

ISSN: 2695-2556 (Online)

ISSN: 2651-5679 (Print)

AKSU Journal of Agriculture and Food Sciences 9(2) 106-123

© Faculty of Agriculture, Akwa Ibom State University, Nigeria

Metal Pollution: Sources, Health Effects and Antioxidant Composition of Vegetables Cultivated in Urban Lagos, Nigeria

^{1*}Emmanuel Ani, ³ Kelechi L. Ndubuisi, ²Lauretta N. Ofodile, ¹Oyekachi Otika

¹Environmental Biology Unit, Department of Biological Sciences, Yaba College of Technology, Yaba, Lagos, Nigeria

²Mushroom Research and Training Laboratory, Yaba College of Technology, Yaba, Lagos, Nigeria

³Microbiology Unit, Department of Biological Sciences, Yaba College of Technology, Yaba, Lagos, Nigeria

*Corresponding Author Email: in4glory6@gmail.com

Abstract

High heavy metal pollution of the environment has been tied to civilization, urbanization, and industrialization, leading to the overwhelming of natural cleansing and cycling processes in many ecosystems. This study investigates the sources, the extent of pollution and possible health effects of heavy metals via edible vegetables grown in the urban areas of Lagos metropolis. Plants, soil and irrigation water samples were randomly collected in triplicates from vegetable farms in four most industrialized/commercialized Local Government Areas of Lagos State (Ojo, Amuwo-Odofin, Yaba and Kosofe). Dusts and particulate matter deposits on the abaxial leaf surfaces were analyzed for atmospheric deposition. Dried plants were crushed into fine powder before extraction. The physico-chemical, phytochemical and anti-oxidant composition of the plant parts were determined using standard methods. Atomic absorption spectrometer was used to determine heavy metal composition. Plant samples were authenticated as *Allium Schoneoprasum* (LUH 9803), *Lactuca Sativa* L. (LUH 9084) and *Amaranthus* spp. (LUH 9085). The highest concentration of chromium (7.6 ± 0.00), cadmium (5.1 ± 0.04) and zinc (9.7 ± 0.01) were observed at Kosofe while that for copper (5.2 ± 0.04) and lead (15.7 ± 0.03) was found at Ojo and Amuwo-Odofin soil samples respectively. Estimation of the chronic daily intake (CDI), target hazard quotient (THQ), and health risk index (HRI) showed no carcinogenic threat to the food chain, with values under the permissible daily intake limit.

Key words: Heavy metals, Antioxidants, *Allium schoneoprasum*, Irrigation water

1.0 Introduction

Heavy metals (HMs) are group of metals/ metalloids whose specific gravities and atomic densities are greater than 5 and 4 g/ cm³ respectively (Barzegar *et al.*, 2015; Enuneku *et al.*, 2018). Heavy metals naturally occur and persist on the earth's crust. Lately, emission of HMs into the environment, as result of human activities have exceeded the tolerable limits of natural cleansing and cycling processes in many ecosystems. Typical hot spots of heavy metal contamination are urban areas with intensive industrial and mining activities. HMs gain entry into the human body through oral, nasal and skin channels (Ogundele *et al.*, 2019; Orosun *et al.*, 2023). HMs such as Cd, As, Pb, Mn, Fe, Cr, and Hg have long biological half-life, as such interfere with the normal performance of living tissues, resulting in various diseases (Suvarapu and Baek, 2017; Barzegar *et al.*, 2019; Kumar *et al.*, 2020; Prodipto, *et al.*, 2024). In the biological system, HMs metals target cellular processes through induction of oxidative stress, impaired membrane integrity, protein function destabilization, assimilation of nutrients and DNA damage. HMs have also been shown to induce antibiotic resistance through co-selection.

Plants and their products are probably the most important in human diet but may be contaminated with toxic metals like Hg, Cd, Pb, and As, (Esther and Coskun, 2025; Efretuei *et al.*, 2023); Karimi-Maleh *et al.*, 2021; Stefanovic *et al.*, 2008; Dodangeh *et al.*, 2018). Plants and plant products contamination with HMs has been majorly attributed to anthropogenic activities such as discharge of industrial effluents, mining, improper disposal of waste, sewage irrigation of agricultural crops, application of fertilizers (e.g. phosphate) etc. (Shariatifar *et al.*, 2022; Fathabad *et al.*, 2018). Soil, and water contaminations are primarily suggested to be from atmospheric deposition of HMs, resulting in food chain contaminations (Fakhri *et al.*, 2018; Qu *et al.*, 2012).

Amaranthus sp (L) is a tropical annual crop belonging to the family Aaranthaceae with about 70 species (Aguilar *et al.*, 2011). Majority are endemic to North America, with only a few species from Asia, Africa, Australia, and Europe (Iamonico, 2023). *Amaranthus* is rich in proteins (13–22%), lipids (5–13%), dietary fiber (9–14%), vitamins (ascorbic acid, riboflavin, niacin), minerals, among others (Alegbejo, 2014). *Amaranthus* protein is unique in its lysine and methionine composition which serve as natural source of squalene replacement (polyunsaturated triterpene compound) (Park *et al.*, 2020). It's a drought-resistant crop with untapped commercial and industrial potential (Akin-Idowu *et al.*, 2017).

Lactuca sativa (L.), a member of the Asteraceae family is one of the most widely consumed leafy vegetables on the planet (Lawal *et al.*, 2017). While Asteraceae are thought to be the largest family of plants with over 30,000 species (Bessada *et al.*, 2015); Panero and Crozier, 2016), *Lactuca sativa* has been shown to be high in vitamins K, E, and C as well as carotenoids (Shi *et al.*, 2022). It is traditionally used in the management of inflammation, pain, stomach ache, indigestion, and lack of appetite (Noumedem *et al.*, 2017).

Allium schoenoprasum (L) (common names: Spring onion, scallion, Welsh onion, salad onion, etc), is a non-bulbing, bunch-forming green onion belonging to the Liliaceae family (Alam *et al.*, 2023). This plant is mostly grown in northern Nigeria as well as temperate and tropical parts of the world. The leaves are eaten raw as vegetables in soups, rice, salads, etc. (Dery & Zaixiang, 2020).

Toxic metals have been shown to bio-accumulate in organs and tissues of man including the kidney, liver, bone, and brain (Liu *et al.*, 2020; Bjørklund *et al.*, 2017) and have been implicated (especially Hg and Pb) in children and infant developmental disorders such as lowering

intelligence quotient (Heng *et al.*, 2022; Raj & Maiti, 2020). Lead (Pb) and cadmium (Cd) have been implicated in cancer (Parida & Patel, 2023).

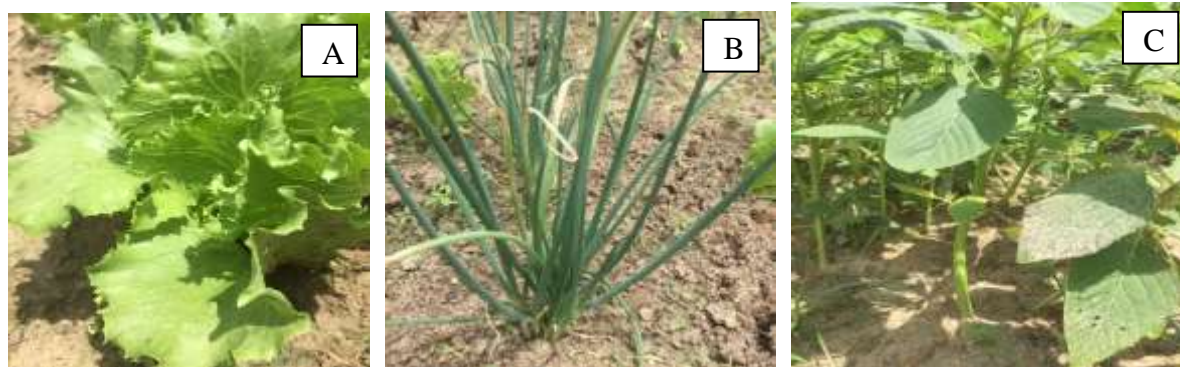


Figure 1.1 (A) *Lactuca sativa* (B) *Allium schoenoprasum* (C) *Amaranthus spp.*

Farming in Nigeria has become a high-risk and low paying job due to increased insecurity caused by banditry, militancy, kidnapping, farmers and herders conflicts, rural-urban migration among others. Most rural farmers can no more go to the farm for fear of being kidnapped or even killed by bandits. Unable to make a living in the rural areas, majority are forced to migrate to the cities. The few available spaces in the city centers have been turned to horticultural gardens and farms with its attendant health risk from metal pollution, owing to human activities. Agrawal *et al.*, (2003) suggests that air pollution of agricultural land around industrial centers and highways account for increased levels of toxic metal uptake by plants in the area (Manisalidis *et al.*, 2020). However, urban agriculture in developing countries play a significant role in managing hunger and improving food security. Irrigation water quality and the accumulation of heavy metals in fresh farm produce presents a research area yet to be thoroughly studied. Little or no attention has been paid to this brewing health emergency. In this study, several metal and environmental indices were used to measure associated health risks of HMs ingestion of the populace, through the consumption of vegetables. This allows for a better understanding of the biological effects of HMs in humans. Children, as a result of their physiological and behavioral patterns, have been reported to be the most responsive age group (Al Osman *et al.*, 2019; Zheng *et al.*, 2023). Urban agriculture has become an increasingly important component of food security in many developing and developed regions. However, the risk of contamination by heavy metals due to proximity to industrial zones, traffic emissions, and the use of untreated wastewater poses significant concerns for public health. This study aims to investigate the extent and impact of metal pollution in vegetables cultivated in urban environments

2.0 Materials and Methods

2.1 Study Area

This study was conducted in Lagos State, Nigeria. Known as the ‘commercial nerve center of Nigeria’, Lagos State is characterized by the heaviest traffic on major highways along where the horticultural farms are located. With average temperature of 24°C, average humidity level of 69, the state has two distinct dry and rainy seasons, which runs between the months of November to March and April to October respectively.

2.2 Sample Collection and Preparation

Plants, soil and irrigation water samples were randomly collected between the months of May and July, in triplicates from vegetable farms in Ojo (6.47586°N, 3.2018°E), Amuwo-Odofin (6.46143°N, 3.312627°E) Yaba (6.5016°N, 3.3685°E) and Kosofe (6.59878°N, 3.409463°E) Local Government Areas in Lagos state, Nigeria. Dusts and particulate matter deposits on the

abaxial leaf surfaces were analyzed for atmospheric deposition. The plant samples were authenticated at the University of Lagos Herbarium as *Allium schoneoprasum* (LUH 9803), *Lactuca sativa* L. (LUH 9084) and *Amaranthus* spp. (LUH 9085). The dried plant sample were ground into a fine powder before extraction.

2.3 Physico-chemical and Phytochemical Composition

The methods of Ejikeme *et al.*, 2014 and Chekroun *et al.*, 2014 were used to determine phytophysicochemical composition of the soil and irrigation water samples.

2.3.1. Anti-oxidant Composition

The Assay of Superoxide Dismutase (SOD) was done by monitoring the superoxide radical-induced nitro blue tetrazolium (NBT) reduction at 560nm, according to the method of Cakmak and Marschner, (1992).

DPPH Assay

This assay was performed only with slight modification to the description of Estrada *et al.*, (2016). The DPPH was prepared by mixing 0.004 g of DPPH in 100 ml methanol. Using methanol as the blank, the control contained only DPPH solution in place of the sample. 2.0 ml of DPPH reagent solution was mixed with an aliquot of 0.5 ml ethanol and aqueous extract. The mixture was vigorously shaken and left to stand at room temperature. An initial spectrophotometric reading of each extract in MeOH was performed. After 30 minutes, quenching of DPPH free radicals, were read at 517 nm from the decrease in absorbance of the test mixture. The results were obtained using the following formula:

$$\% \text{ DPPH Inhibition} = 100 \times \frac{\text{Absorbance of blank} - \text{Absorbance of sample}}{\text{Absorbance control}} \quad \text{.....Equation 3.1}$$

2.3.2 Determination of FRAP Potentials in Samples

This assay is based on the principle of reduction of ferric-tripyridyltriazine (Fe^{3+} -TPTZ) complex to ferrous tripyridyltriazine (Fe^{2+} -TPTZ) by the antioxidants of a sample at low pH. FRAP reagent was prepared by mixing 300 mM acetate buffer, pH 3.6 in 40 mM HCl, and 20 mM FeCl_3 at 10:1:1 v/v/v. 3.400 μL of the reagent and 100 μL of the sample solutions were added to each well and mixed thoroughly. After 30 minutes, the absorbance was measured at 593 nm. A standard curve was prepared using different concentrations of trolox. All solutions were used on the day of preparation. The results were expressed as μmol trolox equivalent/g dw.

2.3.3 ABTS Radical Scavenging Assay

The free radical scavenging activity of the plant extracts was determined using 2,2'-azinobis-(3-ethylbenzthiazoline-6-sulphonic acid) (ABTS), radical cation decolorization assay and 6-hydroxy 2,5,7,8-tetramethylchromane-2-carboxylic acid (Trolox) as a standard. ABTS was dissolved in water to a 7 mM concentration. ABTS radical cation (ABTS^{*+}) was produced by reacting ABTS stock solution with 2.45 mM potassium persulphate (final concentration) and allowing the mixture to stand in the dark at room temperature for 12 to 16 hours before use. The free radical was stable in this form for more than two days when stored in the dark at room temperature. For this study, ABTS^{*+} solution was diluted with ethanol to an absorbance of 0.70 (± 0.02) at 734 nm. Reagent blank reading was also taken (A_0). After the addition of 1.0 ml of diluted ABTS^{*+} solution to 100 μL of each plant extract, the absorbance reading (A_e) was taken exactly 2.5 minutes after initial mixing. The plant extracts were first adequately diluted (where necessary) to fit within the linearity range. The percentage inhibition of absorbance at 734 nm was calculated using the formula

$$\% \text{ inhibition} = \frac{1-Ae}{Ao} \times 100 \quad \dots \dots \dots \text{Equation 3.2}$$

The antioxidant capacity based on the ABTS free radical scavenging ability of the extract was expressed as mmol Trolox equivalence antioxidant capacity (TEAC) per 100 g of plant material.

2.4 Heavy Metals Assay using Atomic Absorption Spectrophotometer

The extracts and the blanks were analyzed in the Federal Institute of Industrial Research (FIIR) CFET Laboratory, Oshodi, Lagos State using atomic absorption spectrophotometer (UNICAM 10230).

2.4.1 Bio Concentration Factor

The ratio of metal concentration in the edible parts of the studied vegetables and the soil was used to calculate the bio-concentration factor (BCF). BCF value less than 1 (< 1), indicates low metal accumulation in the plant, from the soil while BCF value greater than 1 (> 1), indicates high metal accumulation. The BCF were estimated using equation 1 (Ani *et al.*, 2020).

$$BCF = \frac{C_v}{C_s} \quad \dots \dots \dots \text{Equation 3.3}$$

Where C_v = concentration of heavy metal in sample vegetable (mg/kg/dw)

C_s = concentration of heavy metal in soil sample (mg/kg/dw)

2.4.1 Factor Assessments

2.4.1.1 Chronic Daily Intake

The chronic daily intake of the studied metals were calculated using the formula below (EPA 2015).

$$CDI = \frac{C \times IR_i \times ED_i \times EF_i}{BW \times AT} \quad \dots \dots \dots \text{Equation 3.4}$$

Where C = concentration of toxic (heavy) metal in (mg/kg)

IR_i = exposure duration to the toxic (heavy) metal (24hrs)

EF_i = exposure frequency (350 days per year)

BW = body weight average (70kg)

AT = mean exposure years (365 days/year \times number of exposure years)

2.4.1.2 Non-carcinogenic Health Risk

The non-carcinogenic risk of the heavy metal content of the sample vegetables was calculated using the equation 3.

$$EDI = \frac{C \times IR \times ED \times EF}{BW \times AT} \times 10^{-3} \quad \dots \dots \dots \text{Equation 3.5}$$

Where EDI = Estimated daily intake of the heavy metal.

C = Concentration of heavy metal in (mg/kg/dw)

IR = Ingestion rate

EF = Exposure frequency (365 days per year)

BW = Adult body weight average (70kg)

AT = Average time of exposure for non-carcinogenic health risk (25,550days)

ED = Exposure duration (70 years).

2.4.1.3 Target Hazard Quotient (THQ)

This estimates the carcinogenic risk of heavy metals in the plant samples. Plant samples with heavy THQ value less than 1 (< 1) pose no carcinogenic risk to the exposed populace, while plant samples with THQ value greater than 1 (> 1) suggests a carcinogenic health hazard

potential. Health risk hazard is enhanced with increased THQ. The THQ assessment was estimated using equation 4 below.

$$THQ = \frac{EDI}{RFD} \dots\dots\dots \text{Equation 3.6}$$

Where:

EDI = Estimated daily intake

RFD = Oral reference dose of the heavy metal.

2.4.1.4 Health Risk Index (HRI)

The health risk index (HRI) is the estimation of health risk involving more than one heavy metal. The HRI is the sum of the individual heavy metal target hazard quotient. The HRI value less than 1 (< 1) is of no carcinogenic risk, while HRI value greater than 1 (> 1), poses a carcinogenic hazard risk. The HRI was estimated using equation 5.

$$HRI = (THQ_1 + THQ_2 + THQ_3 + THQ_{4\dots\dots} + THQ_n) = \sum THQ \dots\dots\dots \text{Equation 3.7}$$

2.5 Statistical Analysis

Data obtained was analyzed using Statistical Package for Social Sciences (SPSS, Version 20.0). Using a one-way analysis of variance (ANOVA), all data are reported as mean SD of two replicates of each sample, considering ($p < 0.05$).

3.0 Results and Discussion

3.1 Physicochemical, Phytochemical and Antioxidant Composition

The analysed soil samples showed marked variation in physicochemical parameters as presented in Table 3.1. The lowest pH was observed in Ojo (5.74), while Kosofe had the highest (6.27). Organic carbon was observed to be highest in Yaba (14.1%), and lowest in Ojo (2.67%). Salinity measure showed an increasing value of $3.11 < 3.45 < 3.48 < 4.17$ for (Ojo, Amuwo-Odofin, Yaba and Kosofe) respectively. The electrode potential of the soil samples were 27.63, 54.51, 60.91 and, 88.22 for Amuwo-Odofin, Ojo, Kosofe and Yaba respectively. Other results such as phosphate, exchangeable ions are presented in Table 3.1. Results for physico-chemical properties of irrigation water sample are presents in Table 3.2. Results indicate general acidity ($4.78^A \pm 0.11$ - $5.84^C \pm 0.00$). Results for the four locations (Amuwo-Odofin, Ojo, Kosofe and Yaba) show dissolved oxygen (Mg/L) $8.23^B \pm 0.04$, $7.08^A \pm 0.03$, $7.86^B \pm 0.08$, $8.27^B \pm 0.33$, Salinity (ppm) $3.21^D \pm 0.12$, $2.84^{CD} \pm 0.21$, $2.63^{CD} \pm 0.16$, $2.43^C \pm 0.08$ and Chemical Oxygen Demand (COD) $5.06^A \pm 0.54$, $2.19^B \pm 0.04$, $2.73^B \pm 0.09$, $2.25^B \pm 0.06$ respectively (Table 3.2).

Several authors had established a positive correlation between physicochemical properties and metal composition of soil (Ibiene *et al.*, 2011) (Murthuza *et al.*, 2022) (Islamd *et al.*, 2023) (Louhar *et al.*, 2020). In addition, soil biology is negatively affected by excess of heavy metals and synthetic chemicals, altering the physicochemical characteristics of the soil and causing other environmental problems (Qu *et al.*, 2019) (Alengebawy *et al.*, 2021) (Hatami-manesh *et al.*, 2021). Table 3.3 ,presents the phytochemical composition of *Allium schoenoprasum*, *Lactuca sativa* and *Amaranthus spp*. *Allium schoenoprasum*, had highest value for flavonoid ($0.61^F \pm 0.08$), *Amaranthus spp* had the highest value for alkaloids ($0.35^E \pm 0.02$), saponins ($0.13^I \pm 0.00$) and phenol ($6.66^M \pm 0.01$), while *Lactuca sativa* had the highest value for oxalate ($0.11^J \pm 0.00$). The antioxidant composition of the vegetables are presented in Table 3.4. Superoxide Dismutase (SOD) is shown to increase with increasing concentration in all the

vegetables. Highest amount of hydrogen peroxide is found in *Lactuca sativa* ($1.21^Q \pm 0.00$), *Allium schoenoprasum* had the highest amount of DPPH ($0.70^R \pm 0.00$), while *Amaranthus spp.* had the highest amount of FRAP ($3.11^V \pm 0.00$). Generally, low antioxidant activity was observed in the three vegetables sampled, although (Karamać et al., 2019) showed high antioxidant activity in *Amaranthus caudatus*

Table 3.1: Physico-chemical properties of soil samples from 4 L.G.As in Lagos State

Parameters		Locations			
		Amuwo-Odofin	Ojo	Kosofe	Yaba
pH		$6.12^B \pm 0.04$	$5.74^C \pm 0.00$	$6.27^D \pm 0.03$	$6.10^B \pm 0.02$
Conductivity ($\mu\text{S}/\text{cm}$)		$1339.56^V \pm 112.31$	$1068.55^I \pm 9.25$	$811.20^P \pm 7.20$	$950.06^{PI} \pm 4.10$
Electrode potential (mV)		$27.63^C \pm 2.20$	$54.51^B \pm 0.65$	$60.91^B \pm 1.20$	$88.22^D \pm 4.36$
Nitrate (mg/kg)		$12.06^B \pm 0.15$	$14.16^B \pm 1.41$	$8.78^B \pm 1.26$	$11.64^B \pm 2.10$
Phosphate (mg/kg)		$8.51^C \pm 0.54$	$6.19^D \pm 0.06$	$5.81^D \pm 0.01$	$6.47^D \pm 0.13$
Organic carbon (%)		$13.89^B \pm 0.95$	$12.74^B \pm 0.32$	$9.92^A \pm 0.35$	$14.10^B \pm 0.14$
Soil organic matter (%)		$2.21^{CD} \pm 0.04$	$2.67^A \pm 0.10$	$1.77^C \pm 0.13$	$2.32^{DA} \pm 0.13$
Salinity		$3.45^D \pm 0.16$	$3.11^D \pm 0.01$	$4.17^B \pm 0.03$	$3.48^D \pm 0.13$
	K	$11.26^A \pm 0.06$	$6.26^B \pm 0.06$	$10.25^C \pm 0.01$	$9.15^D \pm 0.02$
Exchangeable ions	Ca	$8.65^{BC} \pm 0.72$	$5.97^{AB} \pm 1.62$	$4.16^A \pm 0.07$	$12.11^C \pm 0.14$
	Mg	$5.14^A \pm 0.06$	$3.12^B \pm 0.01$	$7.11^C \pm 0.17$	$8.11^D \pm 0.01$
	Na	$4.61^{BC} \pm 0.02$	$1.88^B \pm 0.98$	$8.40^D \pm 0.28$	$6.01^C \pm 0.00$

\pm = standard deviation values. Values along the same row with different superscripts are significantly different at 5% ($p < 0.005$). L.G.A- Local Government Areas

Table 3.2: Physico-chemical properties of irrigation water from 4 L.G.As in Lagos State

Parameters		Location			
		Amuwo-Odofin	Ojo	Kosofe	Yaba
pH		$5.84^C \pm 0.09$	$5.84^C \pm 0.04$	$4.78^A \pm 0.11$	$5.11^B \pm 0.00$
Conductivity ($\mu\text{S}/\text{cm}$)		$1064.08^C \pm 4.28$	$902.03^B \pm 16.94$	$686.12^D \pm 11.31$	$659.40^D \pm 10.44$
Electrode potential (mV)		$81.22^T \pm 0.14$	$60.76^U \pm 0.23$	$54.17^V \pm 0.01$	$63.06^U \pm 2.84$
suspended solid matter (g/L)		$0.00541^I \pm 0.00$	$0.00004^I \pm 0.00$	$0.00002^I \pm 0.00$	$0.00003^I \pm 0.00$
Salinity (ppm)		$3.21^D \pm 0.12$	$2.84^{CD} \pm 0.21$	$2.63^{CD} \pm 0.16$	$2.43^C \pm 0.08$
Dissolved oxygen (Mg/L)		$8.23^B \pm 0.04$	$7.08^A \pm 0.03$	$7.86^B \pm 0.08$	$8.27^B \pm 0.33$
Nitrate (mg/L)		$3.67^A \pm 0.16$	$2.10^B \pm 0.06$	$1.20^C \pm 0.06$	$2.70^D \pm 0.12$
Phosphate(mg/L)		$0.62^C \pm 0.08$	$1.06^D \pm 0.07$	$0.31^B \pm 0.00$	$0.35^{BC} \pm 0.08$
Total organic carbon (%)		$3.28^B \pm 0.32$	$1.13^C \pm 0.01$	$1.12^C \pm 0.00$	$1.05^C \pm 0.07$
COD		$5.06^A \pm 0.54$	$2.19^B \pm 0.04$	$2.73^B \pm 0.09$	$2.25^B \pm 0.06$
Organic matter (%)		$0.82^P \pm 0.07$	$0.25^P \pm 0.02$	$0.50^P \pm 0.47$	$0.22^P \pm 0.04$
	K	$1.76^N \pm 0.77$	$1.28^N \pm 0.03$	$1.08^N \pm 0.03$	$0.45^N \pm 0.00$
Exchangeable ions	Ca	$1.14^D \pm 0.03$	$0.79^C \pm 0.03$	$0.62^C \pm 0.07$	$0.22^B \pm 0.00$
	Mg	$1.17^Z \pm 0.02$	$0.34^P \pm 0.01$	$2.14^Y \pm 0.04$	$0.28^P \pm 0.09$
	Na	$1.50^H \pm 0.17$	$0.91^E \pm 0.00$	$2.39^R \pm 0.08$	$1.09^E \pm 0.03$

\pm = standard deviation values. Values along the same row with different superscripts are significantly different at 5% ($p < 0.005$). COD: Chemical Oxygen Demand, L.G.A- Local Government Areas

Table 3.3: Phytochemical composition of *Allium schoenoprasum*, *Lactuca sativa* and *Amaranthus* spp.

Sample	<i>Allium schoenoprasum</i>	<i>Amaranthus</i> spp.	<i>Lactuca Sativa</i>
Tannin	0.27 ^A ±0.01	0.62 ^B ±0.01	0.66 ^C ±0.00
Alkaloids	0.24 ^D ±0.04	0.35 ^E ±0.02	0.23 ^D ±0.00
Flavonoids	0.61 ^F ±0.08	0.24 ^G ±0.01	0.16 ^G ±0.00
Saponins	0.11 ^H ±0.00	0.13 ^I ±0.00	0.12 ^{HI} ±0.00
Oxalate	0.06 ^K ±0.01	0.08 ^K ±0.00	0.11 ^J ±0.00
Phenol	5.21 ^L ±0.01	6.66 ^M ±0.01	3.95 ^N ±0.04

± = standard deviation values. Values along the same row with different superscripts are significantly different at 5% (p<0.005).

Table 3.4: Antioxidant, superoxide dismutase (SOD) composition and ABTS radical scavenging activities of *Allium schoenoprasum*, *Lactuca sativa* and *Amaranthus* spp.

Sample	<i>Allium schoenoprasum</i>	<i>Amaranthus</i> spp.	<i>Lactuca Sativa</i>
Antioxidant			
Scavenging Hydrogen Peroxide	0.43 ^O ±0.01	0.89 ^P ±0.00	1.21 ^Q ±0.00
DPPH	0.70 ^R ±0.00	0.18 ^S ±0.00	0.43 ^T ±0.00
FRAP	2.66 ^U ±0.00	3.11 ^V ±0.00	2.23 ^W ±0.01
Superoxide Dismutase (SOD)			
(200µg/ml)	45.00±0.00	10.00±0.00	25.00±0.00
(400µg/ml)	55.50 ^S ±0.71	23.50 ^T ±2.12	37.00 ^U ±1.41
(600µg/ml)	66.50 ^V ±2.12	46.50 ^W ±2.12	49.00 ^X ±4.24
ABTS radical scavenging activities			
ABTS	0.22 ^Y ±0.00	0.10 ^Z ±0.00	0.15 ^A ±0.00

± = standard deviation values. Values along the same row with different superscripts are significantly different at 5% (p<0.005)

3.2 Heavy Metal Concentration of Soil and Irrigation Water

The heavy metal concentration of the analysed farm soil sample for the four locations (Amuwo-Odofin, Ojo, Kosofe and Yaba) show that Chromium (Cr) 6.1±0.04, 4.9±0.00, 7.6±0.00, 3.2±0.02, Cadmium (Cd) 4.3±0.01, 0.00, 5.1±0.04, 0.3±0.01, Zinc (Zn) 7.3±0.02, 4.4±0.01, 9.7±0.01, 8.1±0.00, Copper (Cu) 2.9±0.01, 5.2±0.04, 1.8±0.00, 2.3±0.01 and Lead (Pb) 15.7±0.03, 10.1±0.01, 7.2±0.01, 6.8±0.08 respectively. Kosofe had the highest value for chromium (7.6±0.00), cadmium (5.1±0.04) and zinc (9.7±0.01). The highest value for copper (5.2±0.04) was found at Ojo while the highest value of lead (15.7±0.03) was observed at Amuwo-Odofin. Results, show that cadmium concentrations in Amuwo-odofin (4.3) and Ojo (5.1), are higher than the World Health Organization (WHO) standards for metals in soil samples (WHO, 1996, 1998).

Results for heavy metal concentration of the analysed irrigation water sample for the four locations (Amuwo-Odofin, Ojo, Kosofe and Yaab) show the values for chromium (Cr⁺⁶) 0.01±0.00, 0.04±0.04, 0.30±0.01, 0.26±0.07, zinc (Zn) 0.82±0.02, 1.24±0.01, 0.48±0.09,

1.49±1.63 copper (Cu^{+2}) 0.24±0.01, 0.21±0.00, 0.21±0.00, 0.33±0.01 and lead (Pb^{+2}) 2.02±0.02, 1.88±0.08, 0.50±0.03, 4.80±0.12 respectively. Cadmium and arsenic were not detected in the water sample. Irrigation water is water used to wet agricultural land for crop production and this can be a major source of heavy metal accumulation in edible plant parts (Sha *et al.*, 2023). Table 3.2 summarizes the physico-chemical properties of irrigation water sample. The result showed an acidic pH level of between 4.7 and 5.8. This, is below the WHO and FAO pH range of 6.5–8.5 and 6.4–8.4, for irrigation water respectively. Electrical conductivity was between 659 -1064 $\mu\text{S cm}^{-1}$. This is far above WHO recommended value of 400–600 $\mu\text{S cm}^{-1}$. Electrical conductivity is a measure of dissolved salt in water (Orosun *et al.*, 2023). High amount of dissolved salt may have accounted for the acidity of the irrigation water. Vegetables irrigated with contaminated water may cause serious health hazards to the community (Berhanu *et al.*, 2022; Drechsel *et al.*, 2017; Hussain *et al.*, 2017). Industrial and consumer wastes, open defecation and the presence of uncontrolled landfills, are heavy metal contamination sources of water supply (Obasi *et al.*, 2024; Berihun *et al.*, 2023).

3.4 Metal Concentration in Plant Parts and Biological Concentration Factor (BCF)

Results for metal concentrations in the plants are summarized in Tables 3.5. The analysed plant parts showed a wide range of variation in heavy metal concentration. Metal concentration in Kosofe samples were in the form $\text{Cr} > \text{Zn} > \text{Pb} > \text{Cd} > \text{Cu} > \text{As}$ for roots and $\text{Zn} > \text{Cr} > \text{Pb} > \text{Cd} > \text{Cu} > \text{As}$ for shoots. Of all locations, the highest concentration of Cr was at Kosofe which were all higher than the WHO recommended standard and lowest at Yaba. Zinc (ZN) and Arsenic (As) had the highest concentration in samples for Amuwo-odofin and Ojo respectively (Table 3.5). The presence of Arsenic and Cadmium in the plant samples in quantities higher than WHO recommendation is a call for serious health emergency bearing in mind the consequences of these metals in even trace amounts. Assessment metal pollution sources through atmospheric depositions showed $\text{Pb} > \text{Cu} > \text{Cr} > \text{Zn}$ for all locations. Highest concentration of Pb (4.06) were from Amuwo-odofin while Kosofe had the highest value for Cu(0.66), Cr(0.40) and Zn(0.07). Arsenic and Cadmium were not detected in the atmospheric samples for all locations.

The biological concentration factor (BCF), show that most of the metals were easily absorbed from the soil and readily transferred to the aerial plant parts (Table 3.6). Movement of the metals has been shown to be influenced by soil physico-chemical characteristics. This agrees with this research findings by Tang *et al.*, (2020); Mfon *et al.*, (2022 and Ani *et al.*, (2020. The documented adverse effect of heavy metals on plants and human health, shows mercury, lead, arsenic, and cadmium are toxic metals and have mutagenic effects even at very low concentrations (Jaishankar *et al.*, 2014; Mitra *et al.*, 2022; Hembrom *et al.*, 2020). Human consumption of heavy metal contaminated vegetables may cause immunological disorders, impair psycho-social behavior, and growth retardation. There is an urgent need of increased awareness on the side-effects of heavy metals on human health. Figure 3.1 presents the component loading scatter plot.

Table 3.5: Average concentration of heavy metals in *Allium schoenoprasum*, *Lactuca sativa* and *Amaranthus spp*

Location	Plants	Cr	Cd	As	Zn	Cu	Pb	Cr	Cd	As	Zn	Cu	Pb
Root							Shoot						
Kosofe	LS	4.14±0.02	2.01±0.00	-	3.51±0.13	0.66±0.07	2.33±0.13	3.06±0.07	1.74±0.25	-	3.76±0.07	0.48±0.23	2.52±0.14
	SO	4.84±0.18	2.12±0.00	0.01±0.0	3.47±0.06	0.82±0.01	2.51±0.15	2.85±0.15	1.74±0.10	0.38±0.05	2.16±0.03	0.43±0.05	2.36±0.07
Ojo	AS	2.22±0.14	2.76±0.21	0.02±0.03	3.46±0.21	1.08±0.02	1.29±0.04	0.82±0.01	1.81±0.01	-	2.17±0.08	0.93±0.01	2.61±0.01
	LS	3.41±0.01	-	1.23±0.26	2.54±0.10	0.65±0.07	3.46±0.01	0.90±0.01	-	0.72±0.08	1.95±0.01	0.37±0.08	3.66±0.07
	SO	3.42±0.00	0.10±0.01	1.23±0.00	2.49±0.03	0.62±0.01	3.62±0.01	0.81±0.00	0.04±0.00	1.42±0.00	2.17±0.07	0.27±0.07	3.34±0.22
Amuwo-Odofin	AS	3.27±0.21	-	1.02±0.02	2.66±0.35	0.73±0.01	3.54±0.39	1.16±0.08	-	0.88±0.00	2.09±0.03	1.68±0.17	2.95±0.01
	LS	3.18±0.00	1.91±0.09	-	3.03±0.12	0.52±0.01	3.66±0.08	1.03±0.01	1.23±0.01	-	2.06±0.08	0.21±0.00	2.01±0.00
	SO	1.41±0.28	1.95±0.00	-	2.26±0.21	0.62±0.00	3.20±0.11	0.70±0.03	0.53±0.03	0.06±0.08	1.64±0.34	0.29±0.11	2.44±0.01
Yaba	AS	2.10±0.01	1.92±0.01	-	2.10±0.02	0.46±0.12	7.46±0.48	0.83±0.02	1.04±0.04	-	2.90±0.26	0.37±0.02	5.05±0.08
	LS	1.30±0.16	-	0.61±0.01	1.01±0.00	0.11±0.00	1.26±0.07	0.33±0.01	0.00±0.00	-	2.06±0.05	1.22±0.00	1.32±0.01
	SO	1.41±0.01	-	0.82±0.17	2.59±0.17	0.36±0.34	1.32±0.04	0.61±0.01	-	-	2.92±0.01	0.77±0.01	2.04±0.07
	AS	1.42±0.01	-	1.01±0.00	2.99±0.03	0.36±0.01	2.12±0.01	0.31±0.01	-	-	3.14±0.03	0.32±0.00	0.12±0.00
	WHO	1.30	0.20		99.4	20	0.3	1.30	0.20		99.4	20	0.30

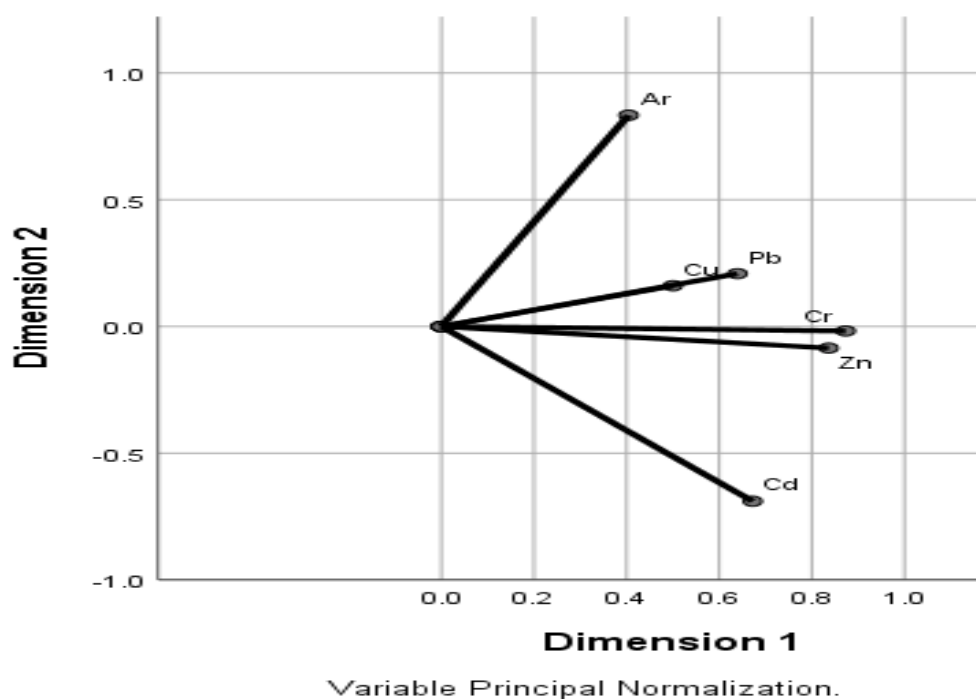
± = standard deviation values. Values along the same column with different superscripts are significantly different at 5% (p<0.005)

Key: AS= *Allium schoenoprasum*, LS= *Lactuca sativa* and SO= *Amaranthus spp*.

Table 3.6: Bio concentration factor (BCF) of *Allium schoenoprasum*, *Lactuca sativa* and *Amaranthus* spp.

SAMPLES		Cr	Cd	Zn	Cu	Pb
Kosofe	LS	1.07	0.90	0.97	0.70	0.94
	SO	1.14	0.89	0.70	0.84	0.81
	AS	0.40	0.90	0.59	0.31	0.71
Ojo	LS	0.95	-	0.08	0.25	0.89
	SO	0.94	-	0.03	0.19	0.80
	AS	1.05	-	1.45	0.71	0.73
Amuwo –odofin	LS	0.84	0.84	0.85	0.28	0.42
	SO	0.43	0.71	0.69	0.35	0.50
	AS	0.55	0.90	0.83	0.40	0.99
Yaba	LS	0.54	0.02	0.72	0.67	0.53
	SO	0.66	0.01	0.94	0.58	0.76
	AS	0.61	0.005	0.89	0.33	0.62

Key: AS= *Allium schoenoprasum*, LS= *Lactuca sativa* and SO= *Amaranthus* spp.

**Figure 3.1: Component loading scatter plot of heavy metal composition in plant samples**

3.5 Factor Assessments

In this study, the heavy metals chronic or estimated daily intake (CDI)/(EDI) were all found below provisional permissible limits of daily intake or oral reference dose limit of USEPA 2021 (Table 3.7). The target hazard quotient of the heavy metal concentration of the vegetables was estimated to determine the carcinogenic exposure risk of adults and children consuming vegetables in sample soils. This research found the THQ of the metals in the vegetables to be of no carcinogenic threat. This is evident as all THQ values were far below 1 (>1) (Table 3.8). The health risk index (HRI) also showed no immediate carcinogenic threat to the food chain.

Table 3.7: Chronic daily or estimated daily intake of heavy metals in the plant parts of *Allium schoenoprasum*, *Lactuca sativa* and *Amaranthus* spp.

		Chronic daily intake (cdi)														
		Leaves					Roots					Shoots				
Sample		Cr	Cd	Zn	Cu	Pb	Cr	Cd	Zn	Cu	Pb	Cr	Cd	Zn	Cu	Pb
Kosofe	<i>Lactuca S</i>	3.2E-5	2.8E-5	6.9E-5	3.6E-6	6.1E-5	9.6E-5	5.5E-5	1.8E-5	1.5E-5	7.9E-5	1.3E-4	6.3E-5	1.1E-4	2.1E-5	7.3E-5
	<i>Amaranthus</i>	3.1E-5	2.2E-5	3.9E-5	8.2E-6	3.1E-5	8.9E-5	5.5E-5	6.8E-5	1.4E-5	7.4E-5	1.5E-4	6.7E-5	2.8E-4	2.6E-5	7.9E-5
	<i>Allium S</i>	0.3E-6	0.2E-5	1.9E-5	1.1E-5	1.9E-5	2.6E-5	5.7E-5	6.8E-5	2.9E-5	8.2E-5	6.9E-5	8.7E-5	1.1E-4	3.4E-5	4.1E-5
Ojo	<i>Lactuca</i>	1.1E-5	ND	0.8E-5	0.9E-5	6.1E-5	2.8E-5	ND	6.1E-5	1.2E-5	1.2E-4	1.1E-4	ND	7.9E-5	2.1E-5	1.1E-4
	<i>Amaranthus</i>	1.3E-5	0.5E-5	3.7E-5	3.6E-6	3.7E-5	2.6E-5	1.3E-6	6.8E-5	8.4E-6	1.1E-4	1.1E-4	3.2E-6	7.8E-5	1.9E-5	1.2E-4
	<i>Allium S</i>	2.4E-5	ND	5.2E-5	4.1E-5	2.9E-5	3.6E-5	ND	6.5E-5	5.3E-5	9.2E-5	1.0E-4	ND	8.4E-5	2.3E-5	1.1E-4
Amuwo- odofin	<i>Lactuca S</i>	2.9E-5	1.5E-5	3.5E-5	3.2E-6	3.3E-5	3.2E-5	3.9E-5	6.4E-5	6.5E-6	6.3E-5	9.9E-5	5.9E-5	9.5E-5	1.6E-5	1.2E-4
	<i>Amaranthus</i>	2.7E-5	1.8E-5	3.6E-5	3.6E-6	8.2E-5	2.2E-5	1.7E-5	5.2E-5	8.9E-6	7.6E-5	4.4E-5	6.1E-5	7.1E-5	1.9E-5	1.0E-4
	<i>Allium S</i>	1.4E-5	2.9E-5	3.5E-5	0.2E-5	9.9E-5	2.6E-5	3.3E-5	9.1E-5	1.2E-5	1.6E-4	6.6E-5	6.0E-5	6.6E-5	1.5E-5	2.4E-4
Yaba	<i>Lactuca S</i>	3.6E-6	0.5E-7	8.8E-5	6.9E-6	3.3E-5	1.0E-5	1.4E-7	6.5E-5	3.8E-5	4.1E-5	4.1E-5	ND	3.2E-5	3.6E-6	3.9E-5
	<i>Amaranthus</i>	3.5E-6	1.2E-7	6.7E-5	6.8E-6	5.7E-5	1.9E-5	ND	9.2E-5	2.4E-5	6.4E-5	4.4E-5	ND	8.2E-5	1.2E-5	4.2E-5
	<i>Allium S</i>	7.9E-6	4.8E-8	3.6E-5	3.6E-6	6.3E-5	0.9E-5	ND	9.9E-5	9.9E-6	3.7E-6	4.5E-5	ND	9.4E-5	1.1E-5	6.6E-5

Key: ND= not detected, E=exponential

Table 3.8: The Target Hazard Quotient of heavy metal concentrations in the plant parts of *Allium schoenoprasum*, *Lactuca sativa* and *Amaranthus* spp.

		Target Hazard Quotient (THQ)														
location/ samples		Leaves					Roots					Shoots				
		Cr	Cd	Zn	Cu	Pb	Cr	Cd	Zn	Cu	Pb	Cr	Cd	Zn	Cu	Pb
Kosofe	<i>Lactuca</i>	0.101	0.028	2.3E-4	9.1E-6	0.018	0.31	0.055	3.9E-4	3.8E-5	0.023	3.645	0.063	3.6E-4	5.3E-5	0.021
	<i>Amaranthus</i>	0.102	0.022	1.3E-4	2.1E-5	0.009	0.29	0.054	2.3E-4	3.4E-5	0.021	0.487	0.067	9.4E-4	6.4E-5	0.023
	<i>Allium S</i>	0.001	0.002	6.3E-5	2.8E-5	0.006	0.08	0.057	2.3E-4	7.3E-5	0.023	0.224	0.087	3.6E-4	8.5E-5	0.012
Ojo	<i>Lactuca</i>	0.036	ND	2.8E-5	2.2E-5	0.017	0.09	ND	2.1E-4	2.9E-5	0.033	0.345	ND	2.7E-4	5.1E-5	0.031
	<i>Amaranthus</i>	0.041	0.005	1.3E-4	9.1E-6	0.011	0.08	0.001	2.3E-4	2.1E-5	0.030	0.346	0.003	2.6E-4	4.9E-5	0.032
	<i>Allium S</i>	0.076	ND	1.7E-4	1.0E-4	0.008	0.12	ND	2.2E-4	1.3E-4	0.027	0.331	ND	2.9E-4	5.7E-5	0.032
Amuwo- odofin	<i>Lactuca</i>	0.094	0.015	1.2E-4	8.1E-6	0.010	0.10	0.039	2.3E-4	1.7E-5	0.018	0.322	0.059	3.2E-4	4.1E-5	0.033
	<i>Amaranthus</i>	0.088	0.019	1.2E-4	9.1E-6	0.023	0.07	0.017	1.7E-4	2.3E-5	0.022	0.143	0.061	2.4E-4	4.9E-5	0.029
	<i>Allium S</i>	0.046	0.029	1.2E-4	2.5E-4	0.028	0.03	0.033	3.0E-4	2.9E-5	0.005	0.213	0.060	2.2E-4	3.9E-5	0.066
Yaba	<i>Lactuca</i>	0.011	5.3E-5	2.9E-4	1.7E-5	0.010	0.03	1.4E-4	2.2E-4	9.6E-5	0.012	0.131	ND	1.2E-4	8.9E-6	0.011
	<i>Amaranthus</i>	0.011	1.2E-4	2.2E-4	1.7E-5	0.016	0.06	ND	3.1E-4	6.1E-5	0.018	0.142	ND	2.7E-4	2.8E-5	0.012
	<i>Allium S</i>	0.025		1.2E-4	9.1E-6	0.018	0.03	ND	3.3E-4	2.5E-5	0.001	0.144	ND	3.1E-4	2.8E-5	0.019

Key: ND= not detected, E=exponential

4.0 Conclusion

This study showed most of the metals assessed are within the USEPA 2020 permissible limit for heavy metals in farm soil except cadmium (Cd) whose concentration was high in two locations (Amuwo-Odofin and Ojo). The irrigation water were however acidic resulting from high dissolved salt. Results for estimated daily intake (EDI), the Target hazard quotient (THQ) and the health risk index (HRI) were found to be of no immediate carcinogenic threat, within the provisional limits of USEPA 2021. Regular monitoring of agricultural farms within the city is strongly recommended in order to regulate (where necessary) anthropogenic contamination with toxic metals.

Conflict of interest

The Authors declare that no conflict of interest exist

References

- Agrawal, M., Singh, B., Rajput, M., Marshall, F., & Bell, J. N. B. (2003). Effect of air pollution on peri-urban agriculture: A case study. *Environmental Pollution*, 126(3), 323–329. [https://doi.org/10.1016/S0269-7491\(03\)00245-8](https://doi.org/10.1016/S0269-7491(03)00245-8)
- Aguilar, E. G., Cantarelli, M. A., Marchevsky, E. J., Escudero, N. L., & Camiña, J. M. (2011). Multielemental Analysis and Classification of Amaranth Seeds According to Their Botanical Origin. *Journal of Agricultural and Food Chemistry*, 59(17), 9059–9064. <https://doi.org/10.1021/jf202610t>
- Akin-Idowu, P., Ademoyegun, O., Olagunju, Y., Aduloju, A., & Adebo, G. (2017). *Phytochemical Content and Antioxidant Activity of Five Grain Amaranth Species*. 5, 249–255.
- Al Osman, M., Yang, F., & Massey, I. Y. (2019). Exposure routes and health effects of heavy metals on children. *BioMetals*, 32(4), 563–573.
- Alam, A., Jahan, A. A. A., Bari, M. S., Khandokar, L., Mahmud, M. H., Junaid, M., Chowdhury, M. S., Khan, M. F., Seidel, V., & Haque, M. A. (2023). Allium vegetables: Traditional uses, phytoconstituents, and beneficial effects in inflammation and cancer. *Critical Reviews in Food Science and Nutrition*.
- Alegbejo, J. (2014). Nutritional Value and Utilization of Amaranthus (*Amaranthus* spp.) – A Review. *Bayero Journal of Pure and Applied Sciences*, 6(1), 136.
- Alengebaw, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M.-Q. (2021). Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. *Toxics*, 9(3), 42. <https://doi.org/10.3390/toxics9030042>
- Ani, E., Adekunle, A. A., Aboluwa, J. B., and Ibrahim, O. A. *Ex-Situ* Characterization of *Luffa aegyptiaca* in Lagos State, Nigeria. *Baghdad Science Journal*, 2020, 17(3):946-952.
- Arit Efretuei, Okon Ekwere, Grace Etukapkan. (2023) Response of Waterleaf (*Talinum Fruticosum*) to Split Doses of Poultry Manure After in-season Intermittent Harvest. *International Journal of Agricultural Science*, 8, 1-12. Accessible at: [014-0001\(2023\).pdf](https://doi.org/10.3390/ijags8010001)
- Barzegar, R., Asghari Moghaddam, A., Adamowski, J., & Nazemi, A. H. (2019). Assessing the potential origins and human health risks of trace elements in groundwater: A case study in the Khoy plain, Iran. *Environmental Geochemistry and Health*, 41(2), 981–1002. <https://doi.org/10.1007/s10653-018-0194-9>

- Barzegar, R., Asghari Moghaddam, A., & Kazemian, N. (2015). Assessment of heavy metals concentrations with emphasis on arsenic in the Tabriz plain aquifers, Iran. *Environmental Earth Sciences*, 74(1), 297–313. <https://doi.org/10.1007/s12665-015-4123-2>
- Berhanu, L., Abebe, M., Gizeyatu, A., Berihun, G., Teshome, D., & Walle, Z. (2022). Evaluation of the Effect of Wastewater Irrigation on the Microbiological Quality of Vegetables in Northeast Ethiopia: Implication for Food-Borne Infection and Intoxications. *Environmental Health Insights*, 16, 117863022211278. <https://doi.org/10.1177/11786302221127856>
- Berihun, G., Abebe, M., Hassen, S., Gizeyatu, A., Berhanu, L., Teshome, D., Walle, Z., Desye, B., Sewunet, B., & Keleb, A. (2023). Drinking water contamination potential and associated factors among households with under-five children in rural areas of Dessie Zuria District, Northeast Ethiopia. *Frontiers in Public Health*, 11, 1199314. <https://doi.org/10.3389/fpubh.2023.1199314>
- Bessada, S. M. F., Barreira, J. C. M., & Oliveira, M. B. P. P. (2015). Asteraceae species with most prominent bioactivity and their potential applications: A review. *Industrial Crops and Products*, 76, 604–615. <https://doi.org/10.1016/j.indcrop.2015.07.073>
- Bjørklund, G., Dadar, M., Mutter, J., & Aaseth, J. (2017). The toxicology of mercury: Current research and emerging trends. *Environmental Research*, 159, 545–554. <https://doi.org/10.1016/j.envres.2017.08.051>
- Cakmak, I., & Marschner, H. (1992). Magnesium Deficiency and High Light Intensity Enhance Activities of Superoxide Dismutase, Ascorbate Peroxidase, and Glutathione Reductase in Bean Leaves. *Plant Physiology*, 98(4), 1222–1227. <https://doi.org/10.1104/pp.98.4.1222>
- Chekroun, K. B., Sánchez, E., & Baghour, M. (2014). The role of algae in bioremediation of organic pollutants. *International Research Journal of Public and Environmental Health*, 1, 19–32.
- Dery, B., & Zaixiang, L. (2020). Dietary Polysaccharides from Allium Species: A Critical Review in Dietary Polysaccharides from Allium Species: Extraction, Characterization, Bioactivity, And Potential Utilization. *Acta Scientific Agriculture*, 4, 15.
- Dodangeh, H., Rahimi, G., Fallah, M., & Ebrahimi, E. (2018). Investigation of heavy metal uptake by three types of ornamental plants as affected by application of organic and chemical fertilizers in contaminated soils. *Environmental Earth Sciences*, 77(12), 473.
- Drechsel, P., Keraita, B., Seidu, R., & Abaidoo, R. C. (n.d.). 9. *Human Health Risks from Wastewater-irrigated Vegetable Farming*.
- Ejikeme, C., Stephen, E., & Eboatu, A. (2014). *Determination of physical and phytochemical constituents of some tropical timbers indigenous to niger delta area of nigeria*. 10, 1857–7881.
- Enuneku, A., Omoruyi, O., Tongo, I., Ogbomida, E., Ogbeide, O., & Ezemonye, L. (2018). Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. *Applied Water Science*, 8(8), 1–13.
- Estrada, S., Cuevas-Vargas, H., & Larios-gómez, E. (2016). Cuevas-Vargas, H., Estrada, S., Larios-Gómez, E. (2016) The effects of ICTs as innovation facilitators for a greater business performance. Evidence from Mexico" *Procedia Computer Science*, 91, 47-56. <https://doi.org/10.1016/j.procs.2016.07.040>
- Esther, C. C. and Coskun G. (2025). Morphological, physiological, and anatomical effects of heavy metals on soil and plant health and possible remediation technologies. *Soil Security*, 18 100178
- Fakhri, Y., Bjørklund, G., Bandpei, A. M., Chirumbolo, S., Keramati, H., Hosseini Pouya, R., Asadi, A., Amanidaz, N., Sarafranz, M., Sheikhmohammad, A., Alipour, M., Baninameh,

- Z., Mohseni, S. M., Sarkhosh, M., & Ghasemi, S. M. (2018). Concentrations of arsenic and lead in rice (*Oryza sativa* L.) in Iran: A systematic review and carcinogenic risk assessment. *Food and Chemical Toxicology*, *113*, 267–277.
- Fathabad, A. E., Shariatifar, N., Moazzen, M., Nazmara, S., Fakhri, Y., Alimohammadi, M., Azari, A., & Mousavi Khaneghah, A. (2018). Determination of heavy metal content of processed fruit products from Tehran's market using ICP- OES: A risk assessment study. *Food and Chemical Toxicology*, *115*, 436–446. <https://doi.org/10.1016/j.fct.2018.03.044>
- Hatami-manesh, M., Mortazavi, S., Solgi, E., & Mohtadi, A. (2021). Assessing the uptake and accumulation of heavy metals and particulate matter from ambient air by some tree species in Isfahan Metropolis, Iran. *Environmental Science and Pollution Research*, *28*(30), 41451–41463. <https://doi.org/10.1007/s11356-021-13524-2>
- Hembrom, S., Singh, B., Gupta, S. K., & Nema, A. K. (2020). A Comprehensive Evaluation of Heavy Metal Contamination in Foodstuff and Associated Human Health Risk: A Global Perspective. In P. Singh, R. P. Singh, & V. Srivastava (Eds.), *Contemporary Environmental Issues and Challenges in Era of Climate Change* (pp. 33–63). Springer Singapore. https://doi.org/10.1007/978-981-32-9595-7_2
- Heng, Y. Y., Asad, I., Coleman, B., Menard, L., Benki-Nugent, S., Hussein Were, F., Karr, C. J., & McHenry, M. S. (2022). Heavy metals and neurodevelopment of children in low and middle-income countries: A systematic review. *PloS One*, *17*(3), e0265536. <https://doi.org/10.1371/journal.pone.0265536>
- Hussain, A., Priyadarshi, M., Said, S., & Negi, S. (2017). Effect of Wastewater on the Soil and Irrigation Process: A Laboratory Study. *Journal of Geographical Studies*, *1*(1), 46–55. <https://doi.org/10.21523/gcj5.17010105>
- Iamónico, D. (2023). Nomenclature Survey of the Genus *Amaranthus* (Amaranthaceae): 12 Questions about *Amaranthus caudatus*. *Plants*, *12*(7), 1566. <https://doi.org/10.3390/plants12071566>
- Ibiene, A., Orji, A., Ezidi, F., and Ngwobia, C. (2011). *Bioremediation of hydrocarbon contaminated soil in the niger delta using spent mushroom compost and other organic wastes*.
- Ifiok Enobong Mfon, Michael Chukwuemeka Oguike, Salvation Ubi Eteng, & Ndifreke Moses Etim. (2022). Causes and Effects of Flooding in Nigeria: A Review. *East Asian Journal of Multidisciplinary Research*, *1*(9), 1777–1792. <https://doi.org/10.55927/eajmr.v1i9.1261>
- Islamd, M. S., Idris, A. M., Islam, A. R. M. T., Phoungthong, K., Ali, M. M., & Kabir, M. H. (2023). Geochemical variation and contamination level of potentially toxic elements in land-uses urban soils. *International Journal of Environmental Analytical Chemistry*, *103*(19), 7859–7876. <https://doi.org/10.1080/03067319.2021.1977286>
- Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, *7*(2), 60–72. <https://doi.org/10.2478/intox-2014-0009>
- Karamać, M., Gai, F., Longato, E., Meineri, G., Janiak, M. A., Amarowicz, R., & Peiretti, P. G. (2019). Antioxidant Activity and Phenolic Composition of *Amaranthus caudatus* during Plant Growth. *Antioxidants*, *8*(6), 173. <https://doi.org/10.3390/antiox8060173>
- Karimi-Maleh, H., Orooji, Y., Karimi, F., Alizadeh, M., Baghayeri, M., Rouhi, J., Tajik, S., Beitollahi, H., Agarwal, S., Gupta, V. K., Rajendran, S., Ayati, A., Fu, L., Sanati, A. L., Tanhaei, B., Sen, F., Shabani-Nooshabadi, M., Asrami, P. N., & Al-Othman, A. (2021). A critical review on the use of potentiometric based biosensors for biomarkers detection. *Biosensors and Bioelectronics*, *184*, 113252. <https://doi.org/10.1016/j.bios.2021.113252>
- Kumar, M., Patel, A. K., Shah, A. V., Raval, J., Rajpara, N., Joshi, M., & Joshi, C. G. (2020). First proof of the capability of wastewater surveillance for COVID-19 in India through

- detection of genetic material of SARS-CoV-2. *Science of The Total Environment*, 746, 141326. <https://doi.org/10.1016/j.scitotenv.2020.141326>
- Lawal, O. A., Ogundajo, A., Avoseh, O., & Ogunwande, I. (2017). *Cymbopogon citratus*. In *Medicinal Spices and Vegetables from Africa: Therapeutic Potential Against Metabolic, Inflammatory, Infectious and Systemic Diseases* (pp. 397–423). <https://doi.org/10.1016/B978-0-12-809286-6.00018-2>
- Liu, T., Liang, X., Lei, C., Huang, Q., Song, W., Fang, R., Li, C., Li, X., Mo, H., Sun, N., Lv, H., & Liu, Z. (2020). High-Fat Diet Affects Heavy Metal Accumulation and Toxicity to Mice Liver and Kidney Probably via Gut Microbiota. *Frontiers in Microbiology*, 11, 1604. <https://doi.org/10.3389/fmicb.2020.01604>
- Louhar, G., Yadav, R., Pawar, A. B., Rekwar, R. K., Verma, A. K., & Yadav, D. K. (2020). Heavy metals distribution and their correlation with physico-chemical properties of different soil series of northwestern India. *The Indian Journal of Agricultural Sciences*, 90(9), 1742–1746. <https://doi.org/10.56093/ijas.v90i9.106620>
- Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and Health Impacts of Air Pollution: A Review. *Frontiers in Public Health*, 8, 14. <https://doi.org/10.3389/fpubh.2020.00014>
- Mitra, S., Chakraborty, A. J., Tareq, A. M., Emran, T. B., Nainu, F., Khusro, A., Idris, A. M., Khandaker, M. U., Osman, H., Alhumaydhi, F. A., & Simal-Gandara, J. (2022). Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University - Science*, 34(3), 101865. <https://doi.org/10.1016/j.jksus.2022.101865>
- Murthuza, K. M., Surumbarkuzhali, N., Narasimhan, C. L., Thirukumaran, V., Chandrasekaran, A., Ganesh, D., & Ravisankar, R. (2022). Magnetic and soil parameters as a potential indicator of soil pollution in the district of Tiruvannamalai, Tamil Nadu, India. *Environmental Earth Sciences*, 81(3), 75. <https://doi.org/10.1007/s12665-022-10196-0>
- Noumedem, J. A. K., Djeussi, D. E., Hritcu, L., Mihasan, M., & Kuete, V. (2017). *Lactuca sativa*. In *Medicinal Spices and Vegetables from Africa* (pp. 437–449). Elsevier. <https://doi.org/10.1016/B978-0-12-809286-6.00020-0>
- Obasi, P. N., Eyankware, M. O., & Edene, E. N. (2024). Contamination of potable water supply sources in the lead–zinc mining communities of Mkpuma Akpatakpa, Southeastern Nigeria. *International Journal of Energy and Water Resources*, 8(2), 225–239. <https://doi.org/10.1007/s42108-022-00199-9>
- Ogundele, L. T., Adejoro, I. A., & Ayeku, P. O. (2019). Health risk assessment of heavy metals in soil samples from an abandoned industrial waste dumpsite in Ibadan, Nigeria. *Environmental Monitoring and Assessment*, 191(5), 1–10. <https://doi.org/10.1007/s10661-019-7454-8>
- Orosun, M. M., Nwabachili, S., Alshehri, R. F., Omeje, M., Alshdoukhi, I. F., Okoro, H. K., Ogunkunle, C. O., Louis, H., Abdulhamid, F. A., Osahon, S. E., Mohammed, A. U., Ehinlafa, E. O., Yunus, S. O., & Ife-Adediran, O. (2023). Potentially toxic metals in irrigation water, soil, and vegetables and their health risks using Monte Carlo models. *Scientific Reports*, 13(1), Article 1. <https://doi.org/10.1038/s41598-023-48489-4>
- Panero, J. L., & Crozier, B. S. (2016). Macroevolutionary dynamics in the early diversification of Asteraceae. *Molecular Phylogenetics and Evolution*, 99, 116–132.
- Parida, L., & Patel, T. N. (2023). Systemic impact of heavy metals and their role in cancer development: A review. *Environmental Monitoring and Assessment*, 195(6), 766. <https://doi.org/10.1007/s10661-023-11399-z>
- Prodipto, B. A., Shafiul, I., Shreejana, K. C. (2024). Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. *Heliyon*, 10(7):e28357

- Qu, C., Chen, W., Hu, X., Cai, P., Chen, C., Yu, X.-Y., & Huang, Q. (2019). Heavy metal behaviour at mineral-organo interfaces: Mechanisms, modelling and influence factors. *Environment International*, 131, 104995. <https://doi.org/10.1016/j.envint.2019.104995>
- Qu, F., Liang, H., He, J., Ma, J., Wang, Z., Yu, H., & Li, G. (2012). Characterization of dissolved extracellular organic matter (dEOM) and bound extracellular organic matter (bEOM) of *Microcystis aeruginosa* and their impacts on UF membrane fouling. *Water Research*, 46(9), 2881–2890. <https://doi.org/10.1016/j.watres.2012.02.045>
- Raj, D., & Maiti, S. K. (2020). Sources, bioaccumulation, health risks and remediation of potentially toxic metal(loid)s (As, Cd, Cr, Pb and Hg): An epitomised review. *Environmental Monitoring and Assessment*, 192(2), 108. <https://doi.org/10.1007/s10661-019-8060-5>
- Shariatifar, N., Seilani, F., Jannat, B., Nazmara, S., & Arabameri, M. (2022). The concentration and health risk assessment of trace elements in commercial soft drinks from Iran marketed. *International Journal of Environmental Analytical Chemistry*, 102(16), 4388–4402. <https://doi.org/10.1080/03067319.2020.1784412>
- Shi, M., Gu, J., Wu, H., Rauf, A., Emran, T. B., Khan, Z., Mitra, S., Aljohani, A. S. M., Alhumaydhi, F. A., Al-Awthan, Y. S., Bahattab, O., Thiruvengadam, M., & Suleria, H. A. R. (2022). Phytochemicals, Nutrition, Metabolism, Bioavailability, and Health Benefits in Lettuce—A Comprehensive Review. *Antioxidants*, 11(6), 1158. <https://doi.org/10.3390/antiox11061158>
- Stefanovic, B., Hutchinson, E., Yakovleva, V., Schram, V., Russell, J. T., Belluscio, L., Koretsky, A. P., & Silva, A. C. (2008). Functional Reactivity of Cerebral Capillaries. *Journal of Cerebral Blood Flow & Metabolism*, 28(5), 961–972. <https://doi.org/10.1038/sj.jcbfm.9600590>
- Suvarapu, L. N., & Baek, S.-O. (2017). Determination of heavy metals in the ambient atmosphere: A review. *Toxicology and Industrial Health*, 33(1), 79–96. <https://doi.org/10.1177/0748233716654827>
- Tang, J., Zhang, L., Zhang, J., Ren, L., Zhou, Y., Zheng, Y., Luo, L., Yang, Y., Huang, H., & Chen, A. (2020). Physicochemical features, metal availability and enzyme activity in heavy metal-polluted soil remediated by biochar and compost. *Science of The Total Environment*, 701, 134751. <https://doi.org/10.1016/j.scitotenv.2019.134751>
- Zheng, K., Zeng, Z., Tian, Q., Huang, J., Zhong, Q., & Huo, X. (2023). Epidemiological evidence for the effect of environmental heavy metal exposure on the immune system in children. *Science of The Total Environment*, 868, 161691.