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Research Article

Heavy Metal Content and Health Risk Assessment of Some Selected Medicinal Plants from Obuasi, a Mining Town in Ghana

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Medicinal plants represent an important class of traditional medicines. This research was conducted to assess the levels of selected heavy metals in some medicinal plants from Obuasi, a mining area in Ghana. Twenty different medicinal crops were sampled for this study. The levels of arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn), nickel (Ni), and lead (Pb) were determined by inductively coupled plasma mass spectroscopy (ICP-MS) after wet digestion. The concentrations (mg/kg) of As, Cd, Cr, Hg, Mn, Ni, and Pb were 1.092 – 0.206, 1.341 – 0.253, 6.603 – 2.005, 0.045 – 0.001, 282.798 – 20.583, 4.967 – 1.676, and 26.410 – 0.629, respectively. Some concentrations of Cr, Cd, As, Mn, and Pb analyzed in all 20 medicinal plant samples exceeded WHO permissible limits for medicinal food while concentrations of Ni, As, and Hg for all the samples were below the WHO permissible limit. The estimated dietary intake (EDI) was compared to the tolerable daily intake recommended by WHO/FAO. Results obtained from hazard indices such as the hazard quotient and carcinogenic risk show that the medicinal plants are not likely to cause cancer if they are consumed over a prolonged period of time.

1. Introduction

Medicinal crops can be defined as plant species that possess therapeutic properties or exert beneficial pharmacological effect on the human or animal body. Herbal medications or concoctions are medicinal plant-derived substances that exist naturally and are used to cure ailments with minimal or no industrial processing [1]. Various parts of medicinal plants including the leaves, roots, barks, fruits, and seeds are found in herbal remedies.

It has been estimated by the World Health Organization (WHO) that 80% of patients in Africa use traditional medicine for their healthcare needs [2]. The Ghana Health Service has increasingly assimilated the use of herbal medicines into mainstream health delivery to acknowledge the essential role herbal medicines play in Ghana's health-care system [3].

In Ghana, some common medicinal plants are *Moringa oleifera* Lam (drumstick tree) for treating jaundice, asthma, cancer, constipation, diabetes, etc. *Piper guineense* (West African black pepper) is known to treat fevers, malaria, and inflammation. Lemon is used to treat scurvy, a condition caused by lack of vitamin C. *Dalbergia saxatilis* (locally known in Ghana as ahoma kyem) is used as a decoction in traditional medicine for treating ailments such as cough, smallpox, skin lesions, bronchial ailments, and toothache. *Tetrapleura tetraptera* (Aidan fruit, locally known as prekese) is cooked in soup and fed to mothers to prevent postpartum contraction. It is also used to treat typhoid and asthma [4, 5].

Mining activities are well known for their deleterious effects on the environment. Most tailings from gold mines are known to contain high levels of heavy metals like arsenic, mercury, cadmium, nickel, lead, copper, and cobalt. The environmental impact of toxic metal pollution and the accompanying health effects remain great areas of concern [6, 7]. Heavy metals may pose serious carcinogenic and noncarcinogenic health risks when consumed above their acceptable threshold limits.

These metals may be transported through soils to reach groundwater or may be taken up by plants, including crops [8]. These contaminants can accumulate during the cultivation, storage, and processing of herbs and may have adverse effects on consumer health [9]. This could result in heavy metal exposure, especially for residents in a mining town like Obuasi and its surrounding villages [10], where both legal and illegal mining are actively done. Heavy metals have been found in soils and groundwater wells [11], organs of sheep and goats (Akoto et al., 2014), and food [13] in Obuasi and other parts of Ghana [7].

Medicinal plants from Obuasi are also likely to be contaminated with these heavy metals. Several works have been done worldwide to ascertain the heavy metal content in some medicinal plants [14–16]. The medicinal plants used in this study were selected based on their popularity amongst herbal medicine practitioners and the masses that frequently patronize them. Most of the plants utilized in Ghana are also frequently found as diverse excipients in local medicines. This work was therefore initiated to determine the levels of selected heavy metals in medicinal plants from Obuasi, a mining town in Ghana.

2. Materials and Methods

2.1. Study Area. Obuasi was chosen particularly due to its long-term exposure to extensive mining activities. Artisanal mining has been documented in the area as early as 1471 [17]. The chief industrial activity in the area is gold mining, and most of the inhabitants of Obuasi engage in illegal small-scale gold mining commonly known as "galamsey." AngloGold Ashanti, one of the wealthiest gold mining companies in Africa, operates an underground mining operation to a depth of 1,500 m in Obuasi [13].

2.1.1. Sample Collection. Fresh commonly used medicinal crop samples comprised of leaves, stems, bark, and roots from the forest and nearby farms in Obuasi (Figure 1), Ghana, were selected. A total number of 20 different raw medicinal plant species were used for this study. The medicinal plant samples were selected based on the information acquired from local traditional herbal practitioners about their usage in disease, diagnosis, and treatment and also based on their popularity amongst the masses that frequently patronize them. The bulk of the samples was packaged in polythene bags and transferred to the laboratory. Plant identification was carried out at Dr. Hilla Limann Technical University's Department of Pharmaceutical Sciences.

Table 1 shows a summary of the medicinal plants, codes, local names, their therapeutic indication, and parts that were used in this study. Samples were washed with double distilled water and dried in an oven at 30°C for a week before pulverization into fine particles using a porcelain mortar and pestle. Samples were then sieved in a 2 mm mesh sieve before the analysis to remove extraneous matter.

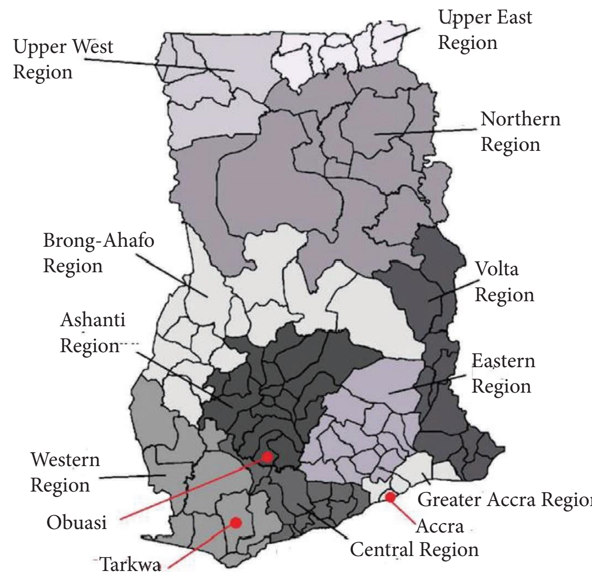

Figure 1: A map of Ghana showing the Obuasi municipal area.

2.1.2. Reagents. Analytical-grade reagents were used throughout the experiment. At a purity greater than 99%, As, Cd, Cr, Hg, Pb, Ni, and Mn were acquired from Sigma-Aldrich (Steinheim, Germany). The metal concentration used to prepare the mixed standard solution was 100 mg/L. The stock solution was diluted with double-deionized water to form the standard working solutions for the calibration curves. The samples were digested with concentrated HNO_3 and HCl (Sigma-Aldrich, Germany)

2.1.3. Digestion of Samples. One (1.0) gram of the preweighed sample was placed in a 100 mL borosilicate beaker. A 10 mL mixture of concentrated nitric acid (HNO_3) and hydrochloric acid (HCl) in a ratio of 1 : 1 was added. The mixture was heated up to a constant temperature of 250°C until a clear solution was obtained. The digest was then transferred into a 50 mL volumetric flask. Double distilled water was added to the mark, and the solution was filtered using a membrane filter (0.45 pm) or Whatman no. 42 filter paper. The clear solution was transferred into previously washed polyethylene bottles for ICP-MS (Perkin Elmer, 2000 series). The run conditions of the ICP-MS were as follows: plasma flow (15 L/min), auxiliary flow (1.2 L/min), nebulizer flow (0.88 L/min), sampling depth (0.5 mm), and pump rate (9 rpm).

Blank and standard analysis was performed by analyzing a standard solution and a blank solution for each of the elements at intervals. To verify the quality of the results, standard solutions were analyzed with each batch of about 10 samples for each element.

2.1.4. Quality Assurance and Quality Control. To ensure the precision, reliability, and accuracy of the results, various quality assurance and control measures were employed in

Table 1: List of traditional medicinal plants and their therapeutic effects.

Scientific and code name	Local name	Part of plant used	Therapeutic indication
Azadirachta indica (AI)	Neem tree	Leaves	Fever, malaria, skin infections
Ocimum viride (OV)	Fever Aduro	Leaves	Fever
Alchornea cordifolia (AC)	Ogyama	Leaves	Gonorrhea, diarrhea, dysentery
Citrus limon (CL)	Lemon	Leaves	Scurvy
Momordica charantia (MC)	Nyanya	Leaves	Ulcer, piles, gastritis, hemorrhoids
Moringa oleifera (MO)	Moringa	Leaves	Asthma, stomach and intestinal ulcer, diabetes, kidney stone
Newbouldia laevis (NL)	Sesemasa	Leaves	Body aches
Alstonia boonei (AB)	Nyamedua	Bark	Malaria, fever, insomnia, chronic diarrhea
Quassia amara (QA1)	Bitter ash wood chips	Bark	Anorexia, constipation, fever
Mangifera indica (MI)	Mango	Bark	Malaria, leukemia
Entandrophragma angolense (EA)	Edinam	Bark	Fever, stomach pain, peptic ulcers, earache, rheumatic pain
Cola nitida (CN)	Cola tree	Bark	Stimulation of breast milk
Alstonia boonei (AB)	Nyamedua	Bark	Measles
Khaya senegalensis (KS)	Mahogany	Bark	Hypertension
Sphenocentrum jollyanum Pierre (SJP)	Kraman Kote	Root	Sexual weakness
Piper guineense (PG)	Esurowisa	Root	Waist pain
Gongronema latifolium (GL)	Ansurogya	Root	Sexual weakness
Paullinia pinnata (PP)	Tuantini	Root	Sexual weakness, malaria
Tetrapleura tetraptera (TT)	Prekese	Fruit	Postpartum contraction
Dalbergia saxatilis (DS)	Ahoma kyem	Stem	Smallpox, toothache
Quassia amara (QA2)	Bitter ash wood chips	Stem	Waist pain

this study. The ICP-MS was calibrated based on a linear four-point calibration curve for each element. The standard calibration curves ($r^2 = 0.998 - 0.997$) were run during measurement. Calibration verification was carried out by analyzing a blank and standard solution for each element at intervals. The quality of the results was determined by analyzing matrix duplicate/matrix spike for each element. Matrix spike recovery was carried out by adding an increasing amount of standard solution to the sample matrix before digestion. The results for the recovery of the metals analyzed in this study are presented in Table 2. Medicinal plant samples were handled with care by using nitrile gloves in the laboratory to avoid contamination. Polyethene bags containing the samples were carefully sealed and coded. All equipment and glassware used for sampling, milling, and drying such as blender, crucibles, and spatula were cleaned with soap water and double distilled water to reduce the possibility of cross-contamination. A blank solution was prepared by the same procedure as used for the digestion of plant samples. To assess the reproducibility of the obtained results, triplicate analysis was conducted for every sample. Results in the text are shown in tabulated form as mean ± SD (standard deviation).

2.1.5. Statistical Analysis. Results obtained were subjected to analysis by SPSS software version 20, and data were reported as standard deviation, average, and 95% confidence interval. A sample *t*-test was performed at a significant level of 0.05 and then compared with standard values.

2.2. Health Risk Assessment. The risk associated with the consumption of medicinal plants contaminated with heavy metal was investigated based on the estimated daily intake (EDI), hazard quotient (HQ), and hazard index (HI). The estimated dietary intake (EDI) in $mg{\cdot}kg^{-1}$ day was calculated using the following equation [7, 18]:

$$\mathbf{EDI} = \frac{\mathbf{C \times IR}}{\mathbf{BW}}, \tag{1}$$

where C is the concentration of the toxic metal present (mg/kg) in the herbal plant. IR is the ingestion rate of herbal plants per day (g/day), and the maximum dosage of 30 g specified in the West African Herbal Pharmacopia [19] was applied. BW, the average body weight (kg), was considered to be 70 kg [20].

The HQ was used to estimate the non-carcinogenic risk of a metal. Oral reference doses (Rfd) in mg/kg/day are as follows: As (0.003), Cd (0.001), Cr (1.5), Hg (0.0001), Mn (0.14), Ni (0.02), and Pb (0.004) [21, 22]. The HQ is expressed as

$$\mathbf{HQ} = \frac{\mathbf{EDI}}{\mathbf{RfD}}. \tag{2}$$

An HQ value less than one is considered safe, and a value higher or equal to one is unsafe and poses a likely adverse health risk to a population.

The hazard index (HI) is the sum of the individual hazard quotients of the metals (HQ of As, Cd, Cr, Hg, Mn, Ni, and Pb) and is expressed as

$$\mathbf{HI} = \mathbf{HQ_1} + \mathbf{HQ_2} +, \ldots, \mathbf{HQ_n}, \tag{3}$$

where HQ_1 is the hazard quotient for the first toxicant, HQ_2 hazard quotient for the second toxicant, and HQ_n is the hazard quotient for the n^{th} toxicant.

2.2.1. Estimated Carcinogenic Risk (ECR). The cancer risk, ECR, was estimated using the following equation:

$$\mathbf{ECR} = \mathbf{EDI} \times \mathbf{CSF}. \tag{4}$$

ECR represents the estimated lifetime of an individual to acquire cancer from exposure to potentially carcinogenic contaminated medicinal herbs. CSF (Pb (0.0085) and As (1.5), mg/kg/day) is the slope factor, which shows the likelihood of the consumer developing cancer when exposed orally to a cancer-causing substance over the average lifespan of 70 years for Ghanaians [23]. Carcinogenic risks within 10^{-4} to 10^{-6} are acceptable [24].

3. Results and Discussion

The concentrations of arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn), nickel (Ni), and lead (Pb) were determined in the different medicinal plants. Recovery studies were performed to validate the methodology. Percentage recoveries in all the plant samples ranged from 96 to 109. The concentrations of all the metals analyzed in the medicinal plant samples together with their World Health Organization (WHO) maximum permissible limits (MPLs) are shown in Table 3.

3.1. Concentration of Heavy Metals

3.1.1. Arsenic (As). From Table 3, the mean arsenic concentration recorded was 0.503 ± 0.445 mg/kg with a range of 0.206 to 1.092 mg/kg. All the samples used for this study recorded As levels below the World Health Organization maximum permissible limit (MPL) of 3.0 mg/kg [25]. *Moringa oleifera* yielded the highest As level of 2.36 mg/kg which was about 78.6% below the MPL. Tawiah [26] did not detect any As in medicinal crops sampled within the Accra Metropolis, Ghana. The variations in As figures can be attributed to the mining activities that take place in Obuasi.

Begaa and Messaoudi [15] also recorded an As range of 0.18 to 5.44 mg/kg in selected medicinal crops from the Djelfa Region of Algeria. Vaculík et al. [27] reported an extremely high arsenic concentration range of 518.6 to 919.9 mg/kg for *Fragaria vesca* plant species on abandoned mining sites in Slovakia. In young adults, high exposure to As, however, causes cruel damage such as cancer of the lungs, liver dysfunction, multi-organ function, and adult respiratory syndromes [28].

3.1.2. Cadmium (Cd). The mean concentration of cadmium (Cd) in Table 3 was 0.620 ± 0.187 mg/kg with a range of 0.253 to 1.341 mg/kg. *Paullinia pinnata* recorded the highest Cd concentration which is about 447% above the WHO MPL

Table 2: Recovery test results.

Metal	Amount added (mg)	Amount found (mg)	Amount recovered (mg)	% recovery
As	0.5	0.9	0.8	99.8 ± 1.1
Cd	0.5	1.2	0.7	99.0 ± 1.2
Cr	0.5	3.5	0.77	101.8 ± 4.3
Hg	0.05	0.1	0.075	100.0 ± 1.3
Pb	5	10.8	7.4375	99.4 ± 1.2
Ni	0.5	5.2	1.0325	103.3 ± 4.8
Mn	2.5	30.8	3.825	100.5 ± 5.3

while *Ocimum viride* (OV) is about 84% below the WHO MPL of 0.3 mg/kg. Cadmium toxicity affects multiple organs in the human body, but it primarily accumulates in the kidneys, where it causes severe damage such as lung hyperinflation, renal tubular destruction, vascular immune system disruption, and kidney stones [29]. This study recorded higher levels of Cd compared to that of Nkansah et al. [30] for medicinal herbs from Kumasi, Ghana. Ogbonna et al. [16] recorded a mean Cd concentration of 2.00 mg/kg for medicinal crops from an industrial area in Enyimba City, Nigeria. Kulhari et al. [31] also had Cd values lower than the WHO permissible limit for frequently utilized medicinal plants from Northwestern India. Dinu et al. [32] recorded Cd content higher than the WHO and European Commission's permissible recommended limits for *Ocimum basilicum* L. in a mining contaminated soil.

3.1.3. Chromium (Cr). The mean chromium (Cr) concentration for the study was 3.150 ± 1.078 mg/kg with a range of 2.005 to 6.603 mg/kg. *Newbouldia laevis* (SM) yielded the highest Cr concentration which was about 507% above the World Health Organization maximum permissible limit (MPL), and *Khaya senegalensis* (KS2) had the least mean concentration which is about 30.04% below the World Health Organization (WHO) maximum permissible limit (MPL). Lartey et al. [33] reported a mean Cr concentration of 6.75 mg/kg for *Moringa oleifera* Lam. from selected areas in Accra, Ghana. Abosede et al. [14] recorded a mean Cr concentration lower than the WHO permissible limit for *Piper guineense* leaves collected from three markets in Lagos, Nigeria. Chromium, though an essential element in human metabolism, is also very toxic by inhalation and dermal route, causing lung cancer, nasal irritation, nasal ulcer, and hypersensitivity reactions like contact dermatitis and asthma [34].

3.1.4. Mercury (Hg). From Table 3, all the samples analyzed recorded mercury concentrations lower than the WHO permissible limit of 0.50 mg/kg. The mean Hg concentration was 0.020 ± 0015 with a range of 0.001 to 0.045 mg/kg. *Entandrophragma angolense* (EA) recorded the least mercury (Hg) concentration which was 0.2% of the WHO permissible limit. Annan et al. [35] did not detect any mercury in medicinal crops sampled from different geographical locations in Ghana. Mercury (Hg), especially methylmercury, is known to cause damage to the kidneys and nerves, and it can rupture the placental barrier, causing harm to the fetus [36].

3.1.5. Lead (Pb). The mean concentration of Pb recorded in this study was 6.140 ± 5.933 mg/kg with a range of 0.629 to 26.410 mg/kg. *Alchornea cordifolia* (AC) recorded the highest mean concentration which was 264.1% greater than the WHO maximum permissible limit (MPL) while *Ocimum viride* (OV) recorded the least concentration. Results from this study were higher than those of Nkansah et al. [30] who reported lead concentrations in a range of 0.44 to 0.89 mg/kg for medicinal plants sampled from Kumasi, Ghana. Lead is one of the most toxic heavy metals and has no nutritive value [37, 38]. Progressive exposure to lead results in a decrease in the performance of the nervous system and affects renal clearance [39]. Inorganic lead is also a carcinogen and may cause miscarriage in pregnant women.

3.1.6. Nickel (Ni). The mean nickel (Ni) concentration was determined to be 3.31 ± 63.648 mg/kg with a range of 1.679 to 4.666 mg/kg. All the samples used in this study recorded concentrations lower than the WHO maximum permissible limit (MPL) of 10.0 mg/kg [25]. *Cola nitida* recorded the highest concentration which was 46.7% less than the WHO maximum permissible limit (MPL). *Piper guineense* (PG) had the least nickel (Ni) concentration 1.679 ± 0.002 mg/kg which was 16.8% less than the WHO MPL of 10.0 mg/kg. Baba and Mohammed [40] also recorded levels of Ni below the WHO MPL for medicinal plants sampled from Kano, Nigeria. Mirosławski and Paukszto [41] recorded a mean concentration of Ni (2.29 mg/kg) for Polish medicinal plants and their infusions.

3.1.7. Manganese (Mn). From Table 3, the mean manganese (Mn) concentration was 74.010 ± 63.648 mg/kg with a range of 20.583 to 282.798 mg/kg. Manganese content was high in a few species, including *Alchornea cordifolia* (282.798 ± 0.004 mg/kg) followed by *Paullinia pinnata* (231.174 ± 0.001 mg/kg),*Quassia amara* (QA1) (142.658 ± 0.001 mg/kg), and *Gongronema latifolium* (135.482 ± 0.003 mg/kg). *Alstonia boonei* (AB2) recorded the lowest manganese (Mn) concentration of 20.583 mg/kg. Annan et al. [42] also reported extremely higher levels of Mn in a medicinal plant, *R. vomitoria* (1455 mg/kg).

Table 3: Levels of heavy metals in medicinal plant samples ($n = 20$).

Code	Botanical name	Mean ± SD concentration (mg/kg)						
		Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Mercury (Hg)	Manganese (Mn)	Nickel (Ni)	Lead (Pb)
DS	*Dalbergia saxatilis*	0.361 ± 0.003	0.553 ± 0.002	2.437 ± 0.003	0.012 ± 0.002	33.839 ± 0.002	4.183 ± 0.003	5.855 ± 0.006
AI	*Azadirachta indica*	0.321 ± 0.001	0.626 ± 0.005	2.936 ± 0.002	0.033 ± 0.002	51.244 ± 0.004	3.978 ± 0.002	3.587 ± 0.003
EA	*Entandrophragma angolense*	0.385 ± 0.001	0.492 ± 0.003	3.376 ± 0.002	0.001 ± 0.001	28.247 ± 0.003	3.740 ± 0.001	1.426 ± 0.002
AC	*Alchornea cordifolia*	0.306 ± 0.006	0.714 ± 0.003	3.414 ± 0.004	0.027 ± 0.003	282.798 ± 0.004	4.340 ± 0.005	26.410 ± 0.002
QA1	*Quassia amara*	1.092 ± 0.005	0.723 ± 0.002	4.139 ± 0.003	0.025 ± 0.003	142.658 ± 0.001	2.681 ± 0.002	2.655 ± 0.005
MI	*Mangifera indica*	0.339 ± 0.001	0.649 ± 0.006	2.933 ± 0.001	0.029 ± 0.002	39.133 ± 0.002	2.310 ± 0.002	3.330 ± 0.003
CN	*Cola nitida*	0.574 ± 0.004	0.542 ± 0.001	3.039 ± 0.003	0.013 ± 0.003	74.192 ± 0.003	4.666 ± 0.002	2.162 ± 0.004
QA2	*Quassia amara*	0.408 ± 0.002	0.596 ± 0.002	2.507 ± 0.001	0.004 ± 0.001	35.821 ± 0.003	1.875 ± 0.003	7.111 ± 0.003
KS	*Khaya senegalensis*	0.479 ± 0.003	0.674 ± 0.004	2.005 ± 0.005	0.005 ± 0.001	28.219 ± 0.001	4.552 ± 0.004	13.026 ± 0.003
SJP	*Sphenocentrum jollyanum* Pierre	0.463 ± 0.002	0.601 ± 0.002	4.602 ± 0.001	0.015 ± 0.003	43.594 ± 0.003	2.447 ± 0.005	4.128 ± 0.001
OV	*Ocimum viride*	0.233 ± 0.004	0.253 ± 0.005	3.218 ± 0.002	0.024 ± 0.001	74.119 ± 0.003	2.411 ± 0.002	0.629 ± 0.003
PP	*Paullinia pinnata*	0.383 ± 0.004	1.34 ± 0.000	2.749 ± 0.004	0.024 ± 0.001	231.174 ± 0.001	3.013 ± 0.004	9.899 ± 0.001
TT	*Tetrapleura tetraptera*	0.474 ± 0.006	0.478 ± 0.004	2.406 ± 0.004	0.045 ± 0.001	29.994 ± 0.001	3.859 ± 0.002	2.277 ± 0.004
PG	*Piper guineense*	0.389 ± 0.001	0.709 ± 0.011	2.8 ± 0.001	0.013 ± 0.003	74.097 ± 0.001	1.679 ± 0.002	3.166 ± 0.003
GL	*Gongronema latifolium*	0.306 ± 0.001	0.602 ± 0.005	2.53 ± 0.004	0.010 ± 0.002	135.482 ± 0.003	2.439 ± 0.001	2.577 ± 0.001
MO2	*Moringa oleifera*	0.471 ± 0.003	0.553 ± 0.001	3.47 ± 0.001	0.018 ± 0.002	41.686 ± 0.002	3.116 ± 0.001	2.649 ± 0.003
AB2	*Alstonia boonei*	0.239 ± 0.002	0.416 ± 0.001	2.89 ± 0.004	0.010 ± 0.001	20.583 ± 0.003	3.354 ± 0.002	20.049 ± 0.002
CL	*Citrus limon*	0.493 ± 0.005	0.496 ± 0.005	2.39 ± 0.005	0.014 ± 0.001	36.546 ± 0.001	2.678 ± 0.001	1.728 ± 0.001
MC	*Momordica charantia*	0.206 ± 0.003	0.634 ± 0.005	2.56 ± 0.003	0.005 ± 0.001	36.968 ± 0.003	4.529 ± 0.003	5.823 ± 0.003
NL	*Newbouldia laevis*	1.04 ± 0.006	0.699 ± 0.002	6.60 ± 0.002	0.008 ± 0.001	39.795 ± 0.001	4.279 ± 0.003	4.333 ± 0.004
Mean		0.45	0.62	3.15	0.02	74.01	3.31	6.14
Max		1.09	1.34	6.60	0.045	282.0	4.67	26.4
Min		0.206	0.253	2.005	0.001	20.6	1.68	0.629
Range (max-min)		0.89	1.09	4.59	0.044	262.0	2.99	25.8
WHO MPL		3.0	0.3	1.30	0.5	44.6	10.0	10.0

SD, standard deviation.

Table 4: EDI for adults (mg/kg (BW)/day).

Code	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Mercury (Hg)	Manganese (Mn)	Nickel (Ni)	Lead (Pb)
DS	0.0002	0.0002	0.0010	0.0000	0.0145	0.0018	0.0025
AI	0.0001	0.0003	0.0013	0.0000	0.0220	0.0017	0.0015
EA	0.0002	0.0002	0.0014	0.0000	0.0121	0.0016	0.0006
AC	0.0001	0.0003	0.0015	0.0000	0.1212	0.0019	0.0113
QA1	0.0005	0.0003	0.0018	0.0000	0.0611	0.0011	0.0011
MI	0.0001	0.0003	0.0013	0.0000	0.0168	0.0010	0.0014
CN	0.0002	0.0002	0.0013	0.0000	0.0318	0.0020	0.0009
QA2	0.0002	0.0003	0.0011	0.0000	0.0154	0.0008	0.0030
KS	0.0002	0.0003	0.0009	0.0000	0.0121	0.0020	0.0056
SJP	0.0002	0.0003	0.0020	0.0000	0.0187	0.0010	0.0018
OV	0.0001	0.0001	0.0014	0.0000	0.0318	0.0010	0.0003
PP	0.0002	0.0006	0.0012	0.0000	0.0991	0.0013	0.0042
TT	0.0002	0.0002	0.0010	0.0000	0.0129	0.0017	0.0010
PG	0.0002	0.0003	0.0012	0.0000	0.0318	0.0007	0.0014
GL	0.0001	0.0003	0.0011	0.0000	0.0581	0.0010	0.0011
MO2	0.0002	0.0002	0.0015	0.0000	0.0179	0.0013	0.0011
AB2	0.0001	0.0002	0.0012	0.0000	0.0088	0.0014	0.0086
CL	0.0002	0.0002	0.0010	0.0000	0.0157	0.0011	0.0007
MC	0.0001	0.0003	0.0011	0.0000	0.0158	0.0019	0.0025
NL	0.0004	0.0003	0.0028	0.0000	0.0171	0.0018	0.0018
TDI (mg/kg/day)	0.0021*	0.000833*	0.3**	0.000571*	0.06**	0.0028**	0.00357*

TDI: tolerable maximum daily intake from *Codex Alimentarius WHO/FAO (General Standard for Contaminants and Toxins in Food and Feed, CXS 193-1995) amended in 2019 and **COT (Committee on Toxicity of Chemicals in Food, Consumer Products, and the Environment, TOX/2015/32), 2015.

Table 5: HQ and HI for adults (mg/kg/day).

Code	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Manganese (Mn)	Nickel (Ni)	Lead (Pb)	HI
DS	0.05	0.24	0.001	0.10	0.09	0.63	1.1
AI	0.05	0.27	0.001	0.16	0.09	0.38	0.9
EA	0.06	0.21	0.001	0.09	0.08	0.15	0.6
AC	0.04	0.31	0.001	0.9	0.09	2.8	4.1
QA1	0.16	0.31	0.001	0.4	0.06	0.28	1.2
MI	0.05	0.28	0.001	0.12	0.05	0.36	0.9
CN	0.08	0.23	0.001	0.23	0.10	0.23	0.9
QA2	0.06	0.26	0.001	0.11	0.04	0.8	1.2
KS	0.07	0.29	0.001	0.09	0.10	1.4	1.9
SJP	0.07	0.26	0.001	0.13	0.05	0.4	1.0
OV	0.03	0.11	0.001	0.23	0.05	0.07	0.5
PP	0.05	0.60	0.001	0.70	0.06	1.10	2.5
TT	0.07	0.20	0.001	0.09	0.08	0.24	0.7
PG	0.06	0.30	0.001	0.23	0.04	0.34	1.0
GL	0.04	0.26	0.001	0.4	0.05	0.28	1.0
MO2	0.07	0.24	0.001	0.13	0.07	0.28	0.8
AB2	0.03	0.18	0.001	0.06	0.07	2.1	2.5
CL	0.07	0.21	0.001	0.11	0.06	0.19	0.6
MC	0.03	0.27	0.001	0.11	0.10	0.6	1.1
NL	0.15	0.30	0.002	0.12	0.09	0.5	1.1

3.2. Human Health Risk Assessment of Heavy Metals. The values for the estimated daily intake for all the heavy metals are presented in Table 4. From the EDI values recorded, the intake of these medicinal plants is therefore not likely to pose any significant health risk to the population.

The hazard quotient (HQ) or non-carcinogenic health risk which measures the risk associated with long-term exposure to a particular metal was calculated from the EDI and oral reference dose as shown in Table 5. HQ values >1 are considered to pose a health risk to consumers while those <1 pose no adverse health risk. The HQ values for all the metals were less than 1 except for Pb in four of the medicinal plants, i.e., AC (2.8), KS (1.4), PP (1.1), and AB2 (2.1). The hazard index (HI) measures the cumulative or combined effect of all the hazards of the metals in a particular food. All the medicinal plants recorded HI values between 0.5 and 4.1 with 45% of the plants recording values greater than 1. This implies that the exposed population is not likely to experience adverse health effects if they continue to consume these plants.

Table 6: Cancer risk and estimated cancer risk.

Code	Arsenic (As)	Lead (Pb)	TCR
DS	$2.32E-04$	$2.13E-05$	$2.53E-04$
AI	$2.06E-04$	$1.31E-05$	$2.19E-04$
EA	$2.48E-04$	$5.19E-06$	$2.53E-04$
AC	$1.97E-04$	$9.62E-05$	$2.93E-04$
QA1	$7.02E-04$	$9.67E-06$	$7.12E-04$
MI	$2.18E-04$	$1.21E-05$	$2.30E-04$
CN	$3.69E-04$	$7.88E-06$	$3.77E-04$
QA2	$2.62E-04$	$2.59E-05$	$2.88E-04$
KS	$3.08E-04$	$4.75E-05$	$3.56E-04$
SJP	$2.98E-04$	$1.50E-05$	$3.13E-04$
OV	$1.50E-04$	$2.29E-06$	$1.52E-04$
PP	$2.46E-04$	$3.61E-05$	$2.82E-04$
TT	$3.05E-04$	$8.29E-06$	$3.13E-04$
PG	$2.50E-04$	$1.15E-05$	$2.62E-04$
GL	$1.97E-04$	$9.39E-06$	$2.06E-04$
MO2	$3.03E-04$	$9.65E-06$	$3.13E-04$
AB2	$1.54E-04$	$7.30E-05$	$2.27E-04$
CL	$3.17E-04$	$6.29E-06$	$3.23E-04$
MC	$1.32E-04$	$2.12E-05$	$1.53E-04$
NL	$6.74E-04$	$1.57E-05$	$6.90E-04$

E represents the exponent of 10^{-xy}.

Table 7: Pearson's correlation.

Metal	Arsenic (As)	Cadmium (Cd)	Chromium (Cr)	Mercury (Hg)	Manganese (Mn)	Nickel (Ni)	Lead (Pb)
Arsenic (As)	1.000						
Cadmium (Cd)	0.177	1.000					
Chromium (Cr)	0.672	0.060	1.000				
Mercury (Hg)	0.006	0.085	−0.060	1.000			
Manganese (Mn)	0.014	0.597	0.039	0.298	1.000		
Nickel (Ni)	0.074	−0.003	0.052	−0.047	−0.011	1.000	
Lead (Pb)	−0.245	0.218	−0.095	−0.035	0.471	0.305	1.000

The degree of correlation and relationship between heavy metals was determined using Pearson's correlation in Microsoft Excel 2019. In Table 7, As shows a positive relationship with Cr while Mn shows a positive correlation with Cd. Hg showed negative correlations with Ni and Pb. Weak correlations of As were observed between Cd, Mn, and Ni. The strongly positive relationship between the metals in Table 7 shows strong significant frequent interactions, toxicity profile, and a common source of pollution whereby weak correlations exhibit no strong significant association between the metals' sources of pollution. In addition, the negative correlations represent a non-significant relationship between the metals.

Generally, cancer risk (CR) values lower than $10–^{6}$ are considered negligible, those above 10^{-4} are deemed unacceptable, and those between 10^{-4}–10^{-6} are considered an acceptable range [43]. From Table 6, CR values are all acceptable, meaning that they are not likely to cause cancer if consumers should ingest them for a prolonged period (see Table 7).

4. Conclusion

The levels of heavy metals in twenty medicinal crops were determined. Heavy metals were detected in all the medicinal crop samples selected for this study. Only one medicinal crop sample (OV) recorded cadmium (Cd) level lower than the MPL of 0.3 mg/kg. Chromium (Cr) levels exceeded the WHO maximum permissible limit (MPL) of 1.3 mg/kg in all the samples. However, mercury (Hg), nickel (Ni), and arsenic (As) levels in all the samples were below the WHO permissible limits of 0.5, 10.0, and 3.0 mg/kg, respectively. Forty and fifteen percent of the samples recorded levels higher than the WHO permissible limit for Mn and Pb, respectively. EDI values were below their recommended tolerable intake values for all the samples. HQ values were also lower than 1. Carcinogenic risk values were in the range deemed acceptable (10^{-4}) for human consumption, indicating no potential long-term adverse health risk to consumers.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Flora Amarh was responsible for conceptualization and methodology. Eric Selorm Agorku was responsible for original draft preparation. Ray Voegboelo was responsible for supervision. Gerheart Ashong was responsible for software. Napoleon Mensah was responsible for validation. Enoch Nortey was responsible for data curation.

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