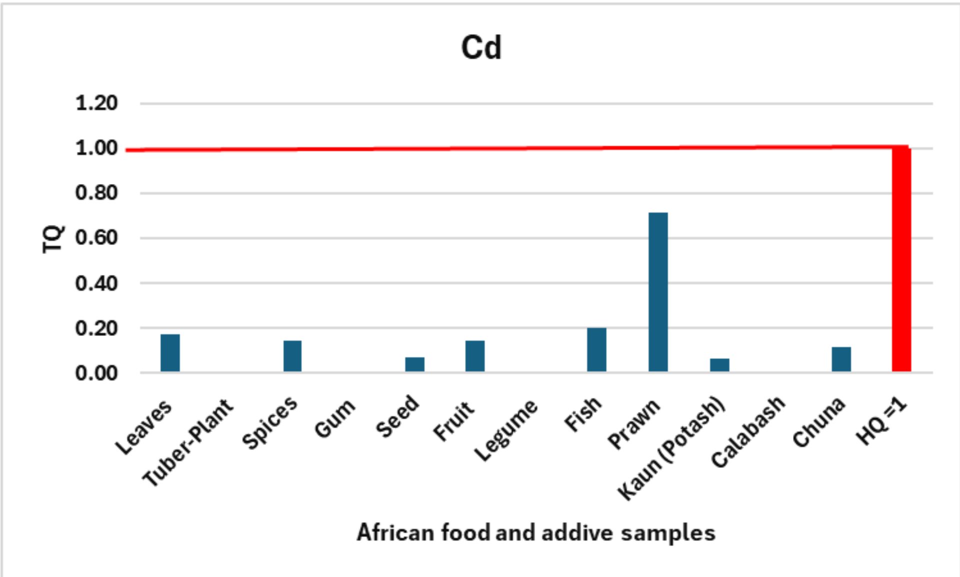
FIGURES

A



B



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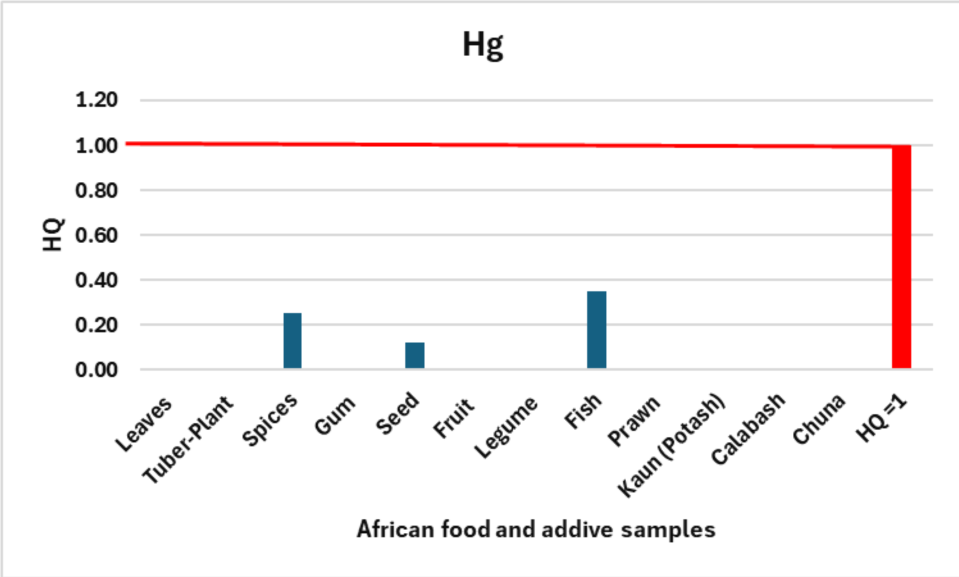
C



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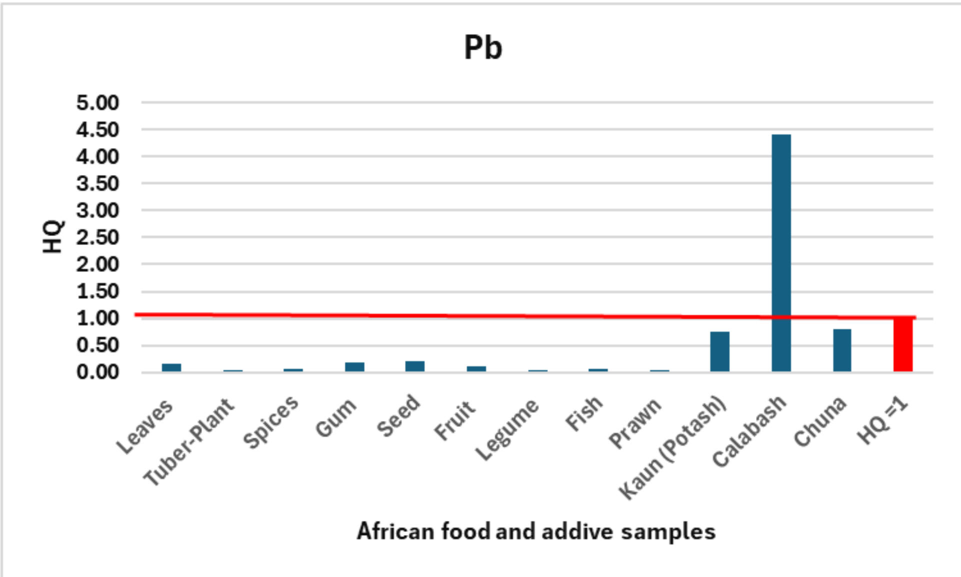

Figure 1: Hazard Quotients (HQ) A, B, C, and D, of As, Cd, Hg and Pb, respectively in all food samples

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TABLES

Table1 Sample information of the African food products on sale in the UK, collected from supermarkets and retailers in different cities.

Common name	**Scientific name**	**Land of origin**	**Common name**	**Scientific name**	**Land of origin**
(A)- Agricultural products: *Legume (n =7)*			***Tuber crop (n =4)***		
Black Eyes Beans	*Vigna unguiculata*	NA*	Yam flour	*Dioscorea*	Nigeria
Red skin peanut	*Arachis hypogaea.*	Cameroon	Cassava dough	*Manihot esculenta Crantz*	Ghana
Red lentils	*Lens culinaris*	NA*	Control onions	*Allium cepa*	Nigeria
Ofor	*Detarium microcarpum.*	Nigeria	Bula (fakes banana)	*Ensete ventricosum*	Ethiopia
Cow peas	*Vigna unguiculata*	Sudan	**(B)-Fishery products: *Fish (n =12)***		
Brown lentils	*Lens culinaris*	NA*	Sardine Morocco	*Sardina pilchardus*	Morocco
Ground peanut	*Arachis hypogaea*	NA#	Aswen fish	*Oreochromis niloticus*	Ghana
Seeds (n =15)			Tilapia	*Oreochromis niloticus*	unknown
Brown rice	*Oryza sativa.*	Ghana	Dried small fish	*Rastrineobola argentea*	Kenya
White rice	*Oryza sativa.*	Ghana	Fish	*Clarias gariepinus*	Ghana
Teff	*Eragrostis tef*	Ethiopia	Kobi fish	*Oreochromis niloticus*	Ghana
Sorghum	*Sorghum bicolor (L.)*	South Africa	Tilapia	*Oreochromis niloticus*	Ghana
Village rice	*Oryza glaberrima.*	Nigeria	Fish powder (made from different fish species)	-	Ghana
Whole white maize	*Zea mays.*	South Africa, Zambia, Zimbabwe	Smoked Barracuda Fillet	*Sphyraena barracuda*	Nigeria

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Corn Dough (masa)	*Zea mays.*	Ghana	Dried Anchovies	*Stolephorus commersonnii*	Nigeria
Sorghum-flour	*Sorghum bicolor.*	Sudan	Kapenta fish	*Limnothrissa miodon*	Zimbabwe
Banku dough (fermented corn and cassava)	*Zea mays L.*	Ghana	Dried Catfish Fillet	*Clarias gariepinus*	Nigeria
Beso Roasted Barely	*Hordeum vulgare.*	Ethiopia	***Prawns (n =2)***		
Ogbono	*Irvingia gabonensis.*	Nigeria	Ground Prawns	*Dendrobranchiata*	Nicaragua
Whole Egusi	*Citrullus lanatus var. colocynthoides.*	NA≠	Whole smoked prawns	*Penaeus vannamei*	Mozambique.
Black seed	*Nigella sativa.*	Sudan	**(C)-Processed foods:** ***Spices (n = 11)***		
Pearl Millet	*Pennisetum glaucum (L.) R. Br.*	South Africa, Zambia, Zimbabwe	Berbere Ground Pepper	*Capsicum*	Ethiopia
Millet	*Pennisetum glaucum*	Sudan	Fenu Greek	*Trigonella foenum-graecum*	Unknown
Leaves (n =11)			Turmeric	*Curcuma longa*	Unknown
Cassava leaves	*Manihot esculenta Crantz*	unknown	Chilli Powder Mitmita	*Capsicum frutescens*	Ethiopia
Ewedo	*Corchorus olitorius*	Cameroon	Banga Spice	*Tetrapleura tetraptera*	Nigeria
Corn husk	*Zea mays*	Ghana	Fasika Spice (spice mixture includes chili peppers, coriander, garlic, ginger, Ethiopian holy basil (besobela) seeds, korarima, rue, ajwain or radhuni, nigella, and fenugreek)-	-	Ethiopia

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Biteku teku	*Amaranthus spp.*	Cameroon	African hot Pepper powder	*Capsicum frutescens*	Nigeria
Okasi leaf	*Gnetum africanum*	Nigeria	Cameroon Pepper	*Piper guineense*	Cameroon
Kawal (fermented leaves)	*cassia obtusifolia*	Sudan	Suya Kebab Powder (blend of peanuts, chili, ginger, and other spices.)	-	Nigeria
Mutsine	*Bidens pilosa*	Zimbabwe	Ground Fennel	*Foeniculum vulgare*	Sudan
Waake leaves	*Sorghum bicolor*	Ghana	Najansa	*Ricinodendro n*	Cameroon
Red leaves	*Telfairia occidentalis.*	Cameroon	**(D)-Non-food (additives):**		
Herbal tea	*Lippia javanica.*	Zimbabwe	***Kaun Potash (n = 1)***		
Bitter leaves	*Vernonia amygdalina*	Nigeria	Kaun Potash	potassium carbonate	Nigeria
Fruits (n =10)			***Calabash (n = 1)***		
Dates Barakawe & Dates Gundil	*Phoenix dactylifera*	Sudan	Long chalk-Calabash chalk	*aluminum Silicate Hydroxide*	Nigeria
Tamarind	*Tamarindus indica*	Sudan	***Gum (n = 1)***		
Okra (frozen whole okra)	*Abelmoschus esculentus*	Egypt	Gum Arabic	*Acacia senegal*	Sudan
Okra (powder)	*Abelmoschus esculentus*	Sudan			

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Baobab	*genus Adansonia*	Ghana			
Lalob	*Balanites aegyptiaca*	Sudan			
Masau	*Ziziphus mauritiana*	Zimbabwe			
Limu	*Citrus aurantifolia*	unknown			
Nabag	*ziziphus*	Sudan			
Hibiscus	*Hibiscus rosa-sinensis*	Sudan			

* Purely African-Africa direct (company name).# African Sun (www.wanis.com). ≠www.onenationafrofood.co.uk- West African cuisine

Table 2: Frequency of detection (%), average concentration (µg/g) in dry weight, and range of concentrations (µg/g) of toxic elements (As, Cd, Hg, Pb) in Leaves (N =22), Tuber-Plant (N =8), Spice (N =22), Gum (N =2), Kaun -Potash-(N =2), Calabash(N =2), Chuna(N =2), Fish (N =24), Seed (N =30), Fruit (N =20), Prawn (N =4), and Legume (N =14).

No.	**Subcategory (n)**	**Toxic element**			
1	**Leaves (N =22)**	**As**	**Cd**	**Hg**	**Pb**
	Frequency of detection (%)	54.5	45.5	0	100
	Mean (µg/g)	0.06	0.12	0	0.4
	Min-Max (µg/g)	0.05-0.09	0.06-0.2	0	0.12-0.81
2	**Tuber-Plant (N =8)**				
	Frequency of detection (%)	0	0	0	25
	Mean (µg/g)	0	0	0	0.1
	Min-Max (µg/g)	0	0	0	0.1-0.1
3	**Seeds (N =30)**				
	Frequency of detection (%)	39.5	5.3	2.6	36.8
	Mean (µg/g)	0.27	0.1	0.1	0.5
	Min-Max (µg/g)	0.1-1.3	0.0-0.1	0.0-0.1	0.1-3.9
4	**Fruits (N =20)**				
	Frequency of detection (%)	15.4	11.5	0	61.5
	Mean (µg/g)	0.1	0.1	0	0.3
	Min-Max (µg/g)	0.1-0.1	0.1-0.1	0	0.1-0.8
5	**Legume (N =14)**				
	Frequency of detection (%)	0	0	0	14.3
	Mean (µg/g)	0	0	0	0.1
	Min-Max (µg/g)	0	0	0	0.1-0.1
6	**Spices (N =22)**				
	Frequency of detection (%)	59.1	4.5	9	77.3
	Mean (µg/g)	0.13	0.1	0.1	0.15
	Min-Max (µg/g)	0.05-0.2	0.1-0.1	0.1-0.1	0.05-0.4

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7	**Fish (N =24)**				
	Frequency of detection (%)	91.7	54.2	33.3	66.7
	Mean (µg/g)	5.9	0.14	0.14	0.14
	Min-Max (µg/g)	0.1-19.3	0.05-0.4	0.1-0.3	0.05-0.43
8	**Prawn (N =4)**				
	Frequency of detection (%)	100	100	0	75
	Mean (µg/g)	24.9	0.5	0	0.1
	Min-Max (µg/g)	18-35.1	0.1-0.9	0	0.1-0.1
9	**Gum (N =2)**				
	Frequency of detection (%)	0	0	0	100
	Mean (µg/g)	0	0	0	0.37
	Min-Max (µg/g)	0	0	0	0.31-0.43
10	**Kaun -Potash-(N =2)**				
	Frequency of detection (%)	100	100	0	100
	Mean (µg/g)	3.9	0.045	0	1.9
	Min-Max (µg/g)	3.3-4.3	0.04-0.05	0	1.7-2.1
11	**Calabash (N =2)**				
	Frequency of detection (%)	100	0	0	100
	Mean (µg/g)	4.9	0	0	11
	Min-Max (µg/g)	4.7-5.1	0	0	10.9-11.1
12	**Chuna(N =2)**				
	Frequency of detection (%)	100	100	0	100
	Mean (µg/g)	0.27	0.08	0	2.03
	Min-Max (µg/g)	0.2-0.27	0.08-0.08	0	1.62-2.44

Table 3: The calculated provisional maximum tolerance daily intake (PMTDI) of toxic elements (As, Cd, Hg, Pb) for different African foods types: leaves, tuber-plant, seeds, fruits, legume, spices, fish, prawns, Gum, non-food -additives (Kaun-potash, long chalk, raja chuna).

PMTDI (µg/kg bw per day)				
PMTDI*	2.1	1	0.57	3.57
Food type	As	Cd	Hg	Pb
Leaves	0.09	0.17	0.00	0.57
Tuber-Plant	0.00	0.00	0.00	0.14
Spice	0.19	0.14	0.14	0.21
Gum	0.00	0.00	0.00	0.53
Kaun -Potash	5.57	0.06	0.00	2.71
Calabash	6.40	0.00	0.00	12.77
Chuna	3.63	0.00	0.00	13.81
Fish	0.84#	0.20	0.20	0.20
Seed	0.14	0.07	0.07	1.14
Fruit	0.11	0.14	0.00	0.43
Prawn	3.56#	0.71	0.00	0.14

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Legume	0.00	0.00	0.00	0.14

*Calculated value based on The provisional tolerance weekly intake (PTWI) from JECFA, 2010 and 2011; FAO/WHO,2011. #Calculated by assuming 10% of the total As is inorganic arsenic, which is toxic.

Table 4: Incremental lifetime cancer risk (ILCR) of As, Cd, Hg and Pb in all food samples.

	Incremental lifetime cancer risk (ILCR)*		
Sample type & (numbers)	**As**	**Cd**	**Pb**
Leaves	7.71E-06	1.25E-04	1.94E-03
Tuber-Plant	0.00E+00	0.00E+00	1.21E-04
Spices	3.62E-05	8.71E-05	2.73E-04
Gum	0.00E+00	0.00E+00	1.66E-03
Kaun	3.26E-02	1.76E-05	4.38E-02
Calabash	5.15E-02	0.00E+00	1.47E+00
Chuna	1.56E-04	5.58E-05	5.00E-02
Fish	7.46E-03	1.71E-04	2.38E-04
Seeds	1.98E-04	4.36E-05	4.98E-03
Fruit	2.14E-05	8.71E-05	1.09E-03
Prawn	1.33E-01	2.18E-03	1.21E-04
Legume	0.00E+00	0.00E+00	1.21E-04

*ILCR$<10^{-6}$ the risk is negligible, $\leq 10^{-4}$ the risk is in an acceptable range, and $\geq 10^{-4}$ the risk is high and requires mitigation.

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