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Heavy metal contamination in medicinal plants: assessing carcinogenic and non-carcinogenic health risks

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Abstract
Medicinal plants have played an undeniable role in treating diseases in mankind. However, these plants may be contaminated by toxic substances like heavy metals. Therefore, this study aimed to determine the contamination and health risks (carcinogenic and non-carcinogenic) of heavy metals in economically important medicinal plants mostly in Northern Nigeria. A total of 72 samples from 12 medical plants were purchased and analyzed for heavy metal (Pb, Cr, As, Cd, Zn, Cu, Ni and Fe) contamination using Atomic Absorption Spectrometry (AAS) after wet digestion. The concentrations of the heavy metals (mg·kg^{-1}) were in the range of 1.71–9.01 for Pb, 0.23–2.08 for Cr, 0.00–0.05 for As, 0.00–0.51 for Cd, 5.08–23.67 for Zn, 1.28–13.45 for Cu, 0.96–1.95 for Ni and 20.58–108.50 for Fe. The results revealed that the plant under study contained unsafe levels of Cr and Cd being higher than the World Health Organization (WHO) permissible limits. The hazard index (HI) was < 1, suggesting a probable non-carcinogenic effect. Similarly, the cancer risk (CR) for children and adults was below the (1.0×10^{-4}) acceptable limit, indicating non-probable cancer development for consumers. Based on the studied results, the samples may not pose a carcinogenic health risk. However, there is a need for the regulatory agency to continuously monitor medicine plants available in the markets for the safety of consumers.

Keywords Carcinogenic · Heavy metals · Health risk · Medicinal plants

1 Introduction

Medicinal plants have found wide usage globally and depict an essential group of diverse medicals, and they have been progressively increasing recently [1]. The consumption of plants for medical uses is well-known as the initial form of therapeutic method [2]. Nearly 80% of the population of Africa rely on medicinal plants for their primary healthcare [3, 4]. Medicinal plants are alternative medicine and are chosen for modern synthetic medicine by a foremost part of the world [5]. Approximately 70–80% of the global population is estimated to rely on non-formulaic

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medications, generally obtained from medicinal plants [3, 6]. These plants can take in contaminants through their roots or by deposition of contaminants onto the leaves from the air [7].

The prevailing misconception that medicinal plants originate from natural sources is essentially safe [8]. Conversely, concerns regarding the safety of medicine plants in previous studies indicated that a considerable level of contaminants was present in medicine plants [4]. The occurrences of toxicity and adverse effects associated with medicinal plants in various parts of the globe have been reported by Ernst, [8]. These toxicities could be a result of the contamination or mineral contents in various plants [9]. Among these contaminants, heavy metals could have a detrimental effect on living organisms [10]. The increase in heavy metal emissions into the environment is a global concern due to anthropogenic activities such as industrial production and agrochemicals [7].

Heavy metal contamination in medicinal plants could be a result of contaminated environment in which the plants were grown [11]. The possibility of heavy metals being transferred to humans in the route uses of plants grown in contaminated areas is a concern for medicinal plants [12]. The WHO perseveres in ensuring the quality of plant products, particularly the analytical control of heavy metals in medicinal plants [13, 14]. The medicinal plants contaminated by these metals can pose health implications to humans [15]. It's reported that prolonged exposure to Cd causes hypertension, lung and prostate cancer, bone and kidney diseases, and emphysema [16–19]. Copper may cause metabolic disorders, kidney and liver damage, anemia and abdominal pain [19, 20]. Lead is reported to cause detrimental effects on the cardiovascular, nervous systems, and renal failure disrupts reproductive systems [19, 21, 22]. This necessitated the WHO and other regulatory agencies to introduce guidelines for the permissible limits of heavy metals in consumable medicinal plants [23].

The incidences of heavy metals have been reported in Nigeria and different parts of the globe; these include almost high concentrations of Zn, Ni, Pb, Cr, Cd, and Cu in medicinal plants, etc. [14, 19, 23–25]. Despite numerous reports on the occurrence of heavy metals in plants, the use of medicinal plants keeps increasing and becoming widely used in Northern Nigeria [15]. Moreover, information on the safety of economically important medicinal plants in Nigeria is limited. Thus, there is a need to determine the heavy metal contamination in medicinal plants and estimate the health risks related to medicinal plant consumption. This study determines the contamination of heavy metals (Pb, Cr, As, Cd, Zn, Cu and Ni) and evaluates the health risks (carcinogenic and non-carcinogenic) in commonly used medicinal plants.

2 Materials and methods

2.1 Samples collection

A total of 72 medicinal plant samples were purchased from the local markets in six cities in Nigeria, namely, Kaduna, Kano, Jos, Lokoja, Gombe, and Maiduguri. The locations are shown (Fig. S1). Sampling locations were selected based on areas with a high production of medicinal plants. A mini survey was conducted before the study among some randomly selected herbal users and vendors to determine the most frequently consumed medicinal plants by the customers [26].

2.2 Samples digestion

All the reagents used were of analytical grade: perchloric acid ($HClO_4$) 70% 1.33 Merck, Darmstadt, Germany and nitric acid (HNO_3) 65%, 1.40 Merck, Darmstadt, Germany. The sample digestion was performed with (HNO_3:$HClO_4$) at a ratio of 1:4, as reported elsewhere [24]. In brief, the plant sample (1.0 g) was transferred into Teflon cups. About (20 mL) of HNO_3 was added and stood for one hour. Approximately 70% (5 mL) of $HClO_4$ was heated for 30 min and then added to the mixture. The mixture was then heated in a fume cupboard for 15 min to reduce the volume of the solution to 10 mL, filtered with a Whatman filter paper (no. 42) into a 50 mL volumetric flask, and marked with deionized water. Blanks were also digested in the same way as samples.

2.3 Quality control

The reagents used were of analytical grade. The detection limits were 0.010, 0.008, 0.008, 0.001, 0.007 0.004, and 0.008, $mg·L^{-1}$ for Pb, Cr, As, Zn, Cd, Cu, Ni, and Fe, respectively. The instrument (AAS model AA320N, Wincom Coy Ltd., China) was calibrated using GFS Fisher's standard reference stock solutions containing 1000 $mg·L^{-1}$ metals under study, with concentrations in the range of 0.5–20 mg·L^{-1} [24]. The limits of detection (LOD) for metals were evaluated using LOD = 3.3 standard deviation $\frac{s(SD)}{b}$. The operating conditions are presented in Table S1. All sample analyses were performed in triplicate, and a recovery analysis was carried out. This was done by determining the concentrations of the metals in triplicate samples of un-spiked and spiked samples, and the mean recovery percentages of the metals ranging from 89 to 113% were obtained. The percentage recoveries were determined using the following equation.

$$\text{Percentage recovery} = \frac{\text{conc. of spiked sample} - \text{conc. of un} - \text{spiked sample}}{\text{spiking conc.}} \times 100 \quad (1)$$

2.4 Statistical analysis

The obtained data from chemical analysis was subjected to simple descriptive statistics (mean and standard deviation), and the mean values obtained were compared with the standard permissible limit. The analysis was performed using (SPSS) version 25. The data generated were used to estimate potential health risks [27, 28].

2.5 Health risk assessment

Health risk assessment is a process evaluating data linked to human health [29], and it can provide informative outcomes concerning exposure to contaminants [18, 30, 31]. For the assessment of health risks for both children and adults, estimated daily intake, non-carcinogenic and carcinogenic risks were employed. The parameters used and assumptions for the assessment are presented in Table S2.

2.5.1 Estimated daily intake (EDI)

The average estimated daily intake (EDI) of the metals depends on both the metal concentration in plants and the amount of consumption of the respective plants. The (EDI) of metals was estimated using the following expression [4, 7, 25, 28].

$$EDI = \frac{C \times F_{IR}}{BW} \quad (2)$$

2.5.2 Non-carcinogenic risk assessment

The non-carcinogenic risk was evaluated by comparing an exposure level over a specified period with a reference dose derived for a similar exposure period. The non-carcinogenic outcome of metals in the plant was evaluated as hazard quotient (HQ) using the following expression [32].

$$HQ = \frac{C \times IR \times EF \times ED}{BW \times AT_{nc} \times RfD} \quad (3)$$

The hazard index (HI) is the $\sum$ HQ of all metals under study. If HI > 1 entail that non-carcinogenic effects may occur [28].

$$HI = HQ_1 + HQ_2 + \ldots + HQ_n \quad (4)$$

2.5.3 Carcinogenic risk assessment

Carcinogenic risk was evaluated using the below expression [4].

$$CR = \frac{C \times IR \times EF \times ED \times SF}{BW \times AT_c} \quad (5)$$

The CR value below (1.0×10^{-6}–1.0×10^{-4}), is on average acceptable or tolerable level, but above indicates probable cancer development [4, 15, 26].

3 Results and discussion

3.1 Heavy metals concentrations in medicinal plants

The mean concentrations of heavy metals in medicinal plant samples from northern Nigeria are presented in Table 1. The mean concentration of Pb ranges from 1.71 to 9.01 mg·kg^{-1}. Lead is an extensively used metal in various applications in industries and is also known as being environmental contaminant [33]. Moreover, lead exposure is highly detrimental to humans with typical symptoms of hypertension, convulsions, chronic nephritis, central nervous system disorders and anemia [34, 35], and early childhood exposure to lead can cause learning deficits, sound effects and low cognitive advancement [36]. The permissible limit of Pb (10 mg·kg^{-1}) is set by the WHO in medicine plants [37]. All the samples under study had concentrations of Pb below the permissible limits set by the WHO. The results obtained in this study exceed the previous values reported (0.25–2.64 mg·kg^{-1}) in India [38], and 0.41–15 mg·kg^{-1} in Kenya [36]. However, the results obtained in this study were lower than the values 1.31–16.24 and 3.06–41.70, reported in similar studies in the Eastern Mediterranean of Turkey [39] and Islamabad, Pakistan [40], respectively.

The concentration of Cr in medicinal plants ranges from 0.23 to 2.08 mg·kg^{-1}. It's reported that Cr regulates nucleic acids, lipoprotein metabolism, carbohydrates, and also enhances insulin action, hence playing a role in glucose metabolism [5, 41, 42], however, its elevated intake causes cardiovascular disorders, reduces blood glucose, and alimentary disorders [23], whereas chronic injection of Cr leads to gastrointestinal cancer [43, 44]. The permissible limit of Cr is 2.0 mg·kg^{-1} set by WHO for plant materials [37, 45]. A comparison with the permissible limit the results of Cr obtained exceeded the limit by 0.50%, and 3.85% in *Annona squamosa* and *Punica granatum,* respectively. However, the values of 0.73–4.79 mg·kg^{-1} reported in a similar study from Nigeria [2] and 0.57 to 2.04 mg·kg^{-1} from Nigeria [36] were above the results obtained in this study.

The concentrations of As in the plant samples ranged from < 0.008 to 0.04 mg·kg^{-1}. Arsenic plays no physiological role and is toxic to the human body. Acute toxicity of As is associated with vomiting, peripheral neuropathy and gastrointestinal symptoms. On the other hand, chronic toxicity could result in the carcinogenesis of organs in the body [5, 7, 46]. The permissible limit set by Malaysia, Canada, and Singapore for As in medicinal plants is 5 mg·kg^{-1} [37]. The values of As obtained in this study were lower than the permissible limit. Similarly, the values of As reported in plant samples in Sanandaj, India, Kurdistan, Iran, Qian'an, China, and Pretoria, South Africa were within the permissible limits [5, 7, 25, 47].

Cadmium causes tenacious poisoning and acute adverse health effects on the kidney, liver, vascular and immune systems [11, 48, 49]. The concentration of Cd ranged from < 0.001 to 0.51 mg·kg^{-1}. The permissible limit of Cd was (0.3 mg·kg^{-1}) set by WHO, China, and Thailand in medicinal plants [23]. Cadmium was above the WHO permissible limit by 41.18%, 3.23%, and 11.76% in *Hibiscus schizopetalus*, *Punica granatum* and *Citrus auratium,* respectively. Reports have shown that cadmium accumulates mostly in leaves and root plants [50, 51]. The result of Cd obtained was comparable to values reported in a similar study, in Nigeria [2], and the United Arab Emirates [1]. Similarly, high Cd concentrations above the values obtained in this study have been reported in medicinal plants from Kumasi, Ghana [52] with cadmium

Table 1 Descriptive statistics of heavy metals concentration (mg·kg-1) in the medicinal plants

S/N	Scientific name	Pb	Cr	As	Cd	Zn	Cu	Ni	Fe
1	*Hibiscus schizopetalus*	1.71 ± 0.08	1.96 ± 0.88	< 0.008	0.51 ± 0.69	19.67 ± 1.19	5.09 ± 0.62	1.95 ± 0.08	86.16 ± 10.11
2	*Cympopogon citratus*	2.24 ± 0.21	0.99 ± 0.01	0.01 ± 0.01	0.25 ± 0.07	5.08 ± 2.47	6.27 ± 0.37	1.01 ± 0.04	81.78 ± 1.77
3	*Guiera senegalensis*	3.32 ± 0.30	0.23 ± 0.18	0.02 ± 0.01	0.06 ± 0.01	6.42 ± 0.54	10.77 ± 0.33	0.96 ± 0.43	72.13 ± 11.88
4	*Syzygium aromatacum*	3.32 ± 0.30	1.17 ± 0.26	< 0.008	0.11 ± 0.04	11.29 ± 1.07	12.93 ± 0.60	0.97 ± 0.33	71.86 ± 1.73
5	*Annona squamosa*	4.80 ± 1.09	2.01 ± 2.53	0.02 ± 0.01	0.14 ± 0.08	20.11 ± 0.31	5.71 ± 3.01	1.64 ± 0.36	102.83 ± 3.85
6	*Erythria senegalensis*	3.68 ± 1.88	1.21 ± 0.25	< 0.008	0.15 ± 0.07	18.45 ± 0.11	13.45 ± 5.06	1.81 ± 0.71	97.52 ± 6.24
7	*Nerium oleander*	4.87 ± 0.69	1.27 ± 0.37	< 0.008	< 0.001	21.64 ± 0.16	2.96 ± 0.28	1.81 ± 0.39	61.30 ± 6.41
8	*Punica* granatum	2.45 ± 0.19	2.08 ± 0.35	0.02 ± 0.01	0.31 ± 0.16	23.67 ± 9.39	1.45 ± 0.14	1.91 ± 0.14	86.78 ± 4.60
9	*Adhatoda vasica*	8.71 ± 0.46	0.65 ± 0.47	0.03 ± 0.03	0.02 ± 0.01	20.52 ± 0.69	12.70 ± 5.18	1.42 ± 0.62	102.92 ± 2.95
10	*Ficus thonnigi*	9.01 ± 1.84	0.43 ± 0.14	0.05 ± 0.02	< 0.001	15.93 ± 0.83	1.28 ± 0.35	1.28 ± 0.35	103.50 ± 6.80
11	*Cassia singueana*	3.13 ± 0.28	1.23 ± 0.28	0.05 ± 0.04	0.06 ± 0.04	16.43 ± 0.14	4.41 ± 0.82	1.52 ± 0.69	20.58 ± 3.58
12	*Citrus auratium*	4.79 ± 0.64	0.95 ± 0.19	< 0.008	0.34 ± 0.21	10.91 ± 1.39	11.20 ± 0.95	1.59 ± 0.40	30.29 ± 3.17

levels ranging from 0.15 to 0.53 mg·kg^{-1}, 0.15–0.73 mg·kg^{-1}, and 0.39–1.58 mg·kg^{-1} from Poland [53] and Ukraine [51]. The findings of this study and those of other cited studies suggest that Cd consternation could be a general issue and needed to be investigated [52].

The Zn concentration in the medicinal plants ranges from 5.08 to 23.67 mg·kg^{-1}. Zinc is an essential element in the human body [5, 34, 54]. It manages the contractibility of muscles and also acts as a co-factor for enzymes in the body [45, 54]. Nevertheless, high zinc intake above the permissible limit can cause toxic effects on blood lipoprotein levels, and the immune system [26, 30]. Prolonged intake can lead to decreased body weight, skin irritation, heart and liver damage [55]. Bhavani et al. reported a level of zinc ranging from 0.21 to 1.07 mg·kg^{-1} [56], which is below the values obtained in the study. Kulhari et al. reported zinc levels ranging from 2.42 to 8.93 mg·kg^{-1} [57] and (12.65–146.67 mg·kg^{-1}) [1], which are higher than the values obtained in the study. Conversely, the level of Zn obtained in this study was below the permissible limit of 100 mg·kg^{-1} [52, 58].

The Cu concentration ranges from 1.28 to 13.45 mg·kg^{-1} in the studied samples. Copper is an essential element in the human system, it regulates oxidation–reduction reactions, energy production, neurotransmitter synthesis, and iron metabolism [1, 59–61]. However, a high intake of copper can cause vomiting, dermatitis, abdominal pain, diarrhea, and liver damage [4, 62–64]. The permissible limit Cu for medicinal plants has not yet been established by WHO. However, the oral RfD limits for medicinal plants set by China and Singapore are 20 and 150 mg·kg^{-1}, respectively [19]. The level of Cu obtained was below the permissible limits set by China and Singapore for all the studied samples. The result of this study was in line with values previously reported from Turkey [64] and Pakistan [65], but higher than values of 0.00–2.54 mg·kg^{-1} reported in herbal medicine [63]. Maobe et al. also reported a level of copper ranging from 0.31 to 1.44 mg·kg^{-1} in medicinal plants [36], which was higher than the value obtained in this study.

The Ni concentration in the samples ranges from 0.96 to 1.95 mg·kg^{-1}. Nickel is vital for Fe metabolism, but toxic at elevated concentrations. Elevated exposure to Ni has been associated with an enlarged risk of high blood pressure, neurological deficit, cardiovascular disease, developmental deficits in childhood and lung cancer [44, 63, 66–68]. The toxicity of Ni in humans is infrequent as a result of low absorption in humans [69]. The WHO permissible limit of Ni for herbs is yet to be established. The level of Ni in this study was below the level reported in Kenya, ranging from 0.09 to 1.6 mg·kg^{-1} [65] and 8.81 to 10.25 mg·kg^{-1} from Baghdad, Iraq [69].

The Fe concentration in the medicinal plants ranges from 20.58 to 102.50 mg·kg^{-1}. The Fe values obtained were above the 15 mg·kg^{-1} permissible limit [52, 58] in all plant samples. The elevated level of Fe in this study might be as a result of where the plants are cultivated, and uptake from the soil could also contribute to appreciable levels. Iron is a vital element and has a considerable role in the metabolism of organisms [7]. However, iron toxicity has a detrimental effect on diverse metabolic functions and cardiovascular systems [70], and causes gastrointestinal disorders such as cramps and bleeding [7]. The values obtained in this study conformed to values reported in a similar study in the Eastern Mediterranean of Turkey, which ranged from 20.71 to 1276.78 mg·kg^{-1} [39], but were higher than reported values of 26.96–1046.25 µg·g^{-1}, 0.97–6.07 mg·kg^{-1}, 11.89–25.30 mg·kg^{-1}, and 2.51–7.60 mg·kg^{-1} from Egypt [71], Kisii Region, Southwest Kenya [36], Northwestern India [57], and Kumasi, Ghana [52].

3.2 Health risk assessment

Daily Intake: The EDI of Pb, Cr, As, Cd, Zn, Cu, Ni, and Fe was evaluated based on the concentration of each metal in the plants as presented in Table S3. The assessment included both children and adults. The incline order of daily intake is as follows: Fe > Zn > Cu > Pb > Cr > Ni > Cd > As. Iron recorded has the highest daily intake of among the metals. Similarly, Kohzadi et al. reported that Fe has the highest EDI among the studied metals [7]. The values of EDI obtained in this study were lower than the RfD values. This suggests that the consumption of the studied medicinal plant may pose no health risk to the consumers of this product.

Non-carcinogenic Risk: The HQs and HIs of metals in medicinal plants are summarized in Table 2. The non-carcinogenic risk of medicinal plants in children and adults was estimated based on HQ. The HQ values of each metal in the medicinal plants were below one in all samples. The values of HI ranged from 4.03×10^{-03}—5.20×10^{-02} in the studied samples. HI values in the studied samples were < 1, indicating no possible non-carcinogenic adverse health risks. Similarly, Meng et al. and Barbes et al. also reported HI < 1 in the medicinal from Qian'an, China [47] and from the South-eastern Region, Romania [72], respectively. This observation indicates the consumption of studied medicinal plants might not pose a non-carcinogenic risk to the public as the HI value (< 1). It has been reported that the value of HI < 1, entails that the exposed population is likely not to experience adverse health effects [49, 73, 74].

Table 2 Hazard quotient (HQ) and hazard index (HI) of heavy metals in medicinal plants

Names of the plants	Age group	HQ								HI
		Pb	Cr	As	Cd	Zn	Cu	Ni	Fe	
Hibiscus schizopetalus	Children	7.13×10^{-03}	7.57×10^{-03}	–	8.50×10^{-03}	1.09×10^{-03}	2.12×10^{-03}	1.63×10^{-03}	2.06×10^{-03}	3.01×10^{-02}
	Adults	5.35×10^{-03}	5.17×10^{-03}	–	6.38×10^{-03}	8.20×10^{-04}	1.59×10^{-03}	1.22×10^{-03}	1.54×10^{-03}	2.51×10^{-02}
Cympopogon citrates	Children	9.33×10^{-03}	5.50×10^{-03}	5.57×10^{-04}	4.17×10^{-03}	2.81×10^{-04}	2.63×10^{-03}	8.40×10^{-04}	1.94×10^{-03}	2.78×10^{-02}
	Adults	7.00×10^{-03}	4.14×10^{-03}	4.17×10^{-04}	3.13×10^{-03}	2.12×10^{-04}	1.69×10^{-03}	6.30×10^{-04}	1.46×10^{-03}	1.89×10^{-02}
Guiera senegalensis	Children	1.38×10^{-02}	1.28×10^{-03}	1.11×10^{-03}	1.00×10^{-03}	3.57×10^{-04}	4.50×10^{-03}	8.00×10^{-04}	1.71×10^{-03}	2.46×10^{-02}
	Adults	1.04×10^{-02}	9.60×10^{-04}	8.33×10^{-04}	7.50×10^{-04}	3.68×10^{-04}	3.38×10^{-03}	6.00×10^{-04}	1.29×10^{-03}	2.11×10^{-02}
Syzygium aromatacum	Children	2.00×10^{-02}	6.50×10^{-03}	–	1.83×10^{-03}	6.27×10^{-04}	5.40×10^{-03}	8.10×10^{-04}	1.71×10^{-03}	3.63×10^{-02}
	Adults	1.50×10^{-02}	4.87×10^{-03}	–	1.38×10^{-03}	1.70×10^{-04}	4.05×10^{-03}	6.05×10^{-04}	1.28×10^{-03}	2.74×10^{-02}
Annona squamosa	Children	7.93×10^{-03}	1.12×10^{-02}	1.11×10^{-03}	2.33×10^{-03}	1.12×10^{-03}	2.38×10^{-03}	1.37×10^{-03}	2.44×10^{-03}	2.88×10^{-02}
	Adults	2.46×10^{-02}	8.37×10^{-03}	8.33×10^{-04}	1.75×10^{-03}	8.37×10^{-04}	1.79×10^{-04}	1.03×10^{-04}	1.84×10^{-03}	4.03×10^{-03}
Erythria senegalensis	Children	1.53×10^{-02}	6.73×10^{-03}	–	2.50×10^{-03}	1.03×10^{-03}	5.60×10^{-03}	1.51×10^{-03}	2.33×10^{-03}	3.46×10^{-02}
	Adults	1.15×10^{-02}	5.03×10^{-03}	–	1.88×10^{-03}	1.70×10^{-04}	4.20×10^{-03}	1.13×10^{-03}	1.74×10^{-03}	2.64×10^{-02}
Nerium oleander	Children	2.03×10^{-02}	7.07×10^{-03}	–	–	1.20×10^{-03}	$1\ 23\times10^{-03}$	1.51×10^{-03}	1.49×10^{-03}	3.28×10^{-02}
	Adults	1.52×10^{-02}	5.27×10^{-03}	–	–	9.03×10^{-04}	9.25×10^{-04}	1.13×10^{-03}	1.09×10^{-03}	2.45×10^{-02}
Punica granatum	Children	1.02×10^{-02}	1.16×10^{-03}	1.11×10^{-03}	5.17×10^{-03}	1.32×10^{-03}	6.05×10^{-04}	1.58×10^{-03}	2.07×10^{-03}	3.37×10^{-02}
	Adults	7.65×10^{-03}	8.67×10^{-03}	8.33×10^{-04}	3.88×10^{-03}	9.83×10^{-03}	4.53×10^{-04}	1.20×10^{-03}	1.54×10^{-03}	2.52×10^{-02}
Adhatoda vasica	Children	3.63×10^{-02}	3.60×10^{-03}	1.67×10^{-03}	3.33×10^{-04}	1.14×10^{-03}	5.30×10^{-03}	1.19×10^{-03}	2.46×10^{-03}	5.20×10^{-02}
	Adults	2.73×10^{-02}	2.71×10^{-03}	1.25×10^{-04}	2.50×10^{-04}	8.53×10^{-04}	3.98×10^{-03}	8.90×10^{-04}	1.84×10^{-03}	3.91×10^{-02}
Ficus thonnigi	Children	3.75×10^{-02}	2.39×10^{-03}	1.11×10^{-03}	–	8.87×10^{-04}	5.33×10^{-04}	1.07×10^{-03}	2.47×10^{-03}	4.60×10^{-02}
	Adults	2.83×10^{-02}	1.79×10^{-03}	8.33×10^{-04}	–	6.63×10^{-04}	4.00×10^{-04}	8.00×10^{-04}	1.84×10^{-03}	3.46×10^{-02}
Cassia singueana	Children	1.31×10^{-02}	6.83×10^{-03}	2.22×10^{-03}	6.67×10^{-04}	9.13×10^{-04}	1.84×10^{-03}	1.27×10^{-03}	4.90×10^{-03}	2.61×10^{-02}
	Adults	8.05×10^{-03}	5.13×10^{-03}	1.67×10^{-03}	5.00×10^{-04}	6.83×10^{-04}	4.75×10^{-03}	9.50×10^{-03}	3.67×10^{-03}	3.07×10^{-02}
Citrus auratium	Children	198×10^{-02}	5.27×10^{-03}	–	5.67×10^{-03}	6.07×10^{-04}	4.68×10^{-03}	1.33×10^{-03}	7.21×10^{-03}	3.68×10^{-02}
	Adults	1.52×10^{-02}	3.97×10^{-03}	–	4.25×10^{-03}	4.53×10^{-03}	4.53×10^{-04}	9.95×10^{-03}	5.41×10^{-03}	2.56×10^{-02}

Carcinogenic Risk: The estimated CR of the studied metals for children and adults is presented in Table 3. All values ranged from 9.27×10^{-8} to 1.48×10^{-5} for children and 8.13×10^{-8}–4.74×10^{-6} for adults. The CR studied metals for children and adults lower the threshold value from 1×10^{-6} to 1×10^{-4} signifying non-possible cancer development. The values of CR obtained in this study are comparable to trends reported in previous studies [4, 72].

4 Conclusion

This study determined the contamination and assessed the non-carcinogenic and carcinogenic health risks of heavy metals in medicinal plants from Northern Nigeria. The results revealed that the studied metals in the medicinal plants were below the permissible limit for the consumed medicinal plants set by the WHO, except for Cr and Cd in some samples, while Fe in all the studied samples. The health risk assessment in the study indicated that the consumption of these plants might not pose a non-carcinogenic risk to local consumers, with HI values < 1 in the studied samples. Similarly, CR for both children and adults was below the threshold value of 1×10^{-6}–1×10^{-4}, indicating non-probable cancer development for consumers. However, there is still a need for constant monitoring of medicinal plants sold in the market to ensure that wholesome and safe medicinal plants are sold for human consumption.

Table 3 Cancer risk (CR) of heavy metals in medicinal plants

Name of the plants	Age group	CR				
		Pb	Cr	As	Cd	Ni
Hibiscus schizopetalus	Children	6.49×10^{-08}	4.38×10^{-06}	–	8.66×10^{-07}	1.48×10^{-05}
	Adults	2.07×10^{-08}	1.40×10^{-06}	–	2.77×10^{-07}	4.74×10^{-06}
Cympopogon citrates	Children	8.50×10^{-08}	2.21×10^{-06}	6.69×10^{-08}	4.26×10^{-07}	7.67×10^{-06}
	Adults	2.72×10^{-08}	7.05×10^{-07}	2.15×10^{-08}	1.36×10^{-07}	2.33×10^{-06}
Guiera senegalensis	Children	1.26×10^{-07}	5.15×10^{-07}	1.34×10^{-07}	1.02×10^{-07}	7.29×10^{-06}
	Adults	4.03×10^{-08}	1.65×10^{-07}	4.29×10^{-03}	3.26×10^{-08}	2.33×10^{-06}
Syzygium aromatacum	Children	1.82×10^{-07}	2.61×10^{-06}	–	1.87×10^{-07}	7.36×10^{-06}
	Adults	5.83×10^{-08}	8.35×10^{-07}	–	5.97×10^{-08}	2.36×10^{-06}
Annona squamosa	Children	7.21×10^{-08}	4.49×10^{-06}	4.29×10^{-03}	2.38×10^{-07}	1.24×10^{-05}
	Adults	2.30×10^{-09}	1.44×10^{-06}	1.34×10^{-07}	7.60×10^{-03}	3.98×10^{-06}
Erythria senegalensis	Children	1.39×10^{-07}	2.70×10^{-06}	–	2.55×10^{-03}	1.37×10^{-05}
	Adults	4.49×10^{-08}	8.65×10^{-07}	–	8.13×10^{-03}	4.40×10^{-06}
Nerium oleander	Children	1.84×10^{-07}	2.84×10^{-06}	–	–	1.37×10^{-05}
	Adults	5.92×10^{-08}	9.05×10^{-07}	–	–	4.40×10^{-06}
Punica granatum	Children	9.27×10^{-08}	4.65×10^{-06}	4.29×10^{-03}	5.24×10^{-07}	1.45×10^{-05}
	Adults	2.98×10^{-08}	1.49×10^{-06}	1.34×10^{-07}	1.68×10^{-07}	4.64×10^{-06}
Adhatoda vasica	Children	3.31×10^{-07}	1.45×10^{-06}	2.01×10^{-07}	3.39×10^{-08}	1.08×10^{-05}
	Adults	1.05×10^{-07}	4.65×10^{-07}	6.44×10^{-08}	1.09×10^{-08}	3.45×10^{-06}
Ficus thonnigi	Children	3.42×10^{-07}	9.60×10^{-03}	3.35×10^{-07}	–	9.71×10^{-06}
	Adults	1.10×10^{-07}	3.07×10^{-07}	1.07×10^{-07}	–	3.11×10^{-06}
Cassia singueana	Children	1.19×10^{-07}	2.75×10^{-06}	3.35×10^{-07}	6.80×10^{-08}	3.69×10^{-06}
	Adults	3.80×10^{-08}	8.90×10^{-07}	1.07×10^{-07}	2.17×10^{-08}	1.15×10^{-06}
Citrus auratium	Children	1.82×10^{-07}	2.12×10^{-06}	–	1.85×10^{-07}	1.21×10^{-05}
	Adults	5.81×10^{-08}	6.80×10^{-07}	–	5.78×10^{-07}	3.86×10^{-06}

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Availability of data The data supporting the findings of this study are available from the corresponding author at reasonable request.

Declarations

Competing interests The authors declare no conflicts of interest.

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