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Ecological and human health risks assessment of heavy metals in vegetables grown in palm oil mill effluents irrigated farmland

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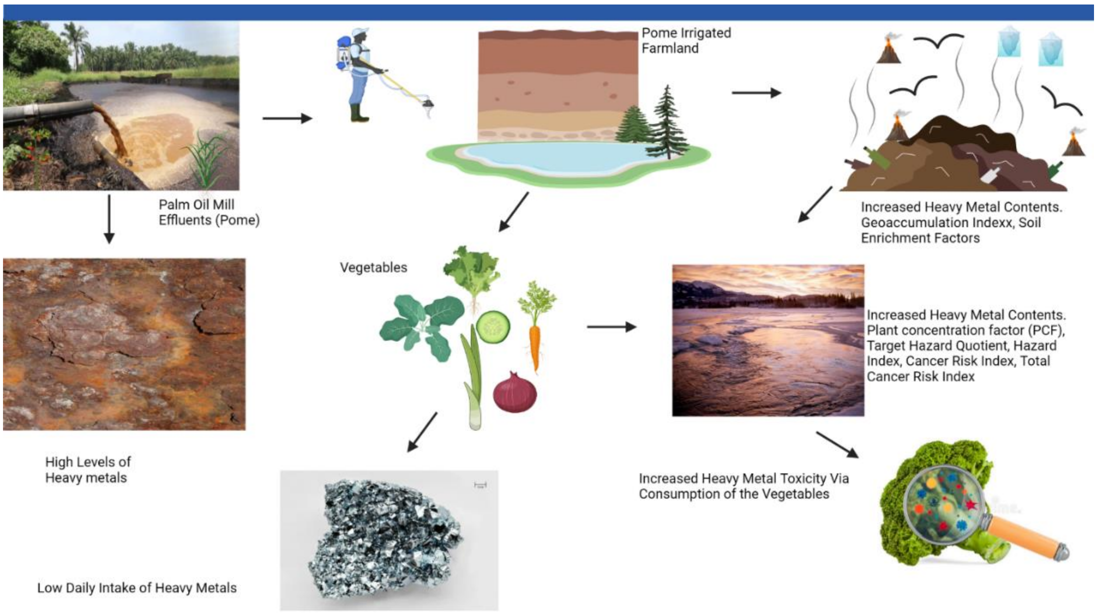
GRAPHICAL ABSTRACT



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ABSTRACT

This study evaluated the impact of heavy metal contents in vegetables grown in a palm oil mill effluents (POME) irrigated farmland on the biomes and well-being of humans that consume the vegetables. In this study, POME, a soil sample from POME irrigated farmland, and selected vegetables were evaluated. The results showed high cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni),) and arsenic (As) and lower zinc (Zn) and copper (Cu) concentrations in POME relative to their respective permissible limits. The soil irrigated with POME had elevated levels of metals, comparable to the control soil, whereas vegetable growing in POME irrigated farmland contained increased amounts of most of the heavy metals above their respective permissible levels in edible vegetables. The plant concentration factors (PCF) of heavy metals detected in the vegetables were less than one except for *V. amygdalina* with PCF>1 for cobalt. The pollution load index of Cd, Cr, Cu, Co, and As in the POME soil were above 50, while high enrichment factors were obtained for Cd, Cr, Pd, Co, and arsenic. The geoaccumulation index indicated that the POME soil was strongly contaminated by Zn, Fe, Pb, Mn, Ni and extremely contaminated with Cd, Cr, Zn, Cu, and Co. The metals levels ingested daily from the vegetables were low, comparable to their respective oral reference doses except for Mn in *V. amygdalina* and As in most of the vegetables. There was a high target hazard quotient for Mn, and As in most of the vegetables with hazard index (H.I.) >1 in each of the vegetables and increased cancer risk for Cd, Cr, Pb, Ni and As toxicity coupled with very high total cancer risks. These findings show that irrigation of farmlands with POME raises the heavy metal levels in vegetables and the risk of heavy metal toxicity.

1. Introduction

Heavy metals are part of minerals naturally found on the Earth's crust that may routinely gain entrance into the human body via contamination in the food chain (Ganjavi et al. 2010). Metals like iron, copper, and zinc are required in small quantities for the normal biochemical and physiological functions in the body and are considered as being essential to human health (Islam et al. 2014). At the same time, others like lead and cadmium are toxic to humans even at low doses (Islam et al. 2014). Prolonged consumption of food and food products with high heavy metal contents could be detrimental to humans, most especially to the kidney, liver, heart and

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nervous system (Jarup. 2003). The increased awareness of the risks foods with high heavy metal contents pose to humans has attracted the attention of both Local and International Agencies that regulate food quality to reduce the permissible levels of toxic metals in food products (Khan et al. 2008). There is increased consumption of vegetables in both rural and urban communities, attributed to the health benefits vegetables offer due to their richness in vitamins, minerals, fibres, carbohydrates, proteins, and beneficial antioxidants that promote good health if regularly consumed in adequate amounts (Zahra and Parisa. 2013). Bio-constituents present in vegetables also help to regulate changes in acidity levels in the body resulting from the digestion process (Bahiru et al. 2019). It is now widely encouraged to consume varieties of vegetables and fruits to maximise their immense health benefits. Although humans are encouraged to consume about 400 mg/kg vegetables/day to stay healthy, measures should be put in place to minimise toxicity associated with the consumption of an increased amount of vegetables containing toxic metals (Cobb et al. 2000). Vegetables are significant components of daily foods consumed in Ezeala, Njaba, Imo State, Nigeria, despite their use of wastewater which may contain high levels of heavy metal contents for irrigation purposes. This study evaluated the ecological and human health risks of heavy metal contents in vegetables grown in POME irrigated farmland.

2. Material and methods

2.1. Vegetables and soil samples

Six edible leafy vegetables, including Amaranthus hybridus (Green leaf); Gongronema latifolium (Utazi); Occidentalis telfairia (Ugu); Vernonia amygdalina (Bitter leaf); Ocimum gratissimum (scent leaf), and Talinum triangulare (Waterleaf), were collected from farmland irrigated with palm oil mill effluents in Ezeala were used for this study. Also, the palm oil mill effluent was used for irrigation purposes from a palm oil milling site at Ezeala. At the same time, the sample soil sample was collected from 0 – 20 cm depth at farmlands irrigated with a palm oil mill effluent and farmland without palm oil mill effluents irrigation in Ezeala.

2.1. Preparations of the samples

The vegetable samples were rinsed with deionised water, dried under shade, pulverised and stored in clean polythene bags whereas, the soil samples were dried under a shade, pulverised and sieved. Similarly, the palm oil mill effluent was filtered using a mesh cloth to remove debris and suspended solids. Subsequently, a known volume was evaporated to total dryness with a crucible of known weight to ascertain the weight of the palm oil mill effluent.

2.2. Digestion of samples and quantification of heavy metals

The soil samples were digested in a triple acid mixture containing HNO_3, $HClO_4$, and H.F., in a 5:1:1 ratio. The filtrate obtained after the digestion of the soil samples were diluted to 50 ml with deionised water for heavy metal analysis. Also, the six vegetable samples and the palm oil mill effluent were digested in a combined acid mixture of HNO_3, and $HClO_4$, in a 5:1 ratio, respectively, according to the method of Allen et al. (1986). The heavy metals in the acid digests of soils, vegetables and palm oil mill effluents samples were analysed using an atomic absorption spectrophotometer (AAS).

2.3. Determination of geoaccumulation index (Igeo)

Geoaccumulation index (Igeo) makes it possible to ascertain the level of contamination caused by a specific pollutant by comparing the concentrations of that pollutant or contaminant in the site under investigation with the concentrations in the reference site. We have employed geoaccumulation index (Igeo) in this study to ascertain the level of heavy metal contamination in the soil from farmland irrigated with POME, as Muller (1969) described. The geoacumulation index was calculated by the equation:

$$\mathrm{Igeo} = \log_2\left(\frac{\mathrm{C_n}}{1.5\mathrm{Bn}}\right) \quad (1)$$

Here, C_n is the concentration of a metal in soil from farmland irrigated with POME; B_n is the concentration of a metal in soil from farmland without POME irrigation, and 1.5 is a correction factor for the difference heavy metal concentrations in uncontaminated soils according to Wei et al. (2009).

2.4. Plant concentration factor (PCF)

Plant concentration factor (PCF) assesses the ability of a vegetable to uptake metals from the soil, and it is largely determined by both soil and plant properties. The plant concentration factor (PCF) was calculated as described by Cui et al. (2005) using Eq. 1.

$$\mathrm{PCF} = \frac{\mathrm{C_{plant}}}{\mathrm{C_{soil}}} \quad (1)$$

Here, C_{plant} and C_{soil} are the metal contents in the vegetables and soil samples, respectively.

2.5. Pollution load index (PLI)

The levels of heavy metal contamination in the soil were assessed using the pollution load index (PLI) method as outlined by Liu et al. (2005) in Eq. 2.

$$\text{Pollution load index (PLI)} = \frac{\mathrm{C_{soil}}}{\mathrm{C_{reference}}} \quad (2)$$

Here, $\mathrm{C_{soil}}$ (Samples) and $\mathrm{C_{reference}}$ are the metal contents in the soil sample from farmland irrigated with POME and a reference soil, respectively.

2.6. Enrichment factor (E.F.)

Enrichment factor was used to determine if the heavy metals in a soil sample from a POME irrigated farmland contributed by the POME applied on the farmland (i.e. anthropogenic source) or from a natural source (geogenic source) according to the method of Lu et al. (2009) using Eq. 3.

$$EF = \frac{C_x / C_{ref}}{B_x / B_{ref}} \quad (3)$$

C_x = concentration of the investigated metal in the soil from farmland irrigated with POME, C_{ref} = concentration of the investigated metal in the soil without POME, B_x = concentration of the reference metal soil from farmland irrigated with POME and B_{ref} = concentration of the reference metal in the soil from farmland without POME. Iron (Fe) was chosen as the reference metal in this study.

2.7. Daily intake of heavy metals

The average amount of heavy metals ingested daily via vegetable consumption was assessed by the method of Rattan et al. (2005) using Eq. 4.

$$\mathrm{DIM} = \frac{C_{metal}\ x\ D_{food\ intake}}{B_{average\ weight}} \quad (4)$$

where, C_{metal}, represent the heavy metal concentrations in the vegetables (mg/kg) as determined by atomic absorption spectrophotometer (AAS), D_{food} intake = daily intake of vegetables. The average daily vegetable intake was 400 g/kg/day, according to WHO/FAO (2003). $B_{average}$ weight = average body weight of consumers of the vegetables, which was 61 kg (the mean of 400 adult body weight measured in the study area using a bathroom scale).

2.8. Target hazard quotient (Non-carcinogenic health risk index)

The target hazard quotient (THQ) of heavy metals in the vegetables was estimated as the ratio of daily intake of a given metal (DIM) to its oral reference (RfD_o) according to Lu et al. (2009) using equation 5.

$$THQ = \frac{DIM}{R_f Do} \quad (5)$$

Values of RfD for Cd, Cr, Zn, Fe, Pb, Mn, Ni, Cu, Co, and As used in this calculation were 1.00, 1500.00, 300.00, 700.00, 4.00, 20.00, 40.00, 0.10, and 0.30 µg/kg/day respectively (Lu et al. 2009). The average body weight of adult consumers was 61 kg.

2.9. Hazardous index (H.I.)

The hazard index of various heavy metals detected in the vegetables was estimated as the sum of the hazard quotients of all the heavy metals present in each of the vegetables as outlined by Lu et al. (2009) using Eq. 6.

$$HI = \sum THQ = THQ_{Fe} + THQ_{Zn} + THQ_{Cu} + THQ_{Cd} + THQ_{Mn} + THQ_{Cr} + THQ_{As} + THQ_{Cu} + THQ_{Pb} \quad (6)$$

2.10. Lifetime cancer risks and cumulative cancer risk

The possibility of lifetime cancer risks in the vegetables from farmlands irrigated with POME through intake of carcinogenic heavy metals was assessed according to the method of Liu et al. (2013) with equation 7.

$$Lifetime\ cancer\ risk = EDI\ x\ CSF \quad (7)$$

where EDI = estimated daily intake of carcinogenic metals (mg/kg/day). The cancer slope factors (CSF) for Cd, Cr, Pb, Ni, and As are 0.38, 0.5, 0.0085, 1.7 and 1.5, respectively. The cancer risk index between 10^{-6}–10^{-4} is recognised as a good indicator by Lu et al. (2009).

2.11. Total cancer risk

The additive cancer risk from consumption of vegetables containing carcinogenic heavy metals was estimated using the method of Liu et al. (2013) according to Eq. 8.

$$Total\ cancer\ risks = \sum_{k=1}^{n} EDI_k CSF_k \quad (8)$$

where EDI was the amount of carcinogenic metal ingested from daily consumption of vegetables and CSF was the cancer slope factor for each of the carcinogenic metals in the vegetables.

2.12. Statistical analysis

The data obtained were subjected to one-way analysis of variance and paired sample t-test, using a statistical package (Statistical Products and Service Solutions, version 22) (SPSS) (Version 22). The significance of the results was obtained at P < 0.05.

3. Results and discussion

Evaluation of Human health risk is a process of calculating the risk to a given population or subpopulations relating to exposure to a particular agent, taking into account the inherent characteristic of the specific target system. It has been established that human exposure to toxic metals or toxic elements commonly known as heavy metals constitutes a major health risk (Yabe et al. 2013). Toxic metals or toxic elements could enter the human system via inhalation of contaminated dust or particles, consumption of drinking water food laden with heavy metals (UI-Islam et al. 2007). This study assessed human health risks of heavy metals in vegetables from farmlands in the Ezeala community irrigated with POME in Njaba, Imo State - Nigeria.

3.1. Heavy metal contents in palm oil mill effluents

The results in Table 1 show that the POME from Ezeala contains high levels of heavy metals, with manganese and cobalt as the most abundant and least abundant heavy metals, respectively. Concentrations of cadmium (Cd), chromium (Cr), lead (Pb), nickel (Ni), and arsenic (As) detected were found to be much higher than their allowed limits in effluents. The concentration of zinc (Zn) and copper (Cu) detected in the POME were lower than their corresponding permissible limits in effluents.

Table 1. Concentrations of heavy metals in palm oil mill effluents.

Heavy metals	Contents, mg/L	Permissible limits
Cd	0.23 ± 0.06	0.1
Cr	0.13± 0.01	0.1
Zn	0.64 ± 0.01	5
Fe	0.73 ± 0.00	NS
Pb	0.23± 0.01	0.015
Mn	4.07± 0.03	NS
Ni	2.15± 0.05	0.1
Cu	1.92± 0.03	3
Co	0.04± 0.01	NS
As	0.65 ± 0.12	0.2

Values are presented as mean ± standard deviation (n = 3), BDL = below detection limit and NS = Not Specified

The levels of heavy metals in the POME indicate that the levels of Mn > Ni > Cu > Fe > As > Zn > Cd > Pb > Cr > Co. The high levels of heavy metals detected in the palm oil mill effluents show that these effluents are rich in heavy metals. These high levels of heavy metals observed in palm oil mill effluents may be attributed to the palm fruits accumulating much of these metals from the palm trees. It can also be attributed to the contamination of palm fruits by heavy metals from soils where these palm fruits were harvested. Preparation of palm fruits with contaminated water, containers or contaminated environment can also lead to increased levels of heavy metals in palm oil mill effluents. Heavy metals contaminated air, dust, and smoke from automotive engines and gas flaring from Neighbouring State (Rivers State) could have contributed to the high levels of heavy metals in effluents. The high levels of heavy metals in palm oil mill effluents in raw forms could lead to environmental contamination. These effluents should be treated to reduce the levels of these metals below their respective permissible safe limit as specified by relevant regulatory bodies for effluents. Discharge of these effluents into water bodies could lead to eutrophication or bioaccumulation of these metals in fishes and other aquatic lives that are consumed by humans. Consumption of such heavy metals contaminated fishes could elicit serious adverse health hazards. Similarly, the use of the effluent for irrigation of farmlands increased their levels of heavy metal contents and increased the chance of crops grown in such farmland accumulating heavy metals. Consumption of such food crops with high levels of heavy metals by humans results in ingestion of these toxic metals, which could cause detrimental health effects to the consumers, including death.

3.2. Heavy metal contents in soils from farmlands irrigated with palm oil mill effluents

The soils from farmlands irrigated with palm oil mill effluents were found to be rich in all the heavy metals analysed with iron as the most abundant heavy metal among all other heavy metals tested (Table 2). The heavy metal concentrations detected in the soil from farmland irrigated with palm oil mill effluents were significantly very high when compared with their respective heavy metal concentrations in the control soil that was not irrigated with POME. The trend of heavy metal concentrations observed in the control soil showed that the concentration of Fe > Mn > Zn > Ni > Cu > (Cr = Co) > Cd > As > Pb while the heavy metal concentrations in soil from farmland irrigated with POME showed that Fe > Ni > Mn > Zn > Cr > Cu > Co > Cd > As > Pb. It was observed that the soil from farmland irrigated with POME contained high heavy metals contents with iron (18.50 ± 0.40 ppm) and lead (0.40 ± 0.01 ppm) as major and least heavy metals, respectively. The trace amount of heavy metals (Cd, Cr, Zn, Fe, Pb, Mn, Ni, Cu, Co, and As) detected in the control soils from the farmlands could be attributed to natural and anthropogenic sources. Leaching of soils, deposition of contaminated dust particles, smokes from exhausts of combustive engines and application of agrochemicals such as fertilisers and pesticides can contribute significant amounts of heavy metals to soils. The significantly high levels of heavy metals detected in soils from farmlands irrigated with palm oil mill effluents relative to their corresponding control soils may be attributed to the high levels of heavy metals in palm oil mill effluents used for the irrigation of these soils. These soils irrigated with palm oil mill effluents might have absorbed and retained much of the heavy metals in the effluents leading to the increased levels of these metals in soils. Palm oil mill effluents irrigated soils had very high levels of cadmium relative to the large amounts of heavy metals in the effluents used for the irrigation of these farmlands. Thus, suggesting that crops grown in these farmlands can absorb and accumulate much cadmium from these soils, posing greater risks to their consumer who could suffer from cadmium toxicity such as cancer or kidney and liver damage. Apart from cadmium, crops grown in these farmlands have increased chances of accumulating toxic metals to the extent that consumers of such food crops may suffer from adverse effects associated with ingestion of high levels of these toxic metals. These findings agree with the findings of Sharma et al. (2007), who reported that the use of pesticides, fertilisers and contaminated irrigation water for agricultural purposes are the major sources of heavy metal enrichment of agricultural soils. Alternative water should be sourced for irrigation purposes to protect our agricultural lands from contaminations, safeguard human health and reduce the cost of managing adverse health effects resulting from consumption of heavy metal contaminated agricultural products.

Table 2. Heavy metal contents in soil from farmland irrigated with POME.

Heavy metals	Soil without POME, mg/L	POME irrigated soil, mg/L
Cadmium (Cd)	0.010±0.00*	1.514±0.02**
Chromium (Cr)	0.020±0.00*	3.122±0.10**
Zinc (Zn)	1.180±0.02*	5.544±0.31**
Iron(Fe)	2.240±0.13*	18.502±0.40**
Lead (Pb)	0.001±0.00*	0.400±0.01**
Manganese (Mn)	1.410±0.01*	6.301±0.21**
Nickel (Ni)	0.330±0.01*	6.242±0.23**
Cupper (Cu)	0.060±0.01*	3.103±0.01**
Cobalt (Co)	0.020±0.00*	2.162±0.02**
Arsenic (As)	0.003±0.00*	1.083±0.11**

Values are presented as mean ± standard deviation (n = 3), and values with Asterisks (* = significant decrease while ** = significant increase) are significantly different from the paired mean at P<0.05.

3.3. Heavy metal contents in vegetables from farmland irrigated with POME

It was observed that cadmium was below the detection limit in A. hybridus while the concentration of cadmium detected in every other vegetable was above the permissible limit of cadmium in vegetables which was 0.001 ppm (Table 3). However, except for the low concentration of cobalt (0.76 ± 0.03 mg/L) detected in A. hybridus, every other heavy metal were detected in concentrations far above their respective permissible limits. Among all the heavy metals detected in the vegetables in the following order: Fe > Zn > Ni > Mn > Co > Cu > Cr > Pb and As. All the heavy metals detected in G. latifolium were above their respective permissible limits. Iron has the least and highest concentrations among all the metals tested, respectively. The result also shows that with the exception of iron and cobalt that was detected in concentrations below their respective permissible limits in T. occidentalis, every other heavy metal were detected in concentrations above their respective permissible limits. In Ocimum gratissimum, considerably high concentrations of heavy metals were detected above their respective permissible limits except for cobalt (0.52 ± 0.04 ppm) that whose concentration was below the permissible limit of 2.00 ppm. It was further observed that the concentrations of Cd, Cr, Pb, Mn, Ni, and Cu, detected in T. triangulare leaves were much higher than their respective permissible safe limits in vegetables, while the concentration of arsenic was found to be lower than its permissible limit of 0.10 ppm in vegetables. However, concentrations of zinc, iron, and cobalt detected were below their respective safe permissible limit. This result shows that the highest concentrations of Cd, Zn, Cu, and As were detected in G. latifolium; the highest concentration of Fe and Cr were detected in A. hybridus; the highest concentration of Mn, Ni and Co were detected in V. amygdalina, and the highest concentration of Pb was detected in T. occidentalis among all the vegetables tested.

Table 3: Heavy metal contents in vegetables from farmland irrigated POME.

Metals	Limits	*A. hybridus*	*G. latifolium*	*T. occidentalis*	*V. amygdalina*	*O. gratissimum*	*T. triangulare*
Cd (ppm)	0.001	BDL	0.03±0.00	0.02±0.00	0.05±0.01	0.01±0.00	0.02±0.00
Cr (ppm)	0.003	0.13±0.01	0.30±0.00	0.04±0.01	0.10±0.02	0.05±0.01	0.03±0.01
Zn (ppm)	2	2.63±0.01	4.23±0.02	2.06±0.03	3.56±0.02	2.86±0.01	1.61±0.02
Fe (ppm)	5	6.71±0.03	5.64±0.03	3.96±0.01	5.56±0.02	5.75±0.02	4.85±0.02
Pb (ppm)	0.01	0.03±0.00	0.08±0.01	0.11±0.00	0.03±0.01	0.10±0.00	0.02±0.00
Mn (ppm)	0.3	1.15±0.02	1.07±0.20	1.18±0.04	2.66±0.02	1.32±0.01	1.17±0.01
Ni (ppm)	0.02	1.73±0.02	1.53±0.03	1.03±0.10	2.49±0.01	0.56±0.01	1.42±0.03
Cu (ppm)	0.01	0.63±0.02	1.23±0.01	0.71±0.01	1.10±0.01	1.15±0.04	0.40±0.01
Co (ppm)	2	0.76±0.03	1.27±0.10	0.61±0.01	2.86±0.12	0.52±0.01	1.31±0.03
As (ppm)	0.1	0.03±0.00	0.13±0.02	0.04±0.00	0.11±0.02	0.08±0.01	0.21±0.03

Values are presented as mean ± standard deviation (n = 3); BDL = below the detection limit; NS = Not Specified

The low levels of cadmium in A. hybridus from Ezeala farm, despite their high levels in the soil, showed either that these metals are tightly bound to the soil colloids or that these vegetables are poor accumulators of these metals. Individuals who consume A. hybridus are not likely to suffer any adverse health effects associated with excess ingestion of cadmium. The high levels of Cr, Zn, Fe, Pb, Mn, and Cu detected in A. hybridus above their respective permissible limits in vegetables could be attributed to these metals being free or weakly bound to soil colloids and the ability of A. hybridus to absorb these metals from the soil easily and bioaccumulate or retain them in large concentrations. The high levels of these metals in A. hybridus constitute high toxicity potentials or risks to individuals who consume this vegetable regularly. Heavy metals like Cr, Pb, and Ni that are potent human carcinogens could cause serious carcinogenic and non-carcinogenic health effects when ingested in excess amounts, while excess intake of non-carcinogenic metals such as Zn, Fe, and Cu could cause many non-carcinogenic deleterious health effects, suggesting this vegetable with high levels of these metals is not fit for human consumption. However, low levels of Co and As detected in A. hybridus from this farm show that it cannot absorb a sufficient amount of these metals from the soil, possibly due to the prevailing soil pH, speciation and solubility of these metals soil. The high levels of all the heavy metals detected in G. latifolium relative to their respective permissible limits could be attributed to the ability of this vegetable to absorb and accumulate heavy metals from the soil and palm oil mill effluents used for the irrigation of the farm. It showed hyperaccumulation of heavy metals in G. latifolium which, may not be suitable for human consumption due to toxic effects associated with ingestion of these heavy metals suggesting that palm oil mill effluents are not suitable for irrigation of farmland cultivated with G. latifolium. Additionally, high levels of heavy metals in T. occidentalis, V. amygdalina, O. gratissimum and T. triangulare show that these vegetables are rich in heavy metals. These could be attributed to their ability to absorb, and hyper accumulate most of these heavy metals in varying concentrations from the soil and palm oil mill effluents used for irrigation of the farm. Some of the heavy metals detected in concentrations below their respective limits could be due to existing soil pH, speciation and solubility of the heavy metals in the soil that usually determine the rate of heavy metal uptake from soil by vegetables. Manganese, nickel and copper are heavy metals that may cause major health hazards to the consumer of vegetables from Ezeala. Thus, the volume of palm oil mill effluents applied for irrigation should be reduced to minimise the number of heavy metals deposited in the soil and vegetables irrigated. In the presence of alternative water for irrigation purposes, palm oil mill effluents should not be used for irrigation to safeguard human health and consumers of these vegetables should be enlightened on the health implications of consuming vegetables with high levels of heavy metals. This will enable them to make informed decisions on their food choice to stay healthy.

3.4. Plant concentration factors (PCF) of heavy metals in vegetables from farmland irrigated with POME

The food chain constitutes the major source of human exposure to heavy metals contaminated soils as plants uptake heavy metals from soils. The plant concentration factors of heavy metals detected in the vegetables significantly differed among the farmlands irrigated with palm oil mill effluents and vegetable types primarily due to the heavy metal content of the effluents, soil nutrient (metals) retention, plants and soil properties. This was in line with the findings of Cui et al. (2004) and Naz et al. (2015) that the plant concentration factor of a given metal varies much with plant type or species. The transfer of heavy metals from the palm oil mill effluents and soil to the vegetables could be attributed to the high level of manganese, nickel, and arsenic concentrations in the vegetables which were in agreement with the findings of Zheng et al. (2007). The plant concentration (or transfer) factors (PCF) obtained for heavy metals detected in the vegetables from farmland irrigated with palm oil mill effluents (POME) in Ezeala show that none of the vegetables has PCF > 1 for all the heavy metals detected except *V. amygdalina* that has PCF > 1 for cobalt as shown in Table 4.

Table 4. Plant concentration factors (PCF) of heavy metals in vegetables from farmland irrigated with POME.

Metals	*A. hybridus*	*G. latifolium*	*T. occidentalis*	*V. amygdalina*	*O. gratissimum*	*T. triangulare*
Cd	NP	0.20±0.02	0.01±0.00	0.03±0.01	0.07±0.00	0.01±0.00
Cr	0.04±0.00	0.10±0.00	0.02±0.00	0.04±0.01	0.02±0.00	0.01±0.00
Zn	0.48± 0.02	0.76± 0.04	0.37± 0.02	0.64± 0.03	0.52± 0.03	0.29±0.01
Fe	0.36± 0.01	0.31± 0.01	0.21± 0.00	0.30± 0.01	0.31± 0.01	0.26±0.01
Pb	0.08± 0.00	0.22± 0.02	0.28± 0.01	0.10± 0.02	0.25± 0.01	0.05±0.00
Mn	0.18± 0.00	0.20±0.03	0.19± 0.00	0.42± 0.01	0.21± 0.00	0.19±0.00
Ni	0.28±0.01	0.25± 0.00	0.17± 0.00	0.40± 0.01	0.09± 0.00	0.23±0.00
Cu	0.21± 0.01	0.40± 0.00	0.23±0.00	0.36± 0.00	0.38± 0.01	0.13±0.00
Co	0.36± 0.01	0.63± 0.04	0.28± 0.00	1.37± 0.04	0.24± 0.00	0.62±0.01
As	0.03±0.00	0.12±0.01	0.04±0.00	0.10±0.01	0.07±0.00	0.19±0.01

Values are presented as mean ± standard deviation (n = 3); NP = Not applicable. PCF < 1 indicates that the plant only absorbs the heavy metal but does not accumulate it, while PCF > 1 indicates that the plant accumulates the heavy metals

It was observed that among all the vegetables analysed, *A. hybridus* has the highest transfer factor for iron than any other vegetables. *G. latifolium* exhibited the highest transfer factors for Cd, Cr, Zn, and Cu among all the vegetables. Also, *V. amygdalina* has the highest transfer factors for Ni and Co; *O. gratissimum* has the highest transfer for manganese, and *T. triangulare* has the highest transfer factor for arsenic than any other vegetables from this farmland. Zinc exhibited the highest transfer factor in *A. hybridus*, *G. latifolium*, *T. occidentalis* and *O. gratissimum* relative to the transfer factors observed for other heavy metals, while cobalt has the highest transfer factor in *V. amygdalina* and *T. triangulare,* respectively. The *A. hybridus* from farmland irrigated with palm oil mill effluents in Ezeala with no concentration factor (PCF) for Cd could be attributed to the no detectable levels of these metals in the vegetables. High concentrations of these metals were detected in the soil, but the vegetable could not absorb these metals to appreciable concentrations due to prevailing soil properties (Shirkhanloo et al. 2015). The quantities of heavy metals in these vegetables were primarily determined by the available concentrations of heavy metals in the soil at any given time and the ability of the soil to retain them by binding them tightly to the soil colloids. Palm oil mill effluents should not be applied to this farmland cultivated with vegetables when they are ready for harvest as their application could increase the level of the heavy metal absorbed by these vegetables. Each of these vegetables has the minimal potential of causing adverse effects, which are in line with the findings of Barone et al. (2015) and Malan et al. *(2015*).

3.5. Pollution load index (PLI) of heavy metals in soils from farmlands irrigated with POME

The data in Table 5 show the pollution load index of heavy metals in soils from farmland irrigated with palm oil mill effluents (POME) in Njaba. The pollution load index of heavy metals detected in POME irrigated soil from Ezeala show that Cd, Pb, Co, and As have a pollution load index greater than 100. The pollution load index observed for Zn, Fe, Mn, and Ni were less than 50, while copper had a pollution load index greater than 50. The high pollution load index (PLI) for cadmium and chromium observed in the soil showed it was heavily polluted by the respective metals (cadmium and chromium) from the effluents used for the irrigation. These pollution load indexes for cadmium and chromium suggest immediate interventions were required to ameliorate their pollution loads respectively and prevent crops and vegetables grown in the soils from absorbing and accumulating these metals in excess concentrations that would pose serious toxic effects to their consumers. The excess pollution load index of cadmium and chromium respectively showed that they posed greater risks to the environment as they could be leached to the sources of drinking water, aquatic bodies, absorbed by plants and edible vegetables ingested by animals and humans, causing adverse health effects. Thus, the levels of zinc and iron in the soils could be said to be within the nontoxic limits and could be attributed to the low level of zinc and iron in the palm oil mill effluents used for irrigation. The high pollution load index (PLI > 100) of lead in the soils irrigated with palm oil mill effluents showed that the soils were heavily polluted by the high lead content in the effluents and required immediate interventions. Similarly, almost all the soils had a high pollution load index for arsenic and required immediate interventions to reduce the levels of arsenic in the soils. The moderate to high PLI values of heavy metals including Cu, Zn, Cr, As and Ni obtained in this study indicated a high presence of these heavy metals in the earth crust that greatly polluted the soils, contrary to the findings of Pradhan and Kumar (2014) who reported their low presence and minimal pollution effects.

Table 5. The pollution load index (PLI) of heavy metals in the soil from farmland irrigated farmland.

Heavy metals	Pollution load index
Cadmium (Cd)	151.0
Chromium (Cr)	156.0
Zinc (Zn)	5.0
Iron(Fe)	8.0
Lead (Pb)	400.0
Manganese (Mn)	4.5
Nickel (Ni)	19.0
Copper (Cu)	51.7
Cobalt (Co)	108.0
Arsenic (As)	360.0

A PLI value of ≥ 100 requires urgent action to reduce the pollution load, and a PLI value of ≥ 50 needs further monitoring of the polluted site. At the same time, a PLI value < 50 shows that drastic actions are required to reduce the pollution load.

3.6. Heavy metals enrichment factors in soils from farmland irrigated with POME

The result in Table 6 shows that with the exception of manganese and zinc that have enrichment factor (E.F.) less than 1 in Ezeala soil and zinc that has E.F. < 1 while every other heavy metal detected in POME irrigated soils has E.F.> 1. The result shows that the highest enrichment factors for cobalt were observed in the soil from farmland irrigated with POME in Ezeala. The trend of enrichment factors observed for heavy metals in POME irrigated soil in Ezeala show that the enrichment for Pb > As > Cr > Cd > Co > Cu > Ni > Mn > Zn respectively, which indicates that lead and zinc have the highest and least enrichment factor among all the heavy metals detected in the soil. Irrigation of farmlands with wastewater can lead to contamination of soil and groundwater by heavy metals, which could endanger human lives (Balkhair and Ashraf, 2016). Enrichment factors (E.F.) of heavy metals are used to differentiate sources of heavy metals between natural and anthropogenic sources. Enrichment factor very close to 1 (E.F. < 10) signifies natural sources, whereas enrichment factors greater than 10 (E.F.> 10) indicate anthropogenic sources. The significant enrichment of cadmium in the soil sample from farmlands irrigated with POME could be attributed to the high level of cadmium observed in the palm oil mill effluents used for the irrigation. The significant enrichment of the irrigated soil with chromium showed that there was efficient absorption and retention of chromium from the palm oil mill effluents by the respective soils. The minimal to significant enrichment of nickel and copper in the soils could be attributed to the natural sources of nickel and copper, respectively, though palm oil mill effluents could have contributed to their concentrations partly. The enrichment factor for cobalt in all the soils showed that only the cobalt observed in the soil from Ezeala farmland was contributed by palm oil mill effluents. The findings suggest that the use of palm oil mill effluents for irrigation heavily enriched the soils with heavy metals and should not be further used as alternative irrigation water to safeguard our environment and protect human health.

Table 6. Enrichment factors (E.F.) of heavy metals in soils from farmlands irrigated with POME.

Heavy metals	Enrichment factors (E.F.)
Cadmium (Cd)	18.13
Chromium (Cr)	18.94
Zinc (Zn)	0.57
Lead (Pb)	48.05
Manganese (Mn)	0.67
Nickel (Ni)	2.29
Cupper (Cu)	6.25
Cobalt (Co)	13.42
Arsenic (As)	44.91

A value of E.F. close to 1 suggests a natural source, whereas those E.F. values > 10 suggest anthropogenic source. E.F. < 2 = minimal enrichment, E.F. 2-5 = moderate enrichment, E.F. 5-20 = significant enrichment, E.F. 20-40 = very high enrichment, and E.F.> 40 = extremely high enrichment.

3.7. Geoaccumulation index of heavy metals in soils from farmland irrigated with POME

The geoaccumulation index of heavy metals in the soil from farmlands irrigated with POME in the six communities in Njaba shows that the geoaccumulation index of Cr and As exceeded 5 in all the soils tested (Table 7). It was also observed that the geoaccumulation index of Fe and Zn in all the soil tested were below 5. The geoacumulation index of the heavy metals detected in soil from farmland irrigated with POME in Ezeala show that Cd, Cr, Cu, Co, and As respectively have geoacumulation index greater than five while Zn, Fe, Pb, Mn and Ni respectively have geoacumulation index less than five. Geoaccumulation index (Igeo) determined the levels of heavy metal contamination of each of the soils irrigated with palm oil mill effluents in comparison with the concentrations of heavy metals in their respective reference soils (Zakir et al. 2015).

Table 7. Geoaccumulation index (I_{geo}) of heavy metals in soil from farmland irrigated with POME.

Heavy metals	Geoaccumulation index (I_{geo})
Cadmium (Cd)	6.65
Chromium (Cr)	6.70
Zinc (Zn)	1.65
Iron(Fe)	2.46
Lead (Pb)	4.74
Manganese (Mn)	1.57
Nickel (Ni)	3.66
Cupper (Cu)	5.11
Cobalt (Co)	6.17
Arsenic (As)	7.91

$I_{geo} \leq 0$ = no contamination
$0 < I_{geo} < 1$ = no contamination/slightly contaminated
$1 < I_{geo} < 2$ = Slightly contaminated
$2 < I_{geo} < 3$ = Slightly/highly contaminated
$3 < I_{geo} < 4$ = highly contaminated
$4 < I_{geo} < 5$ = Highly/excessively contaminated
$5 < I_{geo}$ = excessively contaminated

This gives the degree of heavy metal pollution, which usually ranges from uncontaminated to extremely contaminated soils. The geoaccumulation index of heavy metal contaminations observed in this study showed that all the soils were moderately or strongly contaminated with iron, and that could be attributed to the iron deposited on the soil from palm oil mill effluents used for the irrigation. The Igeo of cadmium in soils was extremely contaminated with cadmium from the effluents. The palm oil mill effluents used for the irrigation of the respective farmlands were highly rich in cadmium which was deposited in the soils. The high values of Igeo observed for Cr, Pb, Co, and As in all the soils showed that these soils were extremely contaminated by Cr, Pb, Co, and As. These observations could be attributed to the high levels of Cr, Pb, Co, and As detected in the respective palm oil mill effluents used for the irrigation of the farmlands that had deposited enormous amounts of these metals on the soils, thereby making them extremely contaminated. The Igeo of zinc in the soils showed that it was moderately contaminated with zinc from the palm oil mill effluents. The varying degree of Mn, Ni, and Cu contamination of the soils from palm oil effluents farms show that the effluents contained varying amounts of Mn, Ni and Cu that were deposited on the soils from their application for irrigated which were in contrast with the findings of Pradhan and Kumar (2014). The high level of contamination of the soils with these metals suggested there was much chance for crops and vegetables from this farmland to be contaminated with Mn, Ni and Cu, which could pose serious adverse health effects to the consumers.

3.8. Daily intake of heavy metals in vegetables from farmland irrigated with POME

The data in Table 8 show the daily intake of heavy metals in vegetables from farmland irrigated in Ezeala. The daily intake of Cd, Cr, Zn, Fe, Pb, Mn, Cu and Co in all the vegetables were below their respective tolerable daily intake. Daily intake of arsenic (As) from *A. hybridus* and *T. occidentalis* were below the tolerable daily intake of arsenic. However, the daily intake of As from consumption of *G. latifolium*, *V. amygdalina*, *O. gratissimum*, and *T. triangulare,* respectively, were above the tolerable daily intake of arsenic (0.3 µg/kg/day). The daily intake of cadmium (Cd) from all the vegetables from farmland irrigated with POME in Ezeala range from 0.07 µg/kg/day in *O. gratissimum* to 0.33 µg/kg/day in *V. amygdalina*. The highest daily intake of Cr, Zn, and Cu were observed in *G. latifolium,* while their respective least daily intake values of 0.2, 10.56, and 2.62 µg/kg/day were observed in *T. triangulare*. The highest daily intake of Fe, Pb, and Mn were observed in *A. hybridus*, *T. occidentalis* and *V. amygdalina,* respectively. Also, it was observed that only the daily intake of As from the consumption of *A. hybridus* and *T. occidentalis* were below the tolerable daily intake of As. The daily intake of As from *G. latifolium*, *V. amygdalina*, *O. gratissimum* and *T. triangulare* were above the tolerable daily intake of As, with *T. triangulare* accounting for the highest daily intake of As.

The daily intake of heavy metals such as Cd, Cr, Zn, Fe, Pb, Ni, Cu and Co in vegetables from farmland irrigated with palm oil mill effluents in Ezeala that were below their respective oral reference doses in all the vegetables showed that the consumers of these vegetables. The local consumer was not ingesting excess amounts of these metals via their daily intake of vegetables and was not exposed to any serious adverse health effects associated with these metals as their ingested doses were not known to cause adverse health effects. This is in line with the findings of Khan et al. (2008); Singh et al. (2010), and Pirsaheb et al. (2016), who had independently reported low daily intake of heavy metals than their tolerable daily intake limits and no human health risk from consumption of vegetables grown under wastewater irrigated farmlands. Chronic ingestion of cadmium even in low concentration could lead to its accumulation in kidneys with resultant kidney disease and likely lung damage and fragile bones. In extreme cases, diabetes, anaemia, cancer, arthritis and cardiovascular diseases could occur (Doamekpor et al. 2016). Whereas, the daily of manganese from ingestion of *V. amygdalina,* which was far above its oral reference dose, showed that individuals that consumed it were greatly predisposed to suffering manganese toxicity or manganism which is a serious neurological disorder. However, there was excess daily ingestion of arsenic from consumption of *G. latifolium*, *V. amygdalina*, *O. gratissimum,* and *T. triangulare* indicated that their consumption portends health hazards because excess ingestion of arsenic could cause both carcinogenic and non-carcinogenic adverse health effects and should be avoided to stay healthy (Doamekpor et al. 2016).

Table 8. Daily intake of heavy metals in vegetables from farmland irrigated with palm oil mill effluents in Ezeala (µg/kg/day).

Vegetables	Cd	Cr	Zn	Fe	Pb	Mn	Ni	Cu	Co	As
A. Hybridus	NC	0.85	17.25	44.00	0.20	7.54	11.34	4.13	4.98	0.2
G. latifolium	0.20	1.97	27.74	36.98	0.52	7.02	10.03	8.07	8.33	0.85
T. occidentalis	0.13	0.26	13.50	25.97	0.72	7.74	6.75	4.66	4.00	0.26
V. amygdalina	0.33	0.66	23.34	36.46	0.20	17.44	16.33	7.21	18.75	0.72
O. gratissimum	0.07	0.33	18.75	36.52	0.66	8.66	3.67	7.54	3.41	0.52
T. triangulare	0.13	0.20	10.56	31.80	0.13	7.67	9.31	2.62	8.59	1.38
RfD_o	1.00	1500	300.00	700.00	4.00	14.00	20.00	40.00	43.00	0.30

NC = Not calculated; RfDo = reference daily intake dose

The daily intake of each of the heavy metals are measured in (µg/kg/day)

3.9. Target hazard quotients (THQ) of heavy metals in vegetables from farmland irrigated with POME

This is in line with the findings of Khan et al. (2008); Singh et al. (2010), and Pirsaheb et al. (2016), who had independently reported low daily intake of heavy metals than their tolerable daily intake limits and no human health risk from consumption of vegetables grown under wastewater irrigated farmlands. Chronic ingestion of cadmium even in low concentration could lead to its accumulation in kidneys with resultant kidney disease and likely lung damage and fragile bones. In extreme cases, diabetes, anaemia, cancer, arthritis and cardiovascular diseases could occur (Doamekpor et al. 2016). Whereas, the daily of manganese from ingestion of *V. amygdalina,* which was far above its oral reference dose, showed that individuals that consumed it were greatly predisposed to suffering manganese toxicity or manganism which is a serious neurological disorder. However, there was excess daily ingestion of arsenic from consumption of *G. latifolium*, *V. amygdalina*, *O. gratissimum,* and *T. triangulare* indicated that their consumption portends health hazards because excess ingestion of arsenic could cause both carcinogenic and non-carcinogenic adverse health effects and should be avoided to stay healthy (Doamekpor et al. 2016). these metals via their daily intake of vegetables and were not exposed to any serious adverse health effects associated with these metals as their ingested doses were not known to cause adverse health effects. The target hazard quotients (THQ) of heavy metals in vegetables from farmland irrigated with palm oil mill effluents in Ezeala (Table 9) show that cadmium, chromium, zinc, lead, copper and cobalt, respectively, have target hazard quotients very much below 1 (unity, i.e. acceptable permissible predictable lifetime risks for non-carcinogens) in all the vegetables. The target hazard quotient of manganese in *V. amygdalina* was above the acceptable permissible predictable lifetime risks for non-carcinogens, while that of other vegetables were observed to be approximately equal to the acceptable permissible predictable lifetime risks for non-carcinogens. The target hazard quotient of nickel in *O. gratissimum* and *T. occidentalis* were far below the acceptable permissible predictable lifetime risks for non-carcinogens. Similarly, the target hazard quotient of nickel in *A. hybridus*, *G. latifolium*, *V. amygdalina* and *T. triangulare* were below the acceptable permissible predictable lifetime risks for non-carcinogens. Furthermore, it was observed that the target hazard quotient of arsenic in *G. latifolium*, *V. amygdalina* and *T. triangulare* were above the acceptable permissible predictable lifetime risks for non-carcinogens while that of *A. hybridus* and *T. occidentalis* were below the acceptable permissible predictable lifetime risks for non-carcinogens.

Table 9. Target hazard quotient of heavy metals in vegetables from farmland irrigated with POME.

Vegetables	Cd	Cr	Zn	Fe	Pb	Mn	Ni	Cu	Co	As
A. hybridus	NPR	0.0006	0.058	0.063	0.050	0.539	0.567	0.103	0.116	0.667
G. latifolium	0.20	0.0013	0.092	0.053	0.130	0.501	0.502	0.127	0.127	2.833
T. occidentalis	0.13	0.0002	0.045	0.037	0.180	0.553	0.338	0.117	0.093	0.867
V. amygdalina	0.33	0.0004	0.078	0.052	0.050	1.246	0.817	0.180	0.436	2.400
O. gratissimum	0.07	0.0002	0.063	0.052	0.165	0.619	0.184	0.189	0.079	1.733
T. triangulare	0.13	0.0001	0.035	0.045	0.033	0.548	0.466	0.066	0.200	4.600

THQ < 1 indicates no adverse health effects, while THQ > 1 or = 1 indicates that adverse health effects are likely to occur, NPR = No predictable health risk

The vegetables have low target hazard quotients for Cd, Cr, Zn, Fe, Pb, Ni, Cu, and Co and, as such, may not be associated with any serious adverse health effects. This could be attributed to the low levels of these metals detected in the vegetables. In like manner, the THQ < 1 for nickel in *A. hybridus*, *G. latifolium*, *T. occidentalis*, *O. gratissimum* and *T. triangulare* indicated that adverse non-carcinogenic health effects due to nickel toxicity were not likely to occur from consumption of these vegetables. Heavy metals detected in these vegetables with target hazard quotients (THQ) below 1 indicate that they are safe for consumption without any risk to human health (Jolly et al. 2013). However, the THQ > 1 for nickel in *V. amygdalina* showed that there was likely non-carcinogenic adverse health effects due to nickel toxicity occurring from a high level of nickel ingested through its consumption. This aligns with the findings of Huang et al. (2008) that there is a great concern for potential health effects for consumption of vegetables with a THQ value higher than one. Additionally, the high target hazard quotients for arsenic in *G. latifolium, V. amygdalina, O. gratissimum*, and *T. triangulare* indicated that there was a likely occurrence of non-carcinogenic adverse health effects due to the high level of arsenic ingested from consumption of these vegetables. *Amaranthus hybridus* and *V. amygdalina* with low target hazard quotient for arsenic (THQ < 1) indicated that there was no likely occurrence of non-carcinogenic adverse health effects from their consumption which could be attributed to the low level of arsenic detected in them.

The data in Table 10 show that all the vegetables from the farmlands irrigated with palm oil mill effluents have a high hazard index (H.I.) above unity (HI > 1). *T. triangulare* has the highest hazard index among all the vegetables from farmland irrigated with palm oil mill effluents in Ezeala.

Table 10. Hazard index (H.I.) of heavy metals in vegetables from farmland irrigated with POME.

Vegetables	Hazard index (H.I.)
A. hybridus	2.164
G. latifolium	5.866
T. occidentalis	4.360
V. amygdalina	5.409
O. gratissimum	5.154
T. triangulare	7.078

The hazard index of the heavy metals is used to assess the cumulative effects of toxic metals ingested through consumption of heavy metal contaminated vegetables (Liu et al. 2013). It is a good predictive measure of possible non-carcinogenic adverse health effects occurring from the consumption of heavy metal-containing food sources by the synergistic action of the individual heavy metals in the food source. The hazard index of heavy metals in the vegetables from each of the palm oil mill effluents irrigated farms were greater than 1 (HI > 1) and indicated that there were serious risks of adverse non-carcinogenic health effects occurring in the individuals that consumed these vegetables with time. The HI > 1 observed in each of the vegetables from their respective farms could be attributed to the contributions of various heavy metals detected in the vegetables at varying concentrations. It was observed that manganese, nickel, and arsenic with high target hazard quotients in almost all the vegetables from each of the farms contributed largely to the high hazard index observed in the vegetables. Arsenic had the largest contribution, followed by manganese and nickel respectively in most of the vegetables from the various farms. According to Lu et al. (2009), HI > 1 indicated that there was a high adverse non-carcinogenic health risk associated with consumption of the substance or foo**.**

3.9. Cancer risks of carcinogenic metals in vegetables from farmland irrigated with palm oil mill effluents in Ezeala

The cancer risks of carcinogenic metals in vegetables from farmland irrigated with palm oil mill effluents in Ezeala show that there is no cancer risk from cadmium in *A. hybridus* (Table 11). The cadmium cancer risk in the vegetables that range from 7.6E-06 – 1.3E-04 $(\text{i.e.} \cong 8 \text{ in } 1{,}000{,}000 - 10{,}000)$ was within the acceptable range of predicted lifetime risks for carcinogens (1.0E-06 – 1.0E-04, i.e. 1 in 1,000,000 – 1 in 10,000) with the lowest and highest cadmium cancer risk occurring in *O. gratissimum* and *V. amygdalina* respectively. The chromium cancer risk in all the vegetables was within the acceptable range of predicted lifetime risks for carcinogens ranging from 1.0E-04 – 9.9E-04 (i.e. 1 in 10,000 – 10 in 10,000) in *T. triangulare* and *G. latifolium,* respectively. In like manner, the lead cancer risk in all the vegetables was within the acceptable range of predicted lifetime risks for carcinogens, with the lowest and highest lead cancer risks occurring in *T. triangulare* (1.1E-06) and *G. latifolium* (4.4E-05), respectively.

However, the nickel cancer risks (6.2E-03 – 2.8E-02, i.e. 6 in 1000 – 3 in 100) in all the vegetables were above the range of acceptable predicted lifetime cancer risks for carcinogens, with *V. amygdalina* and *O. gratissimum* having the highest and least nickel cancer risk among all the vegetables respectively. There were high arsenic risks in *G. latifolium*, *V. amygdalina* and *T. triangulare* (1.1E-03 – 2.1E-03) far above the permissible range of predicted lifetime risks for carcinogens. However, the arsenic cancer risks in *A. hybridus*, *T. occidentalis* and *O. gratissimum* (3.0E-04 – 7.8E-04) were low but are within the permissible range of predicted lifetime risks for carcinogens (1.0E-06 – 1.0E-04).

Table 11. Cancer risks of carcinogenic metal in vegetables from farmland irrigated with palm oil effluents in Ezeala.

Vegetables	Cd	Cr	Pb	Ni	As
A. hybridus	NPR	4.3E-04	1.7E-05	1.9E-02	3.0E-04
G. latifolium	7.6E-05	9.9E-04	4.4E-05	1.7E-02	1.3E-03
T. occidentalis	4.9E-05	1.3E-04	6.1E-06	1.1E-02	3.9E-04
V. amygdalina	1.3E-04	3.3E-04	1.7E-06	2.8E-02	1.1E-03
O. gratissimum	2.7E-05	1.7E-04	5.6E-06	6.2E-03	7.8E-04
T. triangulare	4.9E-05	1.0E-04	1.1E-06	1.6E-02	2.1E-03

Cancer risk index 10^{-6} (1 in 1,000,000) to 10^{-4} (1 in 10,000) represent a minimum acceptable range of predicted lifetime risks for carcinogens, NPR = No predictable health risk

The cancer risks from ingestion of carcinogenic metals (Cd, Cr, Pb, Ni and As) through consumption of vegetables from farmland irrigated with palm oil mill effluents in Ezeala were within the acceptable range of predicted lifetime risk for carcinogens stipulated by Lu et al. (2009). This showed that individuals that consumed the vegetables had an increased chance of developing cancer in their lifetime, and consumption of these vegetables should be minimised or avoided totally to remain healthy. The cancer risks due to chromium ingested via consumption of the vegetables showed that 10 – 99 out of 100,000 persons had an increased risk of developing cancer in their lifetime and indicated that these vegetables posed serious cancer risks to their consumers because of the toxic effects of chromium ingested through these vegetables. The cancer risk in *G. latifolium* and *A. hybridus* showed that there was much lead toxicity associated with these vegetables, with 4 and 2 in every 10 000 people that consumed *G. latifolium* and *A. hybridus,* respectively, having increased lifetime cancer risk. The high cancer risk of nickel observed in all the vegetables indicated that 1 – 3 out of 100 persons could develop cancer in their lifetime due to the high level of nickel ingested from consumption of *A. hybridus*, *G. latifolium*, *T. occidentalis*, *T. triangulare* and *V. amygdalina* respectively. This was contrary to the findings of Okpashi et al. (2019), who reported no nickel cancer risk in vegetables. However, *O. gratissimum* with nickel cancer risk of 6.2E-03 indicated that 6 out of 1,000 persons had increased lifetime cancer risk from high nickel content ingested through this vegetable. The high arsenic cancer risk observed in the vegetables from this farm showed that 1 – 2 out of 1,000 have a high chance of developing cancer in their lifetime due to arsenic toxicity from arsenic ingested via consumption of *V. amygdalina*, *G. latifolium* and *T. triangulare*.

3.10. Total cancer risks of carcinogenic metals in vegetables from farmland irrigated with POME

The total cancer risks of carcinogenic metals in all the vegetables from farmlands irrigated with palm oil mill effluents indicate that there are high cancer risks in all the vegetables (Table 12). It was observed that *V. amygdalina* has the highest cancer risks among all the vegetables from farmlands irrigated with palm oil mill effluents in Ezeala.On the contrary, among all the vegetables from farmlands irrigated with palm oil mill effluents in Ezeala, *T. occidentalis* has the lowest cancer risks. Total cancer risks possessed by all the vegetables from the farmland irrigated with palm oil mill effluents were far above the minimum acceptable range of predicted lifetime risks for carcinogens and range from 7.2E-03 (i.e. 7 in 1000 persons) – 3.00E-02 (i.e. 3 in 100 persons). The high total cancer risks of carcinogenic heavy metals detected in the vegetables from farmlands irrigated with palm oil mill effluents showed that there is increased lifetime cancer risks associated with any of the vegetables. This is due to the excess amount of carcinogenic metals ingested through them and their cumulative carcinogenic effects, mainly from arsenic and nickel in most of the vegetables. This showed that none of the vegetables was free from causing adverse carcinogenic effects even when some of the carcinogenic metals were below the detection limit in most of them because of the additive effects of carcinogenic metals. The high total cancer risk of carcinogenic heavy metals in these vegetables far above the range of predicated lifetime risk for carcinogenic substances showed that drastic intervention such as discontinuation of the use of the palm oil mill effluents for irrigation of the farmlands was required to reduce the levels of these heavy metals in the vegetables. The high total cancer risk of heavy metals observed in the *V. amygdalina* in Ezeala showed that the vegetables contained the highest amounts of carcinogenic metals detected in their respective farms. Thus, individuals that consumed these vegetables ingested excess amounts of the carcinogenic metals contained in the vegetables and have increased lifetime cancer risks than individuals that consumed other vegetables from their respective farms (Zafarzadeh et al. 2018).

Table 12. Total cancer risks of heavy metals in vegetables from farmlands irrigated with POME.

Vegetables	Total cancer risks
A. hybridus	2.00E-02
G. latifolium	1.90E-02
T. occidentalis	1.20E-02
V. amygdalina	3.00E-02
O. gratissimum	7.20E-03
T. triangulare	1.80E-02

4. Conclusions

The findings of this study showed that the palm oil mill effluents contained high concentrations of various heavy metals tested, which greatly deposited high amounts of heavy metals on the soils from farmlands irrigated with palm oil mill effluents. The vegetables contained high levels of many heavy metals detected in them far above their respective permissible limits, and their consumption could lead to heavy metal toxicity. There was a varying degree of uptake of heavy metals from the irrigated soils by the vegetables, with a daily intake of manganese, nickel, and arsenic exceeding oral reference doses for the respective metals in some of the vegetables across the farmlands. There was an increased non-cancer risk for manganese, nickel, and arsenic in most of the vegetables, and the hazard index suggests that there was an enormous non-cancer risk of adverse health effects from the cumulative health effects of various heavy metals detected in the vegetables from the farmlands. There were varying levels of cancer risks and total cancer risks associated with each of the vegetables from each of the farmlands due to varying concentrations of cadmium, chromium, lead, nickel and arsenic ingested through their consumption.

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