Initial Assessment of Heavy Metals in Urban Farming Produce

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ABSTRACT

The study investigated the levels of heavy metals (Hg, As, Cd, Cr, Pb) in frequently consumed vegetables in urban and rural farms in the Philippines and assessed their associated health risks. Results revealed that the Hg concentration was at method detection limit (MDL), while for other heavy metals, the values ranged from <MDL to 0.09 mg/kg (As), <MDL to 0.03 mg/kg (Cd), <MDL to 0.30 mg/kg (Cr), and <MDL to 0.29 mg/kg (Pb). The total metal content in the samples followed the order: Pb>Cr>As>Cd>Hg. Single factor ANOVA demonstrated a significant difference ($\alpha = 0.05$) between urban and rural sites. Assessment of non-carcinogenic risk by combined impact of all metals (Hazard Index, HI) indicated no concern (<1) for both adults and children for Hg, Cd, Cr and Pb except for As in taro and red chili (HI: 1.2 – 1.9) from specific urban sites. The carcinogenic risk by Target Cancer Risk (TCR) assessment was >10E−5 (USEPA limit) for As (1.8E-4 to 7.9E-4) and Cr (1.2E−4 to 1.2E-3) exposing future risk from long-term consumption of contaminated vegetables. While urban farming produce can serve as food source for the community, review of regulatory measures is recommended to avert potential health risks.

Keywords: heavy metals, urban farming, health risk assessment, maximum allowable level, Philippines

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INTRODUCTION

As a developing country, urbanization in the Philippines has grown relatively faster in recent years along with increasing population, especially in Metro Manila and nearby suburbs. Urbanization promises economic advancement; however, it also causes changes in the physical and human environment. For example, it decreases land areas needed for food production. Food security and nutrition, especially of the marginalized sector of urban communities, need to be addressed. A promising strategy to deal with such issues is through urban agriculture or farming. In the context of socio-economic factors and environmental sustainability, urban farming has been considered as a means of sustaining development in urban areas that would contribute to a green economy. In urban farming, organic and innovative gardening and agriculture methods are used instead of synthetic and solid mineral fertilizers. Some of the benefits that can be derived from urban farming are improved human health, betterment of the community as it will supply its own food and as an income generating activity, as well as protection of the environment (Izquierdo et al. 2015).

In Metropolitan Manila, then Quezon City Vice Mayor Joy Belmonte adopted urban farming in 2010 through a project called "Joy of Urban Farming" in cooperation with the Department of Education (DepEd), the Department of Agriculture (DA), and Department of Environment and Natural Resources (DENR). It started with three pilot sites within the Quezon Memorial Circle and has now grown to 166 areas and continues to expand. It aims to "spread green thumbs among city dwellers by creating urban farms that focus on organic produce and innovative gardening methods" (Diega 2018).

However, urban agriculture has its own drawbacks. There are risks to human health linked to practices used in urban farming, such as the ingestion of toxic heavy metal pollutants in agricultural produce grown in urban soils that are potentially contaminated due to anthropogenic causes (i.e., urbanization and industrialization).

Food consumption is a major pathway of human exposure to certain environmental contaminants, accounting for >90% of intake compared to inhalation or dermal routes of exposure (Fries 1995). Soil contamination is prevalent in industrialized and urbanized areas. Toxic heavy metals, such as cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg), have been reported to be present in vegetable produce from urban farming around Kampala City, Uganda (Nabulo et al. 2010). Similar findings were reported elsewhere such as the contamination of heavy metals in cucumber samples produced using three different farming methods (i.e., organic, greenhouse and conventional) in Giza City, Egypt (Mansour et al. 2009). Heavy metals such as Cr and Pb were also found in vegetable produce from urban gardens in various areas of Madrid, Spain (Izquierdo et al. 2015). In China, heavy metals such as arsenic (As), Hg and Pb were detected in edible vegetable parts collected near industrial areas in Shanghai, China (Yang et al. 2014). Elevated Cd levels were also detected in vegetable produce within a peri-urban area along the Yangtze River (Huang et al. 2014). In a study of root crops and leafy vegetables grown in the cities of Buffalo and New York, USA, 9% of leafy vegetables and 47% of root crops contained Pb and Cd (McBride et al. 2014).

Heavy metals are known to have long biological half-lives and a non-biodegradable nature that lead to their chronic accumulation in vegetables from the air, water and soil (Khalef et al. 2022; Tomno et al. 2020). With vegetables as an important component of the human diet, possible heavy metal contamination should not be disregarded as prolonged consumption of contaminated vegetables poses serious health risks to humans (Ametepey et al. 2018; Singh et al. 2011, 2010). An assessment of the concomitant human health risks has to be conducted as it is unequivocally an essential aspect of food quality assurance and safety (Ametepey et al. 2018). Unsafe concentrations may alter various biochemical processes and cellular functions, leading to different health problems such as gastrointestinal dysfunction, nervous system disorders, immune system dysfunction, kidney failure and cancer (Ali et al. 2021; Balali-Mood et al. 2021). Other human health effects such as neuropsychiatric disorders and impacts to the intellectual function in children become apparent after years of exposure even at low concentrations (Balali-Mood et al. 2021). Moreover, cumulative health impacts due to simultaneous exposure to different heavy metals have been reported (Jayasumana et al. 2015; Sulaiman et al. 2020). In the Philippines, the potential health risks associated with the dietary exposure to heavy metals in vegetables from urban farming have never been investigated, to the best of the authors' knowledge. It is in this regard that this study aims to fill the gap by measuring the risks using standard health indices such as average daily dose (ADD), hazard index (HI), target hazard quotient (THQ), representing the non-carcinogenic risk, and target cancer risk (TCR).

Few or no studies have been conducted or published about the food safety of urban farming in the Philippines. This study aims to determine the level of toxic heavy metals, namely Hg, As, Cd, Cr, and Pb, present in vegetable produce from urban farming and their potential health risks in comparison to conventional/rural farming in Benguet and Bulacan. The results of this study can help raise the awareness of communities, specifically vulnerable populations, engaging in urban farming. This will ideally lead to safer urban farming management practices, a system that will at least reduce if not eliminate anthropogenic pollution in urban farming produce.

MATERIALS AND METHODS

Study areas. A total of n=7 sites were chosen for this study. One site was inside the Quezon City Hall compound (a current Joy of Urban Farming project site); two sites in the barangay halls of Barangays Commonwealth and Kaligayahan; and two sites in Quezon City public schools, namely Bagong Silangan Elementary School and Lagro Elementary School. These schools practice urban farming as part of their school-based feeding program. Two additional sampling sites (n=2) were located inside the University of the Philippines Diliman campus. A detailed description of each site is summarized in Table 1.1 and the exact locations are found in Figure 1.

Table 1.1 Selected urban farming sites in Quezon City, Philippines

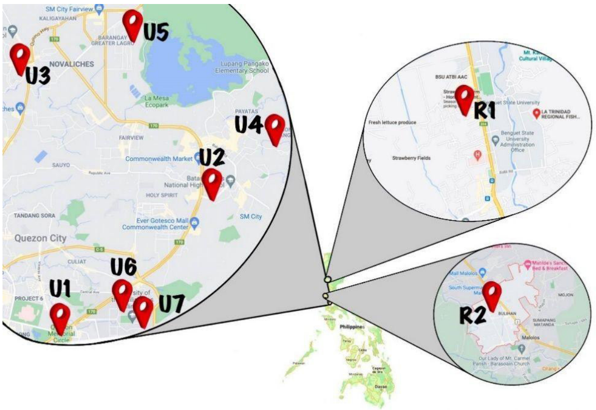
Site	Location	Address	Farming Method	Date of Sampling
U1	Quezon City Hall Compound	Corner of Kalayaan Avenue	Conventional[a]	March 26, 2019
U2	Barangay Commonwealth Hall	Commonwealth Avenue	Hydroponics[b]	April 05, 2019
U3	Barangay Kaligayahan Hall	Quirino Highway	Conventional	August 24, 2019
U4	Bagong Silangan Elementary School	Gen. Villamor St., Brgy. Bagong Silangan	Conventional	April 05, 2019
U5	Lagro Elementary School	Ascension Ave., Lagro Subdivision, Brgy. Greater Lagro, Novaliches	Conventional	August 25, 2019
U6	UP Diliman Task Force on Solid Waste Management Compound	C.P. Garcia Avenue, UP Diliman Campus	Conventional	August 30, 2019
U7	Natural Sciences Research Institute	Corner of Quirino and Velasquez Sts., UP Diliman Campus	Conventional	September 07, 2019

[a] Using soil and water.
[b] Using only water.

Farming sites in La Trinidad, Benguet and Malolos City, Bulacan (Table 1.2) were chosen as background sites to statistically compare the heavy metal content of the urban farming produce to the conventional rural farm produce. Sampling of vegetables, water and soil samples was conducted from March to November 2019 and heavy metal analyses were conducted from April 2019 to March 2020.

Table 1.2. Selected rural farming sites in Luzon, Philippines

Site	Location	Address	Farming Method	Date of Sampling
R1	La Trinidad, Benguet	Benguet State University	Conventional	November 21, 2019
R2	Malolos City, Bulacan	Bulihan, Malolos City, Bulacan	Hydroponics and conventional	November 23, 2019



Source: Google Maps

Figure 1. Map of the sampling sites in Quezon City, Benguet and Bulacan.

Sample collection and pre-treatment. A total of n=20 vegetable samples were collected from the urban farming sites, U1 to U7, and n=11 vegetable samples from the background sites, R1 and R2. The type of vegetables planted in each site were varied. The complete lists of vegetable samples harvested from the selected sites are summarized in Tables 2.1 and 2.2.

Table 2.1 Description of the vegetable samples collected from urban sampling sites

Common Name	**Scientific Name**	**Edible Parts**	**Duration**	**Sampling Location**
Alugbati	*Basella alba Rubra*	Leaves	Perennial	U4 and U5
Celery	*Apium graveolens*	Leaves, stems	Biennial	U1
Chili	*Capsicum annuum*	Fruits, leaves	Short-lived perennial	U7
Eggplant	*Solanum melongena*	Fruits with seeds	Perennial	U1, U4 and U6
Gabi	*Colocasia esculenta*	Leaves ,stalks	Perennial	U3 and U5
Lettuce	*Lactuca sativa*	Leaves, stems	Annual	U1 and U2
Malunggay	*Moringa oleifera*	Leaves	Perennial	U3, U6 and U7
Pechay	Brassica rapa chinensis	Leaves, stalks	Biennial/annual	U1
Saluyot	Corchorus capsularis L.	Leaves	Annual/perennial	U6
Spinach	*Spinacia oleracea*	Leaves	Perennial	U6
Kamote	*Ipomoea Batatas*	Leaves, stalks	Perennial	U3
Upland kangkong	*Ipomea reptans*	Leaves, stalks	Perennial	U4 and U5

Table2.2 Description of the vegetable samples collected from rural sampling sites

Common Name	Scientific Name	Edible Parts	Duration	Sampling Location
Baguio beans	Phaseolus vulgaris	Fruits with seeds	Annual	R1
Finger/long/Tagalog Chili	Capsicum annuum	Fruits with seeds	Short-lived perennial	R2
Lettuce	Lactuca sativa	Leaves, stems	Annual	R1
Mustard	Brassica juncea	Leaves, stalks	Annual	R1
Okra	Abelmoschus esculentus	Seedpods	Annual/perennial	R2
Pechay	Brassica rapa chinensis	Leaves, stalks	Biennial/annual	R1
Spinach	Spinacia oleracea	Leaves	Perennial	R1
Patola	Luffa acutangula	Leaves, fruits with seeds	Perennial	R2
Squash tops	Cucurbita maxima	Leaves, stalks, flowers	Perennial	R2
Kamote	Ipomoea Batatas	Leaves, stalks	Perennial	R2

The samples were harvested and stored in properly labeled resealable storage plastic bags. The non-edible parts were discarded and only the identified edible parts (mainly the leaves, vegetable fruits, stalks and stems) were washed with ultrapure water, air dried and then subjected to homogenization using a blender. The homogenized samples were then stored in a beaker, covered with polyethylene film, and stored in a refrigerator kept at 4 °C.

For soil samples, approximately 100 to 500 g were collected from all sites, except from U2 (which used the hydroponic method). In site U4, two types of soil samples were collected as two different soil mixtures were used—soil mixed with coconut husk and the other with animal manure. The soil samples were stored in properly labeled resealable storage plastic bags. In the laboratory, these samples were mixed thoroughly, air dried, passed through a 2 mm sieve, and their moisture content was analyzed.

For the water samples, about 1 L was collected from each site. The water used for the urban and conventional farming was mainly tap water except for R2, in which river water was being used. The samples were stored in properly labeled high density polyethylene (HDPE) bottles. To preserve the water samples, 2 mL of concentrated nitric acid (HNO_3) was added to bring down the pH to less than 2.

DIGESTION OF SAMPLES

Mercury in vegetables. One gram of homogenized sample was weighed in to a 250 mL Erlenmeyer flask, added with 5 mL concentrated HNO_3 and covered with polyethylene film. The sample was allowed to digest overnight at room temperature. Thereafter, 10 mL 5% chromic acid was added, and the sample was set aside for 30 min at room temperature. The sample was added with 15 mL ultrapure water, a few drops of tributyl phosphate as anti-foaming agent and 4 g hydroxylamine hydrochloride ($HONH_2 \cdot HCl$) crystal (Bouchard 1973).

Cadmium, chromium and lead in vegetables. The AOAC Official Method 972.23 was followed for the sample preparation. Twenty-five grams of homogenized sample was weighed into a porcelain crucible and dried overnight in an oven set at 105 °C. The sample was transferred to a temperature-controlled furnace and was ashed gradually to 500 °C for 16 h. After cooling, the crucible containing the sample was taken from the furnace. The ashed sample was moistened with 2 mL concentrated $HNO_{3,}$ warmed on a hot plate just to dryness and was heated again in the furnace at 500 ˚C for 1 h.

The nitric acid treatment was repeated until a practically carbon-free ash was obtained. The ash was dissolved with 5 mL 1:1 HCl by heating cautiously on a hot plate. The sample was filtered using a Whatman No. 42 filter paper into a 25 mL volumetric flask and was diluted to the mark with ultrapure water. For the analysis of Cr, an aliquot of the sample was transferred quantitatively into a volumetric flask and 10% ammonium chloride solution was added to make up a 1:9 v/v solution (AOAC 1990).

Arsenic in vegetables. The AOAC Official Method 986.15 was followed for the sample preparation using 1 g of homogenized sample weighed into a crucible. The sample was digested to near dryness on a hotplate with 5 mL concentrated HNO_3. Digestion was continued with the addition of 2 mL magnesium nitrate solution to near dryness at low heat. The sample was heated in an oven at 450 °C for 1 h, cooled to room temperature, taken up with 6N HCl, transferred to a 50 mL volumetric flask and diluted to volume with ultrapure water. For arsine generation, 20 mL sample aliquot was measured into a 125 mL Erlenmeyer flask and was added with 2 mL concentrated HCl (AOAC 1990).

For the digestion of the soil samples, the analytical procedures in the United States Environmental Protection Agency (US EPA) Test Methods for Evaluation of Solid Wastes, Physical and Chemical Methods SW-846 Compendium (USEPA 1994) were followed. The digestion of the water samples made use of the procedures in the Standard Methods for the Examination of Water and Wastewater and Official Methods of Analysis (Baird et al. 2017).

INSTRUMENTATION BY ATOMIC ABSORPTION SPECTROPHOTOMETRY

Total Hg was determined by manual cold vapor atomic absorption spectrophotometry (AAS) using the Shimadzu AA-6800 with the manual cold vapor attachment or set-up and Hamamatsu Hg hollow cathode lamp (HCL). The digested sample was quantitatively transferred to the reaction flask, added with 5 mL 10% stannous chloride, and the reaction was permitted to proceed. The absorbance value was recorded through the equipment.

As was analyzed using the hydride generation technique with the Shimadzu HVG-1 accessory attached to the AA-6800 and Hamamatsu As HCL. Continuous flow method was used for the As determination with the following settings: sample suction rate from 0-7 mL/min, reagent (two reagent bottles containing 0.4% w/v $NaBH_4$ and 5M HCl) suction rate from 0-2.5 mL/min, argon carrier gas at 70 mL/min flow rate and the atomizer set at peak height measurement. Two mL 20% KI was added to each standard and sample solution and mixed for at least 30 min. With the hydride cell assembly in place, the flame was ignited, and the reagents and samples were suctioned for 5 min. Absorbance was measured when the instrument readings stabilized.

Cd, Cr and Pb were measured using the flame AAS technique with their corresponding HCLs. Acetylene and compressed air gases were the fuel and oxidant used for the flame generation. Other details of the AAS are tabulated in Table 3.

Table 3. Configuration of the AAS used in the analyses of heavy metals in the vegetable, soil and water sample.

Metal	Wavelength, nm	Lamp Current, mA	Spectral Bandwidth, nm
Mercury	253.6	4	1.0
Arsenic	193.7	12	1.0
Cadmium	228.8	8	1.0
Chromium	357.9	8	0.5
Lead	283.3	10	1.0

Calibration standards. Stock solutions at 1,000 mg/L for Hg, Cd, Cr and Pb were obtained from Inorganic Ventures, USA while the 1,000 mg/L As stock solution was sourced from Merck, USA. Calibration standard solutions were prepared by serial dilution from the stock solutions, i.e., (0, 0.01, 0.05, 0.1, 0.2 and 0.5 μg for Hg), (0, 0.01, 0.02, 0.04, 0.08, 0.10, 0.12 and 0.15 μg/L for As), (0, 0.01, 0.02, 0.05, 0.10, 0.5 and 1.0 mg/L for Cd), (0, 0.04, 0.10, 0.30, 0.50, 1.0 and 2.0 mg/L for Cr) and (0, 0.04, 0.10, 0.40, 1.0, 2.0 and 4.0 mg/L for Pb). Each Cr calibration standard solution was added with 10% ammonium chloride solution to make up a 1:9 v/v standard solution (AOAC 1990).

Quality assurance/quality control (QA/QC) of the analytical procedures for metals in the vegetable samples. Prior to the determination of the heavy metal concentrations in the vegetable samples, the analytical procedures used were evaluated to ensure the quality of the measurement data. The vegetable samples were analyzed using n=2 to 3 replicates with the mean heavy metal concentration reported for each sample. Accuracy, in terms of % recovery of the concentrations of heavy metals spiked into a designated quality control vegetable sample, and precision in terms of percent relative standard deviation (% RSD) were established for each of the heavy metals covered in the study.

A spiked level of 0.01 μg for (low level) and 0.10 μg (high level) for Hg; 0.02 mg/kg for (low level) and 0.20 mg/kg (high level) for Cd; 0.05 mg/kg for (low level) and 0.50 mg/kg (high level) for Cr; 0.04 mg/kg for (low level) and 0.40 mg/kg (high level) for Pb; 0.05 mg/kg for (low level) and 0.50 mg/kg (high level) for Cr; and 0.10 mg/kg for As. A certified reference material (CRM), Sigma Aldrich Trace Metals-1 WP, was used to assess the accuracy of the calibration curves.

Health risk assessment. To assess the potential human health risks associated with the prolonged consumption of vegetables contaminated with heavy metals, the ADD, HI, THQ, and TCR were calculated based on reported toxicity values by Alsafran et al. (2021), Ametepey et al. (2018), and Wongsasuluk et al. (2014).

Risk Assessment Guidance, the following parameters and equations were used:

$$\mathrm{ADD} = \frac{Ci \times IR \times EF \times ED}{BW \times \mathrm{AT}} \tag{1}$$

Where Ci is the metal concentration in the vegetable, mg/kg; IR is the ingestion rate, g/day; EF is the exposure frequency, days/year; ED is the exposure duration, years; BW is the body weight of consumer, kg (for both adult and child); and AT is the average time, years (see Table 4 below).

Table 4. Input exposure parameters used for the calculation of the average daily dose (ADD) values. Age range (classification): 5–10 years old (children); 20–70 years old (adults)

Exposure Parameters	Symbols	Units	Values	References
Concentration	C	mg/kg	See Table 5	This paper
Exposure frequency	EF	d/y	365	Amin et al. 2020
Adults: Ingestion rate	IRa	kg/d	0.343	Limsan 2021
Body weight, ave.	BWa	kg	58.7	DOST-FNRI 2016
Exposure duration	EDa	y	70	DOST-FNRI 2016
Average time	ATa	d	25,550	Amin et al. 2020
Children: Ingestion rate	IRc	g/d	0.081	Gonzales et al. 2016
Body weight, ave.	BWc	kg	20.8	DOST-FNRI 2016
Exposure duration	EDc	y	10	Gonzales et al. 2016
Average time	ATc	d	3,650	Gonzales et al. 2016

Average time = exposure duration x 365 days

$$THQ = \sum HQs \qquad (2)$$

estimates the non-carcinogenic risk of heavy metal ingestion

$$\text{where } Q = \frac{ADD}{RfD},$$

RfD is the oral reference dose considered detrimental

HI = estimates the potential human health risk when more than one metal is consumed

$$= \sum THQs \qquad (3)$$

$$TCR = \sum CRs, \text{ where } CR = ADD \times sf \qquad (4)$$

= cancer risk over a lifetime by individual heavy metal ingestion

Csf = cancer slope factor (different for each heavy metal)

RESULTS AND DISCUSSION

QA/QC. The % recoveries of the high-level spiked concentrations were 98.5% (n=11; 0.10 μg) for Hg, 102% (n=10; 0.10 mg/kg) for As, 88.1% (n=8; 0.20 mg/kg) for Cd, 91.0% (n=6; 0.50 mg/kg) for Cr and 90.0% (n=8; 0.40 mg/kg) for Pb, with % RSD ranging from 2.4% (Hg) to 7.3% (Cr). The % recoveries of the spiked metals ranging from 88.1% (As) to 102% (Hg) are well within the AOAC recommended estimated recovery data of 80-110% at 100 ppb, 1 ppm and 10 ppm analyte concentrations. Similarly, the % RSD obtained are below the estimated precision data of 15% at 100 ppb and 11% at 1 ppm concentrations of the analytes (AOAC International 1998).

The mean recoveries of the CRM (Sigma Aldrich Trace Metals-1 WP) used to assess the accuracy of the calibration curves were 98.9%, 99.1%, 98.7%, 99.0% and 97.1% for Hg (n=11), As (n=12), Cd (n=10), Cr (n=10) and Pb (n=8), respectively, with % RSD ranging from 0.5 to 5.2%.

The method detection limit (MDL) for Hg is 0.004 mg/kg (n=10) calculated based on 1.0 g sample. The MDL for As is 0.009 mg/kg (n=12) calculated based on 1.0 g sample. The MDL for Cd is 0.007 mg/kg (n=24) calculated based on 25 g sample. The MDL for Cr is 0.03 mg/kg (n=8) calculated based on 25 g sample. The MDL for Pb is 0.06 mg/kg (n=11) calculated based on 25 g sample.

HEAVY METALS IN THE VEGETABLES GROWN IN URBAN AND RURAL SITES

Table 5 summarizes the results of the heavy metal analysis of all vegetable samples collected, with the mean concentration values expressed in mg/kg as-received basis and the RSD.

Table 5. Trace heavy metal concentrations (in mg/kg, as-received basis) in the edible portions of the vegetable produce from the urban and rural farming sites.

Location	Sample Name	Hg ± RSD	As ± RSD	Cd ± RSD	Cr ± RSD	Pb ± RSD
U1	Celery	< MDL	**	0.01± 5%	0.1± 6%	0.13± 9%
	Lettuce	< MDL	**	0.01± 4%	0.08± 9%	0.06± 10%
	Eggplant	< MDL	< MDL	< MDL	0.4± 8%	< MDL
	Pechay	< MDL	< MDL	< MDL	0.04± 18%	0.014± 1%
U2	Lettuce	< MDL	< MDL	0.008* ± 10%	< MDL	0.08* ± 10%
U3	Gabi (stalks and leaves)	< MDL	0.06± 11%	< MDL	< MDL	0.15*± 6%
	Kamote (tops)	< MDL	< MDL	< MDL	< MDL	0.12*± 0.1%
	Malunggay	< MDL	< MDL	< MDL	< MDL	0.19*±5%
U4	Eggplant	< MDL	< MDL	< MDL	0.26±3%	<MDL
	Alugbati	< MDL	< MDL	< MDL	<MDL	0.15*±8%
	Upland kangkong	< MDL	< MDL	< MDL	<MDL	0.16*±2%

U5	Alugbati	< MDL	< MDL	0.01*± 0%	< MDL	0.12*± 9%
	Gabi (stalks and leaves)	< MDL	< MDL	< MDL	< MDL	0.20*± 2%
	Upland kangkong	< MDL	< MDL	< MDL	< MDL	0.14*±6%
U6	Eggplant	< MDL	0.01*±103%	0.01*± 2%	< MDL	< MDL
	Malunggay	< MDL	0.03*± 7.5%	< MDL	< MDL	0.29*± 9%
	Saluyot	< MDL	0.03*± 23%	0.01*± 8%	< MDL	0.08*± 9%
	Spinach	< MDL	0.02*±61%	0.02*± 8%	< MDL	0.11*± 6%
U7	Red chili (fruits and leaves)	< MDL	0.09±24%	0.03*± 2%	0.03*±15%	0.19*±0%
	Malunggay	< MDL	< MDL	< MDL	< MDL	0.20±6%
R1	Baguio beans	< MDL	< MDL	< MDL	< MDL	< MDL
	Green ice lettuce	< MDL	0.04±23%	< MDL	< MDL	< MDL
	Iceberg lettuce	< MDL	0.02*±21%	< MDL	< MDL	< MDL
	Mustard	< MDL	0.01*±25%	< MDL	< MDL	< MDL
	Pechay	< MDL	0.04±24%	< MDL	< MDL	< MDL
	Spinach	< MDL	< MDL	< MDL	< MDL	< MDL
R2	Finger/long/ Tagalog chili (fruits)	***	< MDL	< MDL	< MDL	< MDL
	Kamote (tops)	***	0.04±40%	< MDL	0.07*±6%	< MDL
	Okra	***	0.01*±2.4%	< MDL	< MDL	< MDL
	Patola	***	< MDL	< MDL	< MDL	< MDL
	Squash (tops)	***	< MDL	< MDL	< MDL	< MDL

* Within the limit of quantitation (LOQ) and defined as "the lowest level of analyte that can be determined with acceptable performance" calculated as10x standard deviation or 3.333x MDL (Eurachem 2014). Hg LOQ = 0.02 mg/kg, As LOQ = 0.03 mg/kg, Cd LOQ = 0.03 mg/kg, Cr LOQ = 0.1mg/kg, and Pb LOQ = 0.2 mg/kg.

**Not analyzed due to insufficient samples

***Not analyzed due to the COVID-19 pandemic

Mercury. Total Hg concentrations in the vegetables harvested from the urban farms and rural farms or background sites were below the MDL concentration of 0.004mg/kg. The Philippines does not have a safety standard for Hg in foods; however, the Global Agricultural Information Network reported that, based on China's National Food Safety Standard of Maximum Levels of Contaminants in Foods/GB2762-2012 (Bugang and Woolsey 2012), the maximum level of total Hg for fresh vegetables and their products is 0.01 mg/kg.

Arsenic. Total As content detected in vegetables in this study was found to range from MDL (MDL = 0.009 mg/kg) to 0.09 mg/kg for the urban farming sites and MDL to 0.04 mg/kg for the background sites. Six out of the 18 vegetable samples from the urban sites were found to contain As. All vegetables harvested from U6 contained As, but within the LOQ of the method. Taro/gabi stalks and leaves harvested from U3 and red chili fruits and leaves from U7 were also found to have As—0.06 mg/kg and 0.09 mg/kg, respectively. Total As was detected from four vegetable samples from R1 (green and ice lettuce, mustard and pechay) and two from R2 (kamote/sweet potato tops and okra). The Philippines does not have a food safety standard for As in foods. The GB 2762-2012 lists the maximum allowable level (MAL) of total As for fresh vegetables and their products to be at 0.5 mg/kg (Bugang and Woolsey 2012). This study showed that the As levels in the vegetable samples were within the MAL.

Cadmium. The Cd concentrations in all the vegetables collected were found to be within the MDL level, except celery and lettuce from U1, which contained 0.01 mg/kg; eggplant, saluyot and spinach from U6, which contained 0.01, 0.01 and 0.02 mg/kg, respectively; and red chili from U7, which contained 0.03 mg/kg. The detected Cd concentrations were below the LOQ of the analytical method. This study showed that the Cd levels in the vegetables collected from the urban farming sites were below the MAL for Cd in leafy vegetables at 0.2 mg/kg and stalk and stem vegetables at 0.1mg/kg (Codex 2009; PNS/BAFS 2017). The vegetables harvested from R1 and R2 showed Cd concentrations below MDL.

Chromium. All vegetable samples from U1 were found to have Cr, ranging from 0.04 to 0.3 mg/kg. The eggplant sample from U4 was found to have 0.3 mg/kg Cr. The rest of the samples were found to have Cr concentrations below MDL. The Philippines does not have a food safety standard for Cr in vegetables. GB2672-2012 lists the MAL for Cr in vegetables at 0.5 mg/kg (Bugang and Woolsey 2012). The concentration detected in this study was below the MAL.

Lead. Total Pb was found in the vegetables collected from all the urban farming sites, ranging from 0.06 mg/kg to 0.29 mg/kg, except for eggplants from sites U1, U4 and U6, which contained Pb concentrations below the MDL. Similarly, the Pb concentrations in all the vegetable samples from R1 and R2 were below the MDL. The MAL of total Pb in leafy vegetables is 0.3 mg/kg (Codex Alimentarius 2009; PNS/BAFS 2017). Malunggay harvested from U6 was found to have Pb concentration of 0.29 mg/kg, which was close to the MAL.

HEAVY METALS IN WATER AND SOIL

Table 6 and 7 show the heavy metal concentrations in the soil and water used in growing the vegetables in the selected farms, respectively.

Table 6. Heavy metal concentrations in the soils used for the cultivation of the vegetables

Location	Hg ± RSD, mg/kg (dry wt	As ± RSD, mg/kg (dry wt)	Cd ± RSD, mg/kg (dry wt)	Cr ±RSD, mg/kg (dry wt)	Pb ± RSD, mg/kg (dry wt)
U1	< MDL (MDL=0.04)	2.7±8%	< MDL (MDL =1.0)	14±6%	6.4*±11%
U3	< MDL	1.7±8%	< MDL	31±4%	20*±10%
U4 (coconut husk)	< MDL	0.8±5%	< MDL	< MDL (MDL =3.0)	4.9*±17%
U4 (animal manure)	< MDL	3.0±19%	< MDL	43±6%	< MDL (MDL =5.0)
U5	< MDL	3.7±2%	< MDL	38±2%	16*±6%
U6	0.11*±6%	8.8±8%	< MDL	20±5%	44.1±9%
U7	< MDL	2.9±7%	< MDL	8.5*±7%	12*±9%
R1	0.05*±19%	8.0±1%	< MDL	24±4%	37.6±2%
R2	< MDL	2.0±1%	< MDL	28±7%	< MDL

*Within the LOQ (Hg LOQ=0.20mg/kg, Cr LOQ = 20 mg/kg, Pb LOQ = 20 mg/kg)

Table 7. Heavy metal concentrations in the water used for the cultivation of the vegetables

Location	Hg ± RSD, mg/L	As ± RSD, mg/L	Cd ± RSD, mg/L	Cr ± RSD, mg/L	Pb ± RSD, mg/L
U1	< MDL (MDL =0.0001)	< MDL (MDL =0.5)	< MDL (MDL=0.01)	< MDL (MDL=0.04)	< MDL (MDL=0.05)
U2	< MDL	0.5*±11%	< MDL	< MDL	< MDL
U3	< MDL	0.7*±7%	< MDL	< MDL	< MDL
U4	< MDL	< MDL	< MDL	< MDL	< MDL
U5	< MDL	< MDL	< MDL	< MDL	< MDL
U6	< MDL	< MDL	< MDL	< MDL	< MDL
U7	< MDL	< MDL	< MDL	< MDL	< MDL
R1	< MDL	< MDL	< MDL	< MDL	< MDL
R2	< MDL	< MDL	< MDL	< MDL	< MDL

*Within the LOQ (As LOQ = 2.0 mg/L)

Mercury. The total Hg concentration in all the water samples was found to be less than the MDL value. For the soil analysis, most samples were found to be within the MDL; however, Hg was detected in the soil samples from urban site U6 and rural site R1 at 0.11mg/kg dry wt and 0.05 mg/kg dry wt, respectively. These concentrations were below the LOQ of the method at 0.20 mg/kg dry wt. The detected Hg concentration in the soil was below the MAL set by Philippine National

Standard on the Code of Practice for the Production of Organic Soil Amendment or the PNS/BAFS183:2020, which was at 2 mg/kg dry wt (PNS/BAFS 2020).

Arsenic. The As concentration in the water samples was found to be below the MDL, except for the water samples from the urban sites U2 and U4 (0.0005 and 0.0007 mg/L, respectively). The As levels in U2 and U4 were below the MAL of As in water, which is 0.01 mg/L (Codex Alimentarius 2009; DENR 2016; DOH 2017). The As concentrations in the soil samples from U3, U6 and U7 were found to be at 1.7 mg/kg dry wt, 8.8 mg/kg dry wt and 2.9 mg/kg wt, respectively. For the background sites, the As concentrations were 8.0 mg/kg dry wt and 2.0 mg/kg dry wt for R1 and R2, respectively. Studies have indicated that the natural background As concentration in soil ranges from 1–40 mg/kg (Gomez-Caminero et al. 2001). The detected total As concentrations in the soils from all the sampling sites were within the range of naturally occurring As, and below the MAL of 20 mg/kg dry wt (PNS/BAFS 2020).

Cadmium. The cadmium concentrations in both the water and soil samples were at the MDL for all sites, and thus below the MALs (Codex Alimentarius 2009; DENR 2016; DOH 2017).

Chromium. The Cr concentrations in all the water samples were below the MDL value. The Cr concentration in the soils used in all urban sites—except U4 (coconut husk), which was at MDL—ranged from 14 to 43 mg/kg dry wt; however, this concentration is still below the MAL of 150 mg/kg for Cr in compost/soil conditioners (PNS/BAFS 2020).

Lead. The total Pb concentrations in all the water samples were below the MDL value. The total Pb concentrations in the soil samples collected from the urban farms ranged from < MDL to 44 mg/kg dry wt (U6). The total Pb concentration in the soil sample from R1 was found to be at 20.4 mg/kg dry wt, while for R2 the Pb concentration was below MDL. The detected Pb concentrations in all soil samples were below the MAL of 50 mg/kg in compost/soil conditioners (PNS/BAFS 2020). Natural Pb concentration ranges from 10 to 50 mg/kg (Finster et al. 2004; ASTDR 2017; Bi et al. 2017; Navarrete et al. 2017).

STATISTICAL COMPARISON OF HEAVY METALS IN VEGETABLES: URBAN VS. RURAL FARMING

To compare the levels of trace heavy metals between vegetables produced through urban farming and those produced through rural/conventional farming, the analysis of variance (ANOVA) single factor at $\alpha=0.05$ was used.

Mercury. The total Hg concentrations in all the vegetable samples collected from both the urban and rural sites were below the MDL level of 0.004 mg/kg (as-received basis). By simple calculations, it could be concluded that, for this batch of samples, there was no significant difference between vegetable samples produced in urban and conventional rural farming/gardening. While Hg was detected in the soil samples from urban site U6 (0.11mg/kg dry wt) and rural site R1 (0.05 mg/kg dry wt), the Hg concentrations in the vegetables were relatively low (< MDL). The Hg concentrations in the soils were one to two magnitudes lower than the MAL of 2 mg/kg dry wt for soil organic amendments (PNS/BAFS 2020). In addition, the vegetables grown in sites U6 and R1 were those that were harvested within one to two months from the time of planting. Further studies are needed to verify the accumulation of Hg in vegetables that have exposures to low levels of Hg in the soil.

Arsenic. As the calculated F (0.0195) < F_{crit} (4.2100), there is no significant difference between the As concentrations in the vegetables grown using urban and rural farming methods. As in vegetables can come from naturally occurring and/or anthropogenic sources such as application of pesticides, waste incineration, wood combustion, coal combustion and non-ferrous mining activities (Gomez-Caminero et al. 2001). In this study, some anthropogenic sources of As can be ruled out as such activities were not observed in the vicinity of the urban farming sites. Waste incineration is prohibited by the Philippine government. The urban farming sites in Quezon City as well as the two rural sites practiced organic farming, i.e., no pesticides were applied to the vegetables. The possible source of total As in the vegetable samples could be due to naturally occurring As, with leafy vegetables containing more than fruits (Kabata-Pendias 2001). While As is widely found in the natural environment, anthropogenic and geological activities play key roles in its distribution and uptake in plants and vegetables (Baig and Kazi 2012). Vegetables in urban sites like U3, which is proximate to roads and highways, could be contaminated with As from the polluted water, soil, rocks, and leaching from cement (Ho et al. 2021). On the other hand, site U7 has annual to biennial termite control activities to preserve wood in the occupied structures from rot and decay (A. Mallari and E. del Remedio, personal communication with author, June 22 and 23, 2022). Termite control products are known to contain arsenic trioxide. In terms of the potential uptake and bioavailability of As in leafy root vegetables and fruits, it is important to note that the process depends on plant species, varieties within species and other parameters such as soil characteristics or cultivation methods (Clair-Caliot et al. 2021). The concentrations of As in the soil samples ranged from

1.7–8.8 mg/kg (dry wt) and 2.0–8.0 mg/kg (dry wt) for the urban sites and rural sites, respectively. The 8 mg/kg (dry wt) As was obtained in U6 where a materials recovery facility (MRF) is located. The other 8.0mg/kg (dry wt) As was obtained from R1, which is in La Trinidad, Benguet. The As concentrations in the vegetable samples from these sites were relatively higher than those from the other sampling sites.

Cadmium. From the results of the ANOVA single factor analysis, F (4.686) > F_{crit} (4.183), there is a significant difference in the vegetable Cd concentrations between urban and rural farming sites. More detection of Cd was observed in the vegetable samples from the urban sites (n=8 samples) compared to the rural sites where the Cd concentrations in all the vegetable samples were below the MDL value. As the Cd Concentrations in the soils were mostly at the MDL level, exposure of the vegetables to Cd may come from atmospheric or rain deposition (ASTDR 2008; ICdA 2012). Cadmium is easily absorbed by plants, especially leafy vegetables and root crops (Kabata-Pendias 2001).

Chromium. There is no significant difference in the Cr concentrations between the vegetable samples grown in urban sites and those from the rural farming sites (i.e., F (1.504) < F_{crit} (4.183)). Like Cd, there was more detection of Cr in the vegetable samples from the urban sites (n=6 samples), which could be linked to the presence of more industrial activities in urban areas. It is the trivalent Cr species that is commonly present in soil and absorbed by plants, but only in small concentrations (Bielicka et al. 2004; ATSDR 2008). Accumulation of Cr mainly takes place in roots and then translocated to stems and leaves; only a small concentration of Cr reaches the leaves (Kabata-Pendias 2001; Lopeź-Luna et al. 2009).

Lead. The ANOVA single factor analysis (F (30.785) > F_{crit} (4.183)) indicated that there is a significant difference in the Pb concentrations between vegetables grown in urban sites and those from rural farming sites. Most of the vegetable samples from the urban sites exhibited relatively higher concentrations of Pb (n=17) while the Pb concentrations in the vegetable samples from the rural sites were below the MDL value. The elevated Pb concentration could be caused by anthropogenic activities (Bagdatlioglu et al. 2010; McBride et al. 2014; Navarrete et al. 2017). Most of the urban sites are exposed to vehicular emissions. Total Pb concentration in the environment is usually higher in urban areas due to accumulation of lead in gasoline even before leaded gasoline was phased out (Finster et al. 2004; ASTDR 2017; Bi et al. 2017; Navarrete et al. 2017).

HEALTH RISK ASSESSMENT

Humans are exposed to heavy metals via different pathways. One exposure route is through ingestion of vegetables contaminated with heavy metals. In the present study, the human health risk of vegetable consumption associated with the ADD was determined using the mean concentrations of As, Cd, Cr and Pb detected in various vegetables from different urban sites. Separate determinations for health risk of adults and children were performed due to different reported exposure values for IR, BW, ED and AT for each age class (Table 4). It should be noted that the average BW for children (20.8 kg) used in this study focused on the age range of 5 to 10 years old. The ADD values for adults and children are presented in Table 8.

Table 8. Average daily dose (ADD) values, in mg/kg-day, for adults and children from vegetable consumption

Location	Samples	Individuals	ADD, mg/kg-day				
			Hg	As	Cd	Cr	Pb
U1	Celery	Adults	-	=	0.0001	0.0006	0.0008
		Children	-	=	0	0.0004	0.0005
	Lettuce	Adults	-	=	0.0001	0.0005	0.0004
		Children	-	=	0	0	0
	Eggplant	Adults	-	=	-	0.0023	-
		Children	-	=	-	0.0016	-
	Pechay	Adults	-	=	-	0.0002	0.0008
		Children	-	=	-	0	0.0005
U2	Lettuce	Adults	-	-	0	-	0.0005
		Children	-	-	0	-	0
U3	Taro/gabi	Adults	-	0.0004	-	0.0015	0.0009
		Children	-	0	-	0.0010	0.0006
	Kamote/sweet potato tops	Adults	-	-	-	-	0.0007
		Children	-	-	-	-	0.0005
	Malunggay	Adults	-	-	-	-	0.0011
		Children	-	-	-	-	0.0007
U4	Eggplant	Adults	-	-	-	0.0015	-
		Children	-	-	-	0.0010	-
	Alugbati	Adults	-	-	-	-	0.0009
		Children	-	-	-	-	0.0006
	Upland kangkong	Adults	-	-	-	-	0.0009
		Children	-	-	-	-	0.0006

U5	Alugbati	Adults	-	-	0.0001	-	0.0007
		Children	-	-	0	-	0.0005
	Taro/gabi	Adults	-	-	-	-	0.0012
		Children	-	-	-	-	0.0008
	Upland kangkong	Adults	-	-	-	-	0.0008
		Children	-	-	-	-	0.0005
U6	Eggplant	Adults	-	0.0001	0.0001	-	-
		Children	-	0	0	-	-
	Malunggay	Adults	-	0.0002	-	-	0.0017
		Children	-	0	-	-	0.0011
	Saluyot	Adults	-	0.0002	0.0001	-	0.0005
		Children	-	0	0	-	0
	Spinach	Adults	-	0.0001	0.0001	-	0.0006
		Children	-	0	0	-	0.0004
U7	Red chili	Adults	-	0.0005	0.0002	0.0002	0.0011
	(fruit and leaves)	Children	-	0.0004	0	0	0.0007
	Malunggay	Adults	-	-	-	-	0.0012
		Children	-	-	-	-	0.0008
R1	Baguio beans	Adults	-	-	-	-	-
		Children	-	-	-	-	-
	Green ice lettuce	Adults	-	0.0002	-	-	-
		Children	-	0	-	-	-
	Iceberg lettuce	Adults	-	0.0001	-	-	-
		Children	-	0	-	-	-
	Mustard	Adults	-	0.0001	-	-	-
		Children	-	0	-	-	-
	Pechay	Adults	-	0.0002	-	-	-
		Children	-	0	-	-	-
	Spinach	Adults	-	-	-	-	-
		Children	-	-	-	-	-
R2	Finger long/ Tagalog chili (fruit)	Adults	=	-	-	-	-
		Children	=	-	-	-	-
	Kamote/sweet potato tops	Adults	=	0.0002	-	0.0004	-
		Children	=	0	-	0	-
	Okra	Adults	=	0.0001	-	-	-
		Children	=	0	-	-	-
	Patola/sponge gourd	Adults	=	-	-	-	-
		Children	=	-	-	-	-
	Squash tops	Adults	=	-	-	-	-
		Children	=	-	-	-	-

- No calculations for ADD since concentration values are <MDL.

= Samples with no analyses for levels of that particular heavy metal.

The calculated ADD values were used to estimate the non-carcinogenic (using THQs and HIs) and carcinogenic risks (using TCRs) of vegetable consumption contaminated with heavy metals.

Non-carcinogenic risk. The THQs and HIs of the detected metals from the consumption of vegetables by adults and children are presented in Table 9. The oral or ingestion reference doses used were 0.0003 for As (CalEPA 2021), 0.001 for Cd, 1.5 for Cr, and 3.5 for Pb (Ashraf et al. 2021). The THQs for adults varied from 0.19 to 1.8 for As, 0 to 0.18 for Cd, 0.0001 to 0.001 for Cr, and 0.0001 to 0.0005 for Pb; while calculated THQs of As in children mostly showed zero values (similar to Cd) indifferent samples except for red chili from site U7 (THQ = 1.2). Other THQs for children varied from 0 to 0.001 for Cr and 0 to 0.0003 for Pb. The results showed that THQ values for adults were <1 in all samples except for As in taro/gabi from site U3 (1.2) and red chili from site U7 (1.8). Similarly, THQ value of >1 (1.2) for children was observed for As in red chili from site U7. According to Ametepey et al. (2018) and Wang et al. (2012), a THQ value of a metal exceeding 1 is an indication of a non-carcinogenic risk through consumption of vegetables. Results suggest that long-term intake of taro and red chili from specified areas could potentially lead to non-cancer health effects and As could be a major contributor. Thus, contrasting results may be obtained (e.g., Zhou et al. 2016) showing other main THQ contributors than As, such as Cd and Pb in leafy root vegetables (radish, carrot, potato). In general, however, leafy root vegetables always showed the highest THQs in coherence with results of this work. Worth noting is a previous work of Mandal and Suzuki (2002), which reported that the latent period of As poisoning could take years; thus, prolonged low-level intake will have detrimental health effects on humans. In site U7, THQs of As in both adults and children are comparable. These may indicate that children are a sensitive population group in that specific area.

Taking into consideration the additive and/or interactive effects of toxic metals, the HI results signify concern from consumption of taro and red chili fruits and leaves in site U3 by adults, and in U7 for both adults and children.

Table 9. Non-carcinogenic risk (target hazard quotient, THQs) of individual metals and their overall toxic risk (hazard index, HI) from consumption of various vegetables from selected sites.

	THQ								HI	
Samples	As		Cd		Cr		Pb			
	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Celery Site U1 Lettuce	-	-	0.06	0	0.0004	0.0003	0.0002	0.0001	0.06	0.0004

Site U1	-	-	0.06	0	0.0003	0	0.0001	0	0.06	0
U2	-	-	0	0	-	-	0.0001	0	0.0001	0
Eggplant										
Site U1	-	-	-	-	0.002	0.001	-	-	0.002	0.0001
U4	-	-	-	-	0.001	0.001	-	-	0.001	0.0001
U6	0.19	0	0.06	0	-	-	-	-	0.25	0
Pechay										
Site U1	-	-	-	-	0.0002	0	0.0002	0.0002	0.0004	0
R1	0.78	0	-	-	-	-	-	-	0.78	0
Taro/gabi										
Site U3	1.2	0	-	-	-	-	0.0003	0.0002	1.2	0.0002
U5	-	-	-	-	-	-	0.0003	0.0002	0.0003	0.0002
Sweet potato (tops)										
Site U3	-	-	-	-	-	-	0.0002	0.0001	0.0002	0.0001
R2	0.78	0	-	-	0.0003	0	-	-	0.78	0
Malunggay										
Site U3	-	-	-	-	-	-	0.0003	0.0002	0.0003	0.0002
U6	0.58	0	-	-	-	-	0.0005	0.0003	0.5843	0.0003
U7	-	-	-	-	-	-	0.0003	0.0002	0.0003	0.0002
Alugbati										
Site U4	-	-	-	-	-	-	0.0003	0.0002	0.0003	0.0002
U5	-	-	0.06	0	-	-	0.0002	0.0001	0.0584	0.0001
Upland kangkong										
Site U4	-	-	-	-	-	-	0.0003	0.0002	0.0003	0.0002
U5	-	-	-	-	-	-	0.0002	0.0002	0.0002	0.0002
Saluyot										
Site U6	0.58	0	0.06	0	-	-	0.0001	0	0.64	0
Spinach										
Site U6	0.39	0	0.12	0	-	-	0.0002	0.0001	0.51	0.0001
Red chili (fruits/leaves)										
Site U7	1.8	1.2	0.18	0	0.0001	0	0.0003	0.0002	1.9	1.2
Green ice lettuce										
Site R1	0.78	0	-	-	-	-	-	-	0.78	0
Iceberg lettuce										
Site R1	0.39	0	-	-	-	-	-	-	0.39	0
Mustard										
Site R1	0.19	0	-	-	-	-	-	-	0.19	0
Okra										
Site R2	0.19	0	-	-	-	-	-	-	0.19	0

- No calculations for THQ and Hi since concentration values are <MDL.

No THQ and HI calculations for samples with no analyses for heavy metals, and hence were not included in Table 9 (like Hg).

Carcinogenic risk. The TCR due to exposure to As, Cd, Cr and Pb through consumption of contaminated vegetables was calculated using ADD and Csf as indicated in the methods section. The oral cancer factors used were the following: 1.5 for As, 0.38 for Cd, 0.5 for Cr and 0.0085 for Pb (Victor et al. 2018). The TCR values for adults and children are presented in Table 10.

Table 10. Carcinogenic risk (target cancer risk, TCR) of individual metals from consumption of various vegetables from selected sites.

Samples	TCR								Combined Metal	
	As		Cd		Cr		Pb		TCR	
	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children
Celery										
Site U1	-	-	2.2E-05	0	2.9E-04	1.9E-04	6.5E-06	0	3.2E-04	2.0E-04
Lettuce										
Site U1	-	-	2.2E-05	0	2.3E-04	0	3E-06	0	2.6E-04	0
U2	-	-	0	0	-	-	4E-06	0	4E-06	0
Eggplant										
Site U1	-	-	-	-	1.2E-03	7.8E-04	-	-	1.2E-03	1.1E-04
U4	-	-	-	-	7.6E-04	5.1E-04	-	-	7.6E-04	7.2E-05
U6	8.8E-05	0	2.2E-05	0	-	-	-	-	1.1E-04	0
Pechay										
Site U1	-	-	-	-	1.2E-04	0	7E-06	4.6E-06	1.2E-04	6.6E-07
R1	3.5E-04	0	-	-	-	-	-	-	3.5E-04	0
Taro/gabi										
Site U3	5.3E-04	0	-	-	-	-	7.5E-06	5.0E-06	5.3E-04	7.1E-07
U5	-	-	-	-	-	-	9.9E-06	6.6E-06	9.9E-06	9.5E-07
Kamote/sweet potato (tops)										
Site U3	-	-	-	-	-	-	6.0E-06	4.0E-06	6.0E-06	5.7E-07
R2	3.5E-04	0	-	-	2.0E-04	0	-	-	5.6E-04	0
Malunggay										
Site U3	-	-	-	-	-	-	9.4E-06	6.3E-06	9.4E-06	9.0E-07
U6	2.6E-04	0	-	-	-	-	1.4E-05	9.6E-06	2.8E-04	1.4E-06
U7	-	-	-	-	-	-	9.9E-06	6.6E-06	9.9E-06	9.4E-07
Alugbati										
Site U4	-	-	-	-	-	-	7.5E-06	5.0E-06	7.5E-06	7.1E-07
U5	-	-	2.2E-05	0	-	-	6.0E-06	4.0E-06	2.8E-05	5.7E-07

Upland kangkong										
Site U4	-	-	-	-	-	-	7.9E-06	5.3E-06	7.9E-06	7.5E-07
U5	-	-	-	-	-	-	7.0E-06	4.6E-06	7.0E-06	6.6E-07
Saluyot										
Site U6	2.6E-04	0	2.2E-05	0	-	-	4.0E-06	0	2.9E-04	0
Spinach										
Site U6	1.8E-04	0	4.4E-05	0	-	-	5.5E-06	3.6E-06	2.3E-04	5.2E-07
Red chili (fruits and leaves)										
Site U7	7.9E-04	5.3E-04	6.7E-05	0	8.8E-05	0	9.4E-06	6.3E-06	9.5E-04	5.3E-04
Green ice lettuce										
Site R1	3.5E-04	0	-	-	-	-	-	-	3.5E-04	0
Iceberg lettuce										
Site R1	1.8E-04	0	-	-	-	-	-	-	1.8E-04	0
Mustard										
Site R1	8.8E-05	0	-	-	-	-	-	-	8.8E-05	0
Okra										
Site R2	8.8E-05	0	-	-	-	-	-	-	8.8E-05	0

- No calculations for TCR since concentration values are <MDL.

No TCR calculations for samples with no analyses for heavy metals, and hence were not included in Table 10 (like Hg).

Ashraf et al. (2021) reported that TCR values ⩽10−6 relate to low cancer-causing risk, those that lie between 10 E-5 and 10 E-4 relate to moderate cancer-causing risks, and values that lie between 10 E-3 and 10 E-1 signify high risks. The TCR values in bold presented in Table 10 indicate moderate to high cancer-causing risks. Results imply that chronic exposure of both adults and children to Cd and Cr from consumption of celery (from U1) and eggplant (from sites U1 and U4), and exposure to As, Cd and Cr from red chili (fruits and leaves) (from U7) could instigate cancer risk for the population in those areas and their surroundings. From the 16 vegetables samples, 15 have shown to be of high risk for adults based on the combined metal TCR, while 3 samples relate to high stakes for children. Overall, potential risks (carcinogenic and non-carcinogenic) from consumption of contaminated vegetables with heavy metals, even in trace levels, are evident from the findings of this work. While it is difficult to fully understand the toxic dynamics of heavy metals and their multifaceted mechanisms, possible health effects from prolonged consumption maybe attributed to the following: (1) there is no effective mechanism for the elimination of heavy metals from the human body (Alisa and

Ferns 2011; Khanna 2011); (2) the latent period of some metals may take several years (Mandal and Suzuki 2002); (3) heavy metals have long biological half-lives (e.g., the half-life of Pb in human bone is 16–27 years and Cd is 10–30 years) and are non-biodegradable nature (Alisa and Ferns 2011; Tomno et al. 2020; Khalef et al. 2022); and (4) different heavy metals have the capacity for cumulative effects on the body (Jayasumana et al. 2015; Sulaiman et al.2020). However, it is crucial to note that the calculations of the health hazard indices in this study were based on specific reported values for the different exposure parameters used (Table 4). As such, data obtained maybe representative only of a portion of the local population. Nevertheless, considering previous epidemiological and experimental studies that reported that prolonged consumption (over several years) of lowly contaminated vegetables and food crops—e.g., 0.01 mg Cd/100g cabbage, 0.58 mg Cu/100g lettuce, 0.30 mg Pb/100g African spinach (Bahemuka and Mubofu 1999) and <0.04 mg Pb/100g green beans (Zurera-Cosano et al. 1989)—may potentially cause adverse health effects (Waalkes et al. 1999; Khanna 2011). A monitoring scheme of human exposures as well as proper implementation of eco-friendly remediation technologies are suggested to safeguard the well-being of the consumers of such food items.

CONCLUSION

In this study, the chemical safety aspect of selected urban farm produce was established in terms of the presence of toxic trace heavy metals such as Hg, As, Cd, Cr and Pb. This study showed that small concentrations of As, Cd, Cr and Pb were detected in the samples from the urban sites; however, the concentrations detected in the urban farming produce were below the MALs. The order of heavy metals detected in this study is as follows: Pb>Cr>As>Cd>Hg. Pb was detected in 17 samples, Cr in 6 samples, As also in 6 samples, Cd in 8 samples (all below MDL) and all samples were below MDL for Hg. Based on the assessment of the associated health risks from long-term consumption of vegetables from different urban sites, there is potential risk for the populations concerned. However, it is important to note that the obtained values from the calculation of the different health risk indices was attributable to the differences in the body weights, ingestion rates and exposure duration of Filipino adults and children.

Nevertheless, in the context of public safety, actions to reduce anthropogenic activities that contribute to heavy metal pollution are warranted. It is recommended that further research be carried out for other exposure pathways. The present work highlights the need for regular biomonitoring of the presence of heavy metals in vegetables and proper information dissemination to ensure the safety of consumers and prevent possible public health problems.

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