ASSESSMENT OF THE POTENTIAL HEALTH RISKS ASSOCIATED WITH THE CONSUMPTION OF VEGETABLE PLANTS CONTAMINATED BY TRACE METALS (TMS): CASE OF MARKET GARDENING AROUND ANTANANARIVO

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ABSTRACT

In many large Western cities, urban farmers are increasingly accepted and valued. In and around the city of Antananarivo, market gardening continues to develop. The present study contributes to the preservation of the sanitary quality of the foodstuffs grown there. Thus, samples of market garden plants were collected in the city of Antananarivo. Metallic trace elements (TM) contents were determined by X-ray fluorescence spectrometry (XRF). The exposure of adult consumers to TMs in these plants was calculated and the potential health risks associated with them were assessed. A critical contamination of vegetable plants among the most consumed by the population was recorded. TMs are distributed in different ways among the edible organs of these plants, some of which are more accumulative than others. The exposure of adult consumers to each of these contaminants was below tolerable reference doses. However, total risk quotients (THQ) values associated with all the studied TMs are higher than 1 and suggest the presence of a health risk for consumers. Conservation measures for the quality of the environment and vegetable plants are possible.

Keyword: *Health risks, Metallic trace elements, Contamination, Vegetable plants, Antananarivo, Consumers*.

1. INTRODUCTION

A global concern to limit carbon footprints has led to the adoption of various solutions such as local food sourcing to limit distribution and transportation costs. In several large Western cities, urban farmers are increasingly accepted and valued. Among others, in Singapore City, the cultivation of crops on the roofs of buildings and agricultural towers are practiced. In the city of Antananarivo, market gardening in the vicinity and even within the city continues to develop. In a previous study, higher concentrations of TMs in the soils of the city of Antananarivo, particularly in soils used for agriculture (SUA), than those found elsewhere were recorded[1], even though they are systematically transmitted to plants by the root system. The presence of TMs in plant foods contributes, however, to the risks of food safety[2]; and their accumulation in these types of foodstuffs thus puts at risk the health of consumers[3]. Indeed, these contaminants can accumulate in the body.

TMs are minerals that are naturally present in the earth's crust but can also be generated by human activities. They are classified into two main categories: essential minerals and toxic minerals[4]. On one hand, those of the first category are essential for the proper functioning of the organism of living beings, including humans, at minimal quantities but they become toxic when the quantities ingested exceed the admissible safety threshold. Nickel (Ni) is one of these essential nutrients for the body. On the other hand, non-essential TMs, such as cadmium (Cd) and lead (Pb), play no role in the body and are toxic at minute amounts ingested over the long term.

According to the literature, excess exposure to Ni led to a high risk of neurodegeneration[5]. Furthermore, Cd and Pb have been implicated as risk factors for renal cell carcinoma, among others[6]. In particular, Cd is a carcinogen and a bio accumulative contaminant[7]; its accumulation in the body is also an important risk factor for the development of cardiovascular diseases[8]. It modulates gene expression and signal transduction, and reduces the activities of proteins involved in antioxidant defense, interfering with deoxyribonucleic acid (DNA) repair and modifying cancer development and brain function [9]. In addition, Cd has a positive correlation with cytotoxicity in cell lines[10]. As for Pb, it is known as a metal with high neurotoxicity in children[7].

In addition, according to a study conducted by Wang *et al.*, the HI (Hazard Index) for vegetables and products grown near mining and metal smelting areas was greater than 1, revealing a higher health risk for local children near these areas[11]. Another study found an individual risk index for Cd and chromium (Cr) in plants such as cabbage, carrot, green bell pepper, onion and tomato indicates the presence of potential risk in both children and adults[3]. On the other hand, according to other authors, the high concentration of TMs such as Cr and Ni in the vicinity of the residences of patients with chronic kidney disease (CKD) was associated with diagnoses of hypertension, diabetes mellitus and stroke; and patients with long term exposure to heavy metals from the soil showed rapid progression to end-stage renal disease[12]. Other authors have demonstrated the presence of a concomitance of heavy metal imbalance associated with Alzheimer's disease (AD) more than in other neurodegenerative pathologies, such as multiple sclerosis (MS); moreover, the concentration of these elements is independent of the occasional or habitual consumption of fruits and vegetables[13].

In Madagascar, it is known that many people suffer from renal failure but the causes of this pathology are not identified. Since TMs are toxicants with cumulative characteristics, and the kidneys are particularly their storage organs, these cases of chronic kidney disease (CKD) could be associated with consumption of foods highly contaminated with these minerals.

The objective of this study is to provide data on the exposure of consumers to TMs from agricultural vegetables in the city of Antananarivo and on the potential health risk associated with this consumption. It contributes to the preservation of the sanitary quality of food grown in the city of Antananarivo and its peripheries.

2. METHODOLOGY

2.1 Collection and preparation of samples

Sixty samples from twelve species of vegetable plants grown in the city of Antananarivo were collected (Figure 1). These include in particular: *Allium ampeloprasum* (Leek), *Allium schoenoprasum* L. (Chives), *Apium graveolens* (Celery), *Brassica chinensis* (Tisam), *Brassica chinensis jusl var parachinensis* (Pe-Tsaï), *Brassica oleracea* (Cabbage), *Brassica rapa subsp. pekinensis* (Cabbage-Pe-Tsai), *Colocasia esculenta* (Taro - Leaf and Tuber), *Ipomoea batatas* (Sweet Potato - Leaf), *Lactuca sativa* (Salad), *Nasturtium officinale* (Watercress) and *Solanum tuberosum* (Potato - Leaf and Stem). The samples were rapidly transported to the laboratory in isothermal bags, washed as consumed, separated according to edible organs (Leaf, Root, Stem and Tuber), weighed, dried at 85°C for 72 hours, reweighed and ground before TMs evaluations.

2.2 Analysis of TMs in vegetable plants

Eighty-two samples divided into nineteen groups of edible organs of vegetable plants were analyzed by X-ray Fluorescence Spectrometry (Portable XRF - Niton XL3 analyzer). Each sample was analyzed once with XRF for 800 seconds; this time allows the detection of the TMs studied in this work and to obtain the most accurate results possible while eliminating background noise as much as possible. Four TMs including Cd, Cr, Ni and Pb were particularly studied. The analytical material was calibrated with analytical data from vegetable plant samples obtained on Flame Atomic Absorption Spectroscopy (FAAS) ; AIEA 336 (Lichen)[14] was used as a reference for these analyses on (FAAS).

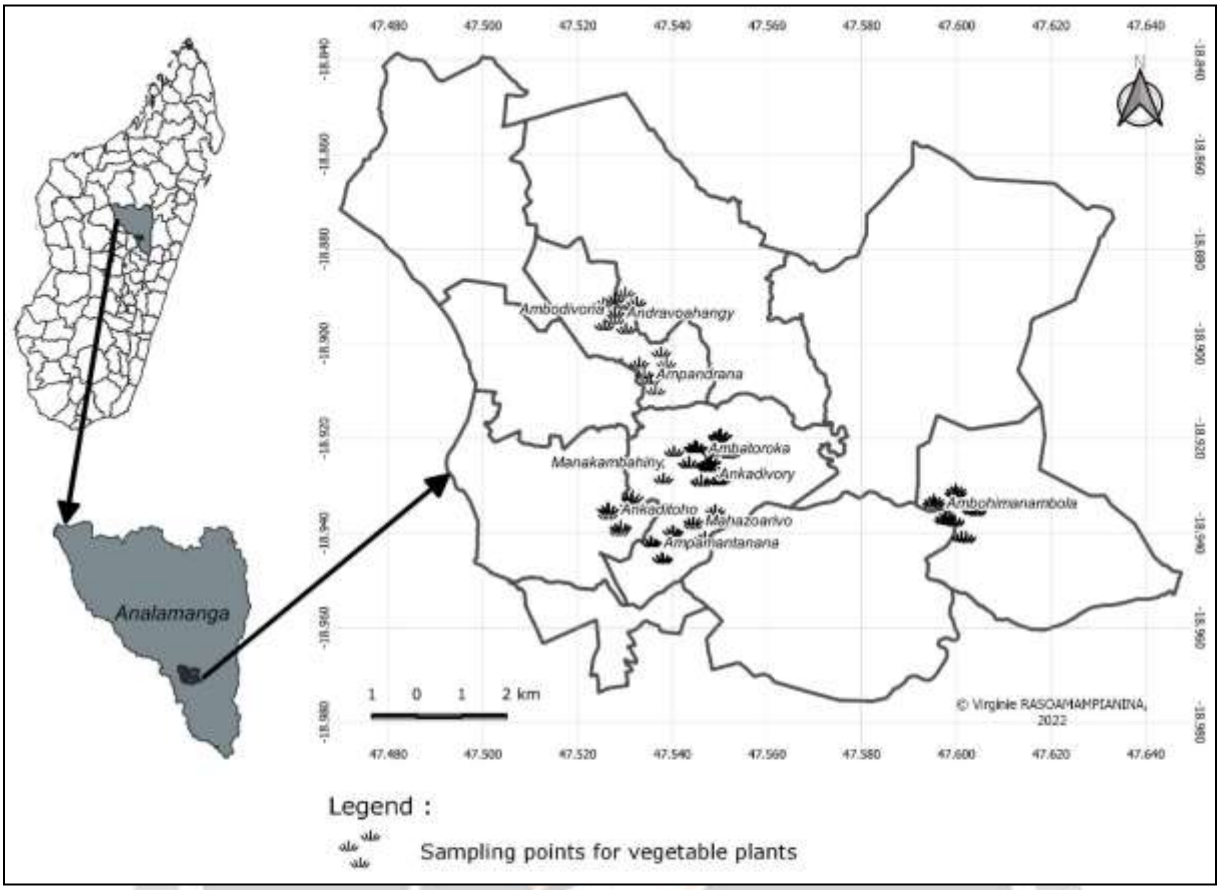

Figure 1: Study site

2.3 Evaluation of the potential health risks associated with the consumption of vegetable plants contaminated by TMs

The daily exposure doses (DED) and the hazard quotient (HQ) for each TM and the total hazard quotient (THQ)[15] for Cd, Cr, Ni and Pb were calculated. Some authors define the hazard quotient as target hazard quotient (THQ) and the sum of the THQs including all the elements studied, as Total metal THQ (THQT)[16], [17]. However, in this work, the HQ (hazard quotient) and the THQ (total risk quotient) were calculated.

DEDs can be equated to average daily intakes (ADIs) according to Peng et al. in 2018[18] and were expressed in µg/kg body weight/day and calculated for each organ of the different vegetable plants according to the following formula:

$$ADI = \frac{Cp * Cf * Ir * Ef * Ed}{Bw * At}$$

Where *ADI* represents the DED; *Cp*, the concentrations of TMs in vegetable plants (µg/g of dry matter). *Cf* represents the conversion factor from fresh weight to dry weight and is obtained by calculating the ratio of fresh weight to dry weight of each of the 19 edible organs of the different vegetable plants. *Ir* represents the ingestion rate (daily consumption) which is calculated, in this study, from the Food and Agriculture Organization of the United Nations (FAO) food availability data in 2018: the amount of vegetables available in Madagascar is 14.6 kg per person per year[19]; the daily consumption of vegetable plants was thus estimated at 0.04 kg per person per day. The recommended potato consumption of 100g[18] was also used as a reference for the amount of vegetable plant ingested in the case of a higher intake by certain groups of consumers. *Ef* represents the frequency of exposure (365 days/year); *Ed*, the duration of exposure (~60 years in Madagascar); *Bw*, the body weight (~60 kg); and *At*: the average time of exposure (60 years = 21900 days).

The hazard quotient is given by the following equation:

$$HQ = \frac{DED}{TDI}$$

Where TDI represents the tolerated daily intake. This was calculated from the toxicological reference values[20]–[23] (Table 1).
The total risk quotient (THQ) results from the sum of HQ for each TM. There is a potential health risk to consumers when the THQ is greater than or equal to 1[15]–[17].

Table 1: Toxicological reference values and tolerated daily doses of TMs

TM	Toxicological reference values				TDD (tolerated daily doses after calculation)		
	Tolerated Dose	**Value**	**Unit**	**Source**	**TDI**	**Unit**	**TDI(µg/kg bw/day**
Cd	PTMI	25	µg/kg bw/month	[20]	0.833	µg/kg bw/day	0.83
Cr : Cr(III)	TDI	0.3	mg/kg bw/day	[21]	0.300	mg/kg bw/day	300.00
Ni	TDI	2.8	µg/kg bw/day	[22]	2.800	µg/kg bw/day	2.80
Pb	PTWI	0.025	mg/kg bw/week	[23]	0.004	mg/kg bw/day	3.57

TM: Trace metals; PTMI: Provisional tolerable monthly intake, TDI: Tolerable daily intake, PTWI: Provisional tolerable weekly intake.

3. RESULTS

3.1 TM contents in samples

Table 2 summarizes the means and standard deviations of TM concentrations ordered in ascending order by edible organs of the different vegetable plants analyzed.

3.1.1 Cd concentrations

That of *S. tuberosum* stems is the highest (1.93±0.16 mg/kg of dry matter) and that of *C. esculenta* tubers is the lowest (0.27±0.04 mg/kg of dry matter). After *S. tuberosum* Stems, *A. graveolens* Stems and *S. tuberosum* leaves contain the most Cd with contents equal to 1.50±0.21 mg/kg of dry matter and 1±0.08 mg/kg of dry matter respectively.

3.1.2 Cr concentrations

That of *A. graveolens* Roots is the highest (7.39±0.78 mg/kg of dry matter) and that of *C esculenta* Tubers is the lowest (2.85±0.6 mg/kg of dry matter). After *A. graveolens* Roots, *A. graveolens* Stems and *A. shoenoprasum* Leaves contain the most Cr with contents equal to 7.20±0.31 mg/kg of dry matter and 7.05±1.29 mg/kg of dry matter respectively.

3.1 3 Ni concentrations

That of *C. esculenta* Leaves is the highest (19.10±17.23 mg/kg ms) and that of *A. ampeloprasum* Stems is the lowest (2.72±0.50 mg/kg ms). After *C. esculenta* leaves, *A. shoenoprasum* stems and *A. graveolens* roots contain the most Ni with respective contents equal to 18.09±5.07 mg/kg ms and 17.54±11.99 mg/kg ms.

3.1.4 Pb concentrations

That of *S. tuberosum* Leaves was the highest (5.47±0.91 mg/kg ms) and that of *S. tuberosum* Stems was the lowest (2.97±0.59 mg/kg ms). After *S. tuberosum* Leaves, *B. oleracea* Leaves and *C. esculenta* Leaves contain the most Pb with contents equal to 5.02±0.76 mg/kg dm and 4.99±1.44 mg/kg dm respectively.

Table 2: Means and standard deviations of TME concentrations in increasing order of edible organs from different vegetable plants

TM contents (mg/kg of dry matter)				Cd			Cr			Ni			Pb		
Plante-Organe	**Id**	**N**	**Lev**	**Id**	**M**	**SD**	**Id**	**M**	**SD**	**Id**	**M**	**SD**	**Id**	**M**	**SD**
A. graveolens - Leaf	**1**	5	1	**17**	0.27	0.04	**17**	2.85	0.60	**12**	2.72	1.35	**14**	2.97	0.59
A. graveolens - Root	**2**	4	2	**12**	0.31	0.06	**4**	2.96	0.34	**17**	2.78	0.50	**17**	2.98	0.04
A. graveolens - Stem	**3**	4	3	**7**	0.31	0.01	**12**	3.34	0.81	**18**	4.25	4.33	**6**	3.27	0.62
B. oleracea - Leaf	**4**	3	4	**9**	0.50	0.17	**9**	4.36	0.67	**9**	4.45	2.36	**12**	3.29	0.68
B. rapasubsp. pekinensis - Leaf	**5**	3	5	**4**	0.52	0.10	**11**	4.43	0.34	**4**	4.80	3.60	**5**	3.35	0.70
A. schoenoprasum - Leaf	**6**	3	6	**16**	0.53	0.08	**18**	4.67	0.58	**13**	5.82	1.44	**19**	3.48	0.53
A. schoenoprasum - Stem	**7**	3	7	**11**	0.58	0.05	**10**	4.81	0.80	**19**	6.16	0.78	**1**	3.63	0.26
N. officinale - Leaf	**8**	9	8	**6**	0.68	0.05	**19**	4.84	1.00	**11**	6.28	1.38	**15**	3.65	0.48
I. batatas - Leaf	**9**	7	9	**18**	0.74	0.14	**8**	5.34	0.82	**5**	6.54	1.53	**8**	3.72	0.85
B. chinensisjusl var parachinensis - Leaf	**10**	7	10	**1**	0.74	0.05	**5**	5.36	0.35	**10**	8.06	2.74	**18**	4.01	0.53
A. ampeloprasum - Leaf	**11**	5	11	**2**	0.81	0.09	**1**	5.38	0.29	**1**	8.06	2.23	**3**	4.04	0.95
A. ampeloprasum - Stem	**12**	5	12	**8**	0.84	0.16	**15**	5.49	0.76	**8**	8.43	2.72	**7**	4.05	0.28
S. tuberosum - Leaf	**13**	3	13	**5**	0.87	0.09	**13**	5.52	0.17	**15**	8.59	3.45	**11**	4.32	1.96
S. tuberosum - Stem	**14**	2	14	**19**	0.88	0.36	**16**	6.15	2.35	**14**	12.86	0.33	**2**	4.41	0.82
L. sativa - Leaf	**15**	4	15	**15**	0.89	0.14	**7**	6.85	1.23	**3**	13.01	2.73	**10**	4.51	1.10
C. esculenta - Leaf	**16**	4	16	**10**	0.95	0.30	**14**	6.87	0.29	**6**	15.45	5.92	**9**	4.74	1.47
C. esculenta - Tuber	**17**	3	17	**13**	1.00	0.08	**6**	7.05	1.29	**2**	17.54	11.99	**16**	4.99	1.44
B. chinensis - Leaf	**18**	4	18	**3**	1.50	0.21	**3**	7.20	0.31	**7**	18.09	5.07	**4**	5.02	0.76
B. chinensis - Stem	**19**	4	19	**14**	1.93	0.16	**2**	7.39	0.78	**16**	19.10	17.23	**13**	5.47	0.91
Total		**82**			**0.76**	**0.36**		**5.20**	**1.45**		**8.65**	**6.72**		**4.04**	**1.09**

Id : identifier, **N** : number, **Lev.** : level of contamination, **M** : mean, **SD**: standard deviation. he edible organs of the different vegetable plants are identified from "Id 1" to "Id 19", and the average TM concentrations are ordered in ascending order from « Level 1 » to « Level 19 ».

3.2 Risk assessment

Tables 3, 4 and 5 summarize respectively the *Cf* from fresh weight to dry weight of each edible organ of the vegetable plants, the values of the TDI and the values of the HQ and THQ related to the consumption of vegetable plants cultivated in the city of Antananarivo. For a consumption of 40 to 100g per day of vegetable plants, the exposure (DED) of adult consumers (body weight: 60kg, average age = 60years) to the studied contaminants (Cd, Cr, Cu, Ni, Pb and Zn) was lower than the tolerable reference doses (tolerated daily doses or TDI); and the values of the hazard quotients (HQ) recorded are all lower than 1 except for Ni for a daily consumption of 100g of *A. graveolens* Root or *C. esculenta* Leaf where the HQ values are 1.563 and 2.116 respectively. Total risk quotients or THQ values related to the four studied TMs were, on the other hand, found with several edible organs of vegetable plants, particularly, if the daily amount of vegetable plants ingested is equal to 100g.

Table 3: Conversion factors (Cf) from fresh weight to dry weight of each edible organ of different vegetable

Plants

Edible organs of different vegetable plants	Conversion factor - *Cf*		Edible organs of different vegetable plants	Conversion factor - *Cf*
A. graveolens - Leaf	0.199		*A. ampeloprasum* - Leaf	0.088
A. graveolens - Root	0.150		*A. ampeloprasum* - Stem	0.132
A. graveolens - Stem	0.096		*S. tuberosum* - Leaf	0.117
B. oleracea - Leaf	0.136		*S. tuberosum* - Stem	0.044
B. rapasubsp. pekinensis - Leaf	0.094		*L. sativa* - Leaf	0.054
A. schoenoprasum - Leaf	0.034		*C. esculenta* - Leaf	0.186
A. schoenoprasum - Stem	0.051		*C. esculenta* - Tuber	0.295
N. officinale - Leaf	0.058		*B. chinensis* - Leaf	0.081
I. batatas - Leaf	0.176		*B. chinensis* - Stem	0.033
B. chinensisjusl var parachinensis - Leaf	0.106			

Table 4: Daily exposure doses (DED) of consumers to TMs in vegetable plants analyzed

Vegetable plants - Organ	Consumer exposure to TMs from vegetable plants analyzed (µg/kg bw/day)								
	Daily intake = 40g					Daily intake = 100g			
	Cd	Cr	Ni	Pb		Cd	Cr	Ni	Pb
A. graveolens - Leaf	0.099	0.715	1.071	0.482		0.247	1.788	2.678	1.206
A. graveolens - Root	0.081	0.737	1.750	0.440		0.202	1.843	4.376	1.100
A. graveolens - Stem	0.095	0.459	0.831	0.258		0.239	1.149	2.076	0.645
B. oleracea - Leaf	0.047	0.268	0.434	0.454		0.118	0.669	1.085	1.135
B. rapasubsp. pekinensis - Leaf	0.055	0.336	0.410	0.210		0.136	0.839	1.024	0.524
A. schoenoprasum - Leaf	0.015	0.160	0.351	0.074		0.038	0.400	0.878	0.186
A. schoenoprasum - Stem	0.011	0.232	0.613	0.137		0.026	0.580	1.533	0.343
N. officinale - Leaf	0.033	0.207	0.327	0.144		0.082	0.518	0.818	0.360
I. batatas - Leaf	0.059	0.511	0.522	0.556		0.148	1.278	1.305	1.390
B. chinensisjusl var parachinensis - Leaf	0.067	0.338	0.567	0.317		0.167	0.845	1.417	0.793
A. ampeloprasum - Leaf	0.034	0.261	0.370	0.255		0.085	0.653	0.926	0.637
A. ampeloprasum - Stem	0.027	0.294	0.239	0.289		0.067	0.734	0.597	0.724
S. tuberosum - Leaf	0.079	0.432	0.456	0.428		0.196	1.080	1.139	1.069
S. tuberosum - Stem	0.057	0.203	0.381	0.088		0.143	0.508	0.953	0.220
L. sativa - Leaf	0.032	0.198	0.309	0.131		0.080	0.494	0.773	0.329

C. esculenta - Leaf	0.066	0.763	2.369	0.620		0.165	1.906	5.923	1.549
C. esculenta - Tuber	0.053	0.561	0.547	0.587		0.133	1.403	1.368	1.467
B. chinensis - Leaf	0.040	0.251	0.228	0.215		0.100	0.626	0.571	0.538
B. chinensis - Stem	0.019	0.107	0.136	0.077		0.049	0.268	0.341	0.192
Total	0.057	0.389	0.647	0.302		0.141	0.971	1.616	0.754

Table 5 : Hazard quotient (HQ) and total hazard quotient (THQ) for TMs in vegetable plants analyzed

Plant-Organ	Daily intake= 40g					Daily intake= 100g				
	HQ (value)				THQ	HQ (value)				THQ
	Cd	Cr	Ni	Pb		Cd	Cr	Ni	Pb	
A. graveolens - Leaf	0.119	0.002	0.383	0.135	0.639	0.297	0.006	0.957	0.338	1.597
A. graveolens - Root	0.097	0.002	0.625	0.123	0.848	0.242	0.006	1.563	0.308	2.119
A. graveolens - Stem	0.115	0.002	0.297	0.072	0.485	0.286	0.004	0.742	0.181	1.212
B. oleracea - Leaf	0.056	0.001	0.155	0.127	0.339	0.141	0.002	0.387	0.318	0.848
B. rapasubsp. pekinensis - Leaf	0.065	0.001	0.146	0.059	0.271	0.164	0.003	0.366	0.147	0.679
A. schoenoprasum - Leaf	0.018	0.001	0.125	0.021	0.165	0.046	0.001	0.313	0.052	0.413
A. schoenoprasum - Stem	0.013	0.001	0.219	0.038	0.271	0.032	0.002	0.547	0.096	0.677
N. officinale - Leaf	0.039	0.001	0.117	0.040	0.197	0.098	0.002	0.292	0.101	0.493
I. batatas - Leaf	0.071	0.002	0.186	0.156	0.415	0.177	0.004	0.466	0.389	1.037
B. chinensisjusl var parachinensis - Leaf	0.080	0.001	0.202	0.089	0.373	0.201	0.003	0.506	0.222	0.932
A. ampeloprasum - Leaf	0.041	0.001	0.132	0.071	0.245	0.102	0.002	0.331	0.178	0.613
A. ampeloprasum - Stem	0.032	0.001	0.085	0.081	0.200	0.081	0.002	0.213	0.203	0.499
S. tuberosum - Leaf	0.094	0.001	0.163	0.120	0.378	0.236	0.004	0.407	0.299	0.945
S. tuberosum - Stem	0.069	0.001	0.136	0.025	0.230	0.172	0.002	0.340	0.062	0.575
L. sativa - Leaf	0.038	0.001	0.110	0.037	0.186	0.096	0.002	0.276	0.092	0.466
C. esculenta - Leaf	0.079	0.003	0.846	0.173	1.101	0.198	0.006	2.116	0.434	2.753
C. esculenta - Tuber	0.064	0.002	0.195	0.164	0.426	0.160	0.005	0.488	0.411	1.064
B. chinensis - Leaf	0.048	0.001	0.082	0.060	0.190	0.120	0.002	0.204	0.151	0.476
B. chinensis - Stem	0.023	0.000	0.049	0.022	0.094	0.058	0.001	0.122	0.054	0.235
Total	0.068	0.001	0.231	0.084	0.385	0.170	0.003	0.577	0.211	0.962

4. DISCUSSION

Numerous investigations on the accumulation of TMs by plants have already been conducted. For example, vegetables such as tomatoes, peppers, white radishes and asparagus have shown low accumulation characteristics of hazardous TMs including Cd, Cr and Pb[11]. Our study concerns different vegetable plants that are among the most consumed by the population in Madagascar. Globally, the concentrations in mg/kg dm of the TMs in the vegetable plants analyzed were in the following order: Ni: 8.65±6.72 > Cr: 5.2±1.45 >Pb: 4.04±1.09 > Cd: 0.76±0.36 (see Table 3). According to Table 6, the Cd contents of *A. graveolens* (stem vegetables) and the Pb contents of all the samples are particularly higher than the levels recommended by the Codex Alimentarius for the different categories of plants if we take into account the values in fresh weights (i.e. contents in mg/kg ms * Cf); those of *A. ampeloprasum* are at the limit of the maximum recommended levels[24].

Table 6 : Average TM contents calculated in relation to the fresh weight of vegetable plants

Plant -Organ	Cf	Contents in mg/kg of fresh matter			
		Cd	Cr	Ni	Pb
A. graveolens - Leaf	0.199	0.148	1.073	1.607	0.724
A. graveolens - Root	0.150	0.121	1.106	2.626	0.660
A. graveolens - Stem	0.096	0.143	0.689	1.246	0.387
B. oleracea - Leaf	0.136	0.071	0.402	0.651	0.681
B. rapasubsp. pekinensis - Leaf	0.094	0.082	0.503	0.614	0.314
A. schoenoprasum - Leaf	0.034	0.023	0.240	0.527	0.111
A. schoenoprasum - Stem	0.051	0.016	0.348	0.920	0.206
N. officinale - Leaf	0.058	0.049	0.311	0.491	0.216
I. batatas - Leaf	0.176	0.089	0.767	0.783	0.834
B. chinensisjusl var parachinensis - Leaf	0.106	0.100	0.507	0.850	0.476
A. ampeloprasum - Leaf	0.088	0.051	0.392	0.555	0.382
A. ampeloprasum - Stem	0.132	0.040	0.440	0.358	0.434
S. tuberosum - Leaf	0.117	0.118	0.648	0.683	0.642
S. tuberosum - Stem	0.044	0.086	0.305	0.572	0.132
L. sativa - Leaf	0.054	0.048	0.296	0.464	0.197
C. esculenta - Leaf	0.186	0.099	1.144	3.554	0.929
C. esculenta - Tuber	0.295	0.080	0.842	0.821	0.880
B. chinensis - Leaf	0.081	0.060	0.376	0.342	0.323
B. chinensis - Stem	0.033	0.029	0.161	0.205	0.115
Total	0.112	0.085	0.583	0.970	0.453

One study showed that the hazard index of the inhabitants related to the four TMs in soil is in the following order: Cr >Pb> Cd > Ni [28]. In the present work, the consumer hazard quotient for the vegetable plants analyzed is in the following order: Ni >Pb> Cd > Cr. This magnitude can be partly explained by the translocation of TMs from soils to crop plants and their accumulation in the latter in different ways, mainly in the edible organs. Our results corroborate those of the literature[15], [25] with daily doses of exposure to TMs in plant foods that are below the permissible or tolerable doses and exposure, particularly to Ni, exceeding the health guide value[26]. HQs for Cr are generally very low. Nevertheless, the results of the present work suggest, in addition, the need for a complete study of the total diet, given the THQ values generally higher than 1. Indeed, the latter suggest the presence of a potential health risk for consumers by consuming, in this case, the Leaves, Roots and Stems of *A. graveolens*, the Leaves of *I. batatas* and the Leaves and Tubers of *C. esculenta*. The THQ values for the Leaves of *S. Tuberosum*, *B. chinensis jusl var parachinensis*, and *B. oleracea* are very close to 1 even though these edible organs of vegetable plants do not yet present a hazard to consumers in terms of contamination by the four studied TMs.

The literature commonly uses a *Cf* equal to 0.085[18], [27]–[29] but for this study, the use of a specific *Cf* to each edible organ of the vegetable plants analyzed allowed to obtain more reliable risk assessment results (HQ and THQ). Nevertheless, particularly for Madagascar, according to the Food and Agriculture Organization of the United Nations (FAO) statistical data in 2018, the amount of vegetables available is at 14.6 kg per person per year [19]; the estimated vegetable consumption of 40g per person per day is thus clearly low. Thus, although the

levels of TMs in vegetable plants are high, the calculated TM HQs associated with their consumption are all underestimated (less than 1). In addition, food consumption, including vegetable plants, is not the only route of exposure to TMs, while the amount ingested used in this study is not valid for heavy consumers, including vegetarians, vegans, and people with low income sources, who consequently have greater health risks from consuming contaminated food.
Exposure through ingestion of TMs or high levels of these contaminants as well as deficiency of essential elements for the body can however be toxic. Studies conducted at the international level have also shown that TMs can be carcinogenic to humans. In 2019, a review on the link between chronic exposure to toxic metals and Alzheimer's disease (AD) stated that there is already a considerable amount of evidence establishing a positive relationship between toxic metal exposure and AD pathogenesis, as the accumulation of toxic metals in the brain has been shown to result in neurodegenerative effects[30]. In cell and animal model systems, Cd and Pb are among the neurotoxicants contributing to canonical AD pathologies; similarly, epidemiological studies in adults have consistently shown that Cd and Pb are associated with impaired cognitive function and cognitive decline, and two studies have reported an association between cadmium and AD mortality[31]. Furthermore, serum Cd and Pb concentrations were significantly higher in patients with obstructive pulmonary disease (OPD) compared to normal control subjects; Cd also appeared to partially mediate the association between smoking and OPD: a dose-response effect between increasing cadmium concentration and progressive deterioration of lung function was observed in smokers[32]. Recent publications have also shown that co-exposure to Mo and Cd could synergistically induce nephrotoxicity by inducing disturbances of calcium homeostasis and autophagy in ducks[33], and exposure to Ni, in electronic waste, led to a high risk of neurodegeneration in residents[5]. For this reason, tolerated doses are set at the international level; among others, those of the joint FAO/WHO committee. These requirements are systematically monitored in many countries.

5. CONCLUSION

This study provided information on the levels of TM contamination (Cd, Cr, Ni and Pb) in edible organs of vegetable plants grown in the vicinity of Antananarivo, as well as data on exposure to TMs and the potential health risk associated with the consumption of these foods. The results allowed to understand that some edible organs of vegetable plants contain particularly more TMs than others. In addition, the TDIs of adult consumers to the studied TMs were lower than the tolerable reference doses used. No health risk was recorded for them considering the HQ values related to each TM of the edible organs of the analyzed plants. However, THQ values associated to all four studied TMs are higher than 1 and suggest the presence of a potential health risk for consumers by consuming some edible organs of vegetable plants. Taking into account the contamination and the preservation of the quality of soils and foodstuffs cultivated on the soils of Antananarivo should be part of the collective concerns to ensure the sanitary security and the sustainable supply of these foodstuffs and the protection of the health of consumers. Hence, the need for remediation measures for soils contaminated by TMs in order to limit as much as possible the transfer of these contaminants into these foodstuffs. For the plants more accumulative of TMs, it would be necessary to consume preferably the edible organs which accumulate less TMs. Thus, it is necessary to classify the vegetable plants according to the factors of bioaccumulation of the TM. In Madagascar, however, the assessment of potential health risks related to consumer exposure to TMs is not yet well developed. Until now, although tools for the rational management of chemicals, including TMs, are being put in place, due to the lack of up-to-date data in the country, it remains difficult to raise awareness of these contaminants that can alter the sanitary quality of foodstuffs, particularly vegetable plants. However, the results recorded on the contamination of vegetable plants by TMs have shown high levels of certain TMs. These results suggest the importance of taking action to reduce health risks to consumers and serve as a reference for future food safety research in the country. Country-specific TDIs may be adopted as a result of this research, especially since some of the reference values used are provisional. However, to obtain realistic TM exposure data, more detailed consumer surveys are needed to determine the exact amount of vegetable plants ingested by all categories of consumers. In addition, special measures to raise public awareness of the potential health risks associated with the consumption of food contaminated with TMs are needed.

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