Human health risk assessment of potentially toxic elements in vegetables irrigated with wastewater from an urban market drain in Zaria, Nigeria

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Abstract

The use of wastewater for the irrigation of vegetables is on the increase because of its richness in nutrients and it reduces the pressure on available freshwater resources. Untreated wastewater may, however, be a source of contamination of the vegetables by potentially toxic elements, which may, in turn, constitute a health risk to consumers. Samples of seven vegetables: cabbage, onion bulbs, bitter leaf, jute mallow, spinach, tomato, and lettuce irrigated with wastewater were collected and analysed for potentially toxic elements using Energy Dispersive X-ray Fluorescence. The Target Hazard Quotient (THQ) and Health Index (HI) were determined based on the estimated daily metal intake of Cd, Ni, Pb, Zn, Cu, Fe, Mg, and Mn through the consumption of these vegetables. Cancer Risk was assessed for Cd, Ni, and Pb. Except for Mg, for which no guideline value was found for vegetables, the concentration of Cu in cabbage and Mn in tomato were found to be within the permissible limit, whereas Cd, Ni, Pb, Zn, and Fe were found to be above the permissible limits of the FAO/WHO in all the vegetables. The Target Hazard Quotient (THQ) shows that adult consumers of all seven vegetables are at risk of non-carcinogenic toxicity of Cd, Ni, and Pb, while in children, the risk extends to Zn, Cu, Fe, and Mn (with tomato as the only exception for Mn). The Health Index being greater than 1 in all vegetables means there is a non-carcinogenic risk health risk associated with the consumption of all vegetables by children and adults. The Target cancer Risk shows that adults are exposed to cancer risk from the consumption of all the vegetables due to Ni and Cd contamination (except onion for cadmium), while in children, the risk extends to Pb (except for onion). The consumption of vegetables irrigated with untreated wastewater from the Sabon Gari market drain is an exposure route to potentially toxic elements such as Cd, Ni, Pb, Zn, Cu, Fe, and Mn, with resultant non-carcinogenic and carcinogenic health risks. These health risks were found to be higher in children.

Introduction

Vegetables are rich sources of carbohydrates, vitamins, minerals, and fibers, and also have beneficial antioxidative effects. They are part of the daily diet in many households due to their nutritive value and affordability and may be consumed raw or cooked with other condiments. Many trace metals such as copper (Cu), iron (Fe), Manganese (Mn), Nickel (Ni), and zinc (Zn) obtained from vegetables are essential for life as vital components of enzymes, while others such as cadmium (Cd) and lead (Pb) have no known benefits to life. The excessive accumulation of trace elements in vegetables and subsequent ingestion makes them potentially toxic to humans.

There is a global concern about the contamination of soil and surface water by wastewater, especially in developing countries. Discharge of untreated wastewater from industries and residential areas is on the increase due to unplanned development, and a large portion of this wastewater is discharged into nearby streams and rivers. Wastewaters have been reported to contaminate the receiving water bodies with heavy metals and other potentially toxic metals.

Due to the uneven distribution of rainfall in time and space, irrigation of vegetables in Northern Nigeria is usually done in the dry season to maintain an all-year-round supply of vegetables in Nigerian markets. The extensive dry season that lasts for six to nine months in northern Nigeria puts a lot of pressure on available water resources. This makes the use of wastewater from residential areas, markets, and industries available options for irrigation. These wastewaters are in most cases rich in organic matter, thus providing not only water for irrigation but a supplementary source of nutrients for the irrigated crops. Unfortunately, wastewater-
irrigated vegetables and other crops have been reported to be contaminated with heavy metals and other potentially toxic elements (PTE)\(^8,18−19\), and could become harmful to humans who feed on them\(^20\). Soils receiving wastewater for irrigation purposes have also been reported to be contaminated with cadmium, lead, chromium, and nickel\(^21\). PTEs have been reported to accumulate more in leafy vegetables irrigated with wastewater than those irrigated with freshwater\(^20,22\). Pesticides, herbicides, inorganic and mineral fertilizers have also been documented as important sources of PTEs in soils and cultivated crops\(^23−25\).

Many wastewater drains in Nigeria have become important sources of water for irrigation during the extensive dry season (November to April). These drains convey effluents from industries, residential areas, abattoirs, and urban markets, and have been reported to be contaminated with heavy metals\(^26−28\). The investigated area, Sabon Gari Market drain is a unique ecosystem that has a consistent supply of wastewater throughout the extended dry season but has been poorly studied. Most studies in the tropics focus on large water bodies, with less attention given to urban drains and seasonal rivers. The absence of regulations and monitoring on the use of wastewater for irrigation of crops in Nigeria gives a lot of concern because of the acute and chronic effects it will have on the three pillars of sustainability: environmental, social, and economic. The generation of data on the bioaccumulation of heavy metals in vegetables irrigated with wastewater from this location will be an important step in the development of policies for the monitoring of wastewater used for irrigation. This study aims to assess the human health risk associated with the consumption of vegetables irrigated with untreated wastewater from the Sabon Gari market drain in Zaria, northern Nigeria.

**Materials And Methods**

**Study area.** The study was carried out in Zaria metropolis, Kaduna State, northwest Nigeria. Zaria is located on the high plains of Northern Nigeria, 652.6 Meters above sea level, some 950km away from the coast, 128 km southeast of Kano, and 64km northeast of Kaduna. Zaria has a northern guinea savannah vegetation type, with a tropical continental climate, comprising defined wet and dry seasons. The extensive dry season (November to April) necessitates the irrigation of vegetable crops to meet the high demand, locally and nationally.

**Sample collection, preparation, and elemental analysis.** Triplicate samples of *Brassica oleraceae* (ABU09056), *Amaranthus hybridus* (ABU090023), *Allium cepa* (ABU01688), *Solanum lycopersicum* (ABU02582), *Chorchorus olitorius* (ABU01108), *Vernonia amygdalina* (ABU06300), and *Lactuca sativa* (ABU02590) were collected from the irrigation fields around the Sabon Gari Market drain (Longitude 11° 30′ N and Latitude 7° 42′ E) from two sampling stations (upstream and downstream) for metal analysis. Identification of plant samples was done in the Ahmadu Bello University (ABUH) herbarium, Department of Botany, Ahmadu Bello University, Zaria. The Vegetable samples were rinsed repeatedly with deionized water to remove debris and surface contaminants. Samples of the same species were then bulked and air-dried to remove excess moisture. Dried vegetable samples were ground using a porcelain mortar and pestle and sieved to attain a uniform particle size. Each sample was put in a small transparent polythene bag and labeled. Analysis of the elemental content of the samples was done using the Energy-dispersive X-ray fluorescence Spectroscopy (EDXRF) method. Pellets of 19mm diameter were prepared from 0.3-0.5kg powder mixed with three drops of organic liquid binder and pressed at 10 tons of pressure in a hydraulic press. Measurements were performed using an annular 25mCi 109Cd as the excitation source, which emits Ag elements was pKeV in which case all elements with lower characteristic excitation energies are accessible for detection in the samples. The system consists furthermore of Si (Li) detector, with a resolution of 170eV for the 5.90KeV line, coupled to a computer-controlled ADC quantitative analysis of the sample done using...
the Emission Transmission (E-T) method that involves the use of pure target material (Mo) to measure the absorption factors in the sample. The Mo target served as a source of monochromatic X-rays, which are excited through the sample by primary radiation and then penetrate the samples on the way to the detector. In this way, the absorption factor is experimentally determined which the program uses in the quantification of the concentration of the elements. In addition, the contribution to the Mo-K peak intensity by the Zr-K is subtracted for each sample. Sensitivity calibration of the system was performed using thick pure metal foils (Ti, Fe, Co, N, Zn, Nb, Zr, Mo, Sn, Ta, and Pb) and stable chemical compounds (K₂CO₃, CaCO₃, Ce₂O₃, WO₃, ThO₂, U₃O₃). The spectra for the samples were collected for 3000s with the 109Cd source and the spectra were then evaluated using the AXIL-QXAS program. 109Cd source was used for the analysis of K, Th, Y, Zr, Nb, and Mo. The explained procedure is based on the protocol of the International Atomic Energy Agency (IAEA)²⁹. Experimental and field studies complied with relevant institutional, national, and international guidelines and legislation.

**Estimated Daily Metal Intake assessment.** The Estimated Daily Metals Intake (EDI) (mg metal/kg body weight/day) which is the estimated daily intake of metal was calculated as follows:

\[ EDI = \frac{C_m X Cf X IR X Ef X De}{Wb X Tav} X 0.001 \]  

Where \( C_m \) represents the metal concentration (mg/kg of dry weight), \( Ef \) represents the exposure frequency (365d/a), \( De \) represents the exposure duration (70), and \( Tav \) represents the average time of exposure (365 days \( \times \) 65). IR represents the average food consumption (300–350 g/person/day)³⁰. In this study, we used the mean of this consumption as 2.2 g/person/day¹⁶, \( Cf \) represents the conversion factor of vegetables into dry weight (0.085)²⁰ and \( Wb \) represents the average body weight of consumers (Adult- 70, Child:15 kg)³¹.

**Target Hazard Quotient (THQ).** The THQ, which is defined as the proportion of probable exposure to heavy metals and concentration at which no negative effect is expected, was calculated as per²⁰:

\[ \text{Target Hazard Quotient (THQ)} = \frac{\text{DIM}}{\text{RfD}} \]  

Where THQ is Target Hazard Quotient, DIM is the average daily intake of metal (mg/kg/day) and RfD is the oral reference dose of the metal (mg/kg/day). The RfD values of 0.0005, 0.004, 0.004, 0.02, 0.7, 0.14, and 0.3 mg/kg/day for Cd, Pb, Cr, Ni, Fe, Mn, and Zn⁸,¹⁶,³².

**Hazard Index (HI).** The HI which is a summation of exposures to more than one pollutant was determined by the addition of THQ values as described by¹⁶. HI is used to estimate the potential heavy metals have on human risks and is the summation of THQs:

\[ HI = (\text{THQ}_i + \text{THQ}_{ii} + \text{THQ}_{iii} \ldots \text{THQ}_{n}) \sum \text{THQ} \]  

Where HI is the hazard index, THQ is the target hazard quotient, and \( \sum \text{THQ} \) is the summation of the target hazard quotients. HI values greater than one, are not acceptable because it is a sign that the metal in question will have a negative health impact on consumers

**Cancer Risk (CR) Assessment.** Cancer Risk was calculated as

\[ CR = \text{DMI} \times \text{CPS} \]  

Where DMI is the estimated daily metal intake and CPS is the Oral cancer slope factor 0.38. 0.0085, 1.7, and 0 (for Cd, Pb, Ni, and Zn, respectively)⁵,³³. Cancer Risk for other metals (Cu, Fe, Mn, and Mg) where not computed due to
the absence of CPS.

**Results And Discussion**

The concentration of potentially toxic elements in vegetables. The concentration of Cd was observed to have the lowest concentration of 3 mg/kg in onion bulbs and the highest of 72 mg/kg in cabbage leaves. Tomato fruits were observed to have the lowest concentration of Ni (38 mg/kg) while lettuce leaves had the highest concentration (575 mg/kg). Onions bulbs had the lowest concentration of Pb (12 mg/kg) while the maximum was recorded in spinach leaves (266 mg/kg). Zn concentration had a range between 102 mg/kg in onion bulbs and 887 mg/kg in bitter leaf leaves. The concentration of Cu ranged from 15 mg/kg in cabbage leaves to 231 mg/kg in Jute mallow leaves. Fe and Mn had the highest concentration of 7932 and 663 mg/kg in bitter leaf leaves, respectively. Fe had the lowest in Jute mallow leaves, 1506 mg/kg, while Mn had the lowest concentration of 7 mg/kg in tomato fruit. Lettuce leaves had the highest concentration of 6234 mg/kg of Mg while the lowest of 1939 mg/kg was obtained in onions leaves (Table 1). With the exceptions of Mg, for which no guideline value was found for vegetables, Cu in cabbage, and Mn in tomato, the other metals (Cd, Ni, Pb Zn, and Fe) were found in concentrations above the permissible limits of the \( \text{FAO/WHO Allowable concentration (mg/kg)} \) in all the vegetables sampled. The above allowable concentration of Cd, Ni, Pb Zn, Cu, Fe and Mn concentration in the seven vegetables analysed may be attributed to the use of untreated wastewater for the irrigation of these vegetables and possibly from the use of manure from incinerated dumpsites as fertilizer. Wastewater and manure have been reported to be rich in nutrients nitrogen and phosphorus \(^{16} \) but have been implicated to be important sources of potentially toxic metals to irrigated crops \(^{8,34-36} \).

### Table 1

Concentration of potentially toxic metals in vegetables (mg/kg) irrigated with wastewater in Zaria Nigeria

<table>
<thead>
<tr>
<th>Botanical name</th>
<th>Common Name</th>
<th>Plant Part</th>
<th>Cd</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brassica oleracea</td>
<td>Cabbage</td>
<td>Leaves</td>
<td>72</td>
<td>121</td>
<td>157</td>
<td>417</td>
<td>15</td>
<td>3067</td>
<td>92</td>
<td>3356</td>
</tr>
<tr>
<td>Allium cepa</td>
<td>Onions</td>
<td>Bulb</td>
<td>3</td>
<td>338</td>
<td>12</td>
<td>102</td>
<td>27</td>
<td>2203</td>
<td>67</td>
<td>1939</td>
</tr>
<tr>
<td>Vernonia amygdalina</td>
<td>Bitter leaf</td>
<td>Leaves</td>
<td>31</td>
<td>459</td>
<td>185</td>
<td>887</td>
<td>179</td>
<td>7932</td>
<td>663</td>
<td>4227</td>
</tr>
<tr>
<td>Corchurus olitorius</td>
<td>Jute mallow</td>
<td>Leaves</td>
<td>28</td>
<td>411</td>
<td>155</td>
<td>201</td>
<td>231</td>
<td>1561</td>
<td>186</td>
<td>2006</td>
</tr>
<tr>
<td>Amaranthus tricolor</td>
<td>Spinach</td>
<td>Leaves</td>
<td>39</td>
<td>284</td>
<td>266</td>
<td>391</td>
<td>92</td>
<td>2975</td>
<td>163</td>
<td>5840</td>
</tr>
<tr>
<td>Solanum lycopersicon</td>
<td>Tomato</td>
<td>Fruit</td>
<td>25</td>
<td>38</td>
<td>149</td>
<td>365</td>
<td>56</td>
<td>2289</td>
<td>7</td>
<td>2257</td>
</tr>
<tr>
<td>Lactuca sativa</td>
<td>Lettuce</td>
<td>Leaves</td>
<td>34</td>
<td>575</td>
<td>215</td>
<td>447</td>
<td>60</td>
<td>1506</td>
<td>416</td>
<td>6234</td>
</tr>
<tr>
<td>FAO/WHO Allowable concentration (mg/kg)</td>
<td></td>
<td></td>
<td>0.05</td>
<td>10</td>
<td>0.1–0.3</td>
<td>2.3–50</td>
<td>40</td>
<td>42.5</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Cd and Pb have no known use in the human body but have been reported to be toxic even at low concentrations \(^6 \). Cadmium has been reported to be an important carcinogen among order human health problems such as kidney...
The earliest report of cadmium toxicity is the “itai-itai” disease, reported in the 1970s (McLaughlin and Singh, 1999). Wastewater may become contaminated with lead through metal smelting, battery recycling, or deposition of scrap electronic devices in waterways. Acute Pb toxicity may lead to the destruction of red blood cells and consequently anaemia, failure in renal and neurological systems, pedagogical limitations seizures, and death.

Ni, Zn, Cu, Fe, and Mn are essential trace elements in man, other animals, and plants. They play vital roles in enzymatic processes, growth, and various development stages. They have all been reported to have adverse effects on man at high concentrations, for example, Mn causes liver cirrhosis, polycythemia, dystonia, and symptoms similar to Parkinson’s disease; risk of Ni contamination includes fibrosis, bronchitis, emphysema, and impaired pulmonary function; carriers of genes of metabolic diseases such as Wilson disease have disorders of copper homeostasis may suffer some long term effects due above threshold concentration in intestinal tracks.

**Health risk assessment. Non-carcinogenic risk.** The Estimated Daily metal Intake (DMI) for adults and children of all the potentially toxic metals from the consumption of these vegetables is provided in Table 2. The highest values of the EDI of metals were observed in Fe, Mn, and Mg. The EDI of Cd and Pb in all the vegetables were observed to be higher than the recommended values while those of Ni and Zn were lower. Except for the EDI of Ni in onions, spinach, and lettuce for children, all EDI of Ni in other vegetables were found to be higher than the recommended levels for adults and children. The EDI of Ni, Zn, and Cu in all the vegetables studied was found to be below the upper tolerable daily limit in both adults and children. Only the EDI of Cd in spinach (for children) was found to be above the upper tolerable daily limit in all the studied vegetables, while the EDI of Pb in children through the consumption of Cabbage, Bitter leaf, Jute mallow, Spinach, tomato, and lettuce were higher than the upper tolerable daily limit. An upper tolerable daily limit is not available for Cr, Fe, Mn, and Mg. Based on the EDI of these metals through the studied vegetables, children are more exposed to health risks via the consumption of these vegetables. Sick/weak adults and pregnant women may be vulnerable to the toxicity of potentially toxic metals.
Table 2
Estimated Daily metal Intake of potentially toxic metals (DMI) (mg/day/kg dry weight) for adults and children by consumption of contaminated vegetables irrigated with wastewater

<table>
<thead>
<tr>
<th>Plant</th>
<th>Cd</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabbage</td>
<td>0.03</td>
<td>0.04</td>
<td>0.06</td>
<td>0.20</td>
<td>0.01</td>
<td>1.00</td>
<td>0.03</td>
<td>1.00</td>
</tr>
<tr>
<td>Onions</td>
<td>0.00</td>
<td>0.10</td>
<td>0.00</td>
<td>0.04</td>
<td>0.01</td>
<td>0.80</td>
<td>0.02</td>
<td>0.70</td>
</tr>
<tr>
<td>Bitter leaf</td>
<td>0.01</td>
<td>0.20</td>
<td>0.07</td>
<td>0.30</td>
<td>0.07</td>
<td>3.00</td>
<td>0.20</td>
<td>2.00</td>
</tr>
<tr>
<td>Jute mallow</td>
<td>0.01</td>
<td>0.20</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.60</td>
<td>0.07</td>
<td>0.70</td>
</tr>
<tr>
<td>Spinach</td>
<td>0.01</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>0.03</td>
<td>1.00</td>
<td>0.06</td>
<td>2.00</td>
</tr>
<tr>
<td>Tomato</td>
<td>0.01</td>
<td>0.01</td>
<td>0.05</td>
<td>0.10</td>
<td>0.02</td>
<td>0.80</td>
<td>0.00</td>
<td>0.80</td>
</tr>
<tr>
<td>Lettuce</td>
<td>0.01</td>
<td>0.20</td>
<td>0.08</td>
<td>0.20</td>
<td>0.02</td>
<td>0.60</td>
<td>0.20</td>
<td>2.00</td>
</tr>
<tr>
<td>Child</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabbage</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
<td>0.70</td>
<td>0.03</td>
<td>5.00</td>
<td>0.20</td>
<td>6.00</td>
</tr>
<tr>
<td>Onions</td>
<td>0.01</td>
<td>0.60</td>
<td>0.02</td>
<td>0.20</td>
<td>0.05</td>
<td>4.00</td>
<td>0.10</td>
<td>3.00</td>
</tr>
<tr>
<td>Bitter leaf</td>
<td>0.05</td>
<td>0.80</td>
<td>0.30</td>
<td>2.00</td>
<td>0.30</td>
<td>10.00</td>
<td>1.00</td>
<td>7.00</td>
</tr>
<tr>
<td>Jute mallow</td>
<td>0.05</td>
<td>0.70</td>
<td>0.30</td>
<td>0.30</td>
<td>0.40</td>
<td>3.00</td>
<td>0.30</td>
<td>3.00</td>
</tr>
<tr>
<td>Spinach</td>
<td>0.07</td>
<td>0.50</td>
<td>0.50</td>
<td>0.70</td>
<td>0.20</td>
<td>5.00</td>
<td>0.30</td>
<td>10.00</td>
</tr>
<tr>
<td>Tomato</td>
<td>0.04</td>
<td>0.07</td>
<td>0.30</td>
<td>0.60</td>
<td>0.10</td>
<td>4.00</td>
<td>0.01</td>
<td>4.00</td>
</tr>
<tr>
<td>Lettuce</td>
<td>0.06</td>
<td>1.00</td>
<td>0.40</td>
<td>0.80</td>
<td>0.10</td>
<td>3.00</td>
<td>0.70</td>
<td>10.00</td>
</tr>
</tbody>
</table>

Recommended daily intake: 0.00 0.50 0.00 8.00 0.90 - - -
Upper tolerable daily intake: 0.06 1.00 0.24 40.00 10.00 - - -

The DMI was used to calculate the Target Hazard Quotient (THQ), which is a ratio of the DMI to the Daily reference dose for each metal. The Target Hazard Quotient shows that consumers of these vegetables are at risk of consuming multiple times higher concentrations of such metals from eating such vegetables. In adults, the consumption of these vegetables translates into ingestion of 1 to 26 times the daily reference dose of Cd; 1 to 11 times that of Ni; 1 to 23 times that of Pb; 0 to 1 of Zn; 0 to 2 of Cu and Mn; and 1 to 4 of Fe. While in children, the risk is 5 to 124 times the reference dose for Cd; 3 to 49 times for Ni; 6 to 130 times the daily reference dose for Pb; 1 to 5 times for Zn; 1 to 10 times for Cu; 4 to 19 times for Fe and 0 to 8 times for Mn (Table 3). A THQ that is 1–5 times higher than the Df is considered of low health risk; 5–10, moderate risk and; if greater than 10, considered high risk

Based on the THQ, there is a low risk of cadmium toxicity when onion bulbs from this irrigated field are consumed by adults, while there is a moderate risk when tomato fruits and jute mallow are consumed. Adult consumers of cabbage, bitter leaf, spinach, and lettuce grown from this location are exposed to a high risk of cadmium toxicity. Adults consuming cabbage, spinach, and tomato fruits cultivated in this area are exposed to a low risk of Ni toxicity based on the THQ. Those consuming onion bulbs, bitter leaves, and jute mallow are associated with high risk, whereas those that consume lettuce are of high risk. Adults consuming onions are exposed to low risk as compared to those consuming all other vegetables in this study are exposed to high risk of Pb poisoning. Adults consuming any of the seven vegetables in this study fall between no risk to low
risk of Zn, Cu, Fe, and Mn toxicity. In children, only onion bulbs are of a low health risk as it relates to cadmium toxicity, all the other vegetables are of high health risk. Tomato is considered of low health risk to Ni, while cabbage is of moderate health risk and all other five are of high health risk when consumed by children. As regards health risks associated with Pb, only onions are of moderate health risk, all other six vegetables are of high risk for child consumption. Except for the bitter leaf which is of high health risk based on THQ, all other vegetables fall between low to moderate health risk for Zn, Cu, Fe, and Mn (Table 3).

Table 3

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Target Hazard Quotient</th>
<th>HI</th>
<th>Target Hazard Quotient</th>
<th>HI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult</td>
<td></td>
<td>Child</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cd</td>
<td>Ni</td>
<td>Pb</td>
<td>Zn</td>
</tr>
<tr>
<td>Cabbage</td>
<td>26</td>
<td>2</td>
<td>16</td>
<td>1</td>
</tr>
<tr>
<td>Onions</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Bitter leaf</td>
<td>11</td>
<td>8</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Jute mallow</td>
<td>10</td>
<td>8</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Spinach</td>
<td>14</td>
<td>5</td>
<td>28</td>
<td>0</td>
</tr>
<tr>
<td>Tomato</td>
<td>9</td>
<td>1</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>Lettuce</td>
<td>12</td>
<td>11</td>
<td>23</td>
<td>1</td>
</tr>
</tbody>
</table>

THQ is acceptable if it does not exceed one, otherwise, the consumption of such vegetable with THQ > 1 constitutes a health risk. Based on this categorization, most of the vegetables fall outside the acceptable value for most of the metals (Table 3).

The Health Index (HI) for the consumption of each of these vegetables is greater than 1 and follows this order onion < tomato < Jute mallow < bitter leaf < lettuce < spinach in both adults and children (Table 3). It represents the combined effects of the consumption of potentially toxic metals from contaminated vegetables. Based on the HI of all the vegetables from this study, the consumption of these vegetables by adults or children has a non-carcinogenic health risk.

Lower EDI, THQ, and HI were recorded by in leafy vegetables grown and sold in Nigeria, respectively. Comparable values were recorded by for Cd in cabbage irrigated with wastewater in India.

Carcinogenic risk. Target Cancer Risk (TCR) in adults who consume each of these vegetables is \( \geq 10^{-3} \) for Cd (except onion bulbs) and Ni but \( < 10^{-3} \) for Pb. While in children, except Pb in onion, the TCR for Cd, Ni, and Pb are \( \geq 10^{-3} \) in all other vegetables (Table 4). TCR values \( \leq 10^{-6} \) are considered low cancer risk, values between \( 10^{-5} \) to \( 10^{-4} \) are considered of moderate cancer risk while values between \( 10^{-3} \) to \( 10^{-1} \) are considered of high cancer risk. Based on the TCR, the consumption of all vegetables by adults constitutes a high cancer risk due to
Cd and Ni (except onion for Cd). Children who consume these vegetables are also exposed to high cancer risk due to Cd, Ni, and Pb (except Onion for Pb). There is no cancer risk associated with all the vegetables in both adults and children due to Zn, in this study.

**Conclusion**

The concentrations of cadmium, nickel, lead, zinc, copper, iron, manganese, and magnesium determined in wastewater-irrigated cabbage, onion, bitter leaf, jute mallow, spinach, tomato, and lettuce were found to be above WHO/FAO recommended levels for human consumption. Non-carcinogenic (estimated daily intake, Target Hazard Quotient, and Health Index) and carcinogenic (Target Cancer Risk) risk assessments show that consumers of these vegetables are at great health risk, with the child population of consumers at greater risk.

**Table 4**

Target cancer risk of potentially toxic metals by consumption of contaminated vegetables. Bold values indicate cancer risk.

<table>
<thead>
<tr>
<th>Plant species</th>
<th>Adult Cd</th>
<th>Adult Ni</th>
<th>Adult Pb</th>
<th>Child Cd</th>
<th>Child Ni</th>
<th>Child Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabbage</td>
<td>1.01E-02</td>
<td>7.56E-02</td>
<td>4.91E-04</td>
<td>4.69E-02</td>
<td>3.53E-01</td>
<td>2.29E-03</td>
</tr>
<tr>
<td>Onions</td>
<td>4.19E-04</td>
<td>2.11E-01</td>
<td>3.75E-05</td>
<td>1.96E-03</td>
<td>9.86E-01</td>
<td>1.75E-04</td>
</tr>
<tr>
<td>Bitter leaf</td>
<td>4.33E-03</td>
<td>2.87E-01</td>
<td>5.78E-04</td>
<td>2.02E-02</td>
<td>1.34E+00</td>
<td>2.70E-03</td>
</tr>
<tr>
<td>Jute mallow</td>
<td>3.91E-03</td>
<td>2.57E-01</td>
<td>4.84E-04</td>
<td>1.83E-02</td>
<td>1.20E+00</td>
<td>2.26E-03</td>
</tr>
<tr>
<td>Spinach</td>
<td>5.45E-03</td>
<td>1.77E-01</td>
<td>8.31E-04</td>
<td>2.54E-02</td>
<td>8.28E-01</td>
<td>3.88E-03</td>
</tr>
<tr>
<td>Tomato</td>
<td>3.49E-03</td>
<td>2.37E-02</td>
<td>4.66E-04</td>
<td>1.63E-02</td>
<td>1.11E-01</td>
<td>2.17E-03</td>
</tr>
<tr>
<td>Lettuce</td>
<td>4.75E-03</td>
<td>3.59E-01</td>
<td>6.72E-04</td>
<td>2.22E-02</td>
<td>1.68E+00</td>
<td>3.14E-03</td>
</tr>
</tbody>
</table>

**Declarations**

**Author contributions:**

YT- experimental design, plant sample collection, data analysis and writing of manuscript

KL- plant sample collection, metal analysis

BA- Manuscript writing

**Data availability**

Data will be made available from corresponding author on reasonable request

**Competing interests**

The authors declare no conflicting interests

**Additional information**
Correspondence and requests for materials should be addressed to YT.

The consent of the vegetable farmers was sought to collect vegetable samples for experimental purpose.

Mal. Umar Gallah of the Ahmadu Bello University Herbarium (ABUH) identified the plant specimens.

References


