Environmental Protection Research
http://ojs.wiserpub.com/index.php/EPR/

Research Article

Impacts of Power Transmission and Distribution on Trace Metals Loads in Soils, *Telfairia Occidentalis* and Related Human Health Problems in South-South, Nigeria

Godwin Asukwo Ebong[1*], Idongesit Bassey Anweting[1], Inemesit Ndarake Bassey[2], Edidiong Emmanuel Ikpe[3]

[1]Department of Chemistry, University of Uyo, Akwa Ibom State, Nigeria
[2]Department of Botany and Ecological Studies, University of Uyo, Akwa Ibom State, Nigeria
[3]Department of Chemistry, Akwa Ibom State University, Mkpat Enin, Nigeria
E-mail: g_ebong@yahoo.com

Received: 4 February 2024; **Revised:** 15 April 2024; **Accepted:** 16 May 2024

Abstract: The generation, transmission, and distribution of power have both positive and negative effects. However, this has not been effectively assessed and documented in the study area. Hence, this research was conducted to assess the impact of power transmission and distribution activities on the levels of trace metals in soil, including *Telfairia occidentalis* (*T. occidentalis*). In this research, topsoil and *T. occidentalis* were obtained from the vicinity with high-tension copper cables at Ikono, Ibiono Ibom, Itu, Uyo, and Uruan in Akwa Ibom State. Similar samples were obtained 100 m away from areas with high-tension copper cables and used as controls. The mean values (mg kg^{-1}) of cadmium (Cd), copper (Cu), iron (Fe), and lead (Pb) obtained in soil were 2.13 ± 1.24, 43.52 ± 9.28, 1,265.84 ± 287.33, and 27.39 ± 5.66, respectively. Whereas, the mean concentrations (mg kg^{-1}) of these metals in *T. occidentalis* were 0.17 ± 0.10, 12.98 ± 2.50, 217.81 ± 62.56, and 1.47 ± 1.40, respectively. The results obtained revealed that the mean concentrations of Cd, Cu, and Fe in soil were higher than their recommended safe limits, while the mean concentrations of Cu, Fe, and Pb in *T. occidentalis* exceeded the limits. The results indicated that the mean concentrations of all metals in the impacted soils were higher than in the control plot for both soil and *T. occidentalis*. Pollution models employed showed that soils and *T. occidentalis* from the studied locations were highly impacted by metals originating mainly from power transmission and distribution activities. The estimated daily intake rate of all the metals through soils and *T. occidentalis* was investigated for the children and adult groups within their recommended oral reference doses except for Cd. The non-cancerous risks for the children and adult groups for both soil and *T. occidentalis* were less than than 1 mg kg^{-1} day^{-1}. However, the children's class was more susceptible. Cancer risks for both the children and adult groups via soil and *T. occidentalis* were within the acceptable limit, but the entire cancer risk for the children via *T. occidentalis* from the Uyo vicinity was higher than the safe limit. This study revealed the effects of power transmission and distribution activities on the metal loads in soil and *T. occidentalis* and the related human health problems. Consequently, consistent exposure to soil particles impacted by high-tension cables and the cultivation of edible plants under high-tension cables should be avoided.

***Keywords*:** high-tension copper cable, *T. occidentalis*, soil contamination, human health risks, Nigeria

DOI: https://doi.org/10.37256/epr.4220244422

1. Introduction

Waste products generated by human activities, especially in the industrial sector, if not properly managed, can seriously contaminate the environment [1, 2]. One of the most common contaminants introduced by anthropogenic activities into the environment is metal. Metals have the potential to bioaccumulate in living cells through ingestion [3-5]. The accumulated metals can cause adverse health problems ranging from cancerous to non-cancerous [6-9]. The generation of electric power in Nigeria in 1896 has resulted in both positive and negative implications associated with the generation, transmission, and distribution [10, 11]. Power generation and transmission are two of the major causes of cancer in humans [12, 13]. Reports have shown that power transmission and distribution activities can elevate the concentrations of metals in the environment [14-18]. Metals such as aluminum (Al), copper (Cu), iron (Fe), cadmium (Cd), and lead (Pb) are closely associated with power transmission and distribution, hence, the environment could be contaminated by these metals over time. Research by Idowu et al. [19] revealed that power generation may also have a negative impact on the aquatic environment.

Studies have shown that high-tension lines can increase concentrations of Cd, Cu, and zinc (Zn) in the terrestrial environment and plants [20-23]. Elevated levels of Cu, Fe, Cd, manganese (Mn), nickel (Ni), Al, Zn, Pb, and calcium (Ca) have been reported in soils and vegetables within the vicinity of power transformers [24-27]. A study by Al-Hiyaly et al. [28] showed that power transmission and distribution activities can increase the level of metals, especially Zn, in soil.

Cu wires are mostly used for high-tension power transmission and distribution due to their electrical conductivity, Cd is used for the installation of lighting columns, and Pb is widely used as a sheathing material in high-voltage power cables [29-31]. Fe is a major component of steel, mostly applied as a transmission and distribution tool in the power grid [32-34]. These metallic components, when corroded, affect the environment negatively and can affect human health through the food chain [8, 35-37]. Based on the reports mentioned above, power generation and transmission activities have the potential to negatively impact the soil, vegetables, environment, and food chain. Hence, consistent human exposure to these activities, either directly or indirectly, might result in adverse health problems. However, no research has been done to assess the impact of power transmission and distribution activities on the human environment. Thus, the necessary information on this sector concerning the impacts and related environmental and human health problems is not available. Consequently, the extent of damage done so far to the environment and human health has not been identified and documented in the area investigated.

Consequently, the assessment of the impact of power transmission and distribution activities on the quality of soil and plants can forestall the related environmental and human health problems. Hence, this study was undertaken to assess the influence of power transmission and distribution activities on the metal loads in terrestrial environments and *Telfairia occidentalis* (*T. occidentalis*). The actual source and ecological risks associated with the levels of these metals in the studied soils have been investigated. The cancerous and non-cancerous health hazards of these trace metals via exposure to the impacted soil and *T. occidentalis* by the children and adult groups were evaluated. The results of this study will serve as baseline data for future studies in the related area and will create awareness of the effects of power transmission and distribution activities on the environment and human health.

2. Methodology

2.1 *Area of study*

The work was conducted at Ikono, Ibiono Ibom, Itu, Uyo, and Uruan local government areas in Akwa Ibom state. The state is within the Niger Delta Region of Nigeria, where intense oil activities are performed. Akwa Ibom State is situated within latitudes (4° 32′ N-5° 33′ N) and longitudes (7° 25′ E-8° 25′ E) with outstanding wet and dry seasons. The state is within a humid tropical region with abundant rainfall. The annual temperature and rainfall vary from 25-29 °C and 2,000-3,000 mm, respectively. The climatic situation of the state favors subsistence as well as commercial farming activities. A larger proportion of the inhabitants within the locations studied depend on farm produce for their livelihood. Activities by the oil companies within the region have impacted negatively on the environment. Hence, regular assessment is necessary to forestall problems along the food chain. The studied local government areas, villages, control plots, and their coordinates are in Table 1.

Table 1. Studied locations and their coordinates

Local government area	Village	Latitude	Longitude
Ikono	Aka Ekpeme	5° 10′ 14″ N	7° 48′ 13″ E
Ibiono Ibom	Use Ndon	5° 10′ 50″ N	7° 54′ 03″ E
Itu	Akon Itam	5° 06′ 20″ N	7° 56′ 35″ E
Uyo	Ewet Offot	5° 01′ 26″ N	7° 56′ 47″ E
Uruan	Idu Uruan	5° 01′ 40″ N	8° 01′ 02″ E
Control plot	Ikot Ayan Ediene	5° 09′ 57″ N	7° 48′ 49″ E

2.2 *Analytical procedures*

Topsoil and *T. occidentalis* samples were obtained within the vicinity of high-tension cables at Ikono, Ibiono Ibom, Itu, Uyo, and Uruan at the designated locations shown in Table 1. Soil and *T. occidentalis* were also obtained at a distance of 100 m from high-tension cables in Ikot Ayan Ikono, Ikono local government area, and used as controls. The collection of topsoils was achieved by using a soil auger, and the samples collected were transferred into polyethylene bags. Sample collection was done for three months between November 2023 and January 2024 during the dry season to avoid the leaching of metal toxicants into the subsoil. Reports have also indicated that metals in the topsoil are associated with anthropogenic sources [38, 39]. The widely consumed *T. occidentalis* was collected at the designated locations using a stainless-steel knife and preserved in a cooler. At each location, samples were obtained from under the high-tension cables and from both sides of the cable lines, then mixed together to form a composite sample for that location. A total of 30 soil and *T. occidentalis* composite samples were obtained and used for this study. The soil and vegetable samples collected were transferred to the laboratory. The soil samples obtained were sun-dried for three days, ground, and filtered. *T. occidentalis* samples collected were first washed with tap water and subsequently with distilled water. The vegetable samples were dried in the air, sliced into small portions, and later dried in an oven at a temperature of 60 °C for 24 hours. One gram of the prepared samples (both the soil and *T. occidentalis*) was digested with aqua regia (a mixture of hydrochloric acid (HCl) and trioxonitrate (V) acid HNO_3 (3 : 1)) and placed on a hot plate. Levels of Cd, Cu, Fe, and Pb in the filtrates were determined using the absorption spectrophotometer (AAS) Unicam 969 model.

2.3 *Estimation of pollution indices*

2.3.1 *Contamination factor (CF)*

The CF signifies a tool applied for the estimation of metal toxicity in the studied location [40]. The CF of the metals determined within the studied soils was calculated with Equation 1.

$$CF = \frac{Cm}{Bm} \tag{1}$$

CF in Equation 1 is the contamination factor, Cm signifies the levels of metals in soils examined, and Bm represents the level of metal at the control plot correspondingly. Contamination factors are categorized into (i) CF < 1 is low contamination, (ii) 1 ≤ CF < 2 denotes low to moderate contamination, (iii) 2 ≤ CF ≤ 3 indicates moderate contamination, (iv) 3 ≤ CF < 4 = moderate to high contamination, (v) 4 ≤ CF < 5 = high contamination, (vi) 5 ≤ CF < 6 = high to very high contamination, and (vii) CF ≤ 6 = extreme contamination [40, 41].

2.3.2 *Ecological risk factor (ERF)*

This research utilized ERF to evaluate the hazards associated with the accumulation of metals in the studied soils by Equation 2, according to Saha et al. [40] and Ebong et al. [42].

$$\mathrm{ERF} = \mathrm{Tr} \times \mathrm{CF} \tag{2}$$

Tr indicates a toxic-response factor, and CF is the contamination factor of the metals. The toxic response factors of the metals, according to Ouchir et al. [43] and Mavakala et al. [44], are as follows: Cd (30.0); Cu (5.00); Fe (6.00); and Pb (5.00). Based on the Fadlillah et al. [45] classifications, ERF is grouped into the following classes: ERF < 40 belongs to the low ecological risk, 40 ≤ ERF < 80 signifies moderate potential risk, 80 ≤ ERF < 160 is a considerable potential risk, 160 ≤ ERF < 320 indicates high potential risk, and ERF ≥ 320 = significantly is a very high risk.

2.3.3 *Potential ecological risk index (PERI)*

The PERI employed for the assessment of negative effects associated with trace metals at the studied locations was estimated with Equation 3.

$$\mathrm{PERI} = \sum(\mathrm{ERF}) \tag{3}$$

According to Al-Anbari et al. [46], PERI is grouped as follows: PERI < 150 is a low ecological pollution level, 150 < PERI < 300 belongs to the moderate ecological pollution level, 300 < PERI < 600 belongs to the severe ecological pollution level class and PERI > 600 is in the serious ecological pollution level class.

2.4 *Estimation of related human health risks*

2.4.1 *Estimated daily intake (EDI) of trace metals*

The EDI rate of trace metals via the studied soils and *T. occidentalis* was calculated using Equation 4.

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{RI}}{\mathrm{BW}} \tag{4}$$

In Equation 4, C denotes the concentration of metals in the samples examined, and RI indicates the daily intake proportion of trace metals through the samples investigated. RI values for children are 0.0002 and 0.118 kg/day for soil and vegetables, respectively. For adults, RI values are 0.0001 and 0.182 kg/day for soil and vegetables, respectively [47, 48]. BW represents body weight, and for both the children and adult groups, BW is 15 and 70 kg, respectively [49, 50].

2.4.2 *Hazard quotients (HQ)*

The HQ related to exposure to trace metals through the studied soils and *T. occidentalis* was determined using Equation 5.

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{Rfd}} \tag{5}$$

In the equation, EDI is the estimated daily intake proportions for the trace metals, and oral reference dose (RfD) for the metals is 0.001, 0.04, 0.07, and 0.004 mg/kg/day for Cd, Cu, Fe, and Pb, respectively [51, 52].

2.4.3 *Hazard index (HI)*

The HI due to exposure to trace metals through the studied soils and *T. occidentalis* was estimated using Equation 6.

$$HI = \sum HQ = HQCd + HQCu + HQFe + HQPb \quad (6)$$

where ΣHQ signifies the summation of the entire HQ of the metals examined in the samples investigated.

2.4.4 *Incremental lifetime cancer risk (ILCR)*

ILCR for the cancer-causing metals for children and adult classes was computed with Equation 7.

$$ILCR = CSF \times EDI \quad (7)$$

where CSF indicates the cancer slope factor for Cd and Pb, which are 8.50E-03 and 5.00E-01, respectively there are no CSF values for Cu and Fe. EDI denotes estimated daily intake proportions of metals via the affected soils and *T. occidentalis*.

2.4.5 *Total cancer risk (TCR)*

TCR for the exposure of children and adult groups to Cd and Pb through the studied soils and *T. occidentalis* was calculated with Equation 8 below.

$$TCR = \sum ILCR = ILCRCd + ILCRPb \quad (8)$$

where ΣILCR indicates the summary of the total ILCR of trace metals assessed in the samples.

Table 2. Levels of metals in soil and *T. occidentalis* from areas impacted by high-tension copper cables

	Cd	Cu	Fe	Pb	Cd	Cu	Fe	Pb
	Top-soil				*T. occidentalis*			
Ikono	1.38	38.41	986.71	26.58	0.07	12.10	183.64	0.84
Ibiono Ibom	1.56	37.60	1,024.05	30.29	0.09	11.36	191.22	0.88
Itu	2.06	42.84	1,360.32	28.25	0.22	11.94	180.57	1.30
Uyo	4.28	59.73	1,695.84	33.47	0.32	17.42	328.41	3.56
Uruan	1.36	39.02	1,260.26	18.38	0.14	12.07	205.19	0.61
Min	1.36	37.6	986.71	18.38	0.07	11.36	180.57	0.61
Max	4.28	59.73	1,695.84	33.47	0.32	17.42	328.41	3.56
Mean	2.13	43.52	1,265.44	27.39	0.17	12.98	217.81	1.47
SD	1.24	9.28	287.33	5.66	0.10	2.50	62.56	1.40
Control	0.04	6.38	253.65	5.14	0.01	0.82	21.83	0.07
MPL	0.8*	36.0*	400.0***	85.0*	0.2**	10.0**	48.0****	0.3**

Min = Minimum; Max = Maximum; SD = Standard deviation; MPL = Maximum permissible limit; * World Health Organization (WHO) [53]; ** Food Agriculture Organization (FAO)/WHO [54]; *** Federal Environment and Protection Agency (FEPA) [55]; **** FAO/WHO [56]

2.5 *Statistical treatment of data*

The data obtained in this study were treated statistically using IBM SPSS Statistic 20 software. Duncan's multiple range tests were employed for the principal component and cluster analysis. Factor analysis of the parameters was carried out with the Varimax rotation technique, and values below 0.608 were insignificant. Hierarchical cluster analysis was carried out on the data obtained using dendrograms.

3. Results and discussion

The levels of Cd, Cu, Fe, and Pb determined in soil and *T. occidentalis* from the studied locations are shown in Table 2.

3.1 *Concentrations of metals in studied soils*

The results of metals in soil impacted by power transmission and distribution activities are in Table 2. Cd in the soils investigated varied from 1.36 to 4.28 mg kg^{-1} with an average concentration of 2.13 ± 1.24 mg kg^{-1}. The range is consistent with 4.21-4.54 mg kg^{-1} reported by Ashraf et al. [57] in soils impacted by industrial activities within the District Kasur, Pakistan. However, the range obtained is lower than 54.50-70.40 mg kg^{-1} reported in the industrial area of Ibeno, Nigeria, by Udoh and Amadi [58]. The mean concentration reported is higher than the 0.8 mg kg^{-1} recommended for soil by the WHO [53]. Consequently, levels of Cd obtained in soils investigated may result in environmental and human health problems, as recorded by Abd Elnabi et al. [59] and Okon et al. [2]. The mean Cd level is also higher than 0.04 mg kg^{-1} obtained in the control plot. This is an indication of the anthropogenic addition of the metal by electric power transmission and distribution activities [1, 42, 60]. The reported high concentrations of Cd in the studied soils could be attributed to the extensive utilization of the metals in installations of lighting columns, hence, they could be leached over time into the environment [29, 30].

Concentrations of Cu in the soils examined varied between 37.60 and 59.73 mg kg^{-1} (Table 2). This range is in agreement with 19.48-61.47 mg kg^{-1} obtained by Ebong et al. [7] in waste-impacted soils in Uyo, Nigeria. Nevertheless, the limit obtained is below the range of 68.47-146.10 mg kg^{-1} reported for industrial soils in Ethiopia by Bahiru and Teju [61]. The mean concentration obtained (43.52 ± 9.28 mg kg^{-1}) is higher than the permissible limit of 36.0 mg kg^{-1} for soil by WHO [53]. Hence, Cu may be a pollutant in the impacted soils and may have adverse health implications for those exposed to it over time [50, 62]. The high concentrations of Cu in the impacted soils could be due to the leaching of Cu high-tension cables into the soil [29]. The average concentration of Cu obtained in the soils investigated is also higher than 6.38 mg kg^{-1} obtained at the control site. Hence, power transmission and distribution activities might have introduced substantial amounts of Cu into the adjoining soil environment [21].

Fe in the impacted soils had a range and mean concentration of 986.71-1,695.84 mg kg^{-1} and 1,265.44 ± 287.33 mg kg^{-1} respectively (Table 2). The obtained range is below 85.0-470.0 mg kg^{-1} reported in soils affected by industrial activities in the Mandideep area of India by Ahirwar et al. [63]. Although the obtained range is lower than 15,500.0-96,700.0 mg kg^{-1} reported in soils around power transformers in Akoko Ondo State, Nigeria, by Ogunlana et al. [64], Fe is naturally high in Nigerian soils however, according to FEPA reported in [55] established a permissible limit of 400.0 mg kg^{-1} [65, 66]. Nevertheless, the mean value obtained is above the permissible limit hence, Fe can pollute the soils investigated. Consequently, prolonged exposure to the reported levels may cause human health problems associated with Fe toxicity [67-69]. Fe, the main component of steel used in high-tension power transmission and distribution tools, could be leached eventually into the soil, thereby elevating the concentrations of the metal [32, 33]. The average value obtained in the impacted soils is higher than 253.65 mg kg^{-1} obtained at the control plot. This shows that power transmission and distribution activities could have contributed some Fe, mainly through steel components, to the studied terrestrial environment [70]. This also confirms that Fe might have been leached into the studied soils from the iron-containing components of the power installations.

Pb in the studied soils ranged from 18.38 to 33.47 mg kg^{-1} with an average concentration of 27.39 ± 5.66 mg kg^{-1} (Table 2). This range is consistent with 23-35 mg kg^{-1} reported by Binh et al. [71] in contaminated soils in Ho Chi Minh City, Vietnam. However, the obtained range is higher than 0.005-0.051 ppm reported in contaminated soils from Bauchi

Metropolis, Nigeria. However, the mean is lower than 17.88 to 383.48 mg kg^{-1} obtained in contaminated agricultural soils within Anka, Zamfara State, Nigeria, by Darma et al. [72]. The mean is also lower than 193.14-211.75 mg kg^{-1} obtained in contaminated soils in Calabar, Nigeria, by Ebong et al. [73]. The average value of Pb obtained is below the 85.0 mg kg^{-1} stipulated for soil by the WHO [53]. Consequently, the metal may not be regarded as a pollutant in the impacted soils. The results revealed that Pb used as a sheathing material in high-voltage power cables may not have been leached enough beyond the recommended limit in soil [31]. However, the average value recorded is above 5.14 mg kg^{-1} recorded in soil from the control plot. Hence, the power transmission and distribution activities in the locations examined might have contributed substantial amounts of Pb into the impacted soils, though within the limit. Although the levels of Pb reported are below the recommended limit, the studied environment should be closely monitored to forestall future problems since metal can be bioaccumulated and Pb is highly poisonous even at low concentrations [74]. Mostly, the highest mean concentrations of the metals were recorded in samples from Uyo, while the lowest mean Cd and Pb concentrations were in Uruan, Cu in Ibiono Ibom, and Pb and Fe in Ikono. This is an indication that, apart from the power transmission and distribution activities, the population growth in Uyo may have contributed additional Pb to the area [75, 76].

3.2 *Concentrations of metals in T. occidentalis from the impacted locations*

The results of metals in *T. occidentalis* from the locations impacted by the power transmission and distribution activities are in Table 2. Cd in *T. occidentalis* from the locations investigated varied between 0.07 and 0.32 mg kg^{-1}, with a mean value of 0.17 ± 0.10 mg kg^{-1}. This range is lower than 0.00-1.80 mg kg^{-1} reported by Sultana et al. [77] in leafy vegetables from the contaminated environment within Dhaka City, Bangladesh. The range is also lower than 0.15-0.54 mg kg^{-1} as reported by Sulaiman et al. [78] in leafy vegetables from Jengka, Malaysia. Nevertheless, the reported range is higher than 0.025-0.080 mg kg^{-1} obtained in spinach from a contaminated environment in Marmara, Turkey, by Zor and Kocaoba [79]. The mean concentration of Cd recorded in *T. occidentalis* is within the permissible limit (0.2 mg kg^{-1}) by FAO/WHO [54]. Hence, Cd may not have adverse health implications for those exposed to the metal via *T. occidentalis* in the studied locations. However, the mean values of Cd in *T. occidentalis* from Itu and Uyo were higher than the acceptable limit. Consequently, the rate of transfer of Cd from soil to *T. occidentalis* at Itu and Uyo was higher than at other locations examined. It could also be inferred that power transmission and distribution activities at Itu and Uyo negatively impacted *T. occidentalis*. Thus, prolonged exposure to Cd through *T. occidentalis* from Itu and Uyo may result in serious problems for both the vegetable and the consumers [80, 81]. The mean Cd level obtained is above 0.01 mg kg^{-1} reported in the unaffected area (control plot). This could be caused by the anthropogenic input of Cd in the studied environment from power transmission and distribution activities.

Concentrations of Cu in *T. occidentalis* obtained from the studied locations ranged between 11.36 and 17.42 mg kg^{-1} with a mean concentration of 12.98 ± 2.50 mg kg^{-1} (Table 2). The obtained range is consistent with 0.39-13.42 mg kg^{-1} obtained in vegetables from contaminated areas of Jhansi, India, by Gupta et al. [82]. The range is higher than 2.96-4.03 mg kg^{-1} obtained at the contaminated area of Dhaka South City, Bangladesh, by Ahmed et al. [83], but lower than 2.10-19.30 mg kg^{-1} reported in leafy vegetables also from Dhaka City, Bangladesh, by Sultana et al. [77]. The mean level of Cu in *T. occidentalis* is above the recommended value of 10.0 mg kg^{-1} by FAO/WHO [54]. Hence, Cu could be considered a pollutant in *T. occidentalis* from all the studied locations. The mean value obtained is also above 0.82 mg kg^{-1}, reported in *T. occidentalis* from the unaffected area (control plot). This is an indication of the anthropogenic addition of Cu, possibly from the corroded copper cables used for the transmission of power at the studied locations [20, 21]. Consequently, levels of Cu reported in *T. occidentalis* from all the studied locations can affect the plant and the consumers negatively [84-87].

The mean concentration and range of Fe in *T. occidentalis* are 217.81 ± 62.56 mg kg^{-1} and 180.57-328.81 mg kg^{-1}, respectively (Table 2). The range reported is lower than 171.10-406.66 mg kg^{-1} in vegetables from manure-impacted soils within Uyo, Nigeria, by Ebong and Etuk [88]. The range is also lower than 37.40-446.40 mg kg^{-1} obtained in contaminated vegetables by Sultana et al. [77]. However, the reported range of Fe is higher than 13.03-127.6 mg kg^{-1} obtained in spinach by Zor and Kocaoba [79]. The average value of Fe obtained in *T. occidentalis* is above the recommended safe limit (48.0 mg kg^{-1}) by FAO/WHO in [56]. Although Fe is an essential element, the elevated levels obtained in this study can affect the vegetable and the consumers [89-91]. The average value obtained is also higher than the 21.83 mg kg^{-1} reported in *T. occidentalis* from the control plot. This confirms that power transmission and distribution activities may have increased the levels of Fe in the soil environment investigated.

Pb in *T. occidentalis* from the impacted locations ranged between 0.61 and 3.56 mg kg^{-1} with a mean value of 1.47 ± 1.40 mg kg^{-1} (Table 2). The range of Pb reported is lower than 0.03-4.64 µg g^{-1} obtained in vegetables from contaminated environments by Kumar et al. [92]. Nevertheless, the obtained range is above 0.03-2.30 mg kg^{-1} reported in contaminated vegetables by Gupta et al. [82]. The average level of Pb in *T. occidentalis* is above the 0.3 mg kg^{-1} recommended by FAO/WHO [54]. Thus, levels of Pb reported in the studied vegetable can cause adverse effects to both the plant and the consumers [31, 93, 94]. The average value recorded is also greater than 0.07 mg kg^{-1} obtained in *T. occidentalis* from the control plot. This indicates that power transmission and distribution activities might have contributed some Pb to the studied environment [31]. The maximum concentrations of the entire metals determined in *T. occidentalis* were recorded in the samples from Uyo.

The general results obtained have shown that metallic components associated with power transmission and distribution installations have impacted negatively on the quality of *T. occidentalis*. Hence, the consumption of *T. occidentalis* from the studied locations may result in health problems associated with these metals. The results of the contamination factor of the metals determined in the studied soils are shown in Figure 1.

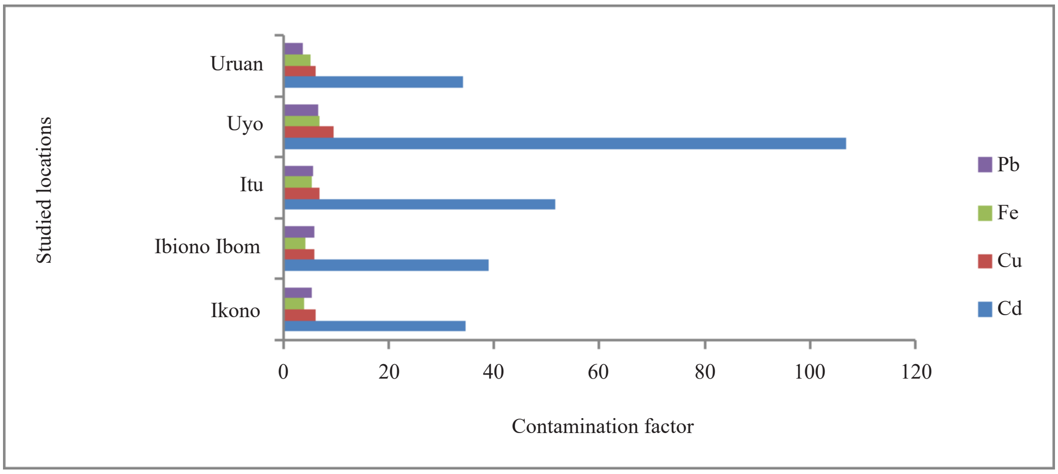

Figure 1. Contamination factor of metals in the studied soils

3.3 *CF of metals in soils investigated*

The CF of trace metals in the impacted locations is illustrated in Figure 1. According to the results obtained, CF for the trace metals varied as follows: (34-51.5) Cd, (5.89-9.36) Cu, (3.89-6.69) Fe, and (3.58-6.5) Pb. The average CF values of the metals were in the order of Cd (53.2) > Cu (6.82) > Pb (5.33) > Fe (4.99). This indicates that Cd was the major contaminant in the impacted soils, and CF is within the extreme contamination class. Although the mean CF level of Cu was also within the extreme contamination category, the obtained average CF value of Cd was relatively very high. The mean CF values of Fe and Pb belong to the belongs to the very high category, respectively [40, 41]. The mean high CF value reported for Cd is consistent with findings by Jin et al. [95]. Consequently, power transmission and distribution activities may have contaminated the studied soils with these metals, mostly Cd.

3.4 *ERF*

The ERF of trace metals in the studied soils is in Table 3. ERF of metals determined ranged as follows: Cd (1,020-3,210), Cu (29.45-46.80), Fe (23.34-40.14), and Pb (17.90-32.55). Correspondingly, Cd is in the significantly very high-risk category, Cu and Fe belong to the moderate potential risk category, whereas Pb is in the low ecological risk group [45]. ERF of metals in the locations investigated followed the order of Cd > Cu > Fe > Pb. The class of Cd obtained is consistent with the results reported by Aendo et al. [96] and Smart et al. [97]. Consequently, levels of Cd obtained at the impacted locations can pose adverse environmental and human health problems over time.

Table 3. ERF of trace metals in the studied soils

	Cd	Cu	Fe	Pb
Ikono	1,035	30.1	23.34	25.85
Ibiono Ibom	1,170	29.45	24.18	29.45
Itu	1,545	33.6	32.16	27.5
Uyo	3,210	46.8	40.14	32.55
Uruan	1,020	30.6	29.82	17.90

3.5 *PERI of trace metals within the impacted soils*

The PERI of trace metals in the studied locations is illustrated in Figure 2. Results of PERI showed a range of 1,098-3,329 between Uruan and Uyo, respectively. This shows that the PERI of the entire location was in the significantly very high-risk category, according to Al-Anbari et al. [46]. This is consistent with the results of PERI recorded by Essien et al. [98], Mugoša et al. [99], and Rahmonov et al. [100] in their studies. The obtained results of PERI also confirmed the toxic nature of metals determined in the studied locations, as reported by Okon et al. [2]. The high PERI values reported call for concern because they have a direct relationship with the health of those exposed to these metal toxicants over time [7, 101, 102]. The PERI results for the studied locations followed the order: Uyo > Itu > Ibiono Ibom > Ikono > Uruan. Hence, the highest PERI value was obtained at Uyo. Consequently, the high population density, which has a direct influence on the volume of waste generated, could have caused the high level of environmental contamination in Uyo [103, 104].

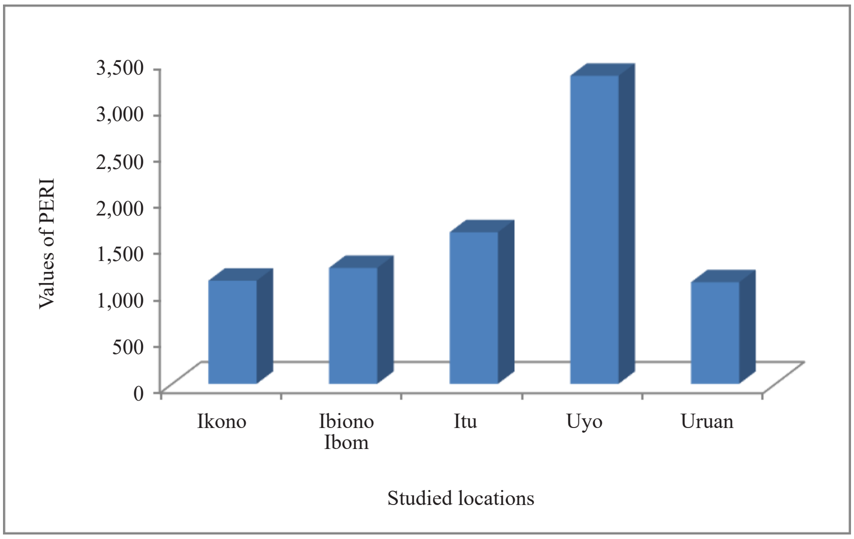

Figure 2. PERI of trace metals within the impacted soils

3.6 *Multivariate analysis of trace metals in the impacted soils and T. occidentalis*

3.6.1 *Principal component analysis of trace metals in the impacted soil and T. occidentalis samples*

Principle component analysis (PCA) was employed to ascertain the source of trace metals analyzed in the soils from the studied locations [105, 106]. Results of PCA in Table 4 show one main source for the trace metals determined in the impacted soils. The source recorded a total variance of 81.6% and an eigenvalue of 3.26, with strong positive loadings on the entire trace metals analyzed. This could be the influence of anthropogenic factors (power transmission and distribution activities) on the quality of the studied soils [107, 108]. Results in Table 4 also indicate one factor as the basis for these metals determined in the impacted *T. occidentalis*. The factor has an eigenvalue of 3.61 and a total variance of 90.2%, with significant positive loadings on the entire metals. This may also signify the impact of power transmission and distribution activities on the buildup of metals in the impacted vegetable [109, 110].

Table 4. Results of PCA of trace metals in the impacted soils and *T. occidentalis*

	Soil	*T. occidentalis*
Trace metal	Principle component 1	Principle component 2
Cd	0.997	0.862
Cu	0.986	0.994
Fe	0.901	0.991
Pb	0.697	0.947
% Total variance	81.6	90.2
Cumulative %	81.6	90.2
Eigenvalue	3.26	3.61

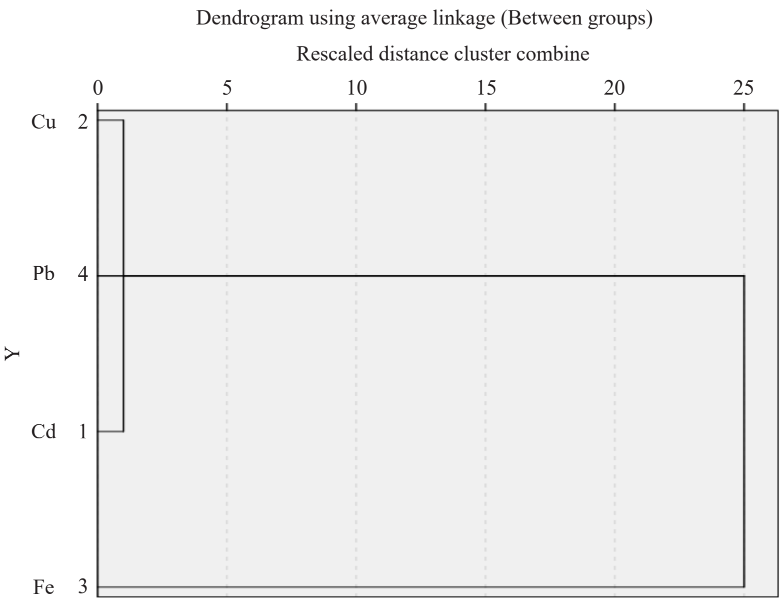

Figure 3. Hierarchical clusters of metals analysed for in the impacted soil and vegetable samples

3.6.2 *Hierarchical clusters of metals analyzed in the impacted soil and T. occidentalis samples*

Hierarchical cluster analysis (HCA) is a tool used in environmental studies to group components with similar sources and properties together [111, 112]. HCA for both the soil and *T. occidentalis* produced similar clusters, as indicated in Figure 3. The figure demonstrates two major clusters: (i) the first cluster connects Cd, Pb, and Cu into one group (ii) the next cluster connects Fe only, similar to the findings by Ebong et al. [73]. The HCA results obtained corroborate the results obtained by PCA concerning the origin of these metals, which could be mainly anthropogenic.

3.7 *Results of human health risks evaluation of trace metals through the impacted soils and T. occidentalis*

3.7.1 *Results of the EDI of metals by the children and adult populations through the impacted soils and T. occidentalis*

The results of the EDI rate of metals by means of exposure to the impacted soils and *T. occidentalis* by the children and adult groups are in Table 5. The EDI rate of trace metals by the child population through the studied soils varied as follows: Cd (1.81E-5-5.71E-4), Cu (5.01E-4-7.96E-4), Fe (1.32E-2-2.26E-2), and Pb (2.45E-4-4.46E-4). However, lower ranges were obtained for the adult population as follows: Cd (1.94E-5-6.11E-6), Cu (5.37E-5-8.53E-5), Fe (1.41E-3-2.42E-3), and Pb (2.63E-5-4.78E-5). EDI values obtained for the children and adult populations for exposure to the metals via the impacted soils were in their RfD by the United States Environmental Protection Agency (US EPA) [51]. However, the children's populations were more susceptible to human health problems related to the metals in the studied soils. This is in agreement with the reports by Ugbede et al. [113] and Yang et al. [114], but different from the results obtained by Wang et al. [115]. Based on the results obtained, prolonged exposure to the impacted soils might not pose adverse human health problems.

Table 5. Results of EDI rate of the metal in the impacted soils and *T. occidentalis*

	Cd	Cu	Fe	Pb	Cd	Cu	Fe	Pb
	Soil							
	Children				Adult			
Ikono	1.84E-5	5.12E-4	1.32E-2	3.54E-4	1.97E-6	5.49E-5	1.41E-3	3.80E-5
Ibiono Ibom	2.08E-5	5.01E-4	1.37E-2	4.04E-4	2.23E-6	5.37E-5	1.46E-3	4.33E-5
Itu	2.75E-5	5.71E-4	1.81E-2	3.77E-4	2.94E-6	6.12E-5	1.94E-3	4.04E-5
Uyo	5.71E-5	7.96E-4	2.26E-2	4.46E-4	6.11E-6	8.53E-5	2.42E-3	4.78E-5
Uruan	1.81E-5	5.20E-4	1.68E-2	2.45E-4	1.94E-6	5.57E-5	1.80E-3	2.63E-5
	T. occidentalis							
	Children				Adult			
Ikono	5.51E-4	9.52E-2	1.45	6.61E-3	1.82E-4	3.15E-2	4.78E-1	2.18E-3
Ibiono Ibom	7.08E-4	8.94E-2	1.50	6.92E-3	2.34E-4	2.95E-2	4.97E-1	2.29E-3
Itu	1.73E-3	9.39E-2	1.42	1.02E-2	5.72E-4	3.10E-2	4.70E-1	3.38E-3
Uyo	2.52E-3	1.37E-1	2.58	2.80E-2	8.32E-4	4.53E-2	8.54E-1	9.26E-3
Uruan	1.10E-3	9.50E-2	1.61	4.80E-3	3.64E-4	3.14E-2	5.34E-1	1.59E-3

The EDI values for the exposure of children to trace metals determined via the consumption of *T. occidentalis* revealed the following ranges: Cd (5.51E-4-2.52E-3), Cu (8.94E-2-1.37E-1), Fe (1.42-2.58), and Pb (4.80E-3-2.80E-2) (Table 5). However, lower EDI values were recorded for the adult population as follows: Cd (1.82E-4-8.32E-4), Cu (2.95E-2-4.53E-2), Fe (4.70E-1-8.54E-1), and Pb (1.59E-3-9.26E-3) (Table 4). Accordingly, the EDI values of Cd for children via *T. occidentalis* obtained from Ikono and Ibiono Ibom were within the recommended limit for RfD by US EPA [51]. However, EDI values of Cd for children via the utilization of *T. occidentalis* from Itu, Uyo, and Uruan were higher than the RfD. Consequently, the ingestion of *T. occidentalis* harvested from these sites can be very harmful to the children population. The EDI values of Cu, Fe, and Pb for children via the studied *T. occidentalis* at all the locations were higher than their Rfd values recommended by US EPA [51]. Thus, the consumption of the impacted vegetable by children can cause non-carcinogenic human health problems related to Cu, Fe, and Pb toxicity. The EDI values of Cd recorded for the adult population via *T. occidentalis* from all the studied locations were within the Rfd limit suggested by US EPA [51]. The EDI values of Cu and Pb for the adult population via *T. occidentalis* were within the Rfd limit at all the locations except Uyo. The EDI values of Fe for the adult population via the impacted *T. occidentalis* were above the recommended Rfd limit. Consequently, the consumption of *T. occidentalis* from impacted locations by the adult population may cause Fe toxicity and its attendants' problems over time. While the prolonged ingestion of *T. occidentalis* by the adult group from Uyo can result in additional health problems linked to high Cu and Pb, the EDI values obtained revealed that for both the children and adult populations, Fe exhibited the highest EDI value. This is similar to the results obtained by Markmanuel et al. [116] and Sani et al. [117].

3.7.2 *Results of HQ of trace metals in the children and adult populations through the impacted soils and T. occidentalis*

Table 6. Results of HQ and HI of trace metal in the impacted soils and *T. occidentalis*

	Cd	Cu	Fe	Pb	HI	Cd	Cu	Fe	Pb	HI
	Soil									
	Children					Adult				
Ikono	1.84E-2	1.28E-2	1.89E-1	8.85E-2	3.09E-01	1.97E-3	1.37E-3	2.01E-2	9.50E-3	3.29E-2
Ibiono Ibom	2.08E-2	1.25E-2	1.96E-1	1.01E-1	3.30E-01	2.23E-3	1.34E-3	2.09E-2	1.08E-2	3.53E-2
Itu	2.75E-2	1.43E-2	2.59E-1	9.43E-2	3.95E-01	2.94E-3	1.53E-3	2.77E-2	1.01E-2	4.23E-2
Uyo	5.71E-2	1.99E-2	3.23E-1	1.12E-1	5.12E-01	6.11E-3	2.13E-3	3.46E-2	1.20E-2	5.48E-2
Uruan	1.81E-2	1.30E-2	2.40E-1	6.13E-2	3.32E-01	1.94E-3	1.39E-3	2.57E-2	5.75E-3	3.48E-2
	T. occidentalis									
	Children					Adult				
Ikono	5.51E-1	2.38E + 0	20.71E + 0	1.65E + 0	25.30E + 0	1.82E-1	7.88E-1	6.83E + 0	5.45E-1	8.35E + 0
Ibiono Ibom	7.08E-1	2.24E + 0	21.43E + 0	1.73E + 0	26.10E + 0	2.34E-1	7.38E-1	7.10E + 0	5.73E-1	8.85E + 0
Itu	1.73E + 0	2.35E + 0	20.29E + 0	2.55E + 0	26.90E + 0	5.72E-1	7.75E-1	6.71E + 0	8.45E-1	8.33E + 0
Uyo	2.52E + 0	3.43E + 0	36.86E + 0	7.00E + 0	49.80E + 0	8.32E-1	1.13E + 0	12.20E + 0	2.32E + 0	16.5E + 0
Uruan	1.10E + 0	2.38E + 0	23.00E + 0	1.20E + 0	27.70E + 0	3.64E-1	7.85E-1	7.63E + 0	3.98E-1	9.18E + 0

The HQ of Cd, Cu, Fe, and Pb within the studied soils in children varied as follows: 1.81E-2-5.71E-2, 1.25E-2-1.99E-2, 1.89E-1-3.23E-1 and 6.13E-2-1.12E-1, respectively (Table 6). Whereas in the adult population, HQ ranged as follows: 1.94E-3-6.11E-3, 1.34E-3-2.13E-3, 2.01E-2-3.46E-2, and 5.75E-3-1.20E-2 for Cd, Cu, Fe, and Pb, respectively (Table 6). Results obtained indicated that HQ values for every metal determined in the impacted soils for the children and adult groups were less than one. Hence, prolonged exposure to the metal toxicants via the impacted soils may not cause serious health hazards to the children and adult groups as well [118]. The risk potentials of HQ were in a decreasing order for soil in the children and adult classes and the entire location as Fe > Pb > Cd > Cu.

The HQ of the metals in children via *T. occidentalis* ranged from 5.51E-1 to 2.52E + 0, 2.24E + 0 to 3.43E + 0, 20.29E + 0 to 36.86E + 0, and 1.20E + 0 to 7.00E + 0 for Cd, Cu, Fe, and Pb, respectively (Table 6). However, lower HQ values obtained for the adult population by means of *T. occidentalis* ranged as follows: 1.82E-1-8.32E-1, 7.38E-1-1.13E + 0, 6.71E + 0-12.20E + 0, and 3.98E-1-2.32E + 0 for Cd, Cu, Fe, and Pb, respectively (Table 6). The HQ values of metals for the children class by *T. occidentalis* were obtained from all the locations except Cd in Ikono and Ibiono Ibom, which were higher than one. Consequently, excluding Cd in Ikono and Ibiono Ibom, the utilization of *T. occidentalis* from the locations investigated might result in adverse human health problems linked with the high content of Cd, Cu, Fe, and Pb [119, 120]. The sequence for the HQ values in the studied soils and *T. occidentalis* from Ikono, Ibiono Ibom, and Uruan for both populations followed the sequence: Fe > Cu > Pb > Cd, whereas at Itu and Uyo it was Fe > Pb > Cu > Cd.

3.7.3 *Results of HI of trace metals in children and adult populations through the studied soils and T. occidentalis*

The results of the HI of trace metals through soil from the impacted locations for both the children and adult groups are in Table 5. For the child population, the HI values were 3.09E-01, 3.30E-01, 3.95E-01, 5.12E-01, and 3.32E-01 at Ikono, Ibiono Ibom, Itu, Uyo, and Uruan, respectively. However, for the adult population, HI values were 3.29E-2, 3.53E-2, 4.23E-2, 5.48E-2, and 3.48E-2 for Ikono, Ibiono Ibom, Itu, Uyo, and Uruan, respectively. The HI values at all the locations and both populations were less than one. Hence, the non-carcinogenic health risks in both populations might not be high [119, 121]. However, the non-carcinogenic health risks were higher in the child population than in the adult group [122, 123]. HQ for children and adults via soil revealed that the metals contributed the following to the entire HI: Cd (6.0%) in Ikono, Ibiono Ibom, and Uruan, 7.0% and 11.0% in Itu and Uyo, respectively (Figure 4: SC1-SC4 and SA1-SA5). Cu contributed 4.0% at all the locations and populations, Fe contributed 61.0%, 59.0%, 65.0%, and 63.0% at Ikono, Ibiono Ibom, Itu, and Uyo (Figure 4: SC1-SC4 and SA1-SA5). However, Fe donated 72.0% and 74.0% for child and adult populations in samples from Uruan (Figure 4: SC1-SC4 and SA1-SA5). Pb contributed 29.0%, 31.0%, 24.0%, and 22.0% in samples from Ikono, Ibiono Ibom, Itu, and Uyo (Figure 4 SC1-SC4 and SA1-SA5). Nevertheless, Pb donated 18.0 and 16.0% to HI in children and adult at Uruan (Figure 4: SC1-SC4 and SA1-SA5). HI in the child and adult populations via soil followed the sequence of Uyo > Itu > Uruan > Ibiono Ibom > Ikono and Uyo > Itu > Ibiono Ibom > Uruan > Ikono, respectively.

The HI of metals in children via the consumption of *T. occidentalis* indicated the following mean values: 25.30E + 0, 26.10E + 0, 26.90E + 0, 49.80E + 0, and 27.70E + 0 for samples from Ikono, Ibiono Ibom, Itu, Uyo, and Uruan respectively. For the adult group, the HI of trace metals via *T. occidentalis* were 8.35E + 0, 8.85E + 0, 8.33E + 0, 16.5E + 0, and 9.18E + 0 for samples from Ikono, Ibiono Ibom, Itu, Uyo, and Uruan, respectively. HI for both the child and adult populations is higher than one, thus, the non-carcinogenic health risks in *T. occidentalis* from the studied locations may have adverse health implications for both populations [121]. A comparison of the HQ with HI values in *T. occidentalis* indicated that for both populations, Cd contributed 2.0%, 3.0%, 6.0%, 5.0%, and 4.0% in samples from Ikono, Ibiono Ibom, Itu, Uyo, and Uruan, respectively (Figure 5: VC1-VC4 and VA1-VA5). Cu donated 9.0% of the HI in samples from Ikono, Itu, and Uruan, but 8.0% and 7.0% at Ibiono Ibom and Uyo, respectively (Figure 5: VC1-VC4 and VA1-VA5). Fe contributed 82.0% in *T. occidentalis* from Ikono and Ibiono Ibom, 75.0%, 74.0%, and 83.0% in the samples from Itu, Uyo, and Uruan, respectively (Figure 5: VC1-VC4 and VA1-VA5). Pb contributed 7.0% in *T. occidentalis* from Ikono and Ibiono Ibom, 10.0% at Itu, and 14% and 4.0% at Uyo and Uruan, respectively (Figure 5: VC1-VC4 and VA1-VA5). HI recorded via *T. occidentalis* followed the order Uyo > Uruan > Itu > Ibiono Ibom > Ikono and Uyo > Uruan > Ibiono Ibom > Ikono > Itu for the children and adult groups, respectively. In both the studied soils and *T. occidentalis*, Fe showed a very high contribution to the total HI values obtained, as reported by Rushdi et al. [124].

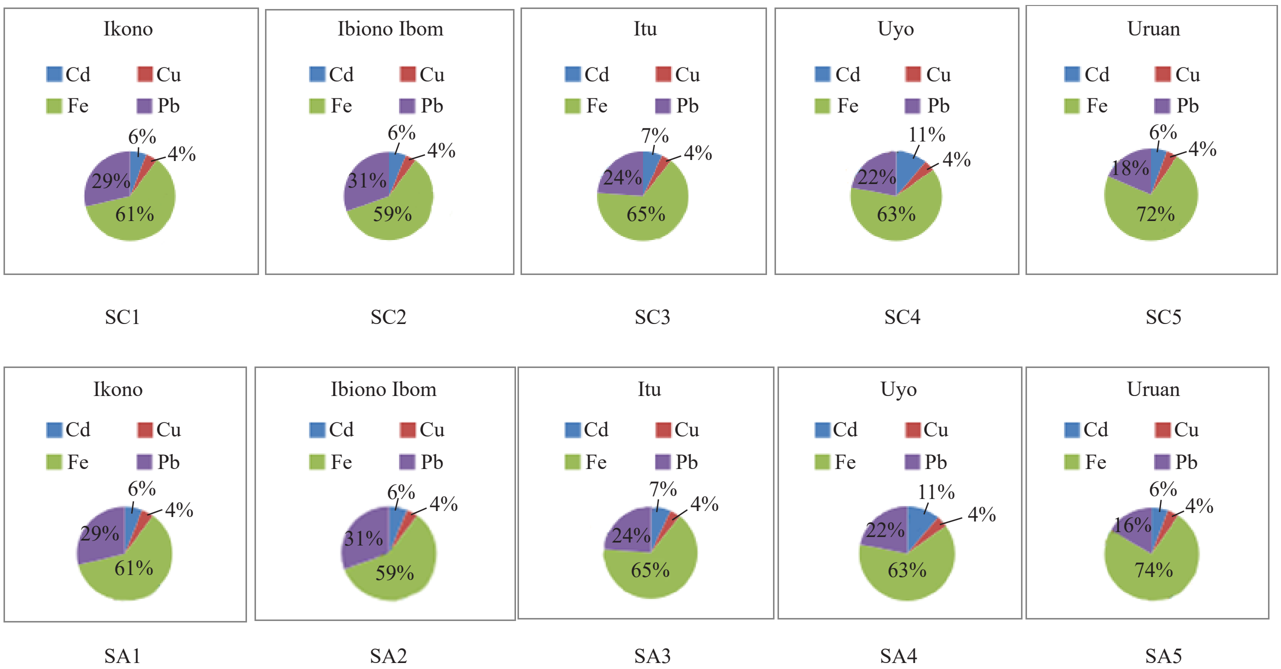

Figure 4. Mean HQ of trace metals for children (SC1-SC5) and adults (SA1-SA5) through the studied soils

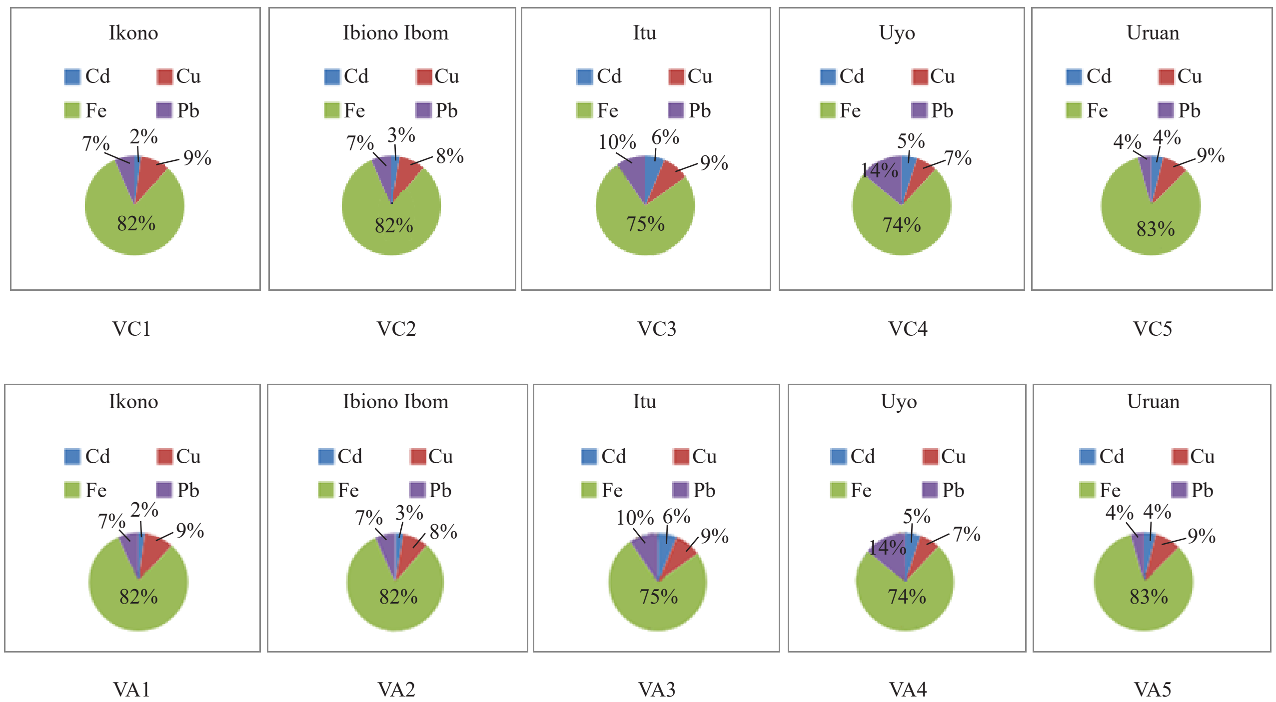

Figure 5. Mean HQ of trace metals for children (VC1-VC5) and adults (VA1-VA5) through *T. occidentalis*

3.7.4 *Results of incremental lifetime cancer risk of trace metals in children and adult populations through the studied soils and T. occidentalis*

Human exposure to Cd and Pb can cause cancer and cancer-related health problems over time, and the potential of these metals resulting in cancer over a lifetime could be appraised by the ILCR [125, 126]. Table 7 shows the results of ILCR for Cd in children via soil between 6.88E-06 and 2.17E-05 in samples from Uruan and Uyo, respectively. Thus, Cd in the children via the impacted soils fluctuated between the low and medium cancer risk categories [127]. Nonetheless, the range obtained is within the acceptable limit of 10-6-10-4 set by the US EPA [49]. ILCR for Pb in children through exposure to soil ranged from 2.08E-06 to 3.79E-06 in samples from Uruan and Uyo, respectively. This range belongs to the acceptable range and is in the low cancer-risk class. ILCR ranges of 7.37E-07-2.32E-06, 2.24E-07, and 4.04E-07 were obtained for Cd and Pb, respectively in adults via the soil from the studied locations. Consequently, the range of Cd varied between negligible and low cancer hazard classes, while Pb belonged to the negligible cancer hazard class [127].

Table 7. Results of ILCR rate of trace metal in the studied soil and *T. occidentalis*

	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb
	Soil				*Telfairia occidentalis*			
	Children		Adult		Children		Adult	
Ikono	6.99E-06	3.01E-06	7.49E-07	3.23E-07	2.09E-04	5.62E-05	9.62E-05	1.85E-05
Ibiono Ibom	7.90E-06	3.43E-06	8.47E-07	3.68E-07	2.68E-04	5.88E-05	8.89E-05	1.95E-05
Itu	1.05E-05	3.21E-06	1.12E-06	3.43E-07	6.57E-04	8.67E-05	2.17E-04	2.87E-05
Uyo	2.17E-05	3.79E-06	2.32E-06	4.04E-07	9.58E-04	2.38E-04	3.16E-04	7.87E-05
Uruan	6.88E-06	2.08E-06	7.37E-07	2.24E-07	4.16E-04	4.08E-05	1.38E-04	1.35E-05

The ILCR values of Cd in children via *T. occidentalis* ranged from 2.09E-04 to 9.58E-04 in samples from Ikono and Uyo, respectively (Table 7). The ILCR of Pb in children via *T. occidentalis* varied between 4.08E-05 at Uruan and 2.38E-04 in the Uyo sample. Hence, the range of ILCR for Cd in children belongs to the high cancer risk class, while that of Pb varied between the medium and high cancer risk classes [127]. However, both ranges are within the permissible cancer risk range (10-6-10-4) according to the US EPA [49]. The ILCR of Cd in adults via *T. occidentalis* varied from 8.89E-05 to 3.16E-04 obtained in samples from Ibiono Ibom and Uyo. The ILCR of Pb in adults through *T. occidentalis* ranged from 1.35E-05 to 7.87E-05 at Uruan and Uyo, respectively. Thus, the ILCR range of Cd in adults via *T. occidentalis* varied between medium and high cancer-risk classes. However, the ILCR range of Pb in adults via *T. occidentalis* belongs to the medium cancer risk class. Results of the cancer risk evaluation also revealed that the highest cancer risk in children and adult populations via soil and *T. occidentalis* was obtained in Uyo. Generally, the cancer-causing potentials of the metals were higher for Cd, and the children group was more liable [128, 129].

3.7.5 *Results of cancer risk of trace metals in children and adult populations through the studied soils and T. occidentalis*

The TCR of trace metals for children and adult populations via the impacted soils is in Table 8. The TCR of metals in children via the studied soils ranged from 8.96E-06 to 2.55E-05. Thus, the TCR of trace metals in children varied between low and medium cancer risk classes, according to the US EPA [127]. The range obtained is within the acceptable range of 10-4 by the US EPA [49]. The TCR of the metals in the adult population through exposure to soil varied from 9.61E-07 to 2.72E-06. Thus, the range varied between the negligible and the low cancer risk classes, but was within the acceptable limit set by the US EPA [49]. However, the probability of cancer risk was higher in the children than in the adult population via exposure to the studied soils. The TCR sequence for the children and adult groups via exposure to the impacted soils followed the order Uyo < Itu < Ibiono Ibom < Ikono < Uruan.

Table 8. Results of TCR of metal in the impacted soils and *T. occidentalis*

	Soil		*T. occidentalis*	
	Children	Adult	Children	Adult
Ikono	1.00E-05	1.07E-06	2.65E-04	1.15E-04
Ibiono Ibom	1.13E-05	1.22E-06	3.27E-04	1.08E-04
Itu	1.37E-05	1.46E-06	7.44E-04	2.46E-04
Uyo	2.55E-05	2.72E-06	1.20E-03	3.95E-04
Uruan	8.96E-06	9.61E-07	4.57E-04	1.52E-04

The TCR of carcinogens in children via the consumption of *T. occidentalis* varied between 2.65E-04 and 1.20E-03. Accordingly, the TCR varied between high and very high cancer risk classes. Results obtained indicated that TCR values at the impacted locations were within the limit (10-4) except for Uyo. Hence, prolonged utilization of *T. occidentalis* from Uyo by the child population could result in cancer and cancer-related ailments. Table 7 indicates the TCR of cancer-causing metals in the adult population by the ingestion of *T. occidentalis*, ranging from 1.04E-04 to 3.95E-04. The range obtained is within the acceptable limit of 10-4 by the US EPA [49]. However, the TCR of metal carcinogens through the ingestion of *T. occidentalis* was higher in the younger generation than the adult class [130]. Variations of TCR among the impacted locations followed the order Uyo < Itu < Uruan < Ibiono Ibom < Ikono for children and Uyo < Itu < Uruan < Ikono < Ibiono Ibom for the adult population.

4. Discussion

The outcome of this study has shown that power generation, transmission, and distribution activities can increase the concentrations of trace metals within the environment. It has also been revealed that elevated metals in the environment can affect human health through prolonged exposure to soil and vegetables. Pollution parameters used have shown that these studied locations were highly contaminated with trace metals. The principal component analysis has confirmed the contribution of power transmission and distribution activities to the elevation of levels of metals in soil and *T. occidentalis*. The estimated daily rates of the metal toxicants in the child population through the ingestion of *T. occidentalis* were above their suitable limits. Hazard indices for the children and adult groups through exposure to the studied soils were less than one. However, these indices were higher than one in both populations via *T. occidentalis*, indicating the tendency for high non-carcinogenic risks mainly through the consumption of the studied vegetable. The cancer risks in adults were within the acceptable limit, however, the risks were higher than in children via *T. occidentalis*. Generally, the children's class was more susceptible to the carcinogenic and non-carcinogenic hazards, mostly through the consumption of *T. occidentalis*. Consequently, farming activities within the high-tension power cables should be prohibited to forestall related environmental and human health problems.

4.1 *Future plans*

The results obtained and observations from others have shown that successive research on the impacts of power transmission and distribution activities should include aquatic ecosystems and other trace metals not considered in this study. Local governments and other edible crops cultivated within the neighborhood of high-tension power lines should be examined for their metal contents and the associated health problems. Other toxic substances, such as polycyclic aromatic hydrocarbons (PAHs), should also be investigated in soils, water, and edible plants found within the vicinity of high-tension power cables. Cultivation of edible crops near high-tension power installations should be seriously discouraged, and the authorities concerned should prosecute the offenders.

Conflict of interest

There is no conflict of interest for this study.

References

[1] Ebong GA, Ita BN, Nyong AB, Benson NU. Seasonal changes in the water quality of Qua Iboe River Estuary and its associated creeks in Ibeno, Nigeria. *Journal of Applied Sciences*. 2006; 9(2): 6469-6482.

[2] Okon AO, Ebong GA, Tombere VP, Anweting IB, Etuk HS, Ambrose I. Toxicity profile of metals in water, sediments and Liza grandisquamis from Iko River, South-South of Nigeria. *International Journal of Frontline Research in Pharma and Bio Sciences*. 2023; 2(2): 1-16. Available from: http://doi.org/10.56355/ijfrpbs.2023.2.2.0020.

[3] Ebong GA, Offiong OE, Ekpo BO. Pollution indices of trace metals in urban dumpsite soils within Akwa Ibom State, Nigeria. *International Research Journal of Pure and Applied Chemistry*. 2015; 6(2): 84-94. Available from: https://doi.org/10.9734/IRJPAC/2015/15331.

[4] Offiong NAO, Inam EJ, Etuk HS, Ebong GA, Inyangudoh AI, Addison F. Trace metal levels and nutrient characteristics of crude oil-contaminated soil amended with biochar-humus sediment slurry. *Pollutants*. 2021; 1(3): 119-126. Available from: https://doi.org/10.3390/pollutants1030010.

[5] Anweting IB, Ebong GA, Okon IE, Etuk HS, Etim IS. Physicochemical characteristics and heavy metals assessment of surface water and sediment from Idim Idaang stream in Ibiono Ibom, Akwa Ibom State, Nigeria. *Journal of Materials and Environmental Science*. 2024; 15(1): 72-83.

[6] Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*. 2014; 7(2): 60-72. Available from: https://doi.org/10.2478/intox-2014-0009.

[7] Ebong GA, Etuk HS, Dan EU. Distribution, pollution index and associated health risk of trace metals in waste-impacted soils within Akwa Ibom State, Nigeria. *Geosystem Engineering*. 2018; 21(3): 121-134. Available from: https://doi.org/10.1080/12269328.2017.1376291.

[8] Mitra S, Chakraborty AJ, Tareq AM, Emran TB, Nainu F, Khusro A, et al. Impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University-Science*. 2022; 34(3): 101865. Available from: https://doi.org/10.1016/j.jksus.2022.101865.

[9] Etuk HS, Ebong GA, Anweting IB, Okon AO, Ekot AE. Sources and health risks of inorganic toxicants in Gallus gallus domesticus (broilers) from poultry farms in Uyo, Nigeria. *British Journal of Multidisciplinary and Advanced Studies*. 2023; 4(5): 1-30. Available from: https://doi.org/10.37745/bjmas.2022.0302.

[10] Olaniyan A, Caux, S, Maussion P. Rural electrification in Nigeria: A review of impacts and effects of frugal energy generation based on some of e-waste components. *Heliyon*. 2024; 10(11): e31300. Available from: https://doi.org/10.1016/j.heliyon.2024.e31300.

[11] Ayamolowo OJ, Buraimoh E, Salau AO, Dada JO. Nigeria electricity power supply system: The past, present and the future. In: *2019 IEEE PES/IAS Power Africa*. Nigeria: IEEE; 2019. p.64-69. Available from: https://doi.org/10.1109/PowerAfrica.2019.8928767.

[12] Carpenter DO. Extremely low frequency electromagnetic fields and cancer: How source of funding affects results. *Environmental Research*. 2019; 178: 108688. Available from: https://doi.org/10.1016/j.envres.2019.108688.

[13] Sorahan TM. Cancer incidence in UK electricity generation and transmission workers, 1973-2015. *Occupational Medicine*. 2019; 69(5): 342-351. Available from: https://doi.org/10.1093/occmed/kqz082.

[14] Agrawal P, Mittal A, Prakash R, Kumar M, Singh TB, Tripathi SK. Assessment of contamination of soil due to heavy metals around coal fired thermal power plants at Singrauli region of India. *Bulletin of Environmental Contamination and Toxicology*. 2010; 85: 219-223. Available from: https://doi.org/10.1007/s00128-010-0043-8.

[15] Zhu C, Tian H, Cheng K, Liu K, Wang K, Hua S, et al. Potentials of whole process control of heavy metals

emissions from coal-fired power plants in China. *Journal of Cleaner Production*. 2016; 114: 343-351. Available from: https://doi.org/10.1016/j.jclepro.2015.05.008.
[16] Fuliful FK, Habi GJ. Heavy metals emitted from power plant in Al-Khairat city effect on the surrounding soil. *AIP Conference Proceedings*. 2020; 2290(1): 050019. Available from: https://doi.org/10.1063/5.0028087.
[17] Martínez-Guijarro R, Paches M, Romero I, Aguado D. Sources, mobility, reactivity, and remediation of heavy metal(loid) pollution: A review. *Advances in Environmental and Engineering Research*. 2021; 2(4): 33. Available from: http://doi.org/10.21926/aeer.2104033.
[18] Pibul P, Jawjit S, Yimthiang S. Soil heavy metal pollution from waste electrical and electronic equipment of repair and junk shops in southern Thailand and their ecological risk. *Heliyon*. 2023; 9(10): E20438. Available from: https://doi.org/10.1016/j.heliyon.2023.e20438.
[19] Idowu GA, Olonimoyo EA, Idowu AM, Aiyesanmi AF. Impact of gas and oil-fired power plants on proximal water and soil environments: Case study of Egbin power plant, Ikorodu, Lagos State, Nigeria. *SN Applied Science*. 2020; 2: 1352. Available from: https://doi.org/10.1007/s42452-020-3150-0.
[20] Hemkes OJ, Hartmans J. Copper content in grass and soil under high-voltage lines in industrial and rural areas. *Trace Substances in Environmental Health*. 1973; 7(7): 5974098. Available from: https://www.osti.gov/biblio/5974098.
[21] Kraal H, Ernst W. Influence of copper high tension lines on plants and soils. *Environmental Pollution (1970)*. 1976; 11(2): 131-135. Available from: https://doi.org/10.1016/0013-9327(76)90025-2.
[22] Jones R. Zinc and cadmium in lettuce and radish grown in soils collected near electrical transmission (hydro) towers. *Water, Air, and Soil Pollution*. 1983; 19: 389-395. Available from: https://doi.org/10.1007/BF00159600.
[23] Jones R, Burgess MSE. Zinc and cadmium in soils and plants near electrical transmission (hydro) towers. *Environmental Science & Technology*. 1984; 18(10): 731-734. Available from: https://doi.org/10.1021/es00128a002.
[24] Hamdy SMA, Al Obiady AHMJ, Al Mashhady AAM. Effects of lead pollution on soil and plants around the powered generators. *Iranian Journal of Science*. 2015; 39(3): 341-343. Available from: https://doi.org/10.22099/ijsts.2015.3159.
[25] Huang X, Hu J, Qin F, Quan W, Cao R, Fan M, et al. Heavy metal pollution and ecological assessment around the Jinsha coal-fired power plant (China). *International Journal of Environmental Research and Public Health*. 2017; 14(12): 1589. Available from: https://doi.org/10.3390/ijerph14121589.
[26] Ogunlana R, Korode AI, Ajibade ZF. Assessing the level of heavy metals concentration in soil around transformer at Akoko community of Ondo State, Nigeria. *Journal of Applied Sciences and Environmental Management*. 2020; 24(12): 2183-2189. Available from: https://doi.org/10.4314/jasem.v24i12.26.
[27] Idowu AA, Iwuoha GN. Toxicity assessment of heavy metals in soils around transformers in University of Port Harcourt, Choba, Nigeria. *International Journal of Advanced Research in Chemical Science (IJARCS)*. 2021; 8(1): 30-34. Available from: http://doi.org/10.20431/2349-0403.0801004.
[28] Al-Hiyaly SA, Mcneilly T, Bradshaw AD. The effects of zinc contamination from electricity pylons-evolution in a replicated situation. *New Phytologist*. 1988; 110(4): 571-580. Available from: https://doi.org/10.1111/j.1469-8137.1988.tb00297.x.
[29] Furuheim KM, Nilsson S, Hvidsten S, Hellesø SM. Water diffusion barrier-A novel design for high voltage subsea cables. *Proceedings of the 23rd Nordic Insulation Symposium*. 2023; 23: 136-139. Available from: https://doi.org/10.5324/nordis.v0i23.2476.
[30] Viespoli LM, Johanson A, Alvaro A, Nyhus B, Berto F. Subsea power cable sheathing: An investigation of lead fatigue performance. *Procedia Structural Integrity*. 2020; 28: 344-351. Available from: https://doi.org/10.1016/j.prostr.2020.10.040.
[31] Mandal GC, Mandal A, Chakraborty A. The toxic effect of lead on human health. *Human Biology and Public Health*. 2022; 3: 1-11. Available from: https://doi.org/10.52905/hbph2022.3.45.
[32] Tan X, Xing J, Chen H, Zhang T. Corrosion and protection of galvanized steel in power grid. *IOP Conference Series: Earth and Environmental Science*. 2020; 508: 012059. Available from: https://doi.org/10.1088/1755-1315/508/1/012059.
[33] Kalt G, Thunshirn P, Krausmann F, Haberl H. Material requirements of global electricity sector pathways to 2050 and associated greenhouse gas emissions. *Journal of Cleaner Production*. 2022; 358: 132014. Available from: https://doi.org/10.1016/j.jclepro.2022.132014.
[34] Zemčík H, Kroupa T, Vaňková T, Zemčík R, Pihera J, Prosr P, et al. Hybrid steel-composite cross-arm for distribution power lines. *Composite Structures*. 2023; 322: 117415. Available from: https://doi.org/10.1016/

j.compstruct.2023.117415.
[35] Nriagu JO. A global assessment of natural sources of atmospheric trace metals. *Nature*. 1989; 338: 47-49. Available from: https://doi.org/10.1038/338047a0.
[36] Ikechukwu EE, Pauline EO. Environmental impacts of corrosion on the physical properties of copper and aluminium: A case study of the surrounding water bodies in Port Harcourt. *Open Journal of Social Sciences*. 2015; 3(2): 143-150. Available from: http://doi.org/10.4236/jss.2015.32019.
[37] Briffa J, Sinagra E, Blundell R. Heavy metal pollution in the environment and their toxicological effects on humans. *Heliyon*. 2020; 6(9): E04691. Available from: https://doi.org/10.1016/j.heliyon.2020.e04691.
[38] Tóth G, Hermann T, Szatmári G, Pásztor L. Maps of heavy metals in the soils of the European Union and proposed priority areas for detailed assessment. *Science of the Total Environment*. 2016; 565: 1054-1062. Available from: https://doi.org/10.1016/j.scitotenv.2016.05.115.
[39] Onwukeme VI, Eze VC. Identification of heavy metals source within selected active dumpsites in southeastern Nigeria. *Environmental Analysis, Health and Toxicology*. 2021; 36(2): E2021008. Available from: https://doi.org/10.5620/eaht.2021008.
[40] Saha A, Gupta BS, Patidar S, Martínez-Villegas N. Evaluation of potential ecological risk index of toxic metals contamination in the soils. *Chemistry Proceedings*. 2022; 10(1): 59. Available from: https://doi.org/10.3390/IOCAG2022-12214.
[41] Wang X, Deng C, Yin J, Tang X. Toxic heavy metal contamination assessment and speciation in sugarcane soil. *IOP Conference Series: Earth and Environmental Science*. 2018; 108(4): 042059. Available from: https://doi.org/10.1088/1755-1315/108/4/042059.
[42] Ebong GA, Etuk HS, Umoren IU, Umanah KI. Effects of NPK fertilizers on trace metals loads in soil and vegetables, bioavailability in vegetables and the related health risk using simulation techniques. *World Journal of Applied Science & Technology*. 2022; 14(2): 42-52. Available from: https://www.ajol.info/index.php/wojast/article/view/247165.
[43] Ouchir N, Aissa LB, Boughdiri M, Aydi A. Assessment of heavy metal contamination status in sediments and identification of pollution source in Ichkeul Lake and river ecosystem, northern Tunisia. *Arabian Journal of Geosciences*. 2016; 9: 539. Available from: https://doi.org/10.1007/s12517-016-2560-1.
[44] Mavakala BK, Sivalingam P, Laffite A, Mulaji CK, Giuliani G, Mpiana PT, et al. Evaluation of heavy metal content and potential ecological risks in soil samples from wild solid waste dumpsites in developing country under tropical conditions. *Environmental Challenges*. 2022; 7: 100461. Available from: https://doi.org/10.1016/j.envc.2022.100461.
[45] Fadlillah LN, Utami S, Rachmawati AA, Jayanto GD, Widyastuti M. Ecological risk and source identifications of heavy metals contamination in the water and surface sediments from anthropogenic impacts of urban river, Indonesia. *Heliyon*. 2023; 9(4): E15485. Available from: https://doi.org/10.1016/j.heliyon.2023.e15485.
[46] Al-Anbari R, Al Obaidy AHMJ, Ali FHA. Pollution loads and ecological risk assessment of heavy metals in the urban soil affected by various anthropogenic activities. *International Journal of Advanced Research (IJAR)*. 2015; 3(2): 104-110. Available from: https://www.journalijar.com/uploads/441_IJAR-4875.pdf.
[47] Nabulo G, Young SD, Black CR. Assessing risk to human health from tropical leafy vegetables grown on contaminated urban soils. *Science of the Total Environment*. 2010; 408(22): 5338-5351. Available from: https://doi.org/10.1016/j.scitotenv.2010.06.034.
[48] Dan EU, Ebong GA, Etuk HS, Daniel IE. Carcinogenic potentials of toxic metals and polycyclic aromatic hydrocarbons in *Telfairia occidentalis* and *Talinum triangulare* impacted by wastewater, Southern Nigeria. *Environmental Protection Research*. 2023; 3(1): 110-129. Available from: https://doi.org/10.37256/epr.3120232136.
[49] United States Environmental Protection Agency (US EPA). *Exposure Factors Handbook: 2011 Edition*. Report number: EPA/600/R-090/052F. 2011.
[50] Tombere VP, Okon AMO, Ebong GA, Akpan AW. Physicochemistry of Iko River Channel in Nigeria and the related human health problems. *Asian Journal of Biological Sciences*. 2023; 16(4): 417-437. Available from: https://doi.org/10.3923/ajbs.2023.417.437.
[51] US EPA. *Integrated Risk Information System (IRIS)*. United States Environmental Protection. 2010.
[52] Ebong GA, Moses EA, Akpabio OA, Udombeh RB. Physicochemical properties, total concentration, geochemical fractions, and health risks of trace metals in oil-bearing soils of Akwa Ibom State, Nigeria. *Journal of Materials & Environmental Sustainability Research*. 2022; 2(4): 1-18. Available from: https://doi.org/10.55455/jmesr.2022.009.
[53] World Health Organization (WHO). *Permissible Limits of Heavy Metals in Soil and Plants*. 1996.
[54] FAO/WHO. *Joint FAO/WHO Food Standards Programme Codex Committee on Contaminants in Foods Fifth*

Session. 2011.
[55] Ekere NR, Ugbor MCJ, Ihedioha JN, Ukwueze NN, Abugu HO. Ecological and potential health risk assessment of heavy metals in soils and food crops grown in abandoned urban open waste dumpsite. *Journal of Environmental Health Science and Engineering*. 2020; 18(2): 711-721. Available from: https://doi.org/10.1007/s40201-020-00497-6.
[56] WHO. *Fruit and Vegetables for Health: Report of the Joint FAO/WHO Workshop, 1-3 September 2004, Kobe, Japan*. 2005. Available from: https://iris.who.int/handle/10665/43143.
[57] Ashraf I, Ahmad F, Sharif A, Altaf AR, Teng H. Heavy metals assessment in water, soil, vegetables and their associated health risks via consumption of vegetables, District Kasur, Pakistan. *SN Applied Sciences*. 2021; 3: 552. Available from: https://doi.org/10.1007/s42452-021-04547-y.
[58] Udoh BO, Amadi AN. Evaluation of heavy metal pollution level in soils and plants around Ibeno Area, Akwa-Ibom State, Niger Delta, Nigeria. *Pacific Journal of Science and Technology*. 2020; 21(1): 290-303. Available from: https://www.researchgate.net/publication/341641031_Evaluation_of_Heavy_Metal_Pollution_Level_in_Soils_and_Plants_around_Ibeno_Area_Akwa-Ibom_State_Niger_Delta_Nigeria.
[59] Abd Elnabi MK, Elkaliny NE, Elyazied MM, Azab SH, Elkhalifa SA, Elmasry S, et al. Toxicity of heavy metals and recent advances in their removal: A review. *Toxics*. 2023; 11(7): 580. Available from: https://doi.org/10.3390/toxics11070580.
[60] Enuneku A, Omoruyi O, Tongo I, Ogbomida E, Ogbeide O, Ezemonye L. Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. *Applied Water Science*. 2018; 8: 224. Available from: https://doi.org/10.1007/s13201-018-0873-9.
[61] Bahiru DB, Teju E. Levels of some selected metals (Fe, Cu and Zn) in selected vegetables and soil around eastern industry zone, central Ethiopia. *African Journal of Agricultural Research*. 2019; 14(2): 78-91. Available from: https://doi.org/10.5897/AJAR2018.13615.
[62] Royer A, Sharman T. *Copper Toxicity*. FL, United States: Stat Pearls Publishing; 2023. Available from: https://pubmed.ncbi.nlm.nih.gov/32491388/.
[63] Ahirwar NK, Gupta G, Singh R, Singh V. Assessment of present heavy metals in industrial affected soil area of Mandideep, Madhya Pradesh, India. *International Journal of Current Microbiology and Applied Sciences*. 2018; 7(1): 3572-3582. Available from: https://doi.org/10.20546/ijcmas.2018.701.419.
[64] Ogunlana R, Korode AI, Ajibade ZF. Assessing the level of heavy metals concentration in soil around transformer at Akoko community of Ondo State, Nigeria. *Journal of Applied Sciences and Environmental Management*. 2020; 24(12): 2183-2189. Available from: https://doi.org/10.4314/jasem.v24i12.26.
[65] Garba ST, Abubakar MA. Source and distribution of the heavy metals: Pb, Cd, Cu, Zn, Fe, Cr, and Mn in soils of Bauchi Metropolis, Nigeria. *American Journal of Engineering Research (AJER)*. 2018; 7(2): 13-23. Available from: https://www.ajer.org/papers/Vol-7-issue-2/B07021323.pdf.
[66] Yahaya SM, Abubakar F, Abdu N. Ecological risk assessment of heavy metal-contaminated soils of selected villages in Zamfara State, Nigeria. *SN Applied Sciences*. 2021; 3: 168. Available from: https://doi.org/10.1007/s42452-021-04175-6.
[67] Abbaspour N, Hurrell R, Kelishadi R. Review on iron and its importance for human health. *Journal of Research in Medical Sciences*. 2014; 19(2): 164-174. Available from: https://pubmed.ncbi.nlm.nih.gov/24778671/.
[68] Marianne WR. Excess iron: Considerations related to development and early growth. *The American Journal of Clinical Nutrition*. 2017; 106: 1600S-1605S. Available from: https://doi.org/10.3945/ajcn.117.155879.
[69] Staniek H, Wójciak RW. The combined effects of iron excess in the diet and chromium(III) supplementation on the iron and chromium status in female rats. *Biological Trace Element Research*. 2018; 184: 398-408. Available from: https://doi.org/10.1007/s12011-017-1203-z.
[70] Onwugbuta GC, Orji OA. Effect of mild steel buried in crude oil polluted soils on the growth response of two maize (*Zea Mays L.*) varieties. *IOSR Journal of Agriculture and Veterinary Science*. 2019; 12(1): 10-16. Available from: doi:10.9790/2380-1201011016.
[71] Binh NTL, Hoang NT, Truc NTT, Khang VD, Le HA. Estimating the possibility of lead contamination in soil surface due to lead deposition in atmosphere. *Journal of Nanomaterials*. 2021; 2021(1): 5586951. Available from: https://doi.org/10.1155/2021/5586951.
[72] Darma A, Ibrahim S, Sani A, Zandi P, Yang J. Appraisal of lead (Pb) contamination and potential exposure risk associated with agricultural soils and some cultivated plants in gold mines. *Environmental Systems Research*. 2022; 11: 14. Available from: https://doi.org/10.1186/s40068-022-00259-3.
[73] Ebong GA, Dan EU, Inam E, Offiong NO. Total concentration, speciation, source identification and associated

health implications of trace metals in Lemna dumpsite soil, Calabar, Nigeria. *Journal of King Saud University-Science*. 2019; 31(4): 886-897. Available from: https://doi.org/10.1016/j.jksus.2018.01.005.

[74] Usman K, Abu-Dieyeh MH, Zouari N, Al-Ghouti MA. Lead (Pb) bioaccumulation and antioxidative responses in Tetraena qataranse. *Scientific Reports*. 2020; 10: 17070. Available from: https://doi.org/10.1038/s41598-020-73621-z.

[75] Pham NM, Huynh TLD, Nasir MA. Environmental consequences of population, affluence and technological progress for European countries: A Malthusian view. *Journal of Environmental Management*. 2020; 260: 110143. Available from: https://doi.org/10.1016/j.jenvman.2020.110143.

[76] Samways D. Population and sustainability: Reviewing the relationship between population growth and environmental change. *The Journal of Population and Sustainability*. 2022; 6(1): 15-41. Available from: https://doi.org/10.3197/JPS.63772239426891.

[77] Sultana R, Tanvir RU, Hussain KA, Chamon AS, Mondol MN. Heavy metals in commonly consumed root and leafy vegetables in Dhaka City, Bangladesh, and assessment of associated public health risks. *Environmental Systems Research*. 2022; 11: 15. Available from: https://doi.org/10.1186/s40068-022-00261-9.

[78] Sulaiman FR, Ibrahim NH, Syed Ismail SN. Heavy metal (As, Cd, and Pb) concentration in selected leafy vegetables from Jengka, Malaysia, and potential health risks. *SN Applied Sciences*. 2020; 2: 1430. Available from: https://doi.org/10.1007/s42452-020-03231-x.

[79] Zor M, Kocaoba S. Determination of metal contents in some green leafy vegetables in Marmara region of Turkey. *SN Applied Sciences*. 2023; 5: 154. Available from: https://doi.org/10.1007/s42452-023-05369-w.

[80] Genchi G, Sinicropi MS, Lauria G, Carocci A, Catalano A. The effects of cadmium toxicity. *International Journal of Environmental Research and Public Health*. 2020; 17(11): 3782. Available from: https://doi.org/10.3390/ijerph17113782.

[81] Haider FU, Liqun C, Coulter JA, Cheema SA, Wu J, Zhang R, et al. Cadmium toxicity in plants: Impacts and remediation strategies. *Ecotoxicology and Environmental Safety*. 2021; 211: 111887. Available from: https://doi.org/10.1016/j.ecoenv.2020.111887.

[82] Gupta N, Yadav KK, Kumar V, Prasad S, Cabral-Pinto MMS, Jeon BH, et al. Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption. *Frontiers in Environmental Sciences*. 2022; 10: 791052. Available from: https://doi.org/10.3389/fenvs.2022.791052.

[83] Ahmed S, Zohra FT, Mahdi MM, Nurnabi M, Alam MZ, Choudhury TR. Health risk assessment for heavy metal accumulation in leafy vegetables grown on tannery effluent contaminated soil. *Toxicology Reports*. 2022; 9: 346-355. Available from: https://doi.org/10.1016/j.toxrep.2022.03.009.

[84] Wuana RA, Okieimen FE. Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Network*. 2011; 2011: 402647.

[85] Taylor AA, Tsuji JS, Garry MR, McArdle ME, Goodfellow WLJ, Adams WJ, et al. Critical review of exposure and effects: Implications for setting regulatory health criteria for ingested copper. *Environmental Management*. 2020; 65: 131-159. Available from: https://doi.org/10.1007/s00267-019-01234-y.

[86] Liu Z, Bai Y, Luo L, Wan J, Wang W, Zhao G. Effects of high dose copper on plant growth and mineral nutrient (Zn, Fe, Mg, K, Ca) uptake in spinach. *Environmental Science and Pollution Research*. 2021; 28, 37471-37481. Available from: https://doi.org/10.1007/s11356-021-13395-7.

[87] Mir AR, Pichtel J, Hayat S. Copper: Uptake, toxicity and tolerance in plants and management of Cu-contaminated soil. *BioMetals*. 2021; 34: 737-759. Available from: https://doi.org/10.1007/s10534-021-00306-z.

[88] Ebong GA, Etuk HS. Levels of essential elements and anions in vegetables from organic matter impacted farm in Uyo, Nigeria. *American Journal of Biological and Environmental Statistics*. 2017; 3(2): 20-25. Available from: https://doi.org/10.11648/j.ajbes.20170302.11.

[89] Li G, Kronzucker HJ, Shi W. Root developmental adaptation to Fe toxicity: Mechanisms and management. *Plant Signaling & Behavior*. 2016; 11(1): e1117722. Available from: https://doi.org/10.1080/15592324.2015.1117722.

[90] Staniek H, Wójciak RW. The combined effects of iron excess in the diet and chromium(III) supplementation on the iron and chromium status in female rats. *Biological Trace Element Research*. 2018; 184: 398-408. Available from: https://doi.org/10.1007/s12011-017-1203-z.

[91] Lapaz AM, Yoshida CHP, Gorni PH, de Freitas-Silva L, Araújo TO, Ribeiro C. Iron toxicity: Effects on the plants and detoxification strategies. *Acta Botanica Brasilica*. 2022; 36: e2021abb0131. Available from: https://doi.org/10.1590/0102-33062021abb0131.

[92] Kumar S, Islam R, Akash PB, Khan MHR, Proshad R, Karmoker J, et al. Lead (Pb) contamination in agricultural products and human health risk assessment in Bangladesh. *Water, Air, & Soil Pollution*. 2022; 233: 257. Available

from: https://doi.org/10.1007/s11270-022-05711-9.
[93] Nas FS, Ali M. The effect of lead on plants in terms of growing and biochemical parameters: A review. *Ecology & Environmental Sciences*. 2018; 3(4): 265-268. Available from: https://doi.org/10.15406/mojes.2018.03.00098.
[94] Collin MS, Venkatraman SK, Vijayakumar N, Kanimozhi V, Arbaaz SM, Stacey RGS, et al. Bioaccumulation of lead (Pb) and its effects on human: A review. *Journal of Hazardous Materials Advances*. 2022; 7: 100094. Available from: https://doi.org/10.1016/j.hazadv.2022.100094.
[95] Jin B, Wang J, Lou W, Wang L, Xu J, Pan Y, et al. Pollution, ecological risk and source identification of heavy metals in sediments from the Huafei River in the eastern suburbs of Kaifeng, China. *International Journal of Environmental Research & Public Health*. 2022; 19(18): 11259. Available from: https://doi.org/10.3390/ijerph191811259.
[96] Aendo P, Netvichian R, Thiendedsakul P, Khaodhiar S, Tulayakul P. Carcinogenic risk of Pb, Cd, Ni, and Cr and critical ecological risk of Cd and Cu in soil and groundwater around the municipal solid waste open dump in central Thailand. *Journal of Environmental and Public Health*. 2022; 2022(1): 3062215. Available from: https://doi.org/10.1155/2022/3062215.
[97] Smart MO, Asabia LO, Roberts AE, Okumodi BO, Ibironke OH. Heavy metal contamination and associated ecological risk on farms around Oluyole industrial area, Ibadan. *Journal of Research in Forestry, Wildlife and Environment*. 2023; 15(2): 121-128. Available from: https://www.ajol.info/index.php/jrfwe/article/view/252329.
[98] Essien JP, Ikpe DI, Inam ED, Okon AO, Ebong GA, Benson NU. Occurrence and spatial distribution of heavy metals in landfill leachates and impacted freshwater ecosystem: An environmental and human health threat. *PLoS ONE*. 2022; 17(2): e0263279. Available from: https://doi.org/10.1371/journal.pone.0263279.
[99] Mugoša B, Đurović D, Nedović-Vuković M, Barjaktarović-Labović S, Vrvić M. Assessment of ecological risk of heavy metal contamination in coastal municipalities of Montenegro. *International Journal of Environmental Research and Public Health*. 2016; 13(4): 393. Available from: https://doi.org/10.3390/ijerph13040393.
[100]Rahmonov O, Sobala M, Środek D, Karkosz D, Pytel S, Rahmonov M. The spatial distribution of potentially toxic elements in the mountain forest topsoils (the Silesian Beskids, southern Poland). *Scientific Reports*. 2024; 14: 338. Available from: https://doi.org/10.1038/s41598-023-50817-7.
[101]Rostami S, Kamani H, Shahsavani S, Hoseini M. Environmental monitoring and ecological risk assessment of heavy metals in farmland soils. *Human and Ecological Risk Assessment: An International Journal*. 2021; 27(2): 392-404. Available from: https://doi.org/10.1080/10807039.2020.1719030.
[102]Chris DI, Anyanwu BO. Pollution and potential ecological risk evaluation associated with toxic metals in an impacted mangrove swamp in Niger Delta, Nigeria. *Toxics*. 2023; 11(1): 6. https://doi.org/10.3390/toxics11010006.
[103]Omololu FO, Lawal AS. Population growth and waste management in metropolitan Lagos. *The Nigerian Journal of Sociology and Anthropology*. 2013; 11(2): 83-100. Available from: https://doi.org/10.36108/NJSA/3102/11(0260).
[104]Ekwule OR, Nwafor OE, Ufedo MI. Per capita solid waste generation and characterization in Makurdi Metropolis, Nigeria. *Journal of Engineering and Sciences*. 2020; 6(1): 33-40. Available from: https://dergipark.org.tr/en/download/article-file/1168562.
[105]Ebong GA, Etuk HS, Dan EU. Multivariate statistical evaluation of ecological risks associated with the uncontrolled ipping method of rban wastes at Uyo village road, Akwa Ibom State, Nigeria. *Singapore Journal of Scientific Research*. 2019; 9(1): 1-12. Available from: doi:10.3923/sjsres.2020.
[106]Yüksel B, Ustaoğlu F, Tokatli C, Islam MS. Ecotoxicological risk assessment for sediments of Çavuşlu stream in Giresun, Turkey: Association between garbage disposal facility and metallic accumulation. *Environmental Science and Pollution Research*. 2022; 29: 17223-17240. Available from: https://doi.org/10.1007/s11356-021-17023-2.
[107]Zeng S, Ma J, Ren Y, Liu GJ, Zhang Q, Chen F. Assessing the spatial distribution of soil PAHs and their relationship with anthropogenic activities at a national scale. *International Journal of Environmental Research and Public Health*. 2019; 16(24): 4928. Available from: https://doi.org/10.3390/ijerph16244928.
[108]Etuk HS, Ebong GA, Dan EU, Udoh HF. Probability of health risk, bioaccumulation, and geochemical fractions of toxic elements in soils and vegetables impacted by Manures in Nigeria. *Environmental Protection Research*. 2022; 2(2): 75-94. Available from: https://doi.org/10.37256/epr.2220221485.
[109]Orisakwe OE, Oladipo OO, Ajaezi GC, Udowelle NA. Horizontal and vertical distribution of heavy metals in farm produce and livestock around lead-contaminated goldmine in Dareta and Abare, Zamfara State, Northern Nigeria. *Journal of Environmental and Public Health*. 2017; 2017: 3506949. Available from: https://doi.org/10.1155/2017/3506949.
[110]Ebong GA, Etuk HS, Dan EU, Ukpeh MD. A comparative study on the metal loads and related human health risks of toxic metals between the vegetables from Southern and Northern regions of Nigeria consumed in Akwa

Ibom State. *World Journal of Advanced Research and Reviews*. 2020; 7(1): 57-72. Available from: https://doi.org/10.30574/wjarr.2020.7.1.0239.
[111]Wendler T, Gröttrup S. Cluster analysis. In: *Data Mining with SPSS Modeler*. Cham: Springer; 2021. p.623-752. Available from: https://doi.org/10.1007/978-3-030-54338-9_7.
[112]Ebong GA, Anweting IB, Etuk HS, Ambrose IS, Okon AO. Impacts of varied industrial activities within southern Nigeria on air environment and human health. *GSC Advanced Research and Reviews*. 2023; 17(03): 134-144. Available from: https://doi.org/10.30574/gscarr.2023.17.3.0469.
[113]Ugbede FO, Osahon OD, Akpolile AF, Oladele BB. Assessment of heavy metals concentrations, soil-to-plant transfer factor and potential health risk in soil and rice samples from Ezillo rice fields in Ebonyi State, Nigeria. *Environmental Nanotechnology, Monitoring & Management*. 2021; 16: 100503. Available from: https://doi.org/10.1016/j.enmm.2021.100503.
[114]Yang L, Wu P, Yang W. Characteristics, health risk assessment, and transfer model of heavy metals in the soil-food chain in cultivated land in Karst. *Foods*. 2022; 11(18): 2802. Available from: https://doi.org/10.3390/foods11182802.
[115]Wang H, Li Y, Fu J, Cheng Q, Wei J, Feng S, et al. Heavy metal characterization and health risk assessment in agricultural soils from an agate dyeing village. *Polish Journal of Environmental Studies*. 2023; 32(2): 1393-1404. Available from: https://doi.org/10.15244/pjoes/156469.
[116]Markmanuel DP, Horsfall MJNR, Orubite OK, Adowei P. Evaluation of concentrations and human health risk of Cu, Zn, Fe in two periwinkles species from three local government areas, Bayelsa State, Nigeria. *Journal of Applied Science and Environmental Management*. 2017; 21(2): 323-328. Available from: https://doi.org/10.4314/jasem.v21i2.13.
[117]Sani A, Idris KM, Abdullahi BA, Darma AI. Bioaccumulation and health risks of some heavy metals in Oreochromis niloticus, sediment and water of Challawa river, Kano, Northwestern Nigeria. *Environmental Advances*. 2022; 7: 100172. Available from: https://doi.org/10.1016/j.envadv.2022.100172.
[118]Abdullahi S, Musa MS. Health risk assessment of some heavy metals in soil samples around identified metal workshops. *FUDMA Journal of Sciences*. 2023; 7(2): 240-245.
[119]Alsafran M, Usman K, Rizwan M, Ahmed T, Al Jabri H. The carcinogenic and non-carcinogenic health risks of metal(oid)s bioaccumulation in leafy vegetables: A consumption advisory. *Frontiers in Environmental Sciences*. 2021; 9: 742269. Available from: https://doi.org/10.3389/fenvs.2021.742269.
[120]Ernyasih E, Mallongi A, Daud A, Palutturi S, Stang S, Thaha AR, et al. Health risk assessment through probabilistic sensitivity analysis of carbon monoxide and fine particulate transportation exposure. *Global Journal of Environmental Science and Management*. 2023; 9(4): 933-950. Available from: https://scholar.unhas.ac.id/en/publications/health-risk-assessment-through-probabilistic-sensitivity-analysis.
[121]Khan A, Khan MS, Egozcue JJ, Shafique MA, Nadeem S, Saddiq G. Irrigation suitability, health risk assessment and source apportionment of heavy metals in surface water used for irrigation near marble industry in Malakand, Pakistan. *PLoS ONE*. 2022; 17(12): e0279083. Available from: https://doi.org/10.1371/journal.pone.0279083.
[122]Johnbull O, Abbassi B, Zytner RG. Risk assessment of heavy metals in soil based on the geographic information system-Kriging technique in Anka, Nigeria. *Environmental Engineering Research*. 2019; 24(1): 150-158. Available from: https://doi.org/10.4491/eer.2018.130.
[123]Kareem SL, Al Mrayan AZM, Al-husseiny RA. Human health risk assessment of heavy metals contaminated soil at Al-Nasiriyah City, Iraq. *Egyptian Journal of Chemistry*. 2022; 65(9): 369-378. Available from: https://doi.org/10.21608/ejchem.2022.113170.5141.
[124]Rushdi MI, Basak R, Das P, Ahamed T, Bhattacharjee S. Assessing the health risks associated with elevated manganese and iron in groundwater in Sreemangal and Moulvibazar Sadar, Bangladesh. *Journal of Hazardous Materials Advances*. 2023; 10: 100287. Available from: https://doi.org/10.1016/j.hazadv.2023.100287.
[125]Goudarzi G, Baboli Z, Moslemnia M, Tobekhak M, Birgani YT, Neisi A, et al. Assessment of incremental lifetime cancer risks of ambient air PM10-bound PAHs in oil-rich cities of Iran. *Journal of Environmental Health Science & Engineering*. 2021; 19: 319-330. Available from: https://doi.org/10.1007/s40201-020-00605-6.
[126]Etuk HS, Ebong GA, Okon AO, Anweting IB, Ekot AE. Spatial and seasonal variations, ecological and human risks of trace metals in major rivers within the oil producing zone of Nigeria. *World Journal of Advanced Pharmaceutical and Medical Research*. 2023; 5(2): 1-17. Available from: http://doi.org/10.53346/wjapmr.2023.5.2.0037.
[127]Xu H, Zhu Y, Dai Bo, Ye DW. National Comprehensive Cancer Network (NCCN) risk classification in predicting biochemical recurrence after radical prostatectomy. *Asian Journal of Andrology*. 2018; 20(6): 551-554. Available from: https://doi.org/10.4103/aja.aja_52_18.

[128]Salam MA, Paul SC, Zain RAMM, Bhowmik S, Nath MR, Siddiqua SA, et al. Trace metals contamination potential and health risk assessment of commonly consumed fish of Perak River, Malaysia. *PLoS ONE*. 2020; 15(10): e0241320. Available from: https://doi.org/10.1371/journal.pone.0241320.

[129]Emmanuel UC, Chukwudi MI, Monday SS, Anthony AI. Human health risk assessment of heavy metals in drinking water sources in three senatorial districts of Anambra State, Nigeria. *Toxicology Reports*. 2022; 9: 869-875. Available from: https://doi.org/10.1016/j.toxrep.2022.04.011.

[130]Munene EN, Hashim NO, Ambusso WN. Human health risk assessment of heavy metal concentration in surface water of Sosian River, Eldoret town, Uasin-Gishu County Kenya. *MethodsX*. 2023; 11: 102298. Available from: https://doi.org/10.1016/j.mex.2023.102298.