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Heavy metal content of selected readily available commercial medicinal plants in Jos Plateau and their potential human health risk

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Abstract

This study determined the level of heavy metal contamination in selected medicinal plants sold in Jos Metropolis and assesses the health risks associated with their consumption. Five commonly used medicinal plants (*Annona senegalensis, Mangifera indica, Psidium guajava, Vernonia amygdalina, and Vitex donniana*) were analyzed for the presence of arsenic (As), cadmium (Cd), copper (Cu), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) respectively using inductively coupled plasma mass spectrometry (ICP-MS). The result showed that the concentrations of As, Cd, Hg, Mn, and Zn in all the plants and Pb levels in two plants, *V. amygdalina* and *V. donniana* were significantly higher than the WHO recommended limits, indicating a potential health hazard. The calculated values of the hazard quotient (HQ), hazard index (HI), and cancer risk (CR) for the heavy metals exceed the acceptable levels for both adults and children, suggesting a high vulnerability to heavy metal toxicity and carcinogenicity with the highest and lowest HI values obtained by *V. amygdalina* (47.3) for children and *P. guajava* (9.63) for adults. The CR associated with Ni and As for adults and children indicated high carcinogenic risk. In contrast, the CR values for Cd and Pb for adults and children indicated a moderate CR. Based on the results and risk assessment provided by this study, the consumption of medicinal plants suggests a high vulnerability to heavy metal toxicity. It can be concluded that the consumption of medicinal plants poses a serious threat to human health due to heavy metal contamination and calls for implementing preventive measures and risk communication among users of these products to safeguard the health of the residents.

Keywords: Environmental pollution; Heavy metals; Medicinal plants; Health risk; Jos metropolis

1. Introduction

The Sustainable Development Goal (SDG) target 3.4 is to ensure by the year 2030, every nation can reduce premature mortality from non-communicable diseases (NCDs) by one-third through prevention, treatment, and promotion of mental health and well-being. Based on 2019 estimate of global mortality data, around three-quarters of the 20.4 premature death among individuals between ages 30-70 years is associated to NCD [1], and cancer is responsible for high risk of premature death among an active population where environmental exposure to toxic compounds is considered a major source of these diseases and reducing the exposure to these harmful elements in the environment and NCD burden is a prerequisite for accelerating sustainable development [2].

The general perception that herbal medicines or plant-derived products are natural, safe, and non-toxic relative to orthodox medicine, which is most often from artificial products, has led to increased use of medicinal plants and herbal preparations in the treatment of illness across the globe [3,4]. This may not necessarily be true, especially where the plant products used in the preparation of the herbal medicines are contaminated. Metals such as Copper (Cu), iron (Fe),

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manganese (Mn), nickel (Ni), and zinc (Zn) are required by plants in trace quantities, and in high amounts, they may become extremely toxic and become a major pathway of human exposure [5,6].

In contrast to organic pollutants, heavy metals are not degradable; as such, they persist in the environment for years; well after point, sources of the pollution have been remediated, and studies have shown that where they are present in the environment, plants grown on such contaminated soil often take up and accumulate these heavy metals into their tissues [7,8]. Consumption of these herbal medicines contaminated with heavy metals constitutes a potential health hazard for the consumer due to their toxic, carcinogenic, and mutagenic effects [9,10]. Hence, the contamination of herbal products with toxic and essential heavy metals depends on many factors, including the soil conditions in which the plant material grows [11].

In Africa, most of the plants used to treat diseases are gotten wild by the local herbal practitioners without discriminating on the environment in which the plant is growing; thus, herbs could serve as a potential source of human exposure to heavy metals for consumers [12]. On the Jos Plateau, medicinal plants are the most accessible and affordable health resources available to the people living in rural areas and some in urban areas. Traditional healers often prescribe them for the treatment of various diseases. Furthermore, the WHO reports that about 65 % of the world's population relies on traditional medicine on a day-to-day basis as their primary form of healthcare [13]. Plants used in the treatment of diseases must be properly screened for possible contaminants to safeguard the public from the potential dangers of contamination of these plant-derived products with toxicants, including heavy metals. The presence of toxic pollutants in medicinal plants can counteract their beneficial effects, as several adverse effects of heavy metals on human health have been known for a long time[14].

The most important sources of heavy metal contamination in the environment are generally from anthropogenic activities, including mining, smelting procedures, chemical industry, traffic, agriculture, industrial effluents, etc. [8,15]. Heavy metals can accumulate in the food chains and present toxic effects to humans and other living beings, even at very low concentrations [8,15–17]. The present study aims to determine the heavy metal concentration in selected medicinal plants commonly sold in Jos metropolis and their potential health risk.

2. Material and methods

2.1. Study Area

Jos Metropolis is located in Plateau State, North Central part of Nigeria, and is host to active tin mining activities dating back to the Colonial rule in Nigeria. Most mine sites are not remediated after mining activities, both past and present, thereby presenting environmental and health threats to the host community. More importantly, many medicinal plants used for the treatment of certain diseases are sourced from the wild grown in the area and sold unregulated. Hence, there is a need to assess the potential public health effects of medicinal plant use among the population.

2.2. Collection of Medicinal Plants Samples

Leaf samples of five selected medicinal plants (*Annona senegalensis, Psidium guajava, Mangifera indica, Vernonia amygdalina,* and *Vitex donniana*) were sourced commercially from traditional healers operating in the Jos metropolis. Each sample was purchased separately from different selling points within the Jos metropolis. Six purchases were made within a period of two months (February to March) in 2019. Each sample was packed in sterilised polyethylene bags and transported to the laboratory. Before sample analysis, each was botanically identified to species level at the University of Jos plant science laboratory. Approximately 20 g of each leaf sample was thoroughly washed with deionized water to remove dust particles and subsequently oven-dried to constant weight at 40 °C. Each dried sample was ground to powder using a pestle and mortar and sieved through a 1.5-mm sieve to ensure uniform distribution of metals in the samples. For further analysis, the powdered samples were kept in clean polyethylene bags at room temperature, pending analysis.

2.3. Digestion of Medicinal Plants Samples

Plant samples and certified reference material (STD CDV-1) were digested according to VG 101 analytical package method and protocol described by Bureau Veritas Mineral Laboratories (former ACME Analytical Laboratories), Vancouver, Canada [18].1.0 g of each previously pulverized plant sample was cold leached with 2 ml nitric acid (HNO_3) (Merck, Darmstadt, Germany) and subsequently digested in a hot water bath for 1 hour. After cooling to room temperature, 6 ml of a modified Aqua Regia solution of equal parts 2:2:2 of concentrated HCl, HNO_3, and DI H_2O was added to each sample and allowed to leach on a heating block of hot water bath at 95 °C for 1 hour. Samples were later made up to 20 ml mark with dilute HCl (Merck, Darmstadt, Germany) and filtered [18].

2.4. Measurement of Heavy Metals

The concentrations of the target heavy metals in the digested samples and certified reference material (plant material) used were determined at Bureau Veritas Mineral Laboratories (former ACME Analytical Laboratories), Vancouver, Canada, according to the VG101 analytical package (protocol for Ultra Trace ICP-MS chemical analysis of multi-acid digested samples) using NexION300 Inductively Coupled Plasma Mass Spectrometry (ICP- MS).

2.5. Quality Assurance and Quality Control

Appropriate quality assurance procedures and precautions were carried out to ensure the reliability of the results. Deionized water was used throughout the study. The glassware was properly cleaned, and the reagents used were of analytical grade. Reagent blank determinations were used to correct the instrument readings. For validation of the analytical procedure, samples were analyzed with Certified Reference Material (CRM) (STD CDV-1). The quality control was expressed in terms of mean recovery percentages, calculated as the ratio between the measured and the expected values for the CRM STD CDV-1 (Table 1). According to previous studies, the method's accuracy was deemed satisfactory when the mean recovery percentage was between 80 and 120% of the expected value [19,20].

2.6. Human Health Risk Assessment

Human health risk assessment was used to estimate the health effects that might result from exposure to non-carcinogenic and carcinogenic chemicals [21,22]. Human health risk upon ingestion of contaminated medicinal plants was calculated based on the model developed by USEPA, and the values used for specific variables were adapted for Nigerian population statistics [23,24].

2.6.1. Estimated daily intake of heavy metals

To appraise the health risk associated with heavy metal contamination for the studied medicinal plants' samples, the estimated daily intake (EDI) (mg/kg/day) of heavy metals through ingestion of contaminated medicinal plants was undertaken based on a daily dose for each heavy metal using equation 1:

$$EDI_{plant}\,Ingestion = \frac{CxIRxEDxEF}{BWxAT} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where C is the concentration of heavy metal in the medicinal plant sample, while the other terms in the equation are ingestion rate (IR), exposure duration (ED), exposure frequency (EF), body weight (BW), and average time (AT), respectively, the IR for average daily ingestion of medicinal plants for adults and children was estimated to be 0.02 kg $person^{-1}day^{-1}$ and 0.01 kg $person^{-1}$ day^{-1} respectively [24–27]; the ED for children and adults were estimated to be 6 and 30 years respectively [22,27]; the EF for adults and children was 350 days [21,22]; the AT for non-carcinogenic risk for adults and children was taken as the product of 365 days and the respective ED of adults and children while the carcinogenic risk was taken as 365 days X 70 years of age for both adults and children [27], and the BW was 15 and 70 Kg for children and adults respectively [22,27].

2.6.2. Hazard Quotient (HQ)

The non-carcinogenic health risk associated with heavy metals exposure through the ingestion of medicinal plants was evaluated for each heavy metal determined in this study using the hazard quotient (HQ) which was obtained by dividing the EDI of each heavy metal via the oral exposure route to its corresponding reference exposure dose (R_fD) [28,29] using equation 2:

$$HQ = \frac{EDI}{RfD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..2$$

The values of RfD maximum permissible oral dose 0.0003 for As, 0.001 for Cd, 0.040 for Cu, 0.0003 for Hg, 0.02 for Mn, 0.020 for Ni, 0.0035 for Pb, and 0.30 for Zn $mg{\cdot}kg^{-1}{\cdot}day^{-1}$ respectively for the heavy metals analysed were adopted from Integrated Risk Information System [22,30]. Where HQ is less than 1 it is concluded there is no obvious risk from the heavy metal over a lifetime exposure, however, a value greater than 1, it is considered the presence of heavy metal may produce an adverse effect over a lifetime exposure. The higher the HQ value, the higher the probability of experiencing long-term carcinogenic effects [22–24,31].

2.6.3. Hazard Index

To evaluate the potential risk to human health through more than one heavy metal in the medicinal plant samples, the hazard index (HI), the sum of the hazard quotients for all the individual heavy metals determined, was calculated for each medicinal plant [28,32]. This was done using equation 3.

$$HI = \sum \mathrm{HQAs} + \mathrm{HQCd} + \mathrm{HQCu} + \mathrm{HQHg} + \mathrm{HQMn} + \mathrm{HQNi} + \mathrm{HQPb} + \mathrm{HQZn}\ , \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where the result for HI is less than 1 indicates chronic risks are unlikely, whereas HIs more than 1 predict noncancerous risks are likely to occur.

2.6.4. Carcinogenic health risk

Cancer health risk estimates represent the incremental likelihood that an individual will develop cancer as a result of specific exposure to a carcinogenic chemical over a lifetime [28]. The CR of each of the carcinogenic elements (As, Hg, Ni, Pb, and Cd) was calculated by multiplying the EDI values for the ingestion of medicinal plants by the cancer slope factor (CSF) for the PTE via the ingestion route using equation 4 [28,33,34].

$$\mathrm{CR} = EDI\ x\ CSF \ldots\ldots\ldots\ldots\ldots\ldots 4$$

where EDI (mg/kg/day) = estimated daily intake averaged over 70 years and CSF = Cancer slope factor (mg/kg/day). The cancer slope factors used for CR calculation were 1.7, 0.0003, 0.0085, and 0.38 (mg/kg/day) for Ni, As, Pb, and Cd, respectively [20]. According to the New York State Department of Health (NYSDOH), CR values ≤ 10^{-6}, indicate low cancer-causing risks, between 10^{-5} and 10^{-4}, indicate moderate cancer-causing risks, and between 10^{-3} and 10^{-1}indicate high cancer-causing risks [33,35]. The lifetime total cancer risk associated with exposure to multiple carcinogenic elements through the consumption of each fruit studied was calculated using equation 5:

$$TCR = \sum CRNi + CRAs + CRPb + CRCd\ \ldots\ldots\ldots\ldots\ldots\ldots .5$$

where TCR represents total cancer risk while CRNi, CRAs, CRPb, and CRCd are cancer risk for Ni, As, Pb, and Cd respectively [33,34,36].

2.7. Statistical Analysis

The results were analyzed statistically using Microsoft Office Excel and the Statistical Package for Social Science (SPSS 23.0 for Windows, SPSS Inc., IL, USA). One-way analysis of variance (ANOVA) followed by Tukey-Kramer's Multiple Comparison was used to assess the variation in concentration of heavy metals in the medicinal plants studied. Results were expressed as mean ± standard deviation and possibilities less than ($p<0.05$) were considered to be statistically significant. Correlation analysis was carried out to study the relationship between heavy metals in medicinal plants and the hypothetical source of heavy metals in the medicinal plants was inferred using principal component analysis (PCA). Kaiser-Meyer-Olkin (KMO) and Bartlett's tests were first performed to determine the suitability of the data obtained in this study for PCA [37]. KMO test estimates sampling adequacy that expresses the proportion of variance among the investigated variables that could be a common variance. Previous authors recommend that a KMO value higher than 0.50 indicates the usefulness of PCA [37,38]. In the present study, the KMO equals 0.599. Bartlett's test of sphericity was performed to examine whether the correlation matrix is an identity matrix.

3. Results

3.1. Results of the Certified Reference Material Used in this Study

The results of the certified reference material (CRM) and the percentage recoveries used to validate the analytical procedure are presented in Table 1. The percentage recovery for the plant CRM ranged between 89.70 –107.40%. Zn had the lowest percentage recovery of 89.70%, while Cr had the highest percentage recovery of 107.40%. The percentage recoveries for the heavy metals determined in the CRM were above 89%.

Table 1 Method accuracy assessment using plant certified reference material (STD CDV-1)

	Certified Reference Material (STD CDV-1)		
Metal	**Measure value mgkg^{-1}**	**Certified value mgkg^{-1}**	**% Recovery**
As	0.28	0.28	100
Cd	0.04	0.04	100
Cu	7.81	8.61	90.70
Hg	410.00	385.00	106.50
Mn	410.00	385.00	106.50
Ni	6.10	6.40	95.30
Pb	0.92	1.00	92.00
Zn	20.90	23.30	89.70

3.2. The results of heavy metal concentrations in selected medicinal plants commonly sold in the market in Jos Plateau

The results of the analysis of heavy metal concentrations in selected medicinal plants commonly used in the treatment of diseases in Jos Plateau is summarized in Table 2. It can be seen from the table that all the heavy metals were detected in all the medicinal plants determined. The mean concentration of As, Cd, Cu, Hg, Mn, Zn, and Pb in *V. amygdalina* and *V. donniana* were significantly ($p< 0.05$) higher than their corresponding WHO maximum permissible limit. There was variation in the concentration of heavy metals in the samples, with Cd having the lowest mean value of 0.81± 0.04 mgkg^{-1} in *P. guajava* while Mn had the highest mean value of 422.67± 2.52 mgkg^{-1} in *V. amygdalina*. The concentration of the toxic heavy metals As, Cd, Hg, and Pb varied with the medicinal plants. The concentration of As was the lowest value in *P. guajava* (1.51 mgkg^{-1}), and its highest was in *A. senegalensis* (1.48 to 6.30 mgkg^{-1}). The results followed a similar trend for Cd, Hg, and Pb where Cd had its lowest value in *P. guajava* (0.81 mgkg^{-1}) and its highest value in *V. donniana* (1.77 mgkg^{-1}). In contrast, Hg had its lowest value in *M. indica* (0.11 mgkg^{-1}) and its highest value in *A. senegalensis* (0.13 mgkg^{-1}). Pb had its lowest value in *P. guajava* (5.43 mgkg^{-1}) and its highest value in *V. donniana* (13.79 mgkg^{-1}).

Table 2 Heavy metal concentrations in selected medicinal plants analysed (mgkg^{-1})

$^{\$}$Heavy metal	*A. senegalensis*	*M.indica*	*P.guajava*	*V. amygdalina*	*V. donniana*	WHO MPL
As	6.30±0.80^{a}	1.59±0.04^{b}	1.51±0.03^{b}	4.31±0.26^{c}	5.60±0.26^{d}	0.2*
Cd	0.94±0.10^{a}	1.28±0.08^{b}	0.81±0.04^{a}	1.67±0.17^{c}	1.77±0.15^{c}	0.3*
Cu	29.97±2.00^{a}	14.09±0.37^{b}	16.83±3.74^{c}	23.87±0.61^{d}	12.29±1.02^{e}	10*
Hg	0.13±0.20^{a}	0.11±0.55^{a}	0.12±1.00^{a}	0.12±1.53^{a}	0.13±3.22^{b}	1*
Mn	292.00±5.00^{a}	30.33±1.53^{b}	26.83±0.76^{c}	422.67±2.52^{d}	44.33±3.51^{e}	2$^{\#}$
Ni	4.40±1.01^{a}	3.67±0.42^{a}	2.43±0.15^{b}	4.10±0.17^{a}	3.97±0.47^{a}	10*
Pb	6.30±0.35^{a}	9.71±0.46^{b}	5.430±0.41^{c}	12.53±0.85^{d}	13.79±2.27^{e}	10*
Zn	102.50±6.00^{a}	142.50±0.50^{b}	110.00±0.50^{c}	157.00±1.00^{d}	176.00±2.00^{e}	100*

Mean values followed by a different letter in a row are significantly different ($p<0.05$) based on Tukey Kramer adjustment; $Samples were analysed in replicate and result presented as mean; #FAO/WHO permissible limit of Mn in edible plants; *WHO permissible limit for heavy metals in herbal medicines.

3.3. Comparison of heavy metal concentrations found in this study with similar studies from the literature

The concentrations of heavy metals in medicinal plants obtained in this study were compared to those found in previous studies from other countries around the world, as summarised in Table 3. Overall, as shown in Table 3, heavy metal concentrations varied among the five medicinal plants determined in this study and those found in other studies around the world. The levels of Cd, Ni, and Zn reported in medicinal plants in the United Arab Emirates were much lower than the corresponding values obtained in this study, whereas the levels of Cu, Mn, and Pb reported in medicinal plants in the United Arab Emirates are much higher than the result from our study [11]. Compared to the reported levels of heavy metals in medicinal plants in China, all but Zn were much higher than the corresponding values obtained in this study [39,40]. Furthermore, As, Cu, Mn, and Zn levels reported in medicinal plants in Pakistan were lower than the values in this study, while the levels of Cd, Hg, Ni, and Pb reported in medicinal plants in Pakistan were several folds higher than the values reported in our study [41–43]. Similarly, the levels of Cd, Cu, and Zn reported in medicinal plants in Jordan were lower than in our study. Still, the Mn, Ni, and Pb levels reported in medicinal plants in Jordan were much higher than in our study [44]. Compared to the reported levels of heavy metals in medicinal plants in Ethiopia, As, Cu, and Mn were lower than the values reported in our study, but the levels of Cd, Ni, Pb, and Zn reported in medicinal plants in Ethiopia were much higher than the values reported in this study [45,46].

Table 3 Comparison of heavy metal concentrations (mg/kg) in this study with other studies from the literature

Area	As	Cd	Cu	Hg	Mn	Ni	Pb	Zn	Reference
This study	6.30± 0.80	1.77± 0.15	29.97± 2.00	0.13± 0.20	422.67± 2.52	4.40± 1.01	13.79± 2.27	176.00± 2.00	
UAE		1.11	156.24		570	3.45	23.52	146.67	[11]
China	14.53	6.2	34.01	8.69	593.48		50.11		[40,47]
Pakistan	0.54	1.66	19.19	1.33	105.56	15.8	10.63	65.85	[41–43]
Jordan		1.27	23.7		715	15.7	19.3	141	[44]
Ethiopia	2.06	6.75	12.3		41.6	11.25	35.97	185	[45,46]

3.4. Correlation analysis

Pearson rank correlation coefficient was calculated to find the relationship and possible sources of heavy metal contamination in the samples of medicinal plants used in the study area. The results of the correlation between all eight heavy metals (As, Cd, Cu, Hg, Mn, Ni, Pb, and Zn) in the medicinal plant samples is summarized in Table 4. Significant positive correlation was observed between As-Cu ($r = 0.51$, $p< .01$), As-Hg ($r = 0.98$, $p< .01$), As-Mn ($r = 0.52$, $p< .01$), As-Ni ($r = 0.79$,$p< .01$), Cd-Ni ($r = 0.50$, $p< .01$), Cd-Pb ($r = 0.99$,$p<.01$),Cd-Zn ($r = 0.97$,$p< .01$), Cu–Hg ($r = 0.58$,$p< .01$), Cu–Mn ($r = 0.82$,$p<.01$), Hg-Mn ($r = 0.56$,$p< .01$), Hg-Ni ($r = 0.71$,$p< .01$), Mn-Ni ($r = 0.61$,$p< .01$), and Pb–Zn ($r = 0.98$,$p< .01$) respectively. These significant and positive correlations observed between most of the heavy metals in the studied medicinal plants indicate a heavy concentration of anthropogenic sources of these materials in the environment.

Except for Cu and Zn ($r = - 0.56$), insignificant negative correlations were observed between Cd and Cu ($r = - 0.33$), Cu and Pb ($r = - 0.38$), and Mn and Zn ($r = - 0.04$), indicating less influence in the availability of these metal in the medicinal plants.

Table 4 Pearson rank correlation coefficient of selected heavy metals in medicinal plants samples in the study area

	As	Cd	Cu	Hg	Mn	Ni	Pb	Zn
As	1							
Cd	0.34	1						
Cu	0.51	-0.33	1					
Hg	0.98**	0.25	0.58	1				
Mn	0.52	0.20	0.82	0.56	1			
Ni	0.79	0.50	0.47	0.71	0.61	1		
Pb	0.31	0.99**	-0.38	0.21	0.14	0.47	1	
Zn	0.16	0.97**	-0.56	0.06	-0.04	0.30	0.98**	1

**. Correlation is significant at the 0.01 level (2-tailed).

3.5. Principal Component Analysis

Principal component analysis (PCA) was used to identify the possible source of heavy metals in medicinal plants. In the present study, the KMO value equals 0.599. The results of PCA of heavy metals in medicinal plants yielded two significant components with eigenvalues higher than 1.00, accounting for a total of 85.51% of the data variation as shown in Table 5, Figure 1 and 2. The first principal component (PC1) explained 44.30% of the calculated variance and was dominated by As, Cd, Cu, Hg, Mn and Ni elements with proportions of 0.840, 0.826, 0.786, 0.738, 0.704, and 0.625 respectively (Table 5), for the non-rotated matrix while the second principal component (PC2) explained 41.21% of the calculated variance and was dominated by Pb and Ni with values of 0.898 and 0.519 having negative loading for Hg, Mn and Zn. Varimax rotation method was used for the components rotation and the rotated loadings are listed in Table 6 showing a strong positive loading for As, Cd, Cu, Hg, Mn, Ni, Pb and Zn.

Table 5 Total variance explained (extraction method: pincipal component analysis) KMO and Bartlett's test for selected heavy metals in medicinal plants

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.860	48.252	48.252	3.860	48.252	**48.252**	3.544	44.302	**44.302**
2	2.981	37.261	85.513	2.981	37.261	**85.513**	3.297	41.211	**85.513**
3	0.675	8.439	93.952						
4	0.381	4.761	98.712						
5	0.060	0.753	99.465						
6	0.023	0.290	99.756						
7	0.011	0.134	99.890						
8	0.009	0.110	100.000						
Kaiser-Meyer-Olkin measure of sampling adequacy					**0.599**				
Bartlett's test of		Approx. Chi-Square 154.905							
sphericity		Degrees of freedom 28							
		Significance 0.000							

Table 6 Factor loading of the principal components extracted for selected heavy metals in medicinal plants

	Component Matrix		Rotated Component Matrix		Communalities
Heavy Metal	**PC1**	**PC2**	**PC1**	**PC2**	
As	0.840	0.351	0.883	0.222	0.828
Cd	0.826	0.186	0.200	0.965	0.971
Cu	0.786	0.423	0.816	-0.510	0.926
Hg	0.738	-0.653	0.883	0.133	0.797
Mn	0.704	-0.687	0.811		0.660
Ni	0.625	0.519	0.772	0.346	0.716
Pb	0.347	0.898	0.151	0.972	0.968
Zn	0.551	-0.819		0.986	0.974

Extraction method: principal component analysis. 2 components extracted.

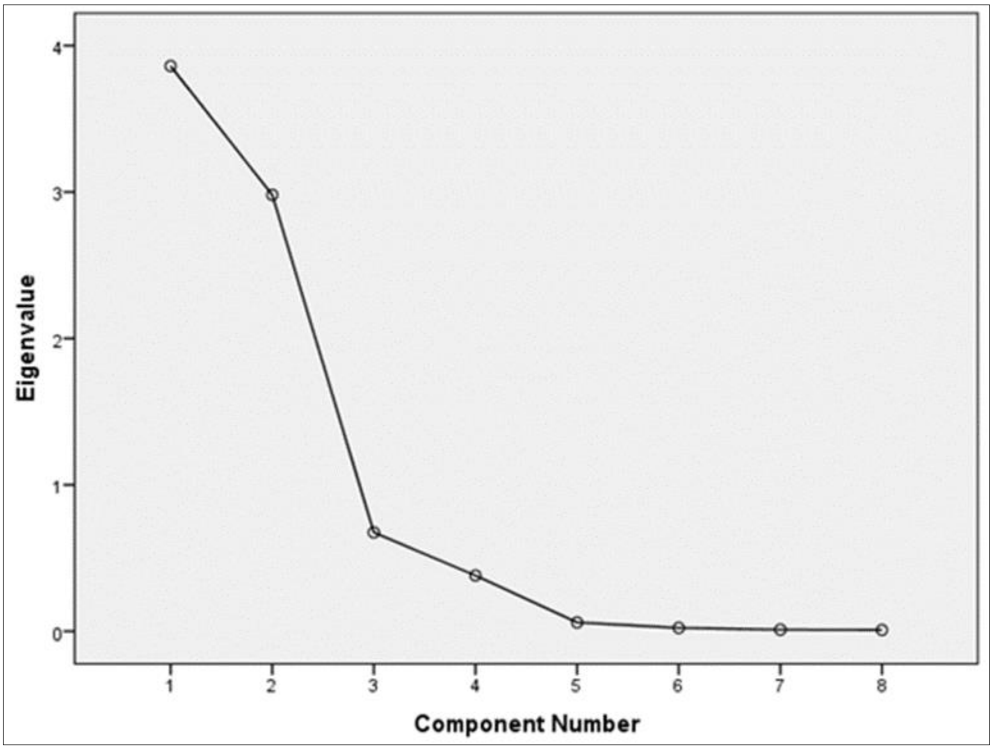

Figure 1 Scree plot for the Eigenvalues indicating the two components

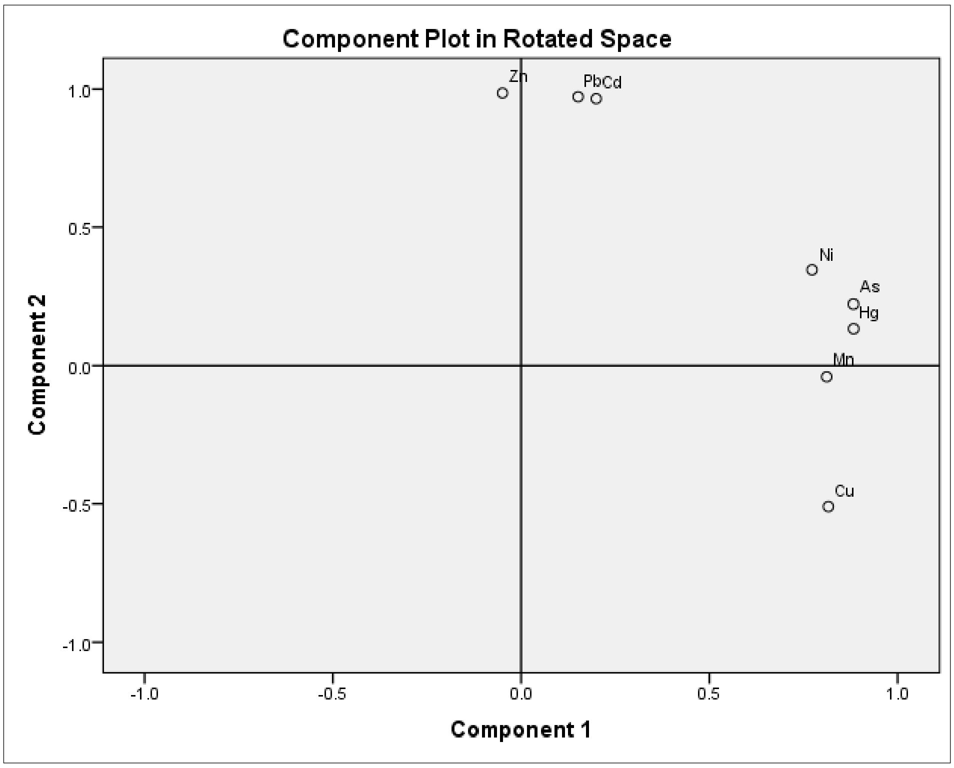

Figure 2 Biplot for the components in rotated space

3.6. Health risk assessment

3.6.1. Estimated daily intakes (EDI) of heavy metals

Table 7 presents the result of EDI of heavy metals in medicinal plants based on predicated ingestion of the medicinal plants by adults and children, respectively. The result showed variation in the daily intake of heavy metals among the studied medicinal plants. EDI values of all the heavy metals were less than 1. The EDI values for children were generally higher than those for adults in all the medicinal plants (Table 7).

Table 7 Estimated daily intake (EDI) values (mg/kg/Day) of eight heavy metals through consumption of medicinal plants sold in Jos Metropolis via the ingestion route of exposure for adults and children

Heavy metals	Medicinal plants									
	A. senegalensis		***M.indica***		***P.guajava***		***V. amygdalina***		***V. donniana***	
	Adults	**children**	**Adults**	**children**	**Adults**	**children**	**Adults**	**children**	**Adults**	**children**
As	0.0017	0.0040	0.0004	0.0010	0.0004	0.0010	0.0012	0.0028	0.0015	0.0036
Cd	0.0003	0.0006	0.0004	0.0008	0.0002	0.0005	0.0005	0.0011	0.0005	0.0011
Cu	0.0082	0.0192	0.0039	0.0090	0.0046	0.0108	0.0065	0.0153	0.0034	0.0079
Hg	0.0353	0.0825	0.0308	0.0718	0.0315	0.0735	0.0336	0.0784	0.0344	0.0803
Mn	0.0800	0.1867	0.0083	0.0194	0.0074	0.0172	0.1158	0.2702	0.0121	0.0283
Ni	0.0012	0.0028	0.0010	0.0023	0.0007	0.0016	0.0011	0.0026	0.0011	0.0025
Pb	0.0017	0.0040	0.0027	0.0062	0.0015	0.0035	0.0034	0.0080	0.0038	0.0088
Zn	0.0281	0.0655	0.0390	0.0911	0.0301	0.0703	0.0430	0.1004	0.0482	0.1125

3.6.2. Hazard quotient (HQ) & hazard index (HI) values for heavy metals in medicinal plants

Table 8 HQ values of eight heavy metals through consumption of selected medicinal plants sold in Jos Metropolis via the ingestion route of exposure for adults and children

Heavy metals	Medicinal plants									
	A. senegalensis		***M.indica***		***P.guajava***		***V. amygdalina***		***V. donniana***	
	Adults	**children**	**Adults**	**children**	**Adults**	**children**	**Adults**	**children**	**Adults**	**children**
As	0.0432	0.1007	0.0109	0.0254	0.0103	0.0241	0.0295	0.0689	0.0384	0.0895
Cd	0.0006	0.0015	0.0009	0.0020	0.0006	0.0013	0.0011	0.0027	0.0012	0.0028
Cu	0.0117	0.0274	0.0055	0.0129	0.0066	0.0154	0.0093	0.0218	0.0048	0.0112
Hg	0.2524	0.5890	0.2199	0.5131	0.2250	0.5251	0.2401	0.5601	0.2459	0.5738
Mn	4.0000	9.3333	0.4155	0.9695	0.3675	0.8576	5.7900	13.5100	0.6073	1.4169
Ni	0.0040	0.0094	0.0034	0.0078	0.0022	0.0052	0.0037	0.0087	0.0036	0.0085
Pb	1.7260	4.0274	2.6603	6.2073	1.4877	3.4712	3.4329	8.0100	3.7781	8.8155
Zn	7.0205	16.3813	9.7603	22.7740	7.5342	17.5799	10.7534	25.0913	12.0548	28.1279
HI	13.0586	30.4700	13.0766	30.5120	9.6342	22.4798	20.2601	47.2736	16.7341	39.0462

The results of the HQ of heavy metals based on predicated ingestion of medicinal plants for adults and children is summarized in Table 8. The results showed HQ values were greater than one for Pb and Zn in all the medicinal plants for adults and children and Mn in *A. senegalensis* and *V. amygdalina* for adults and children and *V. donniana* for children alone, respectively. The remaining heavy metals had HQ values less than one. However, the HI values for all eight heavy metals in the studied medicinal plants were greater than one with *V. amygdalina* (47.3) for children and *P.guajava* (9.63) for adults, recording the highest and lowest values respectively (Table 8). This indicates that intake of these heavy metals through consumption of the studied medicinal plants constitutes a considerable noncancer risk. The children had higher HQ values in most food crops than adults.

3.6.3. Carcinogenic health risk of PTEs in fruits

Table 9 summarises the cancer risks associated with Ni, As, Pb, and Cd for adults and children who consumed any medicinal plants included in this investigation via ingestion. With the exception of *M.indica* (CR=6.53 x 10^{-4}) and *P.guajava* (CR=6.21 x 10^{-4}) for adults, the CR values for As and Ni in all the medicinal plants for both adults and children were 10–3, which are all within the range of 10^{-3} to 10^{-1}, indicating high carcinogenic risk when compared to the NYSDOH CR classification. Whereas except for *A. senegalensis* (CR=9.79 x 10^{-5}) for adults, the CR values for Cd in all the medicinal plants were 10^{-4} while the CR values for Pb in all the medicinal plants for both adults and children were 10^{-5}. This shows that the CR values for Cd and Pb in the studied medicinal plants fall within the range of 10^{-5} to 10^{-4}, indicating that they are associated with a moderate CR when compared to the NYSDOH CR classification. With the exception of *A. senegalensis* (CR=1.11 x 10^{-2}) and *V. donniana* (CR=1.01 x 10^{-2}) for children, the TCR values for all the heavy metals in all the medicinal plants studied for both adults and children were 10^{-3} all of which were within 10^{-3} to 10^{-1} indicating a high carcinogenic risk.

Table 9 CRvalues of four heavy metals through ingestion of selected medicinal plants sold in Jos Metropolis via the ingestion route of exposure for adults and children

		PTE				
Medicinal plant	**Age Group**	**As**	**Ni**	**Cd**	**Pb**	**TCR**
A. senegalensis	Adults	2.59 x 10^{-3}	2.05 x 10^{-3}	9.79 x 10^{-5}	1.47 x 10^{-5}	4.75 x 10^{-3}
	children	6.04 x 10^{-3}	4.78 x 10^{-3}	2.28 x 10^{-4}	3.42 x 10^{-5}	1.11 x 10^{-2}
M.indica	Adults	6.53 x 10^{-4}	1.71 x 10^{-3}	1.33 x 10^{-4}	2.26 x 10^{-5}	2.52 x 10^{-3}
	children	1.53 x 10^{-3}	3.99 x 10^{-3}	3.11 x 10^{-4}	5.28 x 10^{-5}	5.88 x 10^{-3}
P.guajava	Adults	6.21 x 10^{-4}	1.13 x 10^{-3}	8.43 x 10^{-5}	1.26 x 10-5	1.85 x 10^{-3}
	children	1.45 x 10^{-3}	2.64 x 10^{-3}	1.97 x 10^{-4}	2.95 x 10^{-5}	4.32 x 10^{-3}
V. amygdalina	Adults	1.77 x 10^{-3}	1.91 x 10^{-3}	1.74 x 10^{-4}	2.91 x 10^{-5}	3.88 x 10^{-3}
	children	4.13 x 10^{-3}	4.46 x 10^{-3}	4.30 x 10^{-4}	6.81 x 10^{-5}	9.06 x 10^{-3}
V. donniana	Adults	2.30 x 10^{-3}	1.85 x 10^{-3}	1.84 x 10^{-4}	3.21 x 10^{-5}	4.37 x 10^{-3}
	children	5.37 x 10^{-3}	4.31 x 10^{-3}	4.30 x 10^{-4}	7.49 x 10^{-5}	1.01 x 10^{-2}

4. Discussion

Vast numbers of people globally use plant-based medicines. Most of these plants are sourced in the wild, leaving just a few cultivated where several mineral elements accumulate in the plants alongside other heavy materials [4,6,15,48]. Environmental impacts associated with these heavy metals and their human health impact have been a major concern among several stakeholders [49,50]. Based on the results of this study, 100% of the samples were found to contain heavy metals (As, Cd, Cu, Hg, Mn, Ni, Pb, and Zn) at varying concentrations, indicating that the plant-based medicinal products have the ability to cause adverse health effect especially when individuals regularly consume them. This corroborates previous studies that assessed the presence of heavy metals in medicinal plants and showed variation in their ability to take up and accumulate these compounds [51–53]. With the exception of Ni and Pb in *Annona senegalensis, Magnifera indica, and Psidium guajava*, concentrations of these heavy metals were several folds above their corresponding WHO maximum permissible limit in medicinal plants. This observation is in agreement with the previous studies that reported elevated total heavy metal concentrations above WHO maximum permissible limits in medicinal plants [53,54]. Among these heavy metals, As, Cd, Hg, and Pb are considered out-rightly toxic metals and ranked among the priority metals that are of public health significance because they do not have any known biochemical and physiological functions and are known to induce multiple organ damage, even at very low levels of exposure [55–58].

Arsenic (As) is considered harmful to humans, and studies have established anthropogenic sources to include industrial activities, mining, and road traffic. It has been found in high concentrations in environmental media [59–61]. The outcome from the present study showed that the highest mean concentration of As in the studied medicinal plants was 6.30 $mgkg^{-1}$ in *A. senegalensis*. This value is 31.5 times higher than 0.2 $mgkg^{-1}$, WHO's maximum permissible limit in medicinal plants. In contrast to other studies, As concentration for *A. senegalensis* in our study was 5.94 times higher than the reported concentrations of 1.06 $mgkg^{-1}$ reported in China [49], 28.64 times higher than 1.06 $mgkg^{-1}$ in sampled medicinal plants in Bulgaria [62].

In the environment, Cd is toxic to both plants and animals, with half life between 25-30 years, and can accumulate in the liver, kidney, and bones. Exposure occurs primarily via ingestion of contaminated food and water. The highest mean concentration of 1.77 $mgkg^{-1}$ recovered in *V. donniana* was 5.90 times higher than 0.3 $mgkg^{-1}$, the WHO-recommended maximum permissible limit in medicinal plants. The present study found 1.59 times (1.11 $mgkg^{-1}$) higher than the reported values from sampled medicinal plants in the United Arab Emirates [11]. Among the medicinal plants analysed in this study for the presence of Hg, it was found that the greatest predisposition for accumulation of the element was found in *A. senegalensis* 0.13 $mgkg^{-1}$ and the lowest at 0.11 $mgkg^{-1}$ in *M. indica* respectively. Both values were several folds higher than 0.001 $mgkg^{-1}$, the WHO recommended threshold. In contrast to previous studies, Hg recorded in *A. senegalensis* in this study was 2.60 (0.054 $mgkg^{-1}$) times higher than concentrations reported for Hg analysed medicinal plants in Iran and 1.63 (0.08 $mgkg^{-1}$) in China [49,63]. These levels of toxic heavy metals, As Cd, Hg, and Pb, are comparable to those reported by previous researchers, which have been shown to have serious public health implications on human health [56,57,64–66].

Toxic heavy metals have been shown to be harmful, even at low concentrations, when ingested over a long time period, and their health effects may not be immediate but show up after many years due to their bioaccumulation tendency [67,68]. Hence, chronic intake of such toxic heavy metals in the form of medicinal plants could potentially lead to their toxicity, which might affect the nervous system and cause neurological disorders. For example, rice, the food crop, has been identified as a major source of Cd intake, which caused the *itai-itai* disease in Japan in the mid-20th century [65]. The *itai-itai* disease was a combination of osteomalacia and osteoporosis caused by Cd contaminated water used to irrigate local rice fields [57]. Elements such as Cu, Mn, and Zn are essential elements that are required for various biochemical and physiological functions for the ecosystem and humans. However, their presence in high concentrations in food and feed plants, including medicinal plants, are of great concern because of their toxicity to humans and animals [56,69,70]. Intake of heavy metals through consumption of contaminated medicinal plants has long-term detrimental effects on human health, even when the concentrations are well within the tolerable limit for a human being, long term exposure to these metals might bring about bioaccumulation and thus harmful effects on the population.

In this study, the levels of Cu, Mn, and Zn are higher than the reported WHO maximum permissible limits established for medicinal plants, just as previous studies have reported such high levels of essential metals in medicinal plants [71,72]. The population's health risk within the study was assessed based on the United States Environmental Protection Agency (USEPA) model, where a noncarcinogenic risk assessment of ingesting medicinal plants for children and adults in the study was established based on HQ and HI values. The results showed that the HQ values for Pb and Zn in all of the medicinal plants for both adults and children were greater than 1, while the HQ values for Mn were greater than 1 in *A. senegalensis* and *V. amygdalina* for both adults and children and in *V. donniana* for children only. The outcome from the study revealed that the HI values for all the eight heavy metals in the studied medicinal plants were greater than one with *V. amygdalina* (47.3) for children and 20.3 for adults, respectively. This indicates that the intake of Pb, Zn and Mn through consumption of the studied medicinal plants may constitute a potential health risk for both local children and adults. These findings are in agreement with previous studies which reported HQ values greater than one in various food crops [73–76]. Accordingly, HI is important for assessing combined noncarcinogenic health risks due to exposure to heavy metals through food consumption [77]. In the present study, HI values for all eight heavy metals were greater than 1, indicating a possible health risk associated with each heavy metal for children and adults through the consumption of the studied medicinal plants [75,78]. The high HI values observed suggest longer use of the plant product might present possible noncarcinogenic health risks to the consumers even at lower concentrations.

The results of the calculated cancer risks associated with Ni and As through consumption of the medicinal plants investigation for both adults and children lie within the range of 10^{-3} to 10^{-1}, indicating high carcinogenic risk, while the CR values for Cd and Pb in the studied medicinal plants for adults and children fall within the range of 10^{-5} to 10^{-4}, indicating that they are associated with a moderate CR but the TCR values for all the heavy metals in all the medicinal plants studied for both adults and children were within 10^{-3} to 10^{-1} indicating a high carcinogenic risk. This finding is in agreement with previous studies which reported that plant consumption is a significant contributor to CR [20,35,79]. According to NYSDOH, if TCR values are ≤ 10–6, then it relates to low cancer-causing risks; if its values lie between 10^{-5} and 10^{-4}, then it relates to moderate cancer-causing risks; and if values lie between 10^{-3} and 10^{-1}, then it relates to high stakes [79,80]. This confirms previous studies that reported that plants growing in a polluted environment accumulate heavy metals at concentrations that ultimately pose a serious risk to human health when consumed [81]. Our findings suggest that the ingestion of the medicinal plants under investigation may expose people to a risk of cancer due to the presence of Ni, As, Pb, and Cd, just as it did with the noncarcinogenic risk. Hence, longer use of plant products might present possible carcinogenic health risks to consumers.

5. Conclusion

This study determined the concentration of heavy metals in medicinal plants sold in the markets in Jos metropolis and their associated health risk. From the result obtained, medicinal plants sold in the markets in Jos metropolis contain varying concentrations of heavy metals, which are well above WHO guideline values. This makes the consumption of medicinal plants sold in the markets in Jos metropolis highly undesirable and unsafe. Specifically, the results of non-carcinogenic risk of exposure to heavy metals through the consumption of medicinal plants reveal HQ values greater than 1 for Pb and Zn in all the medicinal plants for both adults and children and Mn in *A. senegalensis* and *V. amygdalina* for both adults and children and *V. donniana* for children alone. The HI values for all eight heavy metals in the studied medicinal plants were greater than 1, with *V. amygdalina* (47.3) recording the highest value for children and *P. guajava* (9.63) recording the lowest value for adults. The risk for children was 5 times higher than for adults. The CR values for As and Ni in all the medicinal plants for both adults and children via the ingestion route indicated high carcinogenic risk while the CR values for Cd and Pb in the studied medicinal plants indicated that they are associated with a moderate carcinogenic risk. However, the TCR values from all the heavy metals in all the medicinal plants studied for both adults and children indicated a high carcinogenic risk. Based on the research, there is the need for advocating strict regulatory control of these plant-based products and a precautionary approach among consumers to ensure the reduction of long-term health effects associated with its use.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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