ISSN Online: 2756-3898, ISSN Print: 2714-500X https://doi.org/10.47514/phyaccess.2024.4.2.013

Assessment of Trace Elements Concentration in Selected Vegetables from High and Low Cancer Prevalence Areas in Ondo State, Nigeria

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Received 18-10-2024
Accepted for publication 22-11-2024
Published 25-11-2024

Abstract

This study investigates the potential link between cancer incidence and trace elements and heavy metals intake from locally grown vegetables in Ondo West and Ondo East Local Government Areas of Ondo Stae, Nigeria. It builds on a 2019 study by Adeola and colleagues, which identified a significantly higher cancer incidence in Ondo West compared to Ondo East, with rates three times higher. Five commonly consumed vegetables—Solanum macrocarpon, Talinum triangulare, Amaranthus hybridus, Telfairia occidentalis, and Vernonia amygdalina—were sampled from 47 locations across both regions. The samples were oven-dried, digested, and analyzed using atomic absorption spectroscopy (AAS) to determine the mean concentrations of essential trace elements (magnesium, manganese, and zinc) and toxic heavy metals (lead and cadmium). The estimated daily intake (EDI), daily intake (DI), and chronic daily intake (CDI) were calculated and used to assess the incremental lifetime cancer risk (ILCR), non-cancer hazard quotient (HQ), and non-cancer health index (HI). Contributions to the recommended daily intake of magnesium, manganese, and zinc through vegetable consumption were 12.65%, 40.8%, and 9.6%, respectively, in Ondo West, and 13.7%, 47.7%, and 10.58%, respectively, in Ondo East. The total non-cancer health indices were 0.90 and 0.92 for Ondo West and Ondo East, respectively, indicating no significant non-cancer health risks from consuming these vegetables. However, the ILCR values were calculated as 0.000293 for Ondo West and 0.000416 for Ondo East, exceeding the threshold of 1.0×10^{-5}, suggesting a potential cancer risk. Despite this finding, the study could not account for the notably higher cancer prevalence in Ondo West.

Keywords: Trace elements; Heavy metals; Incremental lifetime cancer risk; Hazard quotient; Health index; Vegetable.

I. INTRODUCTION

Vegetables are a great source of vitamins, minerals, and fibres [1]. They provide nutrients and trace elements necessary for proper growth, body functions, and overall health maintenance [2]. Although vegetables are generally rich in essential trace elements needed for the body to function properly, they could equally contain toxic heavy metals, as contaminants, that are not necessarily beneficial to the body but harmful even in small amounts.

In Nigeria, particularly in the Southwestern region, Solanum Macrocapon (African eggplant), Talinum triangulare (Waterleaf), Amaranthus hybridus (Smooth Amaranth), Telfairia occidentalis (Fluted Pumpkin or Ugwu), and Vernonia amygdalina (Bitter Leaf) are commonly grown and consumed. These vegetables are rich in essential nutrients and offer significant health benefits, such as reducing inflammation, improving heart health, and boosting the immune system.

Solanum Macrocapon is a nutrient-rich vegetable high in fibre, aiding digestion and preventing constipation by promoting regular bowel movements. It contains bioactive compounds such as alkaloids, flavonoids, and phenolic acids, which exhibit potent anti-inflammatory effects by inhibiting pro-inflammatory enzymes and cytokines [3]–[8]. Additionally, the high antioxidant content of African eggplant helps combat oxidative stress, reducing the risk of chronic inflammation and cardiovascular diseases. This vegetable is also beneficial for heart health because of its ability to lower LDL cholesterol levels and regulate blood pressure [3]. Traditional uses of African eggplant include treating digestive problems, cardiac diseases, throat pain, hookworms, bronchitis, and asthma [3]; Talinum Triangulare, commonly known as waterleaf, is packed with essential vitamins such as A and C, calcium, and iron. It also contains dietary fibre and essential amino acids. Waterleaf is renowned for its antioxidant properties, which help protect cells from damage caused by free radicals. It aids in managing blood sugar levels, making it beneficial for individuals with diabetes [9]–[11]. The plant's anti-inflammatory properties help reduce inflammation, while its high vitamin A content supports healthy vision.

Additionally, the vitamin C in waterleaf boosts the immune system, enhancing the body's ability to fight off infections [11]. Amarantus Hybridus is a highly nutritious plant rich in protein, vitamins A, C, and K, folate, calcium, and iron. It also contains dietary fibre and essential amino acids [12]–[15]. Its high antioxidant levels protect against oxidative stress, while its fibre and potassium content help maintain healthy blood pressure and cholesterol levels, promoting heart health. The calcium in amaranth supports strong bones and teeth, and its anti-inflammatory compounds help reduce inflammation throughout the body [12], [13]. Telfairia occidentalis, locally called Ugwu is a vegetable loaded with protein, vitamins A, C, and E, calcium, iron, and potassium. It contains antioxidants and essential fatty acids, making it beneficial for various health aspects. Fluted pumpkin helps regulate blood sugar levels, which is particularly useful for people with diabetes [16]–[18]. Its rich vitamin and antioxidant content boosts the immune system, while its high iron levels prevent anaemia. The potassium in fluted pumpkin helps regulate blood pressure, contributing to heart health.

Furthermore, vegetable's bioactive compounds reduce inflammation in the body [16]–[18]. Veronica Amaygdalina is high in vitamins A, C, and E, calcium, iron, and antioxidants. It has strong antioxidant properties that protect cells from damage caused by free radicals and aid in managing blood sugar levels, making it beneficial for individuals with diabetes [19]–[22]. Bitter leaf also contains compounds with anti-cancer properties and is traditionally used to treat digestive issues, improving overall gut health. Furthermore, its anti-inflammatory properties help reduce inflammation in the body [19], [23], [24].

Essential trace elements such as Zinc (Zn) support immune health, protein and DNA synthesis, cell division, and wound healing, acting as a cofactor for over 300 enzymes [25]–[27], Copper (Cu) aids iron metabolism, production of haemoglobin, antioxidant defences, connective tissue maintenance, and nerve cell development [27], [28], Manganese (Mn) supports bone health, metabolic processes, collagen production, and brain function while protecting cells from oxidative stress [27], [29], Selenium (Se) contributes to antioxidant defences, thyroid function, DNA repair, immune response, and reproductive health [30]–[32], Magnesium (Mg) regulates muscle and nerve function, glucose control, blood pressure, and cardiovascular health, with dietary sources including nuts, seeds, and green leafy vegetables [33], and Iodine (I) is crucial for thyroid hormone production, regulating metabolism and supporting brain development during pregnancy and infancy [34]. Vegetables naturally absorb these elements from the soil, but imbalances due to deficiency or environmental contamination can pose health risks [35].

Heavy metals on the other hand, which are elements of relatively high atomic number, can be toxic even at low concentrations. Among the most toxic heavy metals, posing health concerns to the public are lead (Pb) [36], [37], cadmium (Cd) [38], mercury (Hg) [39], and arsenic (As) [40]. Vegetables can become contaminated with these metals through polluted soil, water, and air, often as a result of industrial pollution, pesticide use, and contaminated water sources. The accumulation of heavy metals in the body can lead to serious health issues, including neurological damage, kidney dysfunction, and cancer, with children and pregnant women being particularly vulnerable [36]–[40].

This study seeks to investigate the levels of essential elements and heavy metals in selected vegetables; Solanum Macrocapon, Talinum triangulare, Amaranthus hybridus, Telfairia occidentalis, and Vernonia amygdalina, commonly cultivated and consumed in two regions of Ondo town (Ondo East and Ondo West). The aim is to ascertain whether an imbalance in the intake of necessary trace elements and heavy metals could be responsible for the enhanced cancer prevalence in one of the two regions of interest (Ondo West) as reported in a previous study by Adeola and colleagues in [41]. In that study, the prevalence of cancer in Ondo West was found to be about three times that of Ondo East [41]. Therefore, this study attempts to determine whether there is a correlation between the occurrence of cancer and the types of foods, especially vegetables that people eat, as vegetables are commonly farmed and consumed locally where they are planted.

II. MATERIALS AND METHODS

A. Materials

The study utilized several materials, including a Parr acid digestion chamber (bomb) for dissolving inorganic or organic samples under elevated temperature and pressure, sub-boiled nitric acid, an electronic weighing balance, a microwave oven, and an atomic absorption spectrometer (AAS). The AAS was accessed at the Central Science Laboratory (CLS) of Obafemi Awolowo University, Ile-Ife.

B. Study Location

The present study was conducted in Ondo East and Ondo West, two adjacent local government areas, in Ondo State Nigeria. The two Local Governments lie between latitude 7.100005 and longitude 4.841694 (latitude 7^0 6' 0.0180'' and longitude 4^0 50' 30.0984''). It has an elevation of 940 ft (287 m). Ondo West is a Local Government Area, with its headquarters in the Ondo metropolis, while Ondo East is a neighbouring Local Government Area, with its headquarters in Bolorunduro. The study area is a tropical rainforest, with distinct wet and dry seasons. Its average monthly temperature ranges between 30 °C and 36 °C respectively. There is a marked dry season from November to March when little or no rain falls [42]. Fig. 1 depicts the study area, highlighting Ondo East and Ondo West.

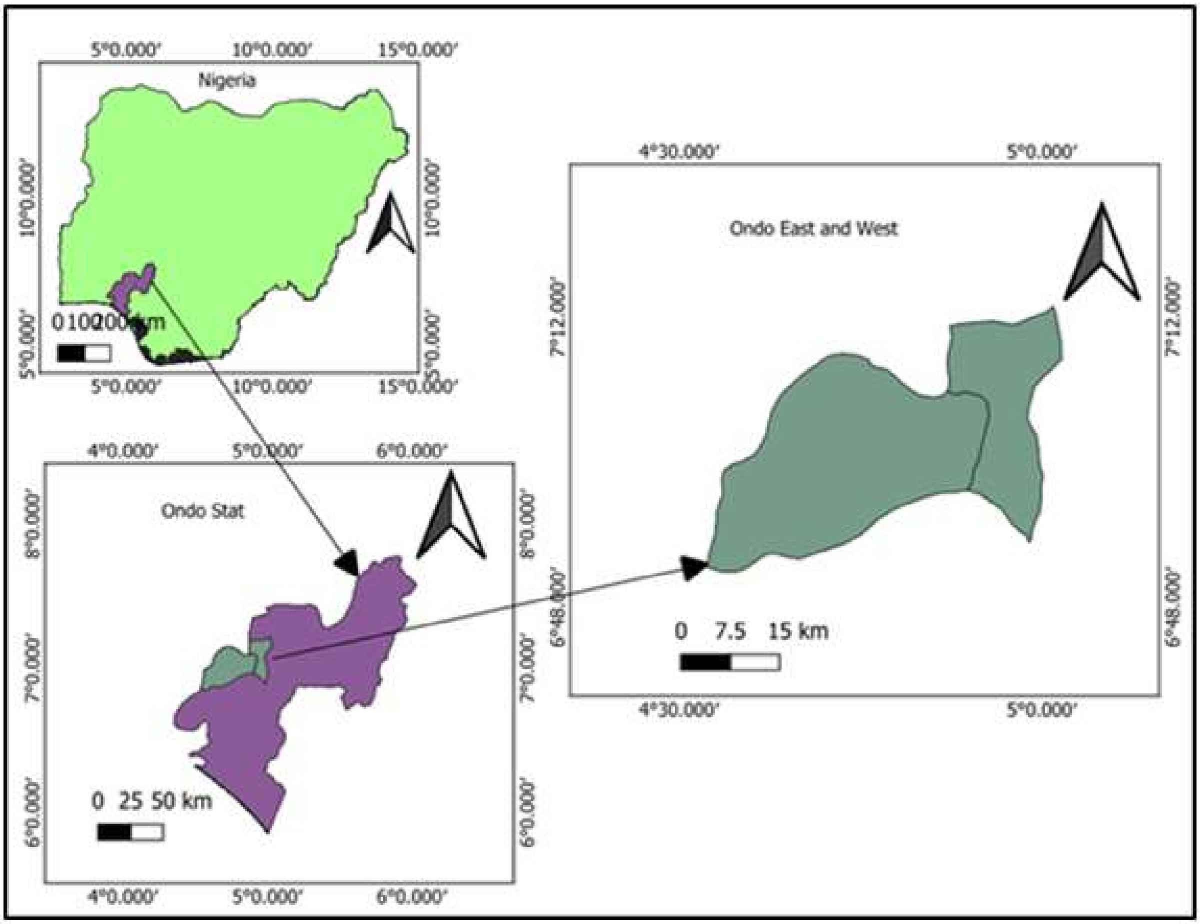

Fig. 1. Study area map highlighting Ondo East and Ondo West.

C. Sample Collection

Through an informal food basket analysis, five types of vegetables—*Solanum macrocapon, Talinum triangulare, Amaranthus hybridus, Telfairia occidentalis, and Vernonia amygdalina*—were identified as commonly grown and consumed in Ondo West and Ondo East. Sixty samples of each vegetable type were collected, with thirty from Ondo West and thirty from Ondo East, spanning 47 locations across the two Local Government Areas. Each sample was carefully placed in a cellophane bag, properly labelled, and transported to the laboratory for analysis.

D. Sample Preparation for AAS

The collected samples were thoroughly washed under running water, rinsed with distilled water, and dried using a clean napkin. Each sample was weighed using an electronic beam balance and then oven-dried at 60°C until a constant weight was obtained. The dried samples were subsequently pulverized into a fine powder in preparation for digestion.

E. Sample Digestion and AAS Analysis

To pre-concentrate the samples, 0.4 grams of each dried and pulverized sample was placed in a Teflon cup, and 11 ml of sub-boiled nitric acid was added. The mixture was gently stirred, the Teflon cup was covered and then placed into an acid digestion chamber (Parr acid digestion bomb). The digestion chamber was secured and heated in a microwave oven for 45 seconds. After cooling completely, the Teflon cup was removed, and 10 ml of the digested sample was transferred to a labelled plastic bottle and prepared for Atomic Absorption Spectrometric (AAS) analysis. AAS analysis was conducted at the Central Science Laboratory (CLS) of Obafemi Awolowo University, Ile-Ife, to determine the concentration of trace elements. The average concentration of the elements in each vegetable sample was calculated for each Local Government area.

F. Concentration in Fresh Sample

Following the AAS analysis, the elemental concentration, C_f (ppm), of the elements in the fresh (wet) vegetables was calculated using (1) and (2).

$$C_f = \frac{C_m(\mu g/ml) \times V_{(ml)}}{M_s(g)} \times M_r \quad (1)$$

$$M_r = \frac{M_s}{M_w} \quad (2)$$

Where C_m is the concentration of the elements in the digested samples, M_r is the ratio of the mass of the dry sample to the mass of the fresh (wet) samples, M_s is the mass of the dried samples digested, M_w is the mass of the wet samples, and V is the volume of the digested samples is made up to?.

G. Daily Intake of Elements (EDI)

The Estimated Daily Intake (EDI) of the trace elements were estimated using (3) [43]–[45].

$$EDI = \frac{C_f(ppm) \times D_{v\_intake(kg/day)}}{B_w(kg)} \quad (3)$$

Where $C_{f\_}$ is the concentration of the elements in fresh vegetables, B_w is the body weight.

The average daily vegetable intake, D_{v_intake}, of 0.069 kg/person/day, for each individual, was estimated using an informal food basket analysis within the study area, and the body weight of 60 kg was used as the average body weight [46]. The Daily Intake (DI) of individual elements was therefore calculated as:

$$DI = EDI \times B_w \quad (4)$$

H. Health Risk Estimation

Both cancer risk and non-cancer risks of heavy metals due to the consumption of vegetables were evaluated for the two communities, Ondo West and Ondo East, using the United States Environment Protection Agency exposure factors handbook [47].

1) Cancer Risk

Exposure to a given heavy metal in vegetables may lead to a probable cancer risk, estimated using the Incremental Lifetime Cancer Risk (ILCR), defined as the incremental probability of a person developing any type of cancer over a lifetime as a result of twenty-four hours per day exposure to a given daily amount of a carcinogenic element for seventy years [48]. The ILCR was calculated using (5) [48]–[50].

$$ILCR = CDI \times CSF \quad (5)$$

Where CDI (in mg/kg B_w/day) is the chronic daily intake of the carcinogenic metal and CSF is the cancer slope factor, defined as the risk produced by a lifetime average dose of mg/kg B_w/day) [48].

$$CDI = (EDI \times EF \times ED)/AT \quad (6)$$

Where EDI refers to the estimated daily intake of a specified heavy metal through the consumption of vegetables, EF is the exposure frequency (73/year, for each vegetable type), ED refers to the exposure duration (55 years, the average lifetime of Nigerians), AT is the assumed total period of exposure (365 x 55).

The total cancer risk resulting from exposure to multiple carcinogenic heavy metals is a summation of the ILCR for all the metals present in the vegetables, i.e.:

$$ILCL_{total} = \sum_i^n ILCR_i \quad (7)$$

An ILCR greater than 1×10−5 indicates a potential risk for developing cancer of any type in a lifetime.

2) Non-cancer Risk

Conversely, the non-cancer risk posed by individual, specific, carcinogenic metals was estimated by calculating the Hazard Quotient (HQ), using (8) [48], [49], [51], [52].

$$HQ = \frac{CDI}{RfD} = \frac{M_r \times D_{i_{metal}}}{RfD \times B_w}\left(\frac{EF \times ED}{AT}\right) \quad (8)$$

Where M_r is the conversion factor for converting the wet mass of the sample to the dry mass of the sample, RfD ($mg/\,kg/day$) is the Reference oral Dose of the metal and B_w(kg) is the average body weight. A HQ of less than one poses no hazard to the populace.

The potential non-cancer risk to human health via the ingestion of more than one non-carcinogenic heavy metal, the Health Risk Index (HRI) was calculated as the sum of all hazard quotients for the individual heavy metals. Thus, the HRI was calculated as:

$$HRI = \sum_i^n HQ_i \quad (9)$$

The oral reference dose, RfD, values for Mn, Cd, Pb, and Zn were 0.14, 0.003, 0.0035, and 0.3 (ppm/day), respectively USEPA IRIS (2011), while Mg has an RfD of 8.25 mg/kg/day. A health risk index value of less than 1 (HRI < 1) is considered safe for the exposed population, while HRI > 1 is considered unsafe [43], [44], [46].

III. RESULTS AND DISCUSSION

The elements analyzed in this study were the essential trace elements (Mg, Mn, and Zn) together with the toxic trace elements (Cd and Pb). The average concentration of these are presented graphically in Fig. 2.

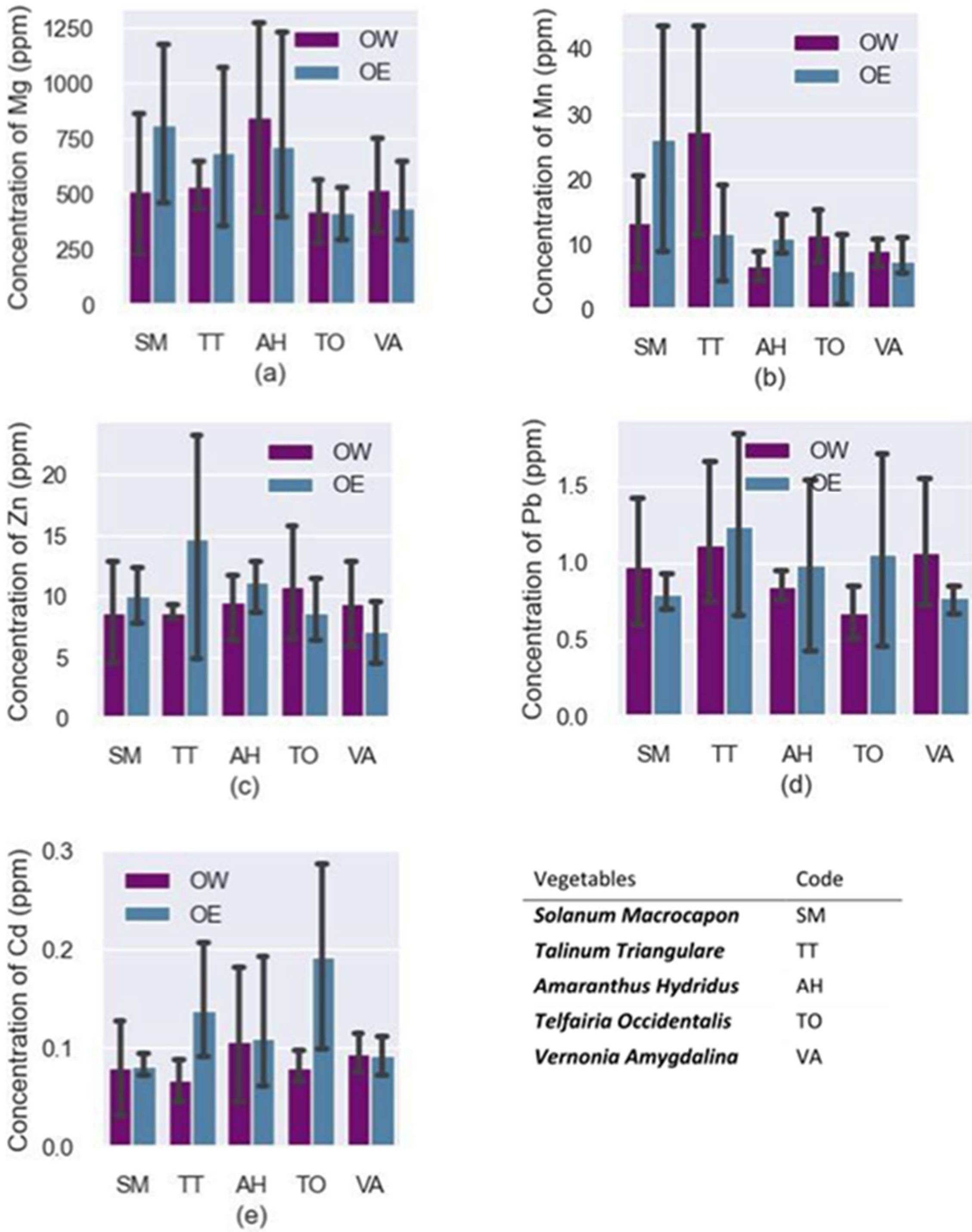

Fig. 2. Mean Concentration of Essential Trace Elements and Toxic Elements in Vegetables Present in Ondo East and West

A. Concentration of Elements in the Vegetable Samples

The average concentration of magnesium (Mg) in the vegetables studied ranged from 426.32 ± 160.25 ppm to 844.87 ± 160.25 ppm in Ondo West, and from 416.05 ± 178.18 ppm to 815.80 ± 178.18 ppm in Ondo East. The overall average concentrations were 568.78 ± 160.25 ppm in Ondo West and 615.71 ± 178.18 ppm in Ondo East. Among the vegetables, *Amaranthus hybridus* had the highest average concentration of Mg in Ondo West, while *Solanum macrocapon* had the highest concentration in Ondo East. Conversely, the average concentration of manganese (Mn) in the vegetables ranged from 9.02 ± 14.42 ppm in *Vernonia amygdalina* to 95.64 ± 14.42 ppm in *Amaranthus hybridus* in Ondo West, and from 6.13 ± 19.85 ppm in *Vernonia amygdalina* to 53.39 ± 19.85 ppm in *Amaranthus hybridus* in Ondo East. The average concentration of zinc (Zn) ranged from 8.68 ± 32.61 ppm in *Talinum triangulare* to 82.00 ± 32.61 ppm in *Solanum macrocapon* in Ondo West, and from 7.2 ± 10.25 ppm in *Vernonia amygdalina* to 30.86 ± 10.25 ppm in *Talinum triangulare* in Ondo East, with a standard deviation of 10.25 in Ondo East. In Ondo West, the average concentration of lead (Pb) varied from 0.68 ± 0.17 ppm in *Telfairia occidentalis* to 1.12 ± 0.17 ppm in *Talinum triangulare*. In Ondo East, Pb concentrations ranged from 0.78 ± 0.19 ppm in *Vernonia amygdalina* to 1.24 ± 0.19 ppm in *Talinum triangulare*. Similarly, cadmium (Cd) concentrations in Ondo West ranged from 0.07 ± 0.01 ppm in *Talinum triangulare* to 0.11 ± 0.01 ppm in *Amaranthus hybridus*, while in Ondo East, Cd levels ranged from 0.09 ± 0.03 ppm in *Vernonia amygdalina* to 0.17 ± 0.03 ppm in *Telfairia occidentalis*.

B. Daily Intake of Metals and Human Health Risk Assessment

Table I presents the daily intake (DI) of the essential elements magnesium (Mg), manganese (Mn), and zinc (Zn), as well as the toxic metals cadmium (Cd) and lead (Pb), for the two locations, Ondo West (OW) and Ondo East (OE). These values were calculated using (3) and (4), averaged across all the vegetables. The table also compares these intakes with the respective Adequate Intake (AI) values for men and women [53].

The comparison indicates that the daily intake of essential elements magnesium (Mg), manganese (Mn), and zinc (Zn) through vegetable consumption in the two communities falls significantly below the recommended adequate intake levels of 310 mg/kg, 1.8 mg/kg, and 6.4 mg/kg, respectively. In Ondo West, vegetable consumption accounted for 12.65%, 40.8%, and 9.6% of the recommended daily intake of Mg, Mn, and Zn, respectively, while in Ondo East, the contributions were 13.7%, 47.7%, and 10.58%, respectively. Although these findings suggest potential deficiencies in these elements, the study acknowledges that vegetables may not be the sole source of these essential trace elements in the two communities.

This study does not definitively establish a link between the prevalence of cancer in the two communities and deficiencies in these trace elements. Further research is needed to explore any potential association.

Additionally, Table II highlights health metrics, including the incremental lifetime cancer risk (ILCR) for individual elements, the total ILCR for the two locations, the non-cancer hazard quotient (HQ) for individual elements, and the non-cancer health index (HI). For both communities, the non-cancer health indices (HI < 1) indicate that vegetable consumption does not pose a non-cancer health risk. However, since ILCR values exceed 1×10^{-5}, there remains a potential risk of developing cancer, which could contribute to the observed prevalence of cancer in these communities.

Table I. Comparison of daily (DI) intake and recommended adequate intake (AI) of the elements in vegetables [53].

Element	DI (OW) (mg/kg)	DI (OE) (mg/kg)	AI-Men (mg/kg)	AI-Women (mg/kg)
Mg	39.25 ± 2.5	42.48 ± 2.5	$400 - 420$	$310 - 420$
Mn	0.94 ± 0.15	0.86 ± 0.15	2.3	1.8
Zn	0.65 ± 0.12	0.72 ± 0.12	9.4	6.8
Pb	0.065 ± 0.012	0.067 ± 0.012		
Cd	0.0059 ± 0.0015	0.0083 ± 0.0015		

Table II. Calculated health metrics, ILCR and HI in the two locations.

Metric	Pb	Cd	Mn	Zn	Total
ILCR (OW)	1.8318×10^{-6}	0.000293			0.000295
ILCR (OE)	$1.8963 \times\times 10^{-6}$	0.000414			0.000416
HQ (OW)	0.0598	0.00558	0.0224	0.00216	0.090 (HI)
HQ (OE)	0.0619	0.00788	0.0053	0.00238	0.092 (HI)

IV. Conclusion

The findings of this study highlight the insufficient daily intake of essential trace elements, magnesium (Mg), manganese (Mn), and zinc (Zn) from vegetable consumption in Ondo West and Ondo East communities, with levels falling significantly below the recommended adequate intake thresholds. While these deficiencies suggest the potential for inadequate nutrition, the study recognizes that vegetables may not represent the sole source of these trace elements in the communities. The study could not establish a definitive link between trace element deficiencies and the prevalence of cancer in these regions, underscoring the need for further research to explore any potential associations. Additionally, health risk metrics reveal no significant non-cancer health risks (HI < 1) from vegetable consumption. However, the elevated incremental lifetime cancer risk (ILCR > 1×10^{-5}) indicates a potential cancer risk that may contribute to the observed prevalence of cancer in these communities. These findings call for a more comprehensive investigation into dietary patterns, environmental exposures, and their implications for public health in the studied areas.

Acknowledgement

The authors acknowledge the support of the staff of Environlab, Department of Physics and Engineering Physics, Obafemi Awolowo University, Ile-Ife, Ondo State, Nigeria.

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