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# Dietary Exposure and Cancer Risk Assessment of Heavy Metals from Fish and Vegetables Consumed in Nguru Wetlands, Yobe State, Nigeria

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## Abstract

Wetland dependent communities may experience chronic dietary exposure to toxic metals through regular consumption of locally produced fish and vegetables. This study assessed arsenic (As), cadmium (Cd), chromium (Cr), and nickel (Ni) in selected fish and vegetables consumed around Nguru Wetlands, Yobe State, Nigeria, and evaluated estimated daily intake (EDI), cancer risk (CR), and total cancer risk (TCR). Tomato, lettuce, and sorrel tissues, together with catfish, tilapia, and ray-finned fish tissues, were collected and analyzed using microwave-assisted acid digestion followed by atomic absorption spectroscopy. In vegetables, the highest measured concentrations were 3.76 ± 0.96 mg/kg As in sorrel root, 9.41 ± 0.00 mg/kg Cd in tomato root, 8.30 ± 4.78 mg/kg Cr in sorrel root, and 3.78 ± 1.28 mg/kg Ni in sorrel root. In fish, the highest concentrations were 3.47 ± 0.89 mg/kg As in tilapia gills, 6.31 ± 1.79 mg/kg Cd in ray-finned fish intestine, 4.32 ± 2.39 mg/kg Cr in tilapia gills, and 3.19 ± 1.25 mg/kg Ni in catfish intestine. The reported EDI values were highest for As in tilapia at 0.000926 mg/kg/day, Cd in tomato at 0.001946 mg/kg/day, Cr in sorrel at 0.001374 mg/kg/day, and Ni in catfish at 0.000931 mg/kg/day. Total cancer-risk values ranged from 0.001830 in lettuce to 0.002909 in tilapia. These findings indicate that fish and vegetables from Nguru Wetlands may represent important dietary exposure pathways for multiple metals and support the need for continued monitoring, improved exposure assessment, and contamination-control measures. Interpretation of chromium-related risk should be made cautiously because total chromium measurements do not distinguish between Cr(III) and Cr(VI) (European Food Safety Authority [EFSA], 2020; International Agency for Research on Cancer [IARC], 2012).

**Keywords:** Dietary Exposure, Cancer Risk, Heavy Metals, Fish, Vegetables, Nguru Wetlands, Arsenic, Cadmium, Chromium, Nickel

## INTRODUCTION

Heavy metals are persistent environmental contaminants that can remain in soils, sediments, surface waters, and biological tissues for extended periods. Their persistence allows them to move through food chains and become relevant to human exposure when contaminated fish, vegetables, or other food commodities are consumed regularly (IARC, 2012; EFSA, 2020). Food-safety assessment therefore requires both measurement of contaminant concentrations and estimation of dietary exposure under realistic consumption assumptions (World Health Organization [WHO], 2020).

Wetlands are productive ecosystems, but their sediments and organic matter can retain contaminants transported by water. Seasonal flooding and hydrological changes may subsequently redistribute these contaminants within the ecosystem, thereby influencing agricultural soils, irrigation water, aquatic organisms, and food crops (Mitsch & Gosselink, 2015).

Nguru Wetlands, within the Hadejia-Nguru wetland system of northeastern Nigeria, support vegetable cultivation and freshwater fishing. The surrounding communities consume vegetables such as tomato, lettuce, and sorrel, together with fish such as catfish, tilapia, and ray-finned fish.

Arsenic, cadmium, chromium, and nickel were selected for assessment because they are environmentally important metals associated with toxicological effects under particular exposure conditions (IARC, 2012; EFSA, 2020). Inorganic arsenic and certain chromium compounds are recognized carcinogenic hazards, while cadmium and nickel are also important contaminants in food and environmental-health assessment (IARC, 2012; EFSA, 2020).

The present study evaluated the concentrations of As, Cd, Cr, and Ni in selected fish and vegetables from Nguru Wetlands. It also estimated dietary exposure using EDI and assessed individual-metal and combined-metal cancer risk using CR and TCR calculations.

## MATERIALS AND METHODS

### Study Design and Sampling

The study used a food contamination and dietary risk assessment design involving vegetables and fish collected from Nguru Wetlands, Yobe State, Nigeria. Vegetable samples were obtained from cultivation sites within the wetland, while fish samples were collected from the Yan Kwarawa section of the wetland.

Three fresh specimens each of tomato, lettuce, and sorrel were collected for vegetable analysis, and three specimens each of catfish, tilapia, and ray-finned fish were collected for fish analysis. Vegetable tissues included roots, stems, leaves, and tomato fruits where applicable, while fish analyses included muscle, gills, and intestinal tissues.

### Sample Preparation

The samples were placed in clean, labelled containers and transported to the laboratory. Vegetables and fish tissues were washed with tap water and rinsed with deionized water to remove adhering soil, sand, and surface debris.

The samples were cut into smaller pieces and air-dried for 24 hours before being oven-dried at 80 °C for 3 hours or until constant weight was achieved. The dried material was ground and passed through a 2.0-mm sieve to obtain a relatively uniform sample matrix.

Acid digestion is widely used to remove organic matter and transfer trace elements from food and biological matrices into solution before instrumental analysis (El Hosry et al., 2023).

### Digestion Procedure

Approximately 0.5 g of each dried sample was weighed into a digestion vessel. Six milliliters of concentrated nitric acid and 2 mL of hydrogen peroxide were added before microwave-assisted digestion.

The digestion program began at 80 °C for 5 minutes and was then increased to 180 °C for 35 minutes, giving a total reported digestion time of 40 minutes. The digested solutions were diluted to 25 mL with deionized water, filtered, and retained for instrumental analysis.

Microwave-assisted digestion can improve digestion efficiency and reduce preparation time when trace elements are extracted from complex food matrices (El Hosry et al., 2023).

### Atomic Absorption Spectroscopic Analysis

The concentrations of As, Cd, Cr, and Ni were determined using a Buck Scientific 210 VGP atomic absorption spectrophotometer. The reported analytical wavelengths were 193.7 nm for As, 228.8 nm for Cd, 357.9 nm for Cr, and 232.0 nm for Ni.

The instrument was calibrated using prepared standards for each element, and blank solutions were used to monitor possible background contributions. Each sample was analyzed in triplicate, and the results were expressed as mean concentrations with standard deviations where available.

Atomic absorption spectroscopy is an established technique for elemental analysis, although its reliability depends on appropriate digestion, calibration, interference control, detection-limit evaluation, and quality-assurance procedures (El Hosry et al., 2023). The U.S. Food and Drug Administration provides formal elemental-analysis procedures for food samples involving acid digestion and instrumental determination of toxic elements (U.S. Food and Drug Administration [FDA], 2020).

### Dietary Exposure Assessment

Dietary exposure was estimated using an adult body weight of 60.7 kg and an average food-ingestion rate of 0.02 kg/day.

The general EDI relationship was expressed as: $EDI = \frac{C \times IR}{BW}$

where C is the metal concentration in food, IR is the ingestion rate, and BW is body weight. Dietary exposure assessments commonly combine concentration, consumption rate, and body weight to estimate chemical intake (WHO, 2020).

The EDI values were used to compare the relative contribution of each food item to exposure to the four metals. Because the analysis used fixed body-weight and ingestion-rate assumptions, the results represent exposure scenarios rather than a complete population exposure distribution.

### Cancer Risk Assessment

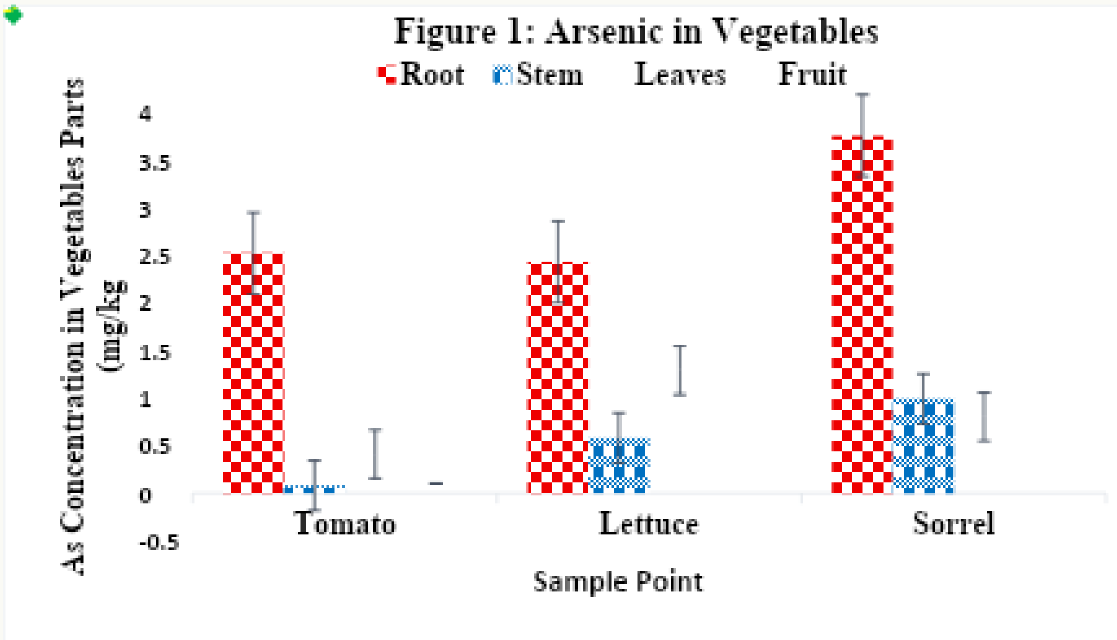
Cancer risk was estimated using the metal specific slope factor approach applied in the thesis calculations. Individual CR values represented the estimated lifetime risk associated with a particular metal and food category, while TCR represented the sum of the individual metal-specific risks included in the assessment.

Risk estimates depend on concentration, ingestion rate, body weight, exposure duration, averaging time, and the toxicity values selected for each metal (WHO, 2020). The present results were therefore interpreted as screening-level estimates rather than direct predictions of observed cancer incidence.

## RESULTS

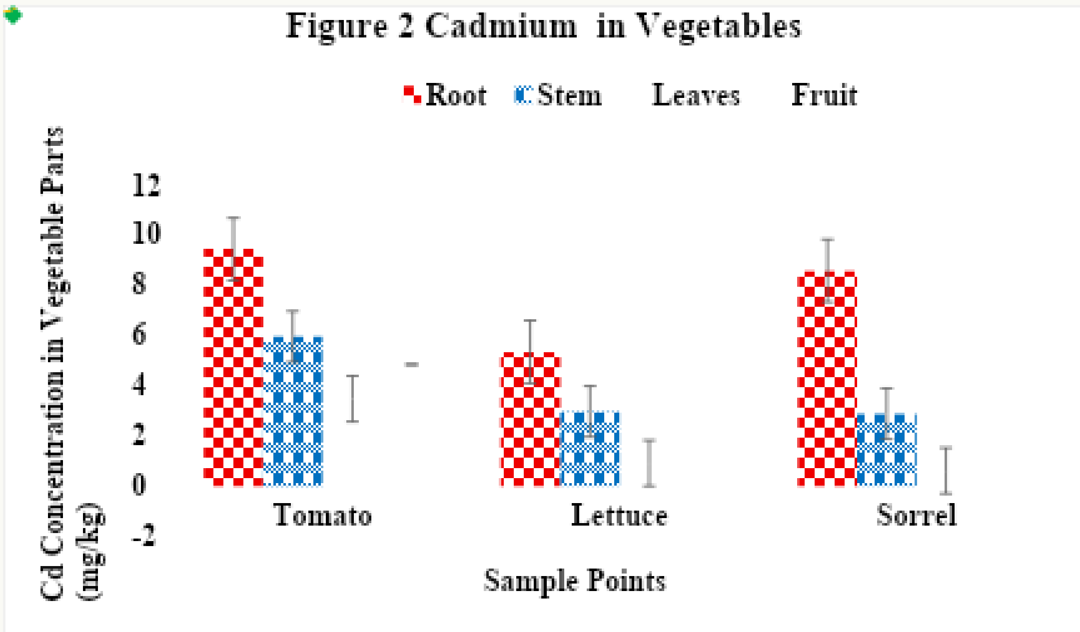
### Arsenic Concentrations in Vegetables




- Arsenic was detected in all reported vegetable tissues. The highest vegetable As concentration was 3.76 ± 0.96 mg/kg in sorrel root, followed by 2.52 ± 1.67 mg/kg in tomato root and 2.43 ± 0.50 mg/kg in lettuce root.
- Among above-ground tissues, lettuce leaf contained 1.29 ± 0.36 mg/kg As, sorrel leaf contained 0.80 ± 0.31 mg/kg, tomato leaf contained 0.41 ± 0.00 mg/kg, tomato fruit contained 0.10 ± 0.64 mg/kg, and tomato stem contained 0.08 ± 0.86 mg/kg.

The distribution indicated greater arsenic accumulation in roots than in most above ground tissues, although arsenic was also present in edible leaves and tomato fruit. The data demonstrate tissue associated contamination but do not independently establish whether soil, irrigation water, fertilizer, or atmospheric deposition was the dominant source.

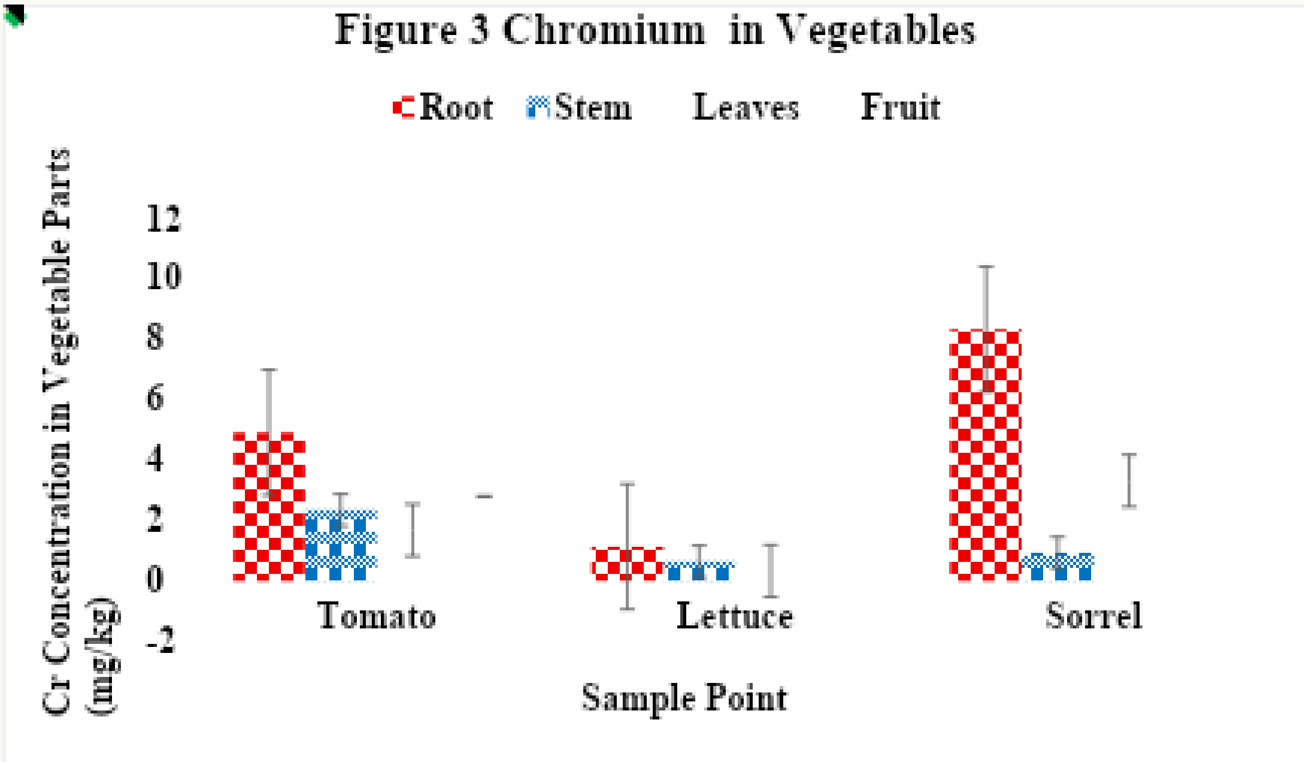
### Cadmium Concentrations in Vegetables



- Cadmium concentrations were high across the vegetable tissues. Tomato root contained 9.41 ± 0.00 mg/kg Cd, sorrel root contained 8.55 ± 4.78 mg/kg, and lettuce root contained 5.32 ± 3.08 mg/kg.
- Tomato stem contained 5.93 ± 0.88 mg/kg Cd, tomato fruit contained 4.82 ± 4.13 mg/kg, tomato leaf contained 3.46 ± 0.00 mg/kg, and lettuce stem contained 2.95 ± 3.36 mg/kg.
- Lettuce leaf and sorrel leaf contained 0.90 ± 0.42 mg/kg and 0.60 ± 0.56 mg/kg Cd, respectively, while sorrel stem contained 2.86 ± 0.84 mg/kg.

The occurrence of 4.82 ± 4.13 mg/kg Cd in tomato fruit is important for dietary assessment because the fruit is an edible plant part. A formal regulatory comparison would require confirmation of the applicable commodity category, wet-weight or dry-weight basis, and regulatory jurisdiction (EFSA, 2020).

**Chromium concentrations in vegetables**

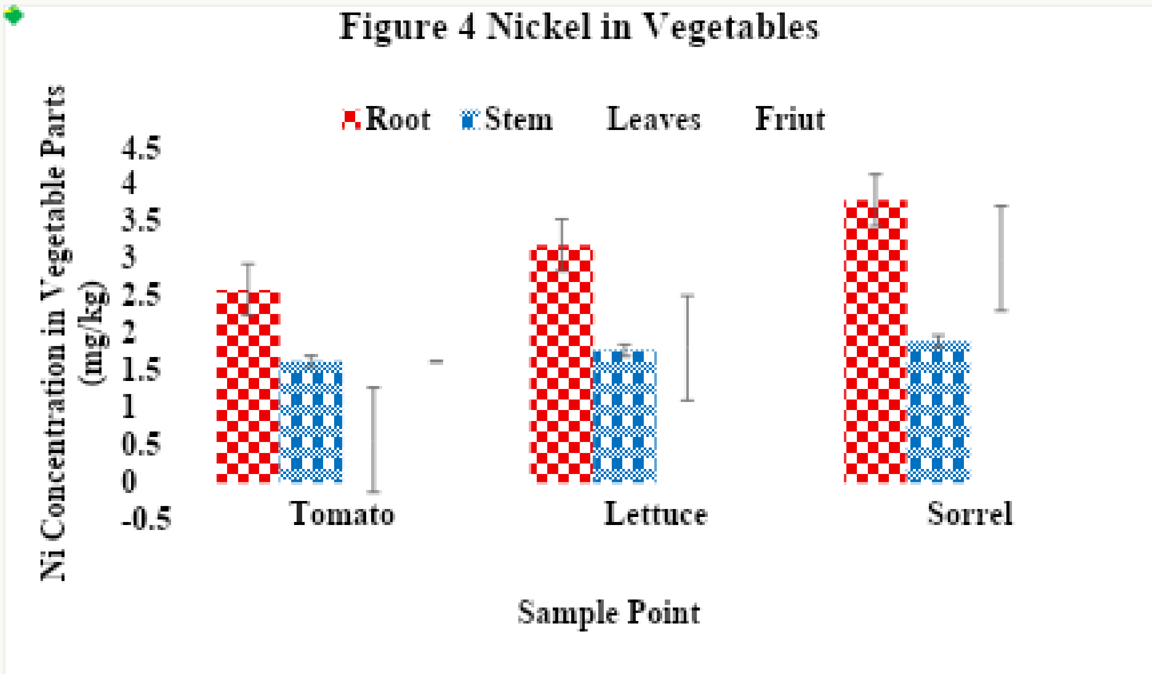



- The highest vegetable Cr concentration was 8.30 ± 4.78 mg/kg in sorrel root, followed by 4.89 ± 1.70 mg/kg in tomato root and 3.29 ± 2.29 mg/kg in sorrel leaf.
- Tomato fruit contained 2.78 ± 1.62 mg/kg Cr, tomato stem contained 2.33 ± 0.68 mg/kg, and tomato leaf contained 1.66 ± 0.00 mg/kg.
- Lettuce root, stem, and leaf contained 1.12 ± 0.31 mg/kg, 0.63 ± 0.38 mg/kg, and 0.37 ± 0.32 mg/kg Cr, respectively.

The results show that chromium was present in roots and above-ground tissues. Because the analysis measured total chromium rather than chromium species, the data cannot determine the proportion present as Cr(III) or Cr(VI). Consequently, the results should not be interpreted as evidence that all measured chromium was Cr(VI) (EFSA, 2020; IARC, 2012).

**Nickel concentrations in vegetables**

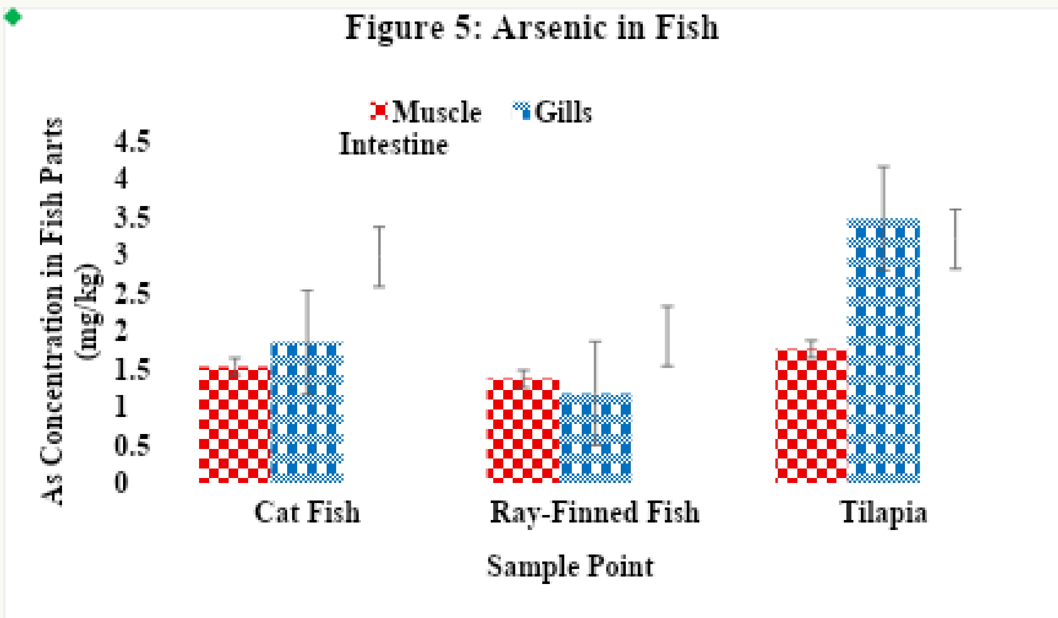



- Nickel was detected in all reported vegetable categories. Sorrel root recorded the highest concentration at 3.78 ± 1.28 mg/kg Ni, followed by lettuce root at 3.18 ± 1.05 mg/kg and tomato root at 2.58 ± 0.48 mg/kg.
- Sorrel stem and leaf contained 1.89 ± 1.40 mg/kg and 1.88 ± 1.41 mg/kg Ni, respectively, while lettuce stem and leaf contained 1.77 ± 1.34 mg/kg and 1.80 ± 1.16 mg/kg.
- Tomato stem and fruit contained 1.62 ± 1.15 mg/kg and 1.62 ± 1.23 mg/kg Ni, respectively, while tomato leaf contained 0.57 ± 0.00 mg/kg.

These results indicate distribution of nickel from roots into above-ground tissues, including edible portions. The food-safety significance of the values should be interpreted using the relevant food category and applicable nickel-risk framework rather than a single universal limit (EFSA, 2020).

**Fish Concentrations**

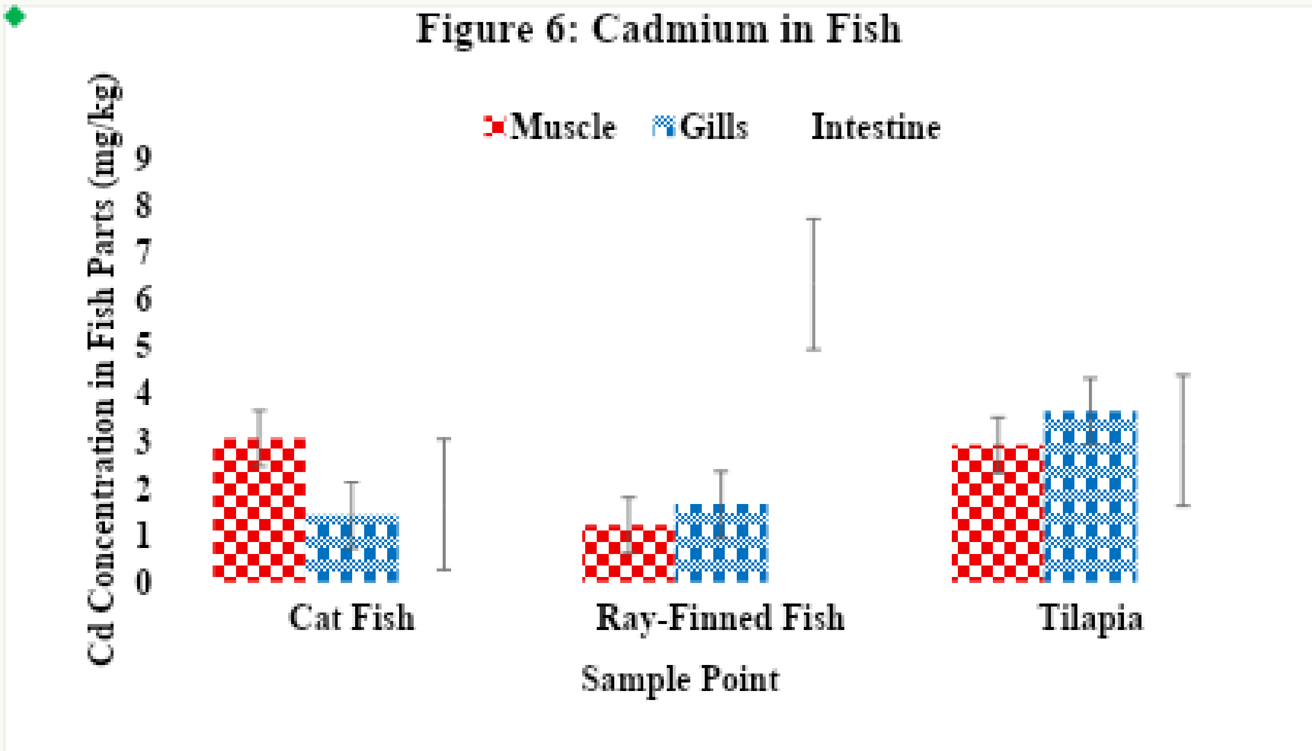
**Arsenic Concentrations in Fish**



- Tilapia gills contained the highest measured fish As concentration at 3.47 ± 0.89 mg/kg, followed by tilapia intestine at 3.20 ± 0.45 mg/kg.
- Catfish intestine contained 2.97 ± 0.29 mg/kg As, while catfish muscle and gills contained 1.53 ± 0.39 mg/kg and 1.85 ± 0.20 mg/kg, respectively.
- Ray-finned fish contained 1.37 ± 0.28 mg/kg in muscle, 1.18 ± 0.32 mg/kg in gills, and 1.93 ± 1.06 mg/kg in intestine.

The fish results show higher arsenic concentrations in gill and intestinal tissues than in most muscle samples. However, the analysis did not distinguish between inorganic and organic arsenic species, which differ substantially in toxicological significance (EFSA, 2020; IARC, 2012).

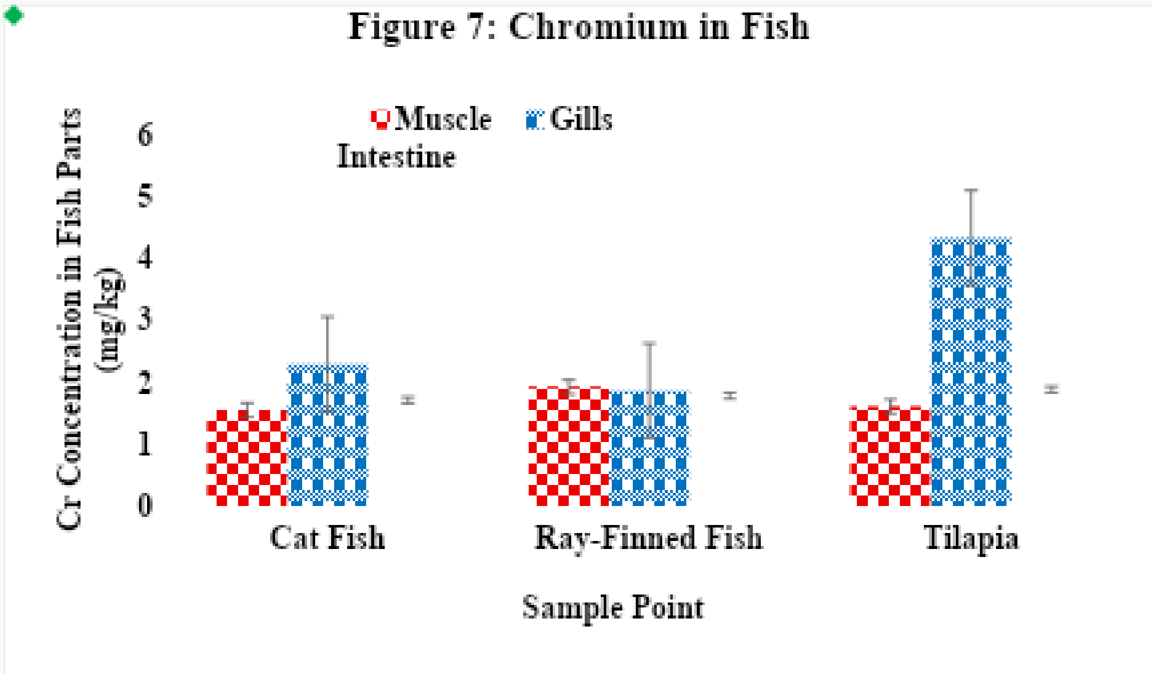
**Cadmium Concentrations in Fish**




- The highest fish Cd concentration was 6.31 ± 1.79 mg/kg in the ray-finned fish intestine.
- Tilapia contained 3.62 ± 0.50 mg/kg Cd in gills, 2.90 ± 0.54 mg/kg in muscle, and 2.59 ± 3.08 mg/kg in intestine.
- Catfish contained 3.05 ± 1.64 mg/kg Cd in muscle, 1.42 ± 0.39 mg/kg in gills, and 1.65 ± 0.27 mg/kg in intestine.
- Ray-finned fish muscle and gills contained 1.21 ± 1.60 mg/kg and 1.65 ± 0.21 mg/kg Cd, respectively.

The high concentration in ray-finned fish intestine may reflect exposure through contaminated food particles or water, but the available data cannot distinguish cadmium in intestinal contents from cadmium incorporated into intestinal tissue. Experimental evidence indicates that waterborne cadmium can accumulate in fish intestines and cause intestinal toxicity (Yu et al., 2021).

**Chromium Concentrations in Fish**




The highest fish Cr concentration was 4.32 ± 2.39 mg/kg in tilapia gills.

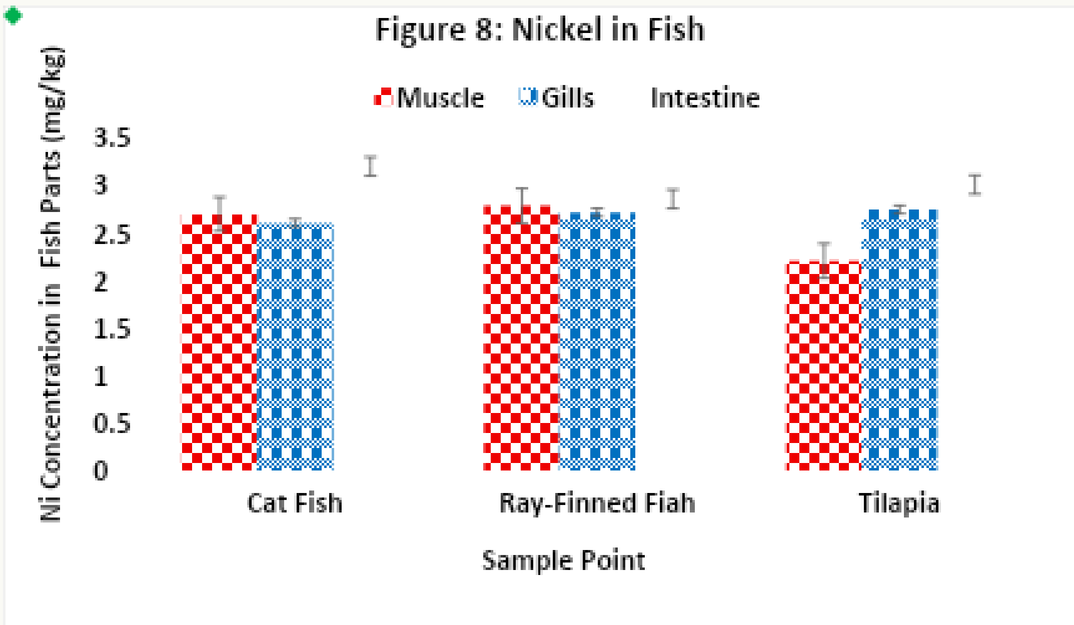
Catfish contained 1.55 ± 0.86 mg/kg Cr in muscle, 2.29 ± 0.85 mg/kg in gills, and 1.71 ± 0.60 mg/kg in intestine.

Ray-finned fish contained 1.92 ± 0.23 mg/kg in muscle, 1.86 ± 0.53 mg/kg in gills, and 1.78 ± 0.28 mg/kg in intestine.

Tilapia contained 1.61 ± 0.90 mg/kg Cr in muscle and 1.88 ± 0.55 mg/kg in intestine in addition to the gill concentration of 4.32 ± 2.39 mg/kg.

The high gill concentration may indicate substantial contact with waterborne chromium, but the present measurements do not establish the chemical form or source of chromium. Total chromium should therefore not be treated as an equivalent measure of Cr(VI) exposure without speciation analysis (EFSA, 2020).

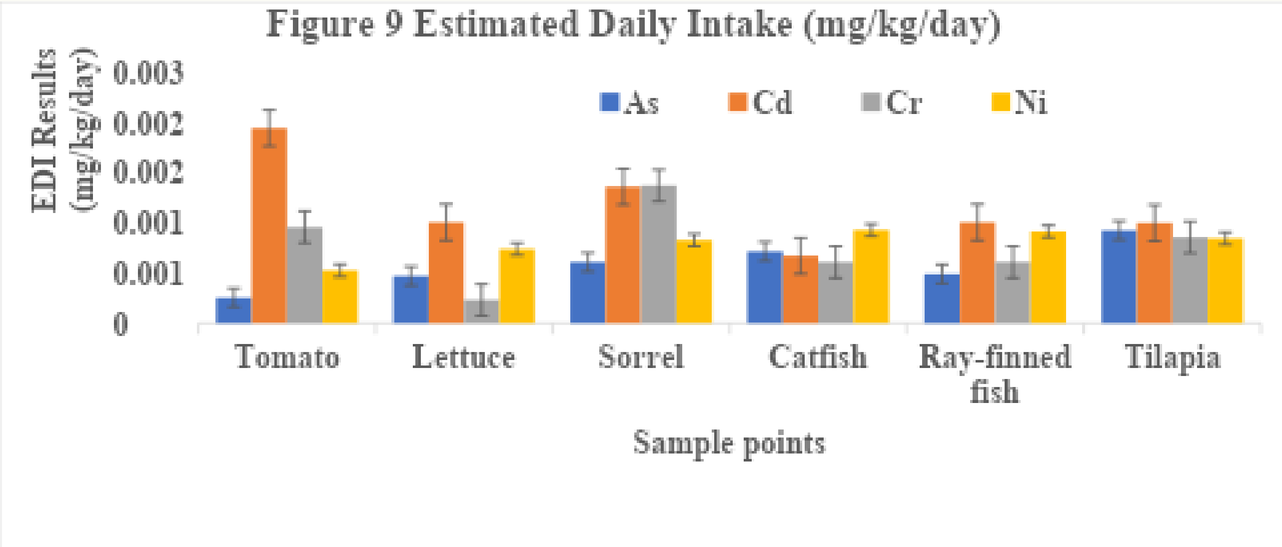
**Nickel Concentrations in Fish**



- The highest fish Ni concentration was 3.19 ± 1.25 mg/kg in catfish intestine, followed by 2.58 ± 0.48 mg/kg in catfish muscle.
- Tilapia contained 2.20 ± 1.45 mg/kg Ni in muscle, 1.77 ± 1.34 mg/kg in gills, and 1.80 ± 1.16 mg/kg in intestine.
- Ray-finned fish contained 1.37 ± 0.28 mg/kg Ni in muscle, 1.18 ± 0.32 mg/kg in gills, and 1.93 ± 1.06 mg/kg in intestine.

The relatively high intestinal Ni concentration in catfish is compatible with a possible contribution from dietary or sediment-associated exposure. However, water, sediment, and prey organisms were not analyzed, so the dominant exposure pathway cannot be confirmed.

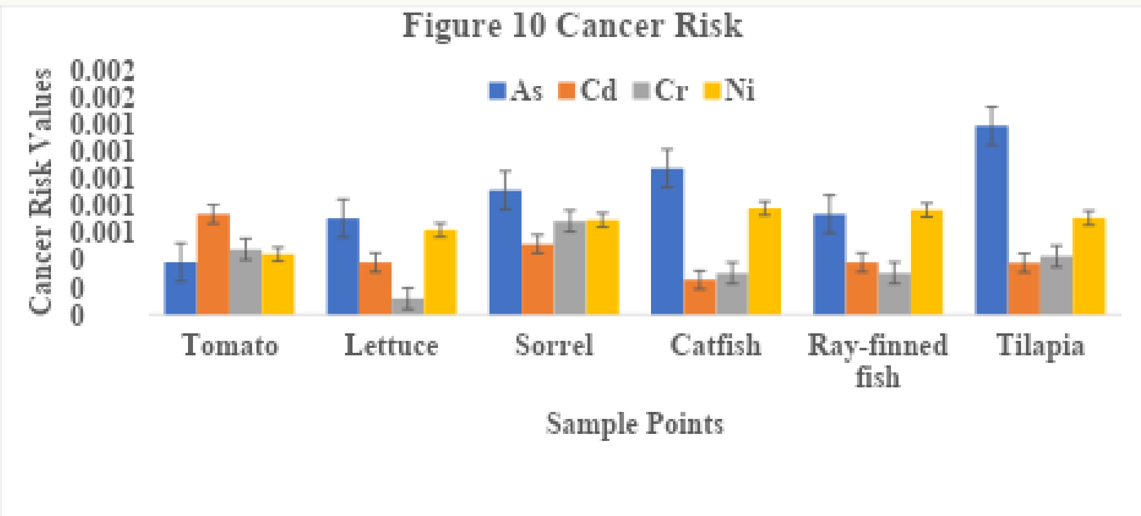
**Estimated Daily Intake**




- The estimated daily intake for As was highest in tilapia at 0.000926 mg/kg/day. The EDI for Cd was highest in tomato at 0.001946 mg/kg/day, the EDI for Cr was highest in sorrel at 0.001374 mg/kg/day, and the EDI for Ni was highest in catfish at 0.000931 mg/kg/day.

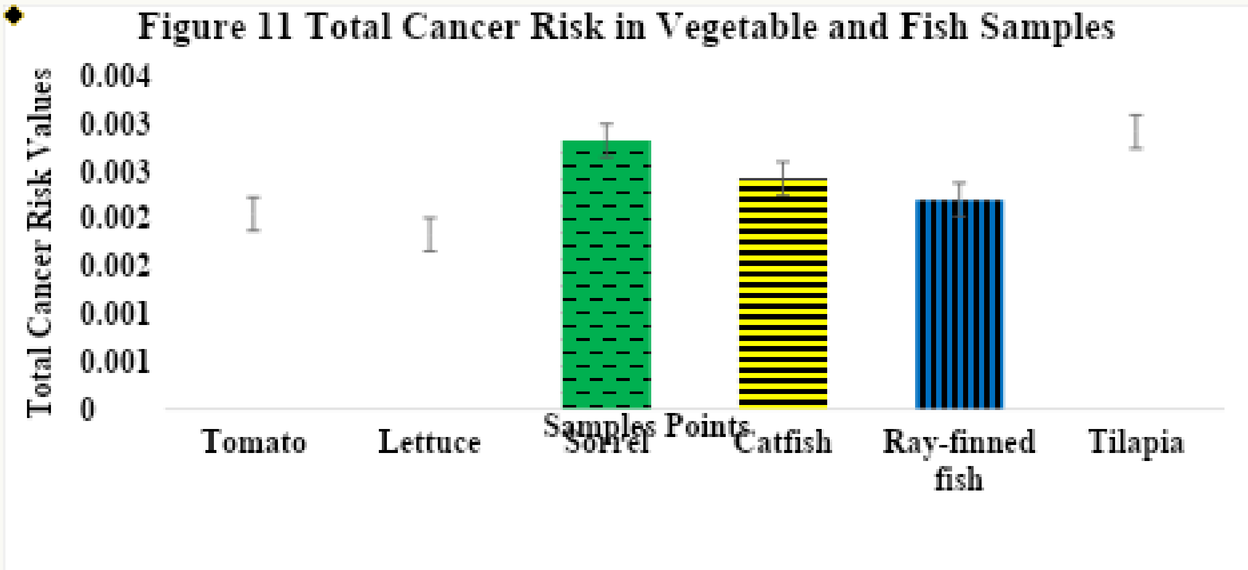
The EDI pattern indicates that exposure was distributed across fish and vegetables rather than being attributable to a single food group. This supports the use of a combined food-basket approach for communities that consume several locally sourced commodities (WHO, 2020).

**Cancer Risk**



- The highest individual As cancer-risk value was 0.001389 in tilapia. The highest Cd cancer-risk value was 0.000739 in tomato, the highest Cr cancer-risk value was 0.000687 in sorrel, and the highest Ni cancer-risk value was 0.000782 in catfish.

**Total Cancer Risk**




- The TCR values were 0.001830 for lettuce, 0.002196 for ray-finned fish, 0.002418 for catfish, 0.002816 for sorrel, and 0.002909 for tilapia.

Tilapia therefore had the highest reported TCR at 0.002909, while lettuce had the lowest reported TCR at 0.001830. These values are model-based screening estimates because they depend on the selected slope factors, intake assumptions, exposure duration, averaging time, and treatment of arsenic and chromium species (WHO, 2020; EFSA, 2020).

**Discussion**

The present study evaluated Nguru Wetlands as a combined dietary exposure system rather than treating fish and vegetables as unrelated commodities. This approach is appropriate because the sampled foods originate from the same wetland environment and may be affected by shared contamination pathways involving irrigation water, surface runoff, sediment transport, or other environmental inputs.

- The vegetable results indicate that roots were important accumulation sites for all four metals. Sorrel root contained 3.76 ± 0.96 mg/kg As, 8.55 ± 4.78 mg/kg Cd, 8.30 ± 4.78 mg/kg Cr, and 3.78 ± 1.28 mg/kg Ni, while tomato root contained 2.52 ± 1.67 mg/kg As, 9.41 ± 0.00 mg/kg Cd, 4.89 ± 1.70 mg/kg Cr, and 2.58 ± 0.48 mg/kg Ni.
- The occurrence of metals in edible plant parts is more directly relevant to dietary exposure than concentrations in roots that are not normally consumed. Tomato fruit contained 0.10 ± 0.64 mg/kg As, 4.82 ± 4.13 mg/kg Cd, 2.78 ± 1.62 mg/kg Cr, and 1.62 ± 1.23 mg/kg Ni. Lettuce leaf contained 1.29 ± 0.36 mg/kg As, 0.90 ± 0.42 mg/kg Cd, 0.37 ± 0.32 mg/kg Cr, and 1.80 ± 1.16 mg/kg Ni, while sorrel leaf contained 0.80 ± 0.31 mg/kg As, 0.60 ± 0.56 mg/kg Cd, 3.29 ± 2.29 mg/kg Cr, and 1.88 ± 1.41 mg/kg Ni.
- These results show that the exposure assessment should focus on the plant parts actually consumed and should not rely solely on whole-plant averages. The results also demonstrate why food-preparation practices and consumption patterns should be incorporated into future exposure assessments.

- The fish results reveal a different exposure pattern. Tilapia was the dominant fish contributor for arsenic and chromium, with gill concentrations of 3.47 ± 0.89 mg/kg As and 4.32 ± 2.39 mg/kg Cr. Ray-finned fish had the highest cadmium concentration in the intestine at 6.31 ± 1.79 mg/kg, while catfish had the highest nickel concentration in the intestine at 3.19 ± 1.25 mg/kg.
- These differences may reflect species-specific habitat use, feeding behavior, and tissue physiology. However, the present study did not measure water, sediment, or dietary sources, so these mechanisms should be treated as plausible interpretations rather than demonstrated pathways.
- The high cadmium concentration in ray-finned fish intestines deserves cautious interpretation. The intestine may accumulate cadmium because it is exposed to ingested contaminated food, sediment particles, and dissolved contaminants. However, the reported analysis does not clarify whether intestinal contents were removed before digestion. Experimental research has shown that waterborne cadmium can accumulate in fish intestine and cause intestinal injury, demonstrating that gastrointestinal tissues can be important cadmium-exposure compartments (Yu et al., 2021).
- The EDI results indicate that no single commodity accounted for the highest exposure to all metals. Tilapia was the leading reported contributor to As exposure at 0.000926 mg/kg/day, tomato was the leading contributor to Cd exposure at 0.001946 mg/kg/day, sorrel was the leading contributor to Cr exposure at 0.001374 mg/kg/day, and catfish was the leading contributor to Ni exposure at 0.000931 mg/kg/day.
- This distribution supports the conclusion that risk-management measures should address the combined local diet rather than focus exclusively on fish or vegetables. Dietary exposure assessment is most useful when consumption rates, body weight, portion size, and exposure duration are appropriately represented (WHO, 2020).
- The reported TCR values indicate that combined-metal exposure contributed substantially to the screening-level risk estimates. Tilapia had the highest TCR at 0.002909, followed by sorrel at 0.002816, catfish at 0.002418, ray-finned fish at 0.002196, and lettuce at 0.001830.
- These values should not be interpreted as measured cancer incidence or as precise predictions for every consumer. Cancer-risk estimates are sensitive to assumptions about consumption, body weight, exposure duration, averaging time, and toxicity values (WHO, 2020).
- The chromium results require particular caution. The study measured total chromium, but chromium toxicity depends strongly on chemical form, and the available data cannot determine whether the measured chromium was predominantly Cr(III), Cr(VI), or another species. Therefore, the Cr-related cancer-risk estimates should be considered screening values rather than definitive evidence of dietary Cr(VI) exposure (EFSA, 2020; IARC, 2012).
- The arsenic results also require speciation caution. The study reported total arsenic concentrations but did not separate inorganic arsenic from organic arsenic species. Because arsenic species differ in toxicological significance, future work should include arsenic speciation if the objective is to produce a refined cancer-risk assessment (EFSA, 2020).
- The analytical procedure provides a useful preliminary assessment, but a journal-level risk study would be strengthened by reporting limits of detection, limits of quantification, certified reference materials, recovery percentages, procedural blanks, calibration statistics, and measurement uncertainty (El Hosry et al., 2023; FDA, 2020).

## LIMITATIONS

The sample size was limited to three specimens per target species or vegetable category. This restricts statistical generalization beyond the sampled locations and sampling period.

The study did not establish seasonal changes in metal concentrations. Wetland hydrology, flooding, irrigation practices, and sediment movement may vary over time, so repeated seasonal sampling would provide a more robust estimate of dietary exposure.

The analysis measured total concentrations without speciation of arsenic or chromium. Consequently, the results cannot identify the proportion of arsenic present as inorganic arsenic or the proportion of chromium present as Cr(VI) (EFSA, 2020).

The dietary-risk calculations used fixed body-weight and ingestion rate assumptions rather than measured consumption data from local households. The resulting EDI and TCR values should therefore be interpreted as scenario-based estimates rather than direct estimates for all residents (WHO, 2020).

## CONCLUSION

Fish and vegetables consumed in Nguru Wetlands contained measurable concentrations of arsenic, cadmium, chromium, and nickel, with substantial differences among commodities and tissues. The highest measured concentrations were 9.41 ± 0.00 mg/kg Cd in tomato root, 8.30 ± 4.78 mg/kg Cr in sorrel root, 3.78 ± 1.28 mg/kg Ni in sorrel root, 3.47 ± 0.89 mg/kg As in tilapia gills, 6.31 ± 1.79 mg/kg Cd in ray-finned fish intestine, 4.32 ± 2.39 mg/kg Cr in tilapia gills, and 3.19 ± 1.25 mg/kg Ni in catfish intestine.

The EDI results identified tilapia, tomato, sorrel, and catfish as the leading contributors to As, Cd, Cr, and Ni exposure, respectively. The reported TCR values ranged from 0.001830 in lettuce to 0.002909 in tilapia.

The findings support continued monitoring of fish and vegetables from Nguru Wetlands. Refined health-risk interpretation will require larger samples, seasonal sampling, validated analytical-quality data, local food-consumption surveys, and species-specific analysis of arsenic and chromium (El Hosry et al., 2023; FDA, 2020; EFSA, 2020).

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