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Consumers' health risks associated with toxic metals in *Moringa oleifera* leaves from South-South Zone of Nigeria

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Abstract: *Moringa oleifera* is widely utilized as herb in many countries of the world, however; the consumption of contaminated herbal product may cause severe health risks to the consumers. This work examined the toxic metal loads in *M. oleifera* leaves and their human health risks in the South-South of Nigeria. The samples were collected from designated locations randomly, treated with standard methods and analyzed for their Cd, Cr, Ni, and Pb contents using atomic absorption spectrophotometer. The ranges (mg kg^{-1}) obtained Cd, Cr, Ni, and Pb were 0.01-0.06, 1.04-4.18, 1.86-6.35, and 0.05-0.23, respectively. The concentrations of Cd and Cr exceeded their limits for herbal products by World Health Organization (WHO). The estimated daily intakes of Cr and Ni by the adults and children via the ingestion of *M. oleifera* leave extracts exceeded their recommended oral reference limits by United State Environmental Protection Agency (USEPA). The hazard quotients of Cr and Ni for the adults and children exceeded one. Hazard indices of the metals at all the locations for both categories of consumers were higher than one. Cancer risk of Cr and Ni exceeded their safe limits by USEPA. The total cancer risk obtained 3.02E-02 to 9.32E-02 and 3.55E-02 to 1.16E-01 for the adults and children respectively exceeded the limit by USEPA. The children class was more susceptible to the carcinogenic and non-carcinogenic risks. Samples obtained from Uyo and Ikot Ekpene indicated very high carcinogenic and non-carcinogenic risks. Consequently, herbal products should be properly screened to ascertain their suitability for human consumption or otherwise.

1. Introduction

Moringer (*Moringa oleifera*) is known to be one of the richest sources of plant-based vitamins, minerals, proteins, β-carotene, and folic acid, though the leaves are the richest source of nutrients (Agboola *et al*., 2016; Adefa and Tefera, 2020). The leaves of *M. oleifera* also contain calcium, potassium, and high proportion of oleic acid (Kasolo *et al*., 2010). The plant parts of *M. oleifera* are very useful as herbs for the treatment of different classes of ailments (Calderon *et al*., 2019). *Moringer oleifera* also known as "miracle tree" is found mainly in the tropics and subtropical regions of the world, nevertheless; the plant originated from India, Afghanistan, Pakistan, and Bangladesh (Pareek *et al*., 2023; Kumar *et al*., 2024). The extracts of *M. oleifera* and other plants have been employed corrosion inhibitors (El Ouadi *et al*., 2016; El Azzouzi *et al*., 2022; Hbika *et al*., 2023; Abakedi *et al*., 2025; Vashi, 2025).

Herbal products prepared from *Moringer* leaves are used for the treatment of malnutrition, to improve breast milk production in lactating women, and to manage conditions such as cancer and diabetes. They also have anti-inflammatory, antimicrobial, and antioxidant potentials (Stohs & Hartman, (2015; Gopalakrishnan *et al*., 2016; deepali *et al*., 2025). Reports have indicated that approximately four billion people in developing countries worldwide depend on herbal products as their primary source of health services (Rishton, 2008; Wachtel-Galor and Benzie, 2012). Moringer related products are widely used in Nigeria as herbs for the treatment of various ailments (Attah *et al*., 2020; Okolie *et al*., 2022). The plant leaves are also used for the preparation of suya and Egusi soup in Nigeria (Babayeju *et al*., 2024; Debola *et al*., 2019). In the South-South Region of Nigeria, *M. oleifera* leaves are used as herbal tea (Okolie *et al*., 2022). Despite the widely consumption rate of moringer-related products as herbs, these herbal products are not properly processed and managed in most countries, thus; several contaminants have been introduced (Opuni *et al*., 2023). Consequently, the health conditions of the consumers of these products have been compromised and may cause severe consequences as reported by Thompson and Darwish (2019). Prolonged exposure to contaminants via foods may cause severe human health problems (Choudhury *et al*., 2022; Zahir *et al*., 2025). Hence, the consumption of contaminated herbal medicinal products can cause health problems such as gastrointestinal disorders, nervous system nervous system abnormalities, hyperthyroidism, liver and kidney problems, neurological disorders, cancers, , psychological disorder, and damage of the lungs to the consumers (Saad *et al*., 2014;Bhattacharya *et al*., 2016). Obviously, persistent exposure to toxic metals through the ingestion of contaminated herbal products may result in both carcinogenic and non-carcinogenic human health risks (Alawadhi *et al*., 2024; Sulaiman *et al*., 2024). The human health risks associated with the processing and consumption of herbal products in developing countries are further exacerbated by the nonexistence or weak regulatory systems that would have effectively monitored the process (Heinrich, 2015). Studies have shown that soil within crude oil-bearing environments, such as the study area, has high levels of toxic metals due to the activities of Oil Companies (Ebong and Mkpenie, 2016; Ebong and Etuk, 2017; Ebong *et al*., 2022a and b). Hence, *M. oleifera* grown within the South-South Zone of Nigeria can accumulate elevated levels of toxic metals (Rashid *et al*., 2023). The high accumulation of toxic metals by herbal plants within the study area has been confirmed by previous studies as indicated in literature (Essiett *et al*., 2011; Ezeabara *et al*., 2014; Vaikosen and Alade, 2017; Obi-iyeke, 2021). Nevertheless, these studies never examined the health implications of these toxic metals on the consumers. Thus, considering the population depending on herbal products and health risks associated with the consumption of contaminated herbal products, the assessment of *M. oleifera* leaves used as herbal product was a necessity to avoid widespread human health problems.

Since the preceding studies on the toxic metals' accumulation in herbal plants within the study area were devoid of the related health risks to the consumers, this study examined the toxic metals loads in *M. oleifera* leaves widely used as an herb in the South-South Region of Nigeria and their related health risks on the consumers. The accurate source(s) of these toxic metals in the studied herbal plant using PCA were also determined. The estimated daily intake rates, cancer and non-cancer risks of these toxic metals in the adults and young consumers of *M. oleifera* leaves herbal products were also appraised in this research.

2. Methodology

2.1. Sample collection, treatment and digestion

For this research, *Moringa oleifera* leaves were randomly collected from five plants each in Itu (5° 08′17″N & 7° 58′ 21″E), Ibiono Ibom (5° 12′36″N & 7° 52′ 54″E), Ikono (5°10′16″N &*7° 55′ 08″E)*, Ikot Ekpene (5° 18'26"N & 7° 53' 31"E), and Uyo (*5° 02'37"N & 7° 53' 43*"E) within the South-South Region of Nigeria. These samples were collected with properly labeled polyethylene bags and transported to Chemistry laboratory at the University of Uyo, Nigeria. These leaves were washed carefully with tap water, followed by distilled water, and then air-dried at room temperature for two weeks (Adefa and Tefera, 2020). Based on the procedures of AOAC (2016), 0.5 g of the samples was weighed into a 50 mL volumetric flask and digested with 8 mL (3:1. v/v) mixture of Conc. HNO_3 (65% pure, Merck, Germany) and Conc. sulphuric acid (95% pure, Sigma-Aldrich, USA). The mixture was later evaporated at 100 °C on a hot plate inside a fume cupboard till a clear coloured solution was achieved. The mixture was allowed to cool and on cooling it was filtered using Whatman No 45 Filter paper into a 25 mL volumetric flask and filled to mark with distilled water. These samples were stored in a refrigerator until the analysis of toxic metals was performed. The concentrations of Cd, Cr, Ni, and Pb in the digested samples were determined using AA Dual atomic absorption spectrophotometer (AAS) following the methods of AOAC (2004).

2.2 Evaluation of Human Health Risks

The impact of toxic metals on the consumers of *M. oleifera* leaves herbal products was evaluated by the determination of the estimated daily intakes of the metals, carcinogenic and non-carcinogenic risks according to the methods of Rojas *et al*. (2023) and Chowdhury *et al*. (2024).

2.3 Estimation of Daily Intake Rate of Toxic Metals

The estimated daily intake (EDI) rate of the toxic metals through the ingestion of herbal products prepared from the studied *M. oleifera* leaves was computed using Eqn. 1:

$$\text{EDI} = \frac{CxIR}{BW} \qquad \textbf{Eqn.1}$$

Where C is the concentration of the toxic metals in the studied *M. oleifera* leaves, IR signifies the ingestion rate, and BW indicates the body weight of the consumers. In this work, IR = 0.25 $Lday^{-1}$ for the children and 0.75 $Lday^{-1}$ for the adults (Katuura *et al*., 2016; Olusola *et al*., 2021) and BW = 60 kg for adults and 16 kg for children (Ishola *et al*., 2025).

2.4 Determination of Hazard Quotient and Hazard Index of Toxic Metals

The hazard quotient (HQ) and hazard index (HI) were used to appraise the non-carcinogenic human health risk of toxic metals through the ingestion of *M. oleifera* leaves herbal products (Dan *et al*., 2023). Hazard quotient (HQ) of the toxic metals was computed with Eqn. 2 following the procedures of Uddin *et al*. (2019) and Olaleye *et al*. (2024).

$$\text{HQ} = \frac{EDI}{Rfd} \qquad \textbf{Eqn. 2}$$

Where EDI indicates the estimated daily intake rate of the toxic metals and Rfd represents the recommended oral reference dose of the metals. The Rfd values of Cd, Cr, Ni, and Pb are 1.00E-03, 3.00E-03, 2.00E-02, and 4.00E-03 $mgkg^{-1}BW^{-1}$, respectively (USEPA, 2006; Ebong *et al*., 2024).
The hazard index of the toxic metals due to the ingestion of *M. oleifera* leaves herbal products by the adults and children was calculated using Eqn. 3 following the methods of Olaleye *et al*. (2024).

$$HI = \sum THQ \qquad \textbf{Eqn. 3}$$

Where $\sum THQ$ denotes the sum of the HQ for Cd, Cr, Ni, and Pb.

2.5 Estimation of Cancer Risks of Toxic Metals

Cancer risk (CR) indicates the probability of a person developing cancer over a lifetime due to exposure to carcinogens via the ingestion of the studied *M. oleifera* leaves herbal products. The CR of Cd, Cr, Ni, and Pb were estimated with Eqn. 4 following the procedures of Olusola *et al*. (2021).

$$CR = EDIxCSF \qquad \textbf{Eqn. 4}$$

Where EDI indicates the estimated daily intake rate of the carcinogens calculated and CSF is the cancer slope factor which according to USEPA (2012) the values for Cd, Cr, Ni, and Pb are 0.38, 0.50, 0.84, and 0.0085mgkg^{-1}day^{-1}, respectively.

2.6 Determination of Total Cancer Risk of Toxic Metals

The TCR of Cd, Cr, Ni, and Pb was computed with Eqn. 5 below following the procedures of Ishola *et al*. (2025):

$$TCR = \sum CR \qquad \textbf{Eqn. 5}$$

Where $\sum CR$ signifies the summation of the cancer risk of Cd, Cr, Ni, and Pb.

2.7 Statistical Analysis

The data obtained from this study were statistically treated using IBM SPSS Statistic version 29.0.2.0 (20) Software. Principal component analysis was done with Varimax Factor analysis on the toxic metals obtained from the analysis of *M. oleifera* leaves. Values from 0.917 and above were considered significant and were used for the interpretation of the results.

3. Results and Discussion

3.1 Concentrations of Toxic Metals in the Studied M. oleifera Leaves

Table 1: Concentrations (mg kg^{-1}) of Toxic metals in *M. oleifera* leaves

	Cd	Cr	Ni	Pb
Itu	0.03	2.31	3.48	0.13
Ibiono Ibom	0.02	2.03	2.11	0.08
Ikono	0.01	1.74	1.86	0.05
Ikot Ekpene	0.03	2.76	5.04	0.17
Uyo	0.06	4.18	6.35	0.23
Mean	0.03	2.60	3.77	0.13
SD	0.02	0.96	1.92	0.07

The concentrations of toxic metals in the studied *M. oleifera* leaves are shown in **Table 1**. The concentrations of Cd varied between 0.01 and 0.06 mg kg^{-1}. The levels of Cd reported are higher than the 0.0011-0.0030 mg kg^{-1}obtained in the leaves of *M. oleifera* by Adejumo *et al*. (2022). However, the range obtained is lower than 0.075-0.182 mg kg^{-1} reported in *Moringer* leaves by Limmatvapirat*et al*. (2015). The mean value of Cd obtained (0.03±0.02 mg kg^{-1}) exceeds the 0.02 mg kg^{-1} safe limit recommended for herbal products by WHO (2007). Prolonged exposure to the reported high levels of Cd in the studied herbal plant could cause inflammation, oxidative stress, damage to cells, and cancer (Yang *et al*., 2025). The concentrations of Cr in the leaves of *M. oleifera* from the designated locations ranged from 1.74 to 4.18 mg kg^{-1}. This range is higher than 1.175-3.285 mg kg^{-1} reported by Limmatvapirat *et al*. (2015) in Moringer leaves but lower than 5.41-30.5 mg kg^{-1} obtained by Adeagbo *et al*. (2024). The mean concentration of Cr (2.60±0.96 mg kg^{-1}) obtained in this study is higher than the recommended safe limit of 0.02 mg kg^{-1} for herbal products by WHO (2007). Hence, the consumers of *M. oleifera* leaves extracts may experience severe health issues such as damage to nerve tissues, kidney, reduced blood glucose, gastrointestinal cancer, alimentary disorders, and damage to the respiratory system (Ghani *et al*., 2012; Ribeiro *et al*., 2020). The concentrations of Ni varied from 1.86 to 6.35 mg kg^{-1} in the studied *M. oleifera* leaves.This range is below the 0.327-0.454 mg kg^{-1} reported by Yawuck and Allems (2016) in Moringer leaves. It is also lower than 42.6-59.0 mg kg^{-1} obtained by Lawan *et al*. (2025) in similar samples. The mean value of Ni obtained in the studied herbal product (3.77±1.92 mg kg^{-1}) is within the recommended safe standard of 10.0 mg kg^{-1} by WHO (2007) for herbal products. Consequently, herbal products produced from the studied *M. oleifera* leaves may not pose health risks associated with Ni toxicity. However, the accumulation of this metal in the studied plant should be closely monitored (Awafung *et al*., 2025). The concentrations of Pb in the *M. oleifera* leaves investigated ranged between 0.05 and 0.23 mg kg^{-1}. The obtained range of Pb is lower than the 0.52-19.9 mg kg^{-1} reported in moringer leaves by Rizabel *et al*., (2024), however, higher than 0.030-0.099 mg kg^{-1} documented for similar herbal product by Agboola *et al*. (2016). The mean value of Pb recorded for the studied herbal product (0.13±0.07 mg kg-1) is within the safe limit of 2.00 mg kg^{-1} recommended for herbal products by WHO (2007). Thus, exposure to herbal products prepared from the studied *M. oleifera* leaves may not cause severe health problems, however; the concentration should be examined periodically because Pb could be harmful at a little concentration above the recommended limit (Nag and Cummins, 2022). It was inferred from the results obtained that the highest concentrations of all the metals were reported in the samples from Uyo, while the lowest levels of all the metals were obtained in the samples from Ikono. Hence, high commercial and industrial activities may have influence on the metal loads in plants (Ebong *et al*., 2020; Long*et al*., 2021; Tochukwu and Ebong, 2024). The metal loads in the *M. oleifera* leaves from the different locations followed a decreasing order of Uyo > Ikot Ekpene > Itu > Ibiono Ibom > Ikono. Consequently, the consumers of *M. oleifera* leaves obtained from locations with high human activities such as Uyo and Ikot Ekpene might be exposed to health risks associated with high levels of metal contaminants as opined by Shetty *et al*. (2023).

3.2 Principal Component Analysis

The principal component analysis (PCA) was employed in this study to ascertain the source(s) of these toxic metals in the studied *M. oleifera* leaves (Anaman *et al*., 2022). The outcome of the PCA of toxic metals in the studied herbal plant is indicated in Table 2. The PCA of the herbal plant revealed one major factor responsible for the toxic metal loads.

Table 2: Results of principal component analysis of toxic metals in the studied *M. oleifera* leaves

	M. oleifera Leaves
	F1
Cd	0.979
Cr	0.986
Ni	0.980
Pb	0.990
% Total Variance	96.8
Cumulative %	96.8
Eigen value	3.87

The factor has Eigen value of 3.87 and contributed a considerable 96.8% of the cumulative variance. The factor indicated strong positive loadings on all the toxic metals determined (Table 2). This could be attributed to the impact of contaminants in the soil on the metal loads in the studied herbal plant (Xin *et al*., 2022; Rashid *et al*., 2023). Hence, the level of soil contamination has direct influence on the quality of the plants (Shahid *et al*., 2015; Rashid *et al*., 2023).

3.3 Estimated daily intake rate of toxic metals via the consumption of M. oleifera leave extracts

The estimated daily intake (EDI) rates of Cd, Cr, Ni, and Pb caused by the intake of herbal products prepared from the leaves of *M. oleifera* obtained from the studied locations were approximated based on the concentrations of each toxic metal in the studied product and the daily intake rate for the adults and children with body weights of 60 and 16 kg, respectively. The results obtained revealed that the EDI of Cd and Pb for the adults and children caused by the intake of studied *M. oleifera* leaves herbal products were within their recommended daily intake reference dose (Rfd) by USEPA (2006) (Table 3). However, the EDIs of Cr and Ni in the studied *M. oleifera* leaves exceeded their Rfd values recommended by USEPA (2006). Hence, the consumption of herbal products prepared from the leaves of the studied M. oleifera may result in health risks associated with Cr and Ni toxicity in adults and children over time. The EDIs in Table 3 indicate increasing trend of Ni > Cr > Pb > Cd. Thus, Ni and Cr were identified as toxic metals with significant risks to both the adults and children consumers of the herbal products. The results obtained indicated higher EDIs for the children than the adults group as observed in herbalproducts by Ssempijja *et al*. (2020). Thus, the children class could be more exposed to the toxicity of these toxic metals than the adults.

Table 3: The estimated daily intake of toxic metals via ingestion of *M. oleifera* leaves by the Adults and children classes

	Adults				**Children**			
	Cd	Cr	Ni	Pb	Cd	Cr	Ni	Pb
Itu	4.00E-04	2.89E-02	4.35E-02	1.60E-03	4.69E-04	3.61E-02	5.44E-02	2.03E-03
Ibiono Ibom	3.00E-04	2.54E-02	2.64E-02	1.00E-03	3.13E-04	3.17E-02	3.30E-02	1.25E-03
Ikono	1.00E-04	2.18E-02	2.33E-02	6.00E-04	1.56E-04	2.19E-02	2.91E-02	7.81E-04
Ikot Ekpene	4.00E-04	3.45E-02	6.30E-02	2.10E-03	4.69E-04	4.31E-02	7.88E-02	2.66E-03
Uyo	8.00E-04	5.23E-02	7.94E-02	2.90E-03	9.38E-04	6.53E-02	9.92E-02	3.59E-03
Mean	4.00E-04	3.26E-02	4.71E-02	1.64E-03	4.69E-04	3.96E-02	5.89E-02	2.06E-03

3.4 Non-carcinogenic health risks of toxic metals via the consumption of M. oleifera leave extracts

The non-carcinogenic risks associated with the exposure to toxic metals caused by the intake of herbal products prepared from *M. oleifera* leaves obtained from the studied locations were estimated by the calculation of hazard quotient (HQ) and hazard index (HI). The results of HQ and HI of the toxic metals are presented in Table 4.

Table 4: Results of non-carcinogenic risk (hazard Quotient and hazard index) of toxic metals Caused by the intake of *M. oleifera* leaves by the adults and children classes

	Adults					**Children**				
	Cd	Cr	Ni	Pb	HI	Cd	Cr	Ni	Pb	HI
Itu	0.40	9.63	2.18	0.40	12.61	0.47	12.03	2.72	0.51	15.73
Ibiono Ibom	0.30	8.47	1.32	0.25	10.34	0.31	10.57	1.66	0.31	12.85
Ikono	0.10	7.27	1.17	0.15	8.69	0.16	7.30	1.46	0.20	9.12
Ikot Ekpene	0.40	11.50	3.15	0.53	15.58	0.47	14.37	3.94	0.67	19.45
Uyo	0.80	17.43	3.97	0.73	22.93	0.94	21.77	4.96	0.90	28.57
Mean	0.40	10.86	2.36	0.41	14.03	0.47	13.21	2.95	0.52	17.14

The results indicated that the values of HQ of Cd and Pb for both the adults and children groups were less than one in samples from all the locations. However, the HQ values of Cr and Ni in all the samples for the adults and children were higher than one. Accordingly, the children and adults groups consuming herbal products of *M. oleifera* leaves from the studied locations could be more vulnerable to risks associated with high Cr and Ni. Nevertheless, the HQ values of the metals in children were higher those of the adults as reported by Belew *et al*. (2024). Hence, the children class was more exposed to the non-carcinogenic risks associated with exposure to high Cr and Ni via the herbal products of the studied *M. oleifera* leaves than the adults.

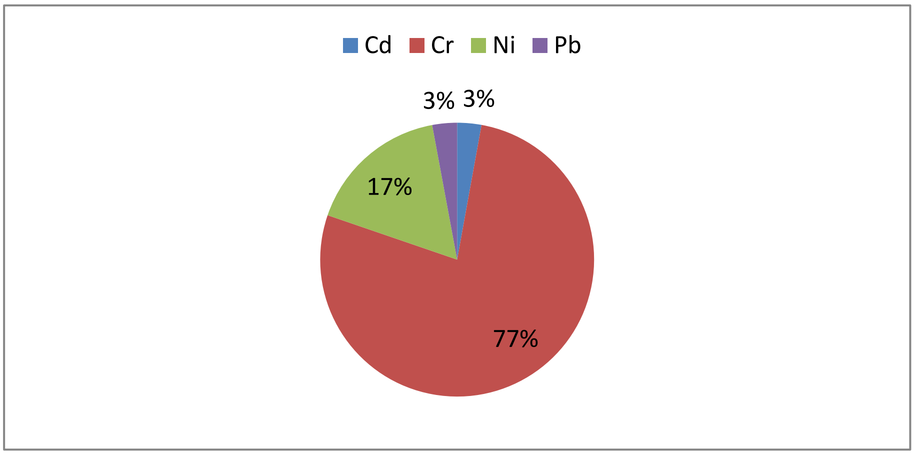

Figure 1: The contributions of HQ of the metals to the HI for the adults and children

The HI values of the toxic metals caused by the intake of herbal products of the studied *M. oleifera* leaves by the adults and children groups are shown in Table 4. The results revealed that the HI values of the metals in samples from the studied locations were higher than one for both the adults and children classes. This is in agreement with the findings by Adeagbo *et al*. (2024) in herbal products. Thus, there is likelihood that samples from all the locations had the potentials of causing non-carcinogenic health risks in the adults and children consumers. The order for the HI values of the metals for the studied locations followed an order of Uyo > Ikot Ekpene > Itu > Ibion Ibom > Ikono. Hence, herbal products prepared from *M. oleifera* leaves from Uyo and Ikot Ekpene could be highly polluted with these toxic metals and may pose adverse health problems on the consumers. Higher HI values of the metals were also recorded for the children class than the adults as documented by Oni *et al*. (2022). Invariably, the children class was more susceptible to the non-carcinogenic risks of these toxic metals via the consumption of herbal products of *M. oleifera* leaves from the studied locations. For the high HI values reported for the adults and children classes, Cr contributed 77%, Ni (17%), while Cd and Pb contributed only 6% for both the adults and children consumers of the studied herbal plant (**Figure 1**). The HI values obtained suggest that the daily intake rate of the toxic metals caused by the consumption of herbal products of *M. oleifera* leaves from the locations examined should be closely checked to forestall their potential negative effects on the consumers (Olokoba, 2024).

3.5 Carcinogenic health risks of toxic metals via the consumption of M. oleifera leave extracts

The cancer risks of the toxic metals caused by the consumption of herbal products of *M. oleifera* leaves from the studied locations were assessed by calculating the cancer risk and total cancer risk (Olaleye *et al*., 2024; Sulaiman *et al*., 2024). The cancer risk (CR) of the toxic metals via the ingestion of herbal products of *M. oleifera* leaves from the studied locations by the adults and children are shown in Table

5. The CR values of the toxic metals due to the ingestion of the studied *M. oleifera* leaves herbal products by the adults varied as follows: 3.80E-05-3.04E-04, 1.09E-02-2.62E-02, 1.96E-02-6.67E-02, and 8.50E-06-2.47E-05 for Cd, Cr, Ni, and Pb, respectively. The CR values of the metals via the ingestion of the studied *M. oleifera* leaves herbal products by the children class ranged as follows: 3.80E-05-3.04E-04, 1.09E-02-2.62E-02, 1.96E-02- 6.67E-02, and 8.50E-06-2.47E-05 for Cd, Cr, Ni, and Pb, respectively.

Table 5: Results of carcinogenic risk and total cancer risk of toxic metals caused by the consumption of *M. oleifera* leaves by the adults and children classes

	Adults					**Children**				
	Cd	Cr	Ni	Pb	TCR	Cd	Cr	Ni	Pb	TCR
Itu	1.52E-04	1.45E-02	3.65E-02	1.36E-05	5.12E-02	1.78E-04	1.81E-02	4.57E-02	1.73E-05	6.40E-02
Ibiono Ibom	1.14E-04	1.27E-02	2.22E-02	8.50E-06	3.50E-02	1.19E-04	1.59E-02	2.77E-02	1.06E-05	4.37E-02
Ikono	3.80E-05	1.09E-02	1.96E-02	5.10E-06	3.05E-02	5.93E-05	1.10E-02	2.44E-02	6.64E-06	3.55E-02
Ikot Ekpene	1.52E-04	1.73E-02	5.29E-02	1.79E-05	7.04E-02	1.78E-04	2.16E-02	6.62E-02	2.26E-05	8.80E-02
Uyo	3.04E-04	2.62E-02	6.67E-02	2.47E-05	9.32E-02	3.56E-04	3.27E-02	8.33E-02	3.05E-05	1.16E-01

The results of CR values for both classes of consumers revealed that, the CR of Cd belongs to the moderate cancer risk class, Cr and Ni belong to the high cancer risk category, while Pb vary between the low and moderate cancer risk classes (NYSDOH, 2007; Olaleye *et al*., 2024). The cancer risk of Cd and Pb for both classes of consumers were within the recommended safe range of 1.00E-06 – 1.00E-04 by USEPA (1989). However, the CR values of Cr and Ni for the adults and children via the ingestion of *M. oleifera* leaves herbal products exceeded the recommended 1.00E-06 – 1.00E-04 by USEPA (1989). Consequently, the consumption of the studied *M. oleifera* leaves herbal products by the adults and children may results severe health risks related to Cr and Ni toxicity. The CR values of the toxic metals via the ingestion of *M. oleifera* leaves herbal products by the adults and children classes followed the decreasing order of Ni > Cr > Cd > Pb. Thus, Ni was the major contributor of cancer risk in the studied *M. oleifera* leaves herbal products as reported by Ssempijja *et al*. (2020) and Udom *et al*. (2022). Nevertheless, the CR values of the metals via the consumption of *M. oleifera* leaves herbal products by the children class were higher than those of the adults group as documented by Sulaiman *et al* (2024).

The total cancer risk (TCR) of the metals caused by the ingestion of the studied *M. oleifera* leaves herbal products by the adults and children are shown in Table 5. The results of TCR of the toxic metals via the ingestion of the studied herbal products by the adults ranged from 3.05E-02 to 9.32E-02. The reported TCR range belongs to the high cancer risk category according to NYSDOH (2007). The TCR values of the carcinogens due to the ingestion of *M. oleifera* leaves herbal products by the children class varied between 3.55E-02 and 1.16E-01. The highest TCR values of the metals due to the consumption of the studied herbal products by the adults and children were reported in the samples from Uyo, while the lowest was obtained in the samples from Ikono. The TCR range of the metals due to the ingestion of the studied herbal products by the children class ranged between high and the very high cancer risk classes (NYSDOH, 2007). The TCR ranges of the metals for the adults and children are also higher than the recommended safe range of 1.00E-6 – 1.00E-4 by USEPA (1989). This is consistent with the findings by Wang *et al*. (2023) on the total cancer risk associated with edible products. Consequently, the consumers of the herbal products made from *M. oleifera* leaves obtained from the studied locations could be exposed to these carcinogens and there could likelihood of developing cancer overtime (Emmanuel *et al*., 2022). The TCR values of the metals due to the ingestion of the studied herbal product by the children class were higher than those of the adults as also reported by Munene *et al*. (2023). Hence, it could be concluded that the children class were more vulnerable to the cancer risk than the adults' class (Ewuola *et al*., 2025; Okoro *et al*., 2025). It was observed that Ni was the major contributor to the overall cancer risk reported followed by Cr. This is consistent with the significant contributions of Ni and Cr to the overall cancer risk reported by Ssempijja *et al*. (2020) and Naseri *et al*. (2021). The total cancer risk of the toxic metals via the ingestion of herbal products of the studied *M. oleifera* leaves by both the adults and children followed a descending trend of Ni > Cr > Cd > Pb. This confirms the high carcinogenicity of Ni and Cr as previously documented in literature (Guo *et al*., 2019; Monga *et al*., 2022). The study has shown that constant ingestion of herbal products prepared from *M. oleifera* leaves from Uyo and Ikot Ekpene could cause adverse health problems to the consumers than samples from other studied locations. This is an indication that consistent human exposure to environment with high levels of commercial and industrial activities may result in cancer risk (Siemiatycki *et al*., 2020; Iwasaki *et al*., 2023).

Conclusion

Following the results obtained from the study, it could be concluded that the leaves of *M. oleifera* from the studied locations were contaminated with Cd and Cr mostly at Uyo and Ikot Ekpene. The daily consumption of *M. oleifera* leaves herbal products could expose the consumers to Cr and Ni toxicity and their related health risks. The adults and young consumers of *M. oleifera* leaves herbal products might be exposed to the non-carcinogenic health problems associated with elevated Cr and Ni. Persistent utilization of herbal products produced from *M. oleifera* leaves from the studied locations might pose the consumers to cancer risks related to Cr and Ni toxicity. The study has also revealed that the children class was more vulnerable to both the carcinogenic and non-carcinogenic risks than the adults. Thus, it could be recommended that herbal plants should be properly screened before consumption. Other toxic substances not examined in this study should be assessed in subsequent studies. Plants used as herbs except *M. oleifera* within and outside the study area should be investigated to establish their suitability or otherwise for human consumption. The studied *M. oleifera* leaves from locations outside the ones investigated in this research should be examined for their levels of toxic substances. Plants within locations with high levels of commercial and industrial activities should not be used as herbs if not properly examined. The processing and utilization of plants and their parts as herbs should be properly monitored and controlled by the agents of governments responsible.

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