Full Length Research Paper

Evaluation of the levels of selected heavy metals in leafy vegetables from irrigation farming sites in Jos, Plateau, Nigeria

Samuel Y. Gazuwa* and Ochube E. Olotuche

Department of Biochemistry, Faculty of Basic Medical Sciences, College of Health Sciences, University of Jos, Jos Nigeria.

Received 25 May, 2021; Accepted 8 July, 2021

leafy vegetables are used in making soups, local salads and diverse forms of foods for human consumption is common in Africa. These vegetables include Brassica oleracea (cabbage), Phaseolus vulgaris (green beans) and Solanum lycopersicum (tomatoes). The area of study is famous for agriculture and mining activities; Farmers cultivate them on degraded farmlands polluted with metals; these vegetables absorb these metals thereby making them enter the food chain. During dry season, water from mining ponds is used for irrigation. Industrial waste water is also used. Levels of cadmium (Cd), Arsenic (As), copper (Cu), and lead (Pb), were assessed using Inductively Coupled Plasma Optically Emitting Spectrophotometer (ICP-OES) equipment. Five samples of each vegetable were collected randomly from different irrigation farms situated at Bassa, Bisichi and Zaramaganda. Graph pad prism-7 multiple comparison tests in a one-way ANOVA was used to compare variations in metal concentrations at 95% confidence limit. Pb, As and Cd were not detected in water samples from Bisichi but mean level of Cd and Pb in water from Bassa and Zaramaganda were 0.932 mg/L (P=0.05) and 1.242 mg/L (P=0.05); 0.84 mg/L (P=0.05) and 16.338 mg/L (P=0.05), respectively relative the FAO/WHO safe limits. Water samples from Bassa contained Cu whose level was above (P=0.05) safe limits; only one was below the standard (P>0.05). Samples from Zaramaganda contained highest levels of the metals. cabbage and green beans from Zaramaganda and Bisichi contained Pb, Cu above (P=0.05) the FAO/WHO limit. Mean Pb content in cabbage and green beans from Bisichi was 2.099 and 0.189 mg/kg respectively. From Bassa, Pb content in tomatoes and green beans were 0.086 and 491.31 mg/kg respectively. From Zaramaganda, Pb content in green beans and tomatoes were 12.31 and 14.522 mg/kg; level of Cd in green beans 0.481 mg/kg. Considering Cu, tomato from Bassa contained highest level, 64.310 mg/kg (P=0.05), green beans from Zaramaganda was 48.251 mg/kg (P=0.05), tomato from Bisichi contained 38.541(P=0.05) relative safe limits. In conclusion, the significant concentrations of Cd, Pb and Cu in the vegetables in the area of study, which are routinely used in making soups, portage and local salads, predispose consumers to, cancer, cardiovascular diseases, inhibition of the heme biosynthesis pathway, hemolysis and febrile reactions due to their respective toxicities.

Key words: Cabbage, tomatoes, green beans, cadmium, arsenic, copper, and lead.

INTRODUCTION

Food safety is a major public concern globally, especially in economically weaker countries. The production of safe food is a key factor in food quality and human health. Vegetables are important components of human diets
due to their high nutrients content such as vitamins, minerals, folate, dietary fibre, ascorbic acid, carotene and other nutrients. They are useful in managing ailments resulting from micronutrients deficiency such as night blindness and anaemia (Asdeo and Looker, 2011). Reports from various studies have indicated that the consumption of various types of vegetables can significantly prevent chronic heart diseases and some types of cancers especially of the gastrointestinal tract such as colon cancer (Lawal and Audu, 2011; Temple and Schrauver, 2012).

Heavy metals and their compounds easily contaminate arable farm lands and are a global concern (Laughlin and Agrawal, 2015). They are the most contaminants of soil ecosystems and hence the food chain. For example, lead is a known toxic heavy metal that inhibits the activity of γ-aminolaevinic acid dehydratase, which catalyses the committed step of heme synthesis (hematopoietic system). It easily accumulates in the kidney posing danger to human health (Engwa et al., 2019; Patrick, 2006). The sources of heavy metals contamination of vegetables include waste water used for irrigation (Mapanda et al., 2005), pesticides and fertilizers, and industrial emissions. High concentrations of heavy metals were reported in vegetables from untreated waste water irrigated areas (Singh et al., 2010; Sharma et al., 2007).

Dry season farmers use contaminated waters to irrigate their farms. Area of study is famous for dry season irrigation farming and the vegetables produced from these farms are sold to consumers in and around the locations. The use of industrial waste water for irrigation is of serious concern in Nigeria because these effluents are highly polluted with heavy metals, chemicals and metabolic compounds (Jarup et al., 1998). Chronic exposure to heavy metals results in the disruption of vital biochemical pathways and could adversely affect vital organs such as the kidneys, and so on. Generally, humans are exposed to heavy metals by consumption of contaminated foodstuffs such as fruits, vegetables and drinking water (Qaisar et al., 2012). Consumption of fruits and vegetables contaminated with Cd, Pb has been reported to cause cancer of the pancreas, urinary bladder or prostate (Turkdogan et al., 2002). This work was designed to assess the levels of selected heavy metals in some vegetables commonly consumed in the study areas, and to compare their concentration with FAO/WHO maximum permissible limits in vegetables.

**MATERIALS AND METHODS**

**Study locations**

The area of study encompassed Bassa, Bisichi and Zaramaganda.

**Bisichi** was selected due to abundant mining ponds in the area used by dry season farmers for irrigation. **Zaramaganda** was chosen because of its proximity to the NASCO industries where soaps, detergents, cosmetics, foods such as biscuits, flakes of cereals and fibre are manufactured using medley of chemicals and reagents. Similarly, the Jos International Breweries and the Makery smelting plant (processing tin and columbite) share a common fence with NASCO Industry. Using a GPSMAP 78s GARMIN device, elevation, sampling locations and their surroundings features were determined.

**Collection of samples**

Samples of vegetables and water were obtained from irrigation farms situated at Bassa, Bisichi and Zaramaganda, and with coordinates, elevation and location as follows; **Bassa**: elevation = 1271 m; location (N): 095°54'8.21" E = 008°48'33.80". **Bisichi**: elevation =1230 m; location (N): 094°22'4.13" E = 008°54'50.96". **Zaramaganda**: elevation = 1280 m; location (N): 095°13'3.12" E = 008°52'15.06"

Vegetable samples used were *Brassica oleracea* (cabbage), *Phaseolus vulgaris* (green beans) and *Solanum lycopersicum* (tomatoes). They were randomly collected from different farms in the study locations and kept in properly labeled polythene bags and taken to the laboratory for processing and analysis. Samples were washed with tap water to remove any soil particles and rinsed with distilled water. The edible portions of the vegetable samples were air-dried in the open laboratory for twenty four hours to reduce the water content. Thereafter, all the samples were oven-dried at 70°C for 24 h. The dried samples were then pulverised using a Teflon pestle and mortar, sieved with muslin cloth and stored in airtight containers until required for digestion.

**Digestion of samples**

1 g each of the pulverized samples from each sampling site was weighed and placed in crucibles. Each sample was digested using a mixture of trioxonitrate (V) acid, (HNO₃) monoxochlorate (I) acid (HOCl) and hydrochloric acid (HCl) in the ratio of 1:6:1 respectively. Hot plates were used in heating the samples with intermittent addition of 3 ml of the digestion mixture until white precipitate was obtained. The digested samples were dissolved in 2 ml of trioxonitrate (V) acid for 10 minis, rinsed and allowed to cool and then transferred into 100 ml volumetric flask and made up to the mark with distilled water. For water samples, 20 ml of water samples were mixed with 2.5 ml of HNO₃ before analysis.

**Analysis of samples**

The samples were analysed for Cd, Pb, Cu, As, using Inductively Coupled Plasma Optically Emitting Spectrophotometer (ICP-OES). All reagents used were of analytical grade.

**Operating conditions for ICP-OES Machine**

Power, 1350W, plasma flow, 13.0 L/min, nebulizer flow, 1.00 L/min, auxiliary flow, 1.25 L/min, sampling depth, 2.0 mm, scanning times, 160 times, exit plate, 0V, pump rate, 20 rpm, rinse time, 10 s, replicates 5, replicate read time, 8 s, instrument stabilization, 8 s.

*Corresponding author E-mail: sygazuwa@gmail.com; gazuwa@unijos.edu.ng. Tel: 08036907936.*

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/).
Table 1. Mean levels of Pb, Cd, As, Cu, in water used for irrigation in different parts of the area of study.

| Location      | Pb              | Cd              | As     | Cu              |
|---------------|-----------------|-----------------|--------|-----------------|
| Bassa         | 0.842±0.01<sup>b</sup> | 0.932±0.01<sup>b</sup> | ND     | 1.042±0.01<sup>a</sup> |
| Bisichi       | ND              | ND              | ND     | 0.983±0.01<sup>b</sup> |
| Zaramaganda   | 16.338±0.05<sup>b</sup> | 1.242±0.001<sup>b</sup> | ND     | 1.841±0.01<sup>b</sup> |
| FAO/WHO       | 0.01            | 0.003           | 0.01   | 1.0             |

ND=Not detected. Values are means of three determinations (± SEM); n=5.
<sup>a</sup>below the permissible level of Pb, Cd and Cu stated by FAO/WHO.
<sup>b</sup>above the permissible level of Pb, Cd, Cu, Fe, Mn and Cr stated by FAO/WHO.

Table 2. Mean values of Pb, Cd, As and Cu, in vegetables from irrigated farms in different parts of the area of study. Metals (mg/kg).

| Location      | Crop       | Pb     | Cd     | As     | Cu       |
|---------------|------------|--------|--------|--------|----------|
| Bassa         | Cabbage    | 0.001±0.00<sup>a</sup> | 0.002±0.00<sup>a</sup> | ND     | 31.431±0.001<sup>b</sup> |
| Green beans   | ND         | 0.001±0.00<sup>a</sup> | ND     | 34.340±0.001<sup>b</sup> |
| Tomato        | 0.0086±0.001<sup>b</sup> | 0.059±0.001<sup>a</sup> | ND     | 64.310±0.011<sup>b</sup> |
| Bisichi       | Cabbage    | 2.099±0.001<sup>b</sup> | 0.209±0.001<sup>b</sup> | ND     | 0.209±0.001<sup>b</sup> |
| Green beans   | 0.189±0.001<sup>b</sup> | 0.241±0.001<sup>b</sup> | ND     | ND     |
| Tomato        | ND         | ND     | ND     | 38.541±0.001<sup>b</sup> |
| Zaramaganda   | Cabbage    | 12.310±0.015<sup>b</sup> | 0.043±0.009<sup>a</sup> | ND     | 28.331±0.001<sup>b</sup> |
| Green beans   | 14.522±0.001<sup>b</sup> | 0.481±0.001<sup>b</sup> | ND     | 48.251±0.001<sup>b</sup> |
| Tomato        | 13.824±0.199<sup>b</sup> | 0.041±0.001<sup>a</sup> | ND     | ND     |
| FAO/WHO       | Cabbage    | 0.1    | 0.05   | 0.01   | 0.4      |
| Green beans   | 0.1        | 0.1    | 0.2    | 0.4    |
| Tomato        | 0.05       | 0.05   | 0.2    | 0.4    |

ND=Not detected. Values are means of three determinations (± SEM); n=5.
<sup>a</sup>below the permissible level of Pb, Cd and Cu stated by FAO/WHO.
<sup>b</sup>above the permissible level of Pb, Cd, Cu, Fe, Mn and Cr stated by FAO/WHO.

RESULTS

Table 1 contains mean levels of Pb, Cd, As, Cu, in water used for irrigation in different parts of area of study. The highest level of the metals was detected in the water sample from Zaramaganda while the lowest was detected in the sample from Bassa. Table 2 bears the mean levels of Pb, Cd, As and Cu in vegetables from irrigated farms within the area of study. Arsenic was not detected in samples from all the locations. The highest concentration of Pb and Cd were detected in the vegetable samples from Zaramaganda, with green beans having the highest level.

Figure 1 shows the comparative concentrations of heavy metals (Pb, Cd and Cu) in selected irrigation water sites in different parts of the area of study. Zaramaganda has the highest concentration of lead above (P=0.05) the maximum permissible limit set by FAO/WHO. It was not detected in the irrigation water from Bisichi. The mean level of detected cadmium and copper in Zaramaganda were above (P=0.05) the maximum permissible limit set by FAO/WHO while that of Bassa and Bisichi were within maximum permissible limits.

Figure 2 shows the comparative mean levels of Pb (mg/kg) in vegetables from irrigated farms in the area of study. Cabbage, green beans and tomatoes from Zaramaganda had the highest levels of Pb while green beans from Bisichi had the lowest value. Lead was not detected in all the vegetable samples from Bisichi.

Figure 3 shows the comparative mean levels of Cd (mg/kg) in vegetables from irrigated farms in area of study. The detected mean levels of cadmium in cabbage from Bisichi, green beans from Zaramaganda and Bisichi were above the FAO/WHO maximum permissible limit.
while cadmium was not detected in cabbage from Bassa and tomato from Bisichi.

DISCUSSION

This work sought to analyze levels of cadmium (Cd), lead (Pb) Copper (Cu) and arsenic (As) in samples of water and vegetables from the area of study (Bassa, Bisichi and Zarmaganda). Because the area of study is famous for mining tin, columbite, and ores of other metals, numerous mining ponds abound in the milieu. Industries such as Nasrideen Company (NASCO), Jos International Breweries (JIB), Makeri Smelting Plant (MSP) are situated around Zarmaganda area. Hence, industrial effluents are discharged into water bodies. Farmers use water from mining ponds (ponds in Bassa and Bisichi) which contain heavy metals for dry season irrigation purposes. The levels of these metals in the samples were generally above maximum permissible limits set by WHO/FAO. That being the case, the crucial biological functions of mineral elements such as calcium, phosphorus, zinc and others could negatively. This can be seen in the context of structural analogs; cadmium competes with zinc for binding the active sites of enzymes because it is structurally similar to zinc which is a co-factor of the DNA polymerases I, II, and III. Cabbage and green beans from Zarmaganda contained highest Pb level in that order. From Zarmaganda, green beans contained 0.481 mg/kg Cd. Cd content in green beans and cabbage from Bisichi were 0.241 and 0.20 mg/kg levels respectively and above safe limits (P=0.05). Tomatoes from Bassa, Zarmaganda and Bisichi contained Cu thus: 64.31, 48.25, and 38 mg/kg in that order. This poses hazard to humans via the food chain (Gazuwa and Timothy, 2019; Alam et al., 2003; Asdeo and Looker, 2011), and (Khan et al., 2011). They reported that the use of waste water generally led to changes in the physicochemical characteristics of soils and consequently heavy metal uptake by vegetables. Similar work done by Patrick (2006) reported high levels of lead in soil and vegetables irrigated with old tin mining ponds water in Barkin Ladi local government area of Plateau state, Nigeria. On the other hand, Nimyel et al.
Figure 2. Comparative levels of lead (mg/kg) in vegetables from irrigated farms in area of study.

(2015) have demonstrated that wild vegetables obtained from Dengi metropolis contained Cd and Pb at levels below the permissible limits (P>0.5).

Table 1 bears the mean values of selected heavy metals in water used for irrigation in different parts of area of study. Mean levels of Pb, Cd and Cu in water samples...
from Zaramaganda were above the WHO/FAO maximum permissible limits (P=0.5) in this order: Pb > Cd > Cu. This may be attributed to high industrial activities in the area. This is in agreement with the work done by Laughlin and Agrawal (2015) which showed that heavy metals were among the pollutants in industrial waste water. Also, effluents from a print textile industry and Nigerian breweries that discharge their waste water into the Lagos lagoon have been reported by (Adebayo et al., 2007) to contain high levels of manganese, lead, cadmium, chromium, iron and copper. Orish et al. (2017) reported levels of Pb above WHO/FAO permissible limits in soils and water of Dilimi river, Bukuru and Barkin Ladi Local Government Area of Plateau state. Gazuwa and Timothy (2019) reported significant concentration Pb, Cd and Fe (P = .05) in vegetables and soil samples in Dengi, Plateau state. Further, Michael et al. (2018) reported levels of Pb, Cd, and Fe in cabbage cultivated using irrigation water from ex-mining ponds. The presence of these metals in vegetables and water at levels above their permissible limits is a threat to consumers since these metals ultimately enter the food chain and accumulate up to toxic levels (Athar et al., 2019). These heavy metals are not easily excreted from the body and therefore accumulate over time to toxic levels affecting metabolism and absorption of mineral elements and perhaps antioxidant capacities the absorption and metabolism of micronutrient elements with the possibility of losing their other biological functions. Bello et al. (2020) reported low blood iron, zinc and copper levels owing to interaction with cadmium and lead.

Table 2 bears the mean concentration of heavy metals in vegetables obtained from irrigated farms within the area of study. The results revealed mean levels of Pb in all the vegetables from Zaramaganda, cabbage from Bassa, to be above (P=0.5) the maximum permissible limits set by WHO/FAO. The level of Cd in green beans obtained from Zaramaganda and Bisichi, cabbage from Bisichi were above the safe limits and statistically significant (P=0.05). Comparing these results with the mean levels of these metals in the water samples from the three locations, it can be stated that high levels of

![Figure 3. Comparative levels of cadmium (mg/kg) in vegetables from irrigated farms in area of study.](image-url)
these metals in vegetables from Zarmaganda was as a result of absorption from the soil and water used for irrigating these crops. These results are similar to that of (Lente et al., 2014) and (Samuel et al., 2008) who reported high levels of heavy metals in vegetables obtained from Accra and Kumasi metropolis of Ghana. Also, Dabak et al. (2013) have reported the presence of heavy metals above WHO maximum permissible limits in vegetables. Green beans from Bassa contained 491.31 mg/kg Pb burden; in tomatoes, Pb was 0.086 mg/kg. Level of Cu was 64.31 mg/kg. These values, especially Pb in green beans is alarming because it is above (P=0.05) the safe acceptable limits. The Pb content of green beans, tomatoes were 12.31 and 14.52 mg/kg in samples from Zarmaganda; both above (P=0.05) safe limits. The Pb content in samples obtained from Bisichi in cabbage and green beans were 2.099 and 0.189 respectively; both of which were higher (P=0.05) safe limits. The level of Cu in tomatoes was 38.54 mg/kg.

From biochemical standpoint, the prime targets to lead toxicity are the heme synthesis enzymes, thiol-containing antioxidants and enzymes superoxide dismutase, catalase, glutathione peroxidase, glucose 6-phosphate dehydrogenase and antioxidant molecules like GSH and enzymes superoxide dismutase, limits. The level of Cu in tomatoes was 38.54 mg/kg.

Pb interacts in two ways: it binds strongly to sulfhydryl groups and electron donor groups in general, thereby changing the configuration of a wide range of proteins. Because of its similarity to other divalent cations such as calcium and zinc, it interferes with the vast array of cellular mechanisms that are regulated by and mediated by these cations (Lidsky and Schneider, 2003). Because of the ubiquity of electron donor groups and divalent cations throughout the human body, the pathophysiology of lead toxicity is quite complex and involves virtually every organ system.

Lead is thought to undermine the normal synaptic pruning process in young brains, likely underlying the cognitive and behavioral changes seen in young children with excessive lead exposure (Souza et al., 2013). Peripheral neuropathy is a common manifestation of chronic lead toxicity in adults. The most severe neurologic manifestations of lead toxicity such as seizures and coma occur in acute lead encephalopathy, which is thought to be at least in part secondary to lead-induced cerebral microvascular changes leading to cerebral edema and resultant increased intracranial pressure (Souza et al., 2013). Lead causes anemia by being a potent inhibitor of multi-enzyme activities involved in heme synthesis as well as enzymes involved in maintaining erythrocyte cell membrane integrity, which leads to decreased production and increased destruction of erythrocytes, respectively (Lidsky and Schneider, 2003). For example, the classic appearance of basophilic stippling is thought to represent clumps of degraded RNA, which is normally cleared by an enzyme known as pyrimidine-5'-nucleotidase that is inhibited by lead (Valentine et al., 1976).

Studies have shown that cadmium has toxic effects on the human body. For example, cadmium reaches the kidney in form of cadmium-metallothionein (Cd-MT). Cd-MT is filtrated in the glomerulus, and subsequently reabsorbed in the proximal tubules. It then remains in the tubules cells as is not easily excreted from the body. An increasing cadmium load in the kidney is known to cause a higher calcium excretion, thus leading to a higher risk of kidney stones.

The urinary cadmium excretion was shown to correlate with the degree of cadmium induced kidney damage: A urinary excretion of 2.5 µg cadmium per gram creatinine reflects a renal tubular damage degree of 4% (Qaisar et al., 2012). The primary markers of kidney damage however, are the urinarily excreted β2-microglobulin, N-acetyl-α-D-glucosaminidase (NAG), and retinol-binding-protein (RBP) (Bernard, 2004). The China Cad-Study showed significantly higher values for urinary β2-Microglobulin and RBP in people with high blood cadmium concentration than in people with normal values (Qaisar et al., 2012).

Several studies in the 20th Century showed a connection between cadmium intoxication and bone damage, e.g. bone damage and the itai-itai disease, under which patients show a wide range of symptoms such as low grade of bone mineralization, high rate of fractures, increased rate of osteoporosis, and intense bone associated pain. Underlying osteoporosis, possibly enhanced by cadmium intoxication, was suggested to be the actual reason for the observed symptoms (Kazantzis, 2004). Cadmium is similar to calcium and replaces calcium in the bone mineral composition.

Cupric and cuprous forms of Cu are implicated in the generation of reactive oxygen species thereby participating in redox reactions. Antioxidants such as glutathione, ascorbate reduce cupric to cuprous form which is capable of catalyzing the decomposition of H₂O₂ to form •OH by the Fenton reaction.

Among the metals essential for diverse biological phenomena is copper (Cu). This metal is a co-factor associated with prosthetic groups or bound to proteins. This metal, through a complex system of transporters and chaperone proteins, is tightly regulated. It is implicated in hepatic disorder and neurodegenerative changes if its homeostasis is perturbed. It has capacity to spark off oxidative damage through Cu-induced cellular toxicity.
Current trends indicate that several factors, including lipid metabolism, gene expression and activation of acidic shingomyelinase, are involved in its toxicity (Lisa et al., 2014). Experimental studies confirmed that copper can induce DNA strand breaks and also oxidation of nitrogenous bases in presence of free oxygen radicals (Godwill et al., 2019). The toxicity of copper induces numerous pathologic phenomena which are deleterious to the well being of humans (Amor and Tariq, 2021). Albeit copper plays critical functions such as being a co-factor in some redox reactions, excess predisposes to cellular components. It can induce not only oxidative stress but DNA damage as well as reduction of cell proliferation Copper metabolism plays an important role in physiologic homeostasis. Copper toxicity, however, induces several pathologic processes that are detrimental to human health. While copper is required as an important catalytic cofactor in redox chemistry for many proteins, when present in excess, free copper ions can cause damage to cellular components.

**Conclusion**

The study has shown higher levels of the selected heavy metals in vegetables cultivated using industrial waste and mining pond water for irrigation. The significant concentrations of Cd, Pb and Cu in the vegetables in the area of study, which are routinely used in making portage, soups and local salads, predispose consumers to ailments such as cancer, cardiovascular diseases, inhibition of the heme biosynthesis pathway, hemolysis and febrile reactions owing to their respective toxicities. The use of industrial effluents (waste water) and mining ponds water for irrigation purposes by farmers should be banned by Government. This is because consumption of vegetables irrigated on such farmlands with water from mining ponds or industrial effluents puts the consumers at risk of heavy metals poisoning. Crops should not be cultivated on farmlands within the vicinities of mining ponds and industries to check the exposure to these toxic metals. Heavy metals are non biodegradable. They possess long biological half-lives therefore could accumulate to toxic concentrations.

**CONFLICT OF INTERESTS**

The authors have not declared any conflict of interests.

**REFERENCES**

Adebayo MM, Rana SV Boora, PR (2007). Anti-peroxidative Mechanisms offered by selenium against liver injury caused by cadmium and mercury in Rats. Bulletin of Environmental Contaminants Toxicology 2015, 48, 120-124. 
Alam MM, Barregard L, Schultz A, Skarping G (2003).Heavy metals contamination of vegetables grown by irrigation using industrial waste water.

Amor R, Tariq S (2021). Toxicity of Copper. Treasure Island (FL): Publisher; Statpearls https://europepmc.org/article/mbk/557456
Asdeo A, Looker S, (2011). A comparative analysis of trace metals in vegetables. Research Journal of Environmental Toxicology 5(2): 125-132.
Athan H, Manjeeta P, Shashikant, D (2019). Experimental study on accumulation of heavy metals in vegetables irrigated with treated wastewater. Applied Water Science; volume 9 (122).
Bello HT, Sylvester OO, Innocent NO, Imelda NN, Irene LS, Enyinna O, Saidi O, Rebecca MG, Bassey EB, Bernard A (2004). Renal dysfunction induced by cadmium: biomarkers of renal critical effects. Biometals 17(5):519-523. 10.1023/B:BIOM.0000045731.75602.b9
Dingkwoet JD, Solomon MD, Gabriel SM (2013). Comparative study of some heavy and trace metals in selected vegetables from four Local Government Areas of Plateau State, Nigeria. Journal of Environmental Science, Toxicology and Food Technology 6(3):86-93. 
De Souza A, Narvencar KP, Desai PK, D’Costa Z, Nilajkar G (2013). Adult lead encephalopathy. Neurological Research 35(4-5): 54-58.doi:0000000115. 
Engwa GA, Ferdinand PU, Nwalo FN, Unachukwu MN (2019). Mechanism and health effects of heavy metal toxicity in humans. Poisoning in the modern world-new tricks for an old dog 10. 
Gazuwa SY, Timothy HO (2019). Evaluation of the anti-nutrients, nutrients and phytochemicals and metals content of five leafy vegetables in Dengi metropolis. International Journal of Biochemistry Research and Reviews 24(3): 1-8. IJBCRR 44652 ISSN: 2231-086X, NLMID: 101654445. 
Godwill AE, Paschaline UF, Friday NN, Marian NU (2019). Mechanism and Health Effects of Heavy Metal Toxicity in Humans. DOI: 10.5772/intechopen.82511 
Lente I, Ofosu-Anim J, Brimah AK, Atlemeo S (2014). West African Journal of Applied Ecology 22(1):41-58. 
Jarup L, Berglund M, Elinder CG, Nordberg G, Vahter M (1998). Health effects of cadmium exposure—a review of the literature and a risk estimate. Scandinavian Journal of Work Environmental Health 24(1):1-51. 
Qaisar M, Audil R, Sheikh, SA, Muhammad B (2012). Current status of toxic metals addition to environment and its consequences. In The plant family Brassicaceae. Springer, Dordrecht pp. 35-69. 
Kazantzis G (2004). Cadmium, osteoporosis and calcium metabolism. Biometals 17(5):493-498.
Lawal JP, Audu LE (2011). Interaction of metals and thiols in cell damage and glutathione distribution: potentiation of mercury toxicity by dithiothreitol. Toxicology Letter 156:93-100. 
Lidsky TI, Schneider JS (2003). Lead neurotoxicity in children: basic mechanisms and clinical correlates. Brain 126(1):5-19. 
Gaetke LM, Chow-Johnson HS, Chow CK (2014). Copper: toxicological relevance and mechanisms. Archives of toxicology 88(11):1929-1938. 
Mapanda F, Mangwayana EN, Nyamangara J, Giller KE (2005). The effect of long term irrigation using wastewater on heavy metal contents of soils under vegetables in Harare, Zimbabwe. Agriculture, Ecosystems & Environment, 107(2-3):151-165.
Laughlin Mc, Agrawal EO (2015). Effects of heavy metals contaminated vegetables. Indian Journal of Pharmacology pp. 201-208. 
Micheal H, Ogenyi RA, Doguna O (2018). Assessment of heavy metal concentration in water, soil and vegetables in ex-mining ponds, Jos South LGA, Plateau state, Nigeria. International Journal of Scientific and Research Publications 8(8). DOI:10.29322/JSRP.8.8.2018.p80107 
Khan MJ, Jan MT, Tullah F, Khan NU, Arif M, Perveen S, Alam S, Jan AU (2011).The effect of using waste water for tomato, Pakistan Journal of Botany 43(2):1033-1044. 
Nemssadz K, Sanikidze T, Ratiain L, Gabunia L, Sharashidenidze T (2009). Mechanisms of lead-induced poisoning. Georgian Medical News (172-173):92-96. 
Nimyel DN, Egila JN, Lohdip YN (2015). Heavy metal concentrations in some vegetables grown in a farm treated with urban solid waste in Kuru Jenta, Plateau state, Nigeria. British Journal of Applied Science and Technology 8(2): 139-147, 2015, article number: BJAST.2015, 192.ISSN: 2231-0843.
Orish E, Orisakwe E, Ayuba D, Herbert O, Chidi M, Nnaemeka AU (2017). Lead levels in vegetables from artisanal mining sites of Dilimi river, Bukuru and BarkinLadi, North Central Nigeria: cancer and non-cancer risk assessment. Asian Pacific Journal of Cancer Prevention 18(3):621-627. doi:10.22034/APJCP.2017.18.3.621

Patrick PU (2006). Role of metallothionein in cadmium-induced hepatotoxicity and nephrotoxicity. Pathogenesis of skin cancer peroxidations. Biological Trace Element Research 28:83-97.

Samuel NO, Ebenezer M, Dela S, Shoji R, Esi A (2008). Heavy metals uptake by vegetables cultivated on urban waste dumpsites: A case study of Kumasi, Ghana. Research Journal of Environmental Toxicology 2:92-99.

Sharma DP, Thoren J, Barregard L, Schutz A, Skarping G (2007). Heavy metals contamination of vegetables grown by irrigation using industrial waste water. 66(2):258-266.

Singh GT, Cheryan M, Cosgrove DJ (2010). Hazards of heavy metals contamination. British Medical Bulletin 68(1):167-182.

Temple RU, Schrauzer GN (2012). Effect of selenium antagonists on cancer susceptibility; New Aspects of Chronic heavy metal toxicity. Journal of UOEH 9:208-215.

Turkdogan EL, Sheikh ZA, Zaman K (2002). Oxidative stress as a mechanism of chronic cadmium-induced hepatotoxicity and renal toxicity and protection by antioxidants. Toxicology and Applied Pharmacology (154):256-263.

Valentine WN, Paglia DE, Fink K, Madokoro G (1976). Lead poisoning: association with hemolytic anemia, basophilic stippling, erythrocyte pyrimidine 5'-nucleotidase deficiency, and intra erythrocytic accumulation of pyrimidines. The Journal of Clinical Investigation 58(4):926-932. Doi:10.1172/JCI108545.