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The Carcinogenic and Non-Carcinogenic Health Risks of Metal(oid)s Bioaccumulation in Leafy Vegetables: A Consumption Advisory

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High levels of metal(oid)s in soil or food pose a severe health risk to humans. The potential toxicants find their way into the living systems via the food chain, following bioaccumulation in edible plants, including leafy vegetables grown in or irrigated with contaminated soil or water, respectively. The current study determines the levels of vanadium (V), chromium (Cr), nickel (Ni), copper (Cu), arsenic (As), lead (Pb), and cadmium (Cd) in leafy vegetables (rocca, coriander, and parsley) grown in different open irrigated farms in Qatar and investigates their potential human health risks (carcinogenic and noncarcinogenic). The mean concentrations of V, Cr, Ni, Cu, As, Cd, and Pb in rocca are 17.09, 6.41, 1.70, 13.04, 14.72, 0.90, and 6.36 mg/kg, respectively; in coriander are 15.91, 6.03, 1.38, 15.30, 16.86, 0.43, and 5.00 mg/kg, respectively; and in parsley are 16.25, 6.26, 2.19, 17.97, 16.60, 0.51, and 5.46 mg/kg, respectively. The mean levels of V, Cr, As, Cd, and Pb were observed to be higher than the recommended World Health Organization (WHO)/Food and Agriculture Organization (FAO) values. The target hazard quotient (THQ) values of Cu and As were found to be greater than 1 for the adult population. For the two elements (i.e., Cu and As), the THQ varied from 1.03 to 1.42 and 1.17 to 1.44 in men. In women, the values ranged from 1.20 to 1.65 and 1.35 to 1.55, for Cu and As, respectively. The hazard index (HI) of rocca, coriander, and parsley was 3.99, 4.10, and 4.43, respectively, in men, 4.64, 4.76, and 5.14, respectively, among women. The carcinogenic risk (CR) of Cr, Ni, and As ranged from 7.16×10^{-4} to 7.61×10^{-4}, 5.57×10^{-4} to 8.85×10^{-4}, and 5.24×10^{-3} to 6.01×10^{-3}, respectively, in men. In women, it ranged from 8.31×10^{-4} to 8.83×10^{-4}, 6.47×10^{-4} to 1.03×10^{-3}, and 6.09×10^{-3} to 6.97×10^{-3}, respectively, in all vegetables. In crux, the consumption of rocca, coriander, and parsley grown in selected farms in Qatar poses a major health risk (both noncarcinogenic and carcinogenic) to the consumer. As a result, we recommend that vegetables grown in the studied areas be closely monitored to protect consumer health.

Keywords: arsenic, chromium, nickel, vegetables, carcinogenic health risk, Qatar

1 INTRODUCTION

Exponential population growth and boosts in agriculture, construction, oil and gas, and waste generation increase environmental pollution and pose concerns for both human and environmental health (Verma et al., 2020; Yuan et al., 2020). Toxic metal(oid)s such as lead (Pb), copper (Cu), arsenic (As), and chromium (Cr) are dangerous (Cheng and Yap, 2015; Usman et al., 2020a), and they potentially appear in human bodies through ingestion of contaminated food, skin exposure, and inhalation (Ihedioha et al., 2017). Health problems can result from prolonged exposure to high toxic concentrations (Yuan et al., 2020). Previous reports documented the occurrence of potential toxic metal(oid)s investigated in the present study in both cultivated (Peng et al., 2016) and noncultivated soil (Usman et al., 2019; Usman et al., 2020b) in Qatar. Additionally, more recently, Alsafran et al. (2021) found that As, Cr, and Ni concentrations in agricultural soil were higher than the USEPA recommended level and pose significant risks to human health, particularly children.

Through vegetable consumption (Bigdeli and Seilsepour, 2008), humans may easily ingest these harmful contaminants, commonly found on the surface of fresh vegetables and their tissues. According to several studies, vegetables grown on contaminated soil worldwide accumulate high concentrations of toxic metal(oid)s (Chang et al., 2014; Ismail et al., 2014; Gupta et al., 2021). Türkdogan et al. (2003) linked an increased risk of gastrointestinal cancer to consuming vegetables loaded with high Pb, Cu, and Cd concentrations. Therefore, the importance of investigating metal(oid) accumulation in edible plants, particularly in leafy vegetables cultivated in Qatar, and risks to human health following ingestion cannot be overemphasized.

The quantity of potential toxic metal(oid) individual ingestion via vegetable consumption determines the level of toxicity in humans. In order to determine the potential dangers to human health posed by toxic metal(oid)s through vegetable consumption, various indices, and parameters are used (Gupta et al., 2019). The indices include estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI), and cancer risk (CR) that can help discover the noncarcinogenic and carcinogenic hazards of metal(oid)s in terms of human health. HI summarizes noncarcinogenic hazards, and CR estimates the chance that children or adults will develop cancer after being exposed to potential carcinogenic elements over a lifetime. The element As has been reported to cause cancer in various organ of humans, including those of the bladder, kidney, skin, lung, and liver (Xiong et al., 2013). People exposed to high Cd level risk develop proliferative prostatic lesions, bone fractures, kidney disease, hypertension, and cancer of the lungs (Satarug et al., 2003; Kolluru et al., 2019). Many studies investigated other potential human health risks of consuming metal(oid)-contaminated vegetables in other parts of the world, including India (Gupta et al., 2021), China (Ji et al., 2018), Pakistan (Alam et al., 2003), Ethiopia (Gebeyehu and Bayissa, 2020), and Bangladesh (Shaheen et al., 2016). However, to the best of our knowledge, no study has been reported about vegetables cultivated on metal(oid)-contaminated soil in Qatar, as well as health risks associated with the consumption of leafy vegetables.

Source identification of potential toxins in the soil can be a starting point for creating controls that aim to manage soil quality better, while also protecting human health and the environment. The concentration of metal(oid)s in soil are contributing to both anthropogenic and natural sources. Geological parent materials are a primary natural source. Anthropogenic sources include untreated industrial effluent discharge, fertilizers, pesticides, aerosols in the atmosphere, exhaust from vehicles, and irrigation with wastewater (Lu et al., 2012; Sun et al., 2013; Huang et al., 2015). Several kinds of research used the decision tree analysis (Zhang et al., 2008), absolute principal component scoring/multiple linear regression (APCS/MLR), and principal component analysis (PCA) (Qu et al., 2013; Haji et al., 2016), stochastic models (Hu and Cheng, 2013), isotope labeling (Cheng and Hu, 2010), ensemble models (Wang et al., 2015), and geo-statistical models (Sun et al., 2013) to identify pollution sources.

Previously, we reported high levels (in the cultivated soil) of some of the elements studied here (Alsafran et al., 2021). The objectives of the current study were to determine the levels of As, Cd, Cr, Cu, Ni, Pb, and V in three major leafy vegetables (rocca, coriander, and parsley) grown in the same cultivated soil and evaluate the human health risks among the adult (male and female) population in Qatar. This work is the first to document metal(oid) accumulation in Qatar-produced vegetables and their associated health risks in humans to the best of our knowledge. Given the country's commitment to boost local production for food security in recent years, the importance of this study cannot be overemphasized. Our findings will help inform policies regarding agriculture production and the creation of contamination management strategies and regulations that protect the health of humans and the environment. It will also reinforce the need for sustained growth and political will towards creating an environment sustainable for health.

2 MATERIALS AND METHODS

2.1 Sampling Sites

One of Qatar's most remarkable characteristics is its arch surface expression. Another notable characteristic is that the peninsula is covered with pebbles and sand that have detached from outcropped limestone (Peng et al., 2016; Al-Sulaiti et al., 2017). While there is insufficient knowledge about lithological events in Qatar, the country's exterior predominately rests on layers of clay and limestone (Alsafran et al., 2021; Fourniadis, 2010). Earlier studies on metal(oid) remediation in Qatar's natural soil have found that the concentrations of some elements were below detection limit (Usman et al., 2019; Al-Thani and Yasseen, 2020). Therefore, no proof suggesting that the lithological events magnify metal concentrations exist. This research used irrigated, open farms located in central and northwestern Qatar (**Figure 1**). From January to April 2020, 70 km away from the center of Doha, 10 different locations were

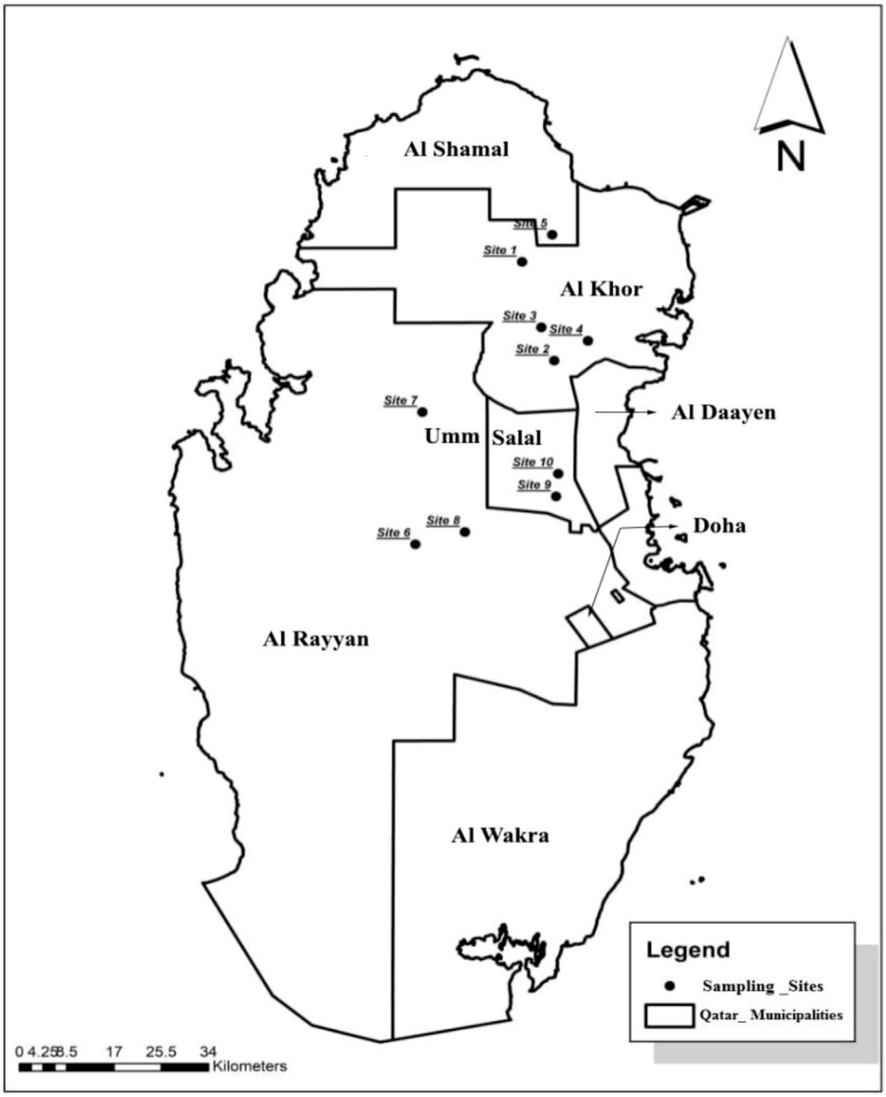

FIGURE 1 | Sampling locations.

chosen to collect 150 vegetable samples (50 each for rocca, coriander, and parsley). The locations of the samplings were randomly chosen (**Figure 1**) and their coordinates were documented (**Supplementary Table S1**). The vegetables cultivated from the locations included mint, parsley, vegetable silk, spinach, silk, lettuce, coriander, dill, onion, and rocca. Imported soil, peat moss, and compost manure were commonly used to improve the fertility of the soil.

2.2 Samples Collection and Preparation

The edible parts of the vegetable samples (rocca, coriander, and parsley) were collected into pre-cleaned and sterilized separate polyethylene bags for plant samples. About 1 kg of each of the vegetables was separately collected from five randomly selected subsampling sites and pooled together to form a composite. The rotten portions were removed, and the remaining samples were carefully packed and immediately transported to the laboratory for further processing and analysis.

In the laboratory, the samples were treated with acid (0.01% HCl) and thoroughly washed with tap and distilled water to remove soil and particulate matter. To facilitate drying, the cleaned samples were chopped into small pieces using a plastic knife. Subsequently, the samples were air-dried in a hot air oven at 50–60°C for 24 h to remove moisture and maintain constant mass. The dried materials were grounded into a fine powder using a mortar and pestle and passed through a 2 mm mesh size sieve. The sieved samples were finally stored in polyethylene bags and kept in desiccators until digestion and analysis.

2.3 Metal(oid)s Quantification

Analytical grade hydrochloric acid (HCl), nitric acid (HNO_3), and hydrofluoric acid (HF) were used to prepare the samples for the microwave-assisted digestion process. Before digestion, all glassware were washed with HCl and deionized water. These samples were gradually agitated and moved into a Microwave Digestion System MARS 6 (CEM Corporation, USA) at rotating temperatures. At the end of digestion cycles, the digests were transferred into 150 ml flasks, cooled, and filtered. Lastly, deionized water was used to produce 150 ml of each of the samples.

After digestion, the concentrations of potential toxic metal(oid)s were determined by interpolating specimens into an Inductively Coupled Plasma (ICPMS) NexIon 300D, (PerkinElmer, USA). Conforming to the USEPA classifications, along with previous reports (Peng et al., 2016; Al-Thani and Yasseen, 2020), public health risks were considered when choosing the type of analyses to do (Usman et al., 2019; Usman et al., 2020b). In order to ensure valid, quality, controlled results, the National Institute of Standards and Technology for apple leaves 1515, laboratory duplicates at every 10th sample, and reagent blanks were used. The % recovery of the quantified metal(oid)s in the certified material were between 94.5 and 102%. For reagent blanks and lab duplicates, the concentrations (mg/kg) were below the detection limit and corresponded to that of the samples (±0.94 mg/kg), respectively.

2.4 Estimated Daily Intake (EDI)

The metal(oid) mean concentrations of three leafy vegetables (rocca, coriander, and parsley), as well as the estimated daily consumption of the vegetables (g), was used to calculate the element's estimated daily intake (EDI) using the equation described by Gebeyehu and Bayissa (2020).

$$EDI = \frac{E_f \times E_d \times F_{ir} \times C_m \times C_f}{B_w \times T_a} \times 0.001,$$

where E_f = exposure frequency (365 days/year); E_d = exposure period (for men 77 years, women 81 years), which is equivalent to the average life span; F_{ir} = average vegetable consumption (240 g/person/day), as defined by the World Health Report (WHO, 2002) for low fruit and vegetable intake. C_m = metal concentration (mg/kg dry weight); Cf = concentration conversion factor for fresh vegetable weight to dry weight (0.085) (Arora et al., 2008); B_w = body weight (85.9 kg for men, 74 kg for women); and T_a = average exposure period (Ed 365 days/year), and 0.001 stands for unit conversion factor.

2.5 Non-Carcinogenic Risk

2.5.1 Target Hazard Quotient

The target hazard quotient (THQ) values were calculated to evaluate noncarcinogenic human health risks from the consumption of heavy metal-contaminated leafy vegetables. It was determined as the proportion of average daily metal consumption to an oral reference dose of each metal (USEPA, 2012) and can be expressed by the following equation.

$$THQ = \frac{EDI}{RfD},$$

where EDI represents the population's average daily metal consumption in mg/day/kg body weight and RfD is the oral reference dosage (mg/kg/day) values for each of metal of concern. The RfD values of V, Cr, Ni, Cu, As, Cd, and Pb were 0.007, 0.003, 0.02, 0.04, 0.0003, 0.001, and 0.0035 mg/kg/day, respectively (Gebeyehu and Bayissa, 2020). Whether the THQ < 1, it is usually assumed to be secure for the risk of noncarcinogenic effects; if THQ > 1, it is assumed that there is a greater likelihood of noncarcinogenic effects as the value rises.

2.5.2 Hazard Index

The metal(oid)s overall human risk, the hazard index (HI) is calculated as the sum of all THQs estimated for specific heavy metals.

$$\mathrm{HI} = \sum_{n=1}^{i} THQ_n;\ i = 1, 2, 3, \ldots\ldots n,$$

where HI is the sum of various metal hards, there is no apparent health impact if HI < 1. An HI > 1.0, on the other hand, indicates the possibility of an adverse health effect. HI > 10 has been linked to a severe chronic health impact.

2.5.3 Carcinogenic Risk

The cancer risk (CR) presented to human health by individual potential carcinogenic metals was calculated. Then, the cumulative cancer risk (TCR), which may promote carcinogenic effects depending on exposure dose, was then calculated from ingestion of metal(oid)s (Cr, Ni, As, Pb, and Cd).

$$CR = EDI \times C_{SF},$$

$$\mathrm{TCR} = \sum_{n=1}^{i} CR_n;\ i = 1, 2, 3, \ldots\ldots n,$$

where CR = cancer risk over a lifetime by individual heavy metal ingestion, EDI = estimated daily metal intake of the population in mg/day/kg body weight, CSF = oral cancer slope factor in (mg/kg/day), and n is the number of heavy metals considered for cancer risk calculation. The CSF values of Cr, Ni, As, Pb, and Cd were 0.5, 1.7, 1.5, 0.38, and 0.01 mg/kg/day, respectively (Gebeyehu and Bayissa, 2020). For single carcinogenic metals and multi carcinogenic metals, the permissible limits are 10^{-6} and < 10^{-4}, respectively (Tepanosyan et al., 2017).

2.6 Statistical Analysis

The effects of local farm location (10 sites), vegetable crops (three crops), and their interactions on the metal(oid) concentrations were examined using the analysis of variance of a factorial experiment. Paired mean comparisons were performed using Tukey's test when the F-test indicated significant effects at the level of $p < 0.05$. The relationship of elemental concentrations in plant samples was investigated by the means of principal component analysis (PCA). All observation data were mean-centered and standardized prior to PCA, and only principal components with eigenvalues > 1 were considered (Kaiser and Rice, 1974).

TABLE 1 | Metal(oid) concentrations (mg/kg dry weight) in the vegetable (rocca, coriander, and parsley) samples.

		V	Cr	Ni	Cu	As	Cd	Pb
Rocca	Min	0.65	1.33	0.00	7.34	0.19	0.10	0.94
	Max	50.95	15.20	9.50	20.45	37.11	1.90	14.37
	Mean	17.09	6.41	1.70	13.04	14.72	0.90	6.36
	S.D.	18.31	4.55	2.39	3.66	11.43	0.50	4.14
Coriander	Min	1.06	1.49	0.00	9.16	0.32	0.00	1.11
	Max	48.52	17.82	10.82	22.64	43.24	1.93	13.09
	Mean	15.91	6.03	1.38	15.30	16.86	0.43	5.00
	S.D.	16.71	4.43	2.54	3.33	14.14	0.59	3.13
Parsley	Min	1.03	1.33	0.00	11.20	0.00	0.00	1.31
	Max	44.05	14.77	8.84	25.62	41.81	5.13	14.29
	Mean	16.25	6.26	2.19	17.97	16.60	0.51	5.46
	S.D.	16.36	3.97	2.43	3.89	12.63	0.87	3.79
MPL[a]		1.5	2.3	10	40	0.1	0.05	0.1

[a]*Permissible limits (mg/kg) were adopted from (FAO/WHO, 2011).*

All statistical analyses were performed using Minitab Computer Software ver. 17.

3 RESULTS AND DISCUSSION

3.1 Metal(loid)s Concentrations in the Vegetables

Since vegetables are valuable components of the everyday human diet, it is critical to maintaining their quality. If grown in a contaminated environment, they can accumulate high metal(oid) concentrations that could negatively affect human health after consumption (Alam et al., 2003). Potential toxic metal(oid)s accumulate more quickly in edible portions of vegetables, particularly leafy vegetables, than in fruit and grain crops (Mapanda et al., 2005). Their concentrations vary between vegetables due to their differential vegetable absorption ability for different elements (Singh et al., 2010). The levels of metal(oid)s in vegetable samples (rocca, coriander, and parsley) grown in the farmlands in different municipalities in Qatar were examined, and the findings are summarized in **Table 1**.

The contents of V, Cr, Ni, Cu, As, Cd, and Pb in rocca varied from 0.65 to 50.95, 1.33 to 15.20, 0.00 to 9.50, 7.34 to 20.45, 0.19 to 37.11, 0.10 to 1.90 and 0.94 to14.37 mg/kg, respectively; in coriander 1.06 to 48.52, 1.49 to 17.82, 0.00 to 10.82, 9.16 to 22.64, 0.32 to 43.24, 0.00 to 1.93, and 1.11 to 13.09 mg/kg, respectively; in parsley 1.03 to 44.05, 1.33 to 14.77, 0.00 to 8.84, 11.20 to 25.62, 0.00 to 41.81, 0.00 to 5.13 and 1.31 to14.29 mg/kg, respectively (**Table 1**). Overall, the mean concentrations of V, Cr, Ni, Cu, As, Cd, and Pb in rocca are17.09, 6.41, 1.70, 13.04, 14.72, 0.90, and 6.36 mg/kg, respectively; in coriander are 15.91, 6.03, 1.38, 15.30, 16.86, 0.43, and 5.00 mg/kg, respectively; and in parsley are 16.25, 6.26, 2.19, 17.97, 16.60, 0.51, and 5.46 mg/kg, respectively. The overall accumulation of metal(oid)s were as follows for rocca: V > As > Cu > Cr > Pb > Ni > Cd; coriander: As > V > Cu > Cr > Pb > Ni > Cd; and parsley: Cu > As > V > Cr > Pb > Ni > Cd. The mean levels of V, Cr, As, Cd, and Pb in the studied vegetables were found to be higher than the recommended value proposed by the WHO/FAO, indicating that they are potentially unsafe to consume. Consistent with our findings, other studies involving different leafy vegetables (Kananke et al., 2014) including coriander (Souri et al., 2018), and parsley (Delbari and Kulkarni, 2014) found that the levels of As, Cd, Cu, and Cr were significantly higher than the recommended safe limits.

Our results are further supported by the findings of Gupta et al. (2021), Chang et al. (2014), Luo et al. (2011), and Zhuang et al. (2009), all of which clearly showed that leafy vegetables accumulate potential toxic elements, and to a greater degree than non-leafy vegetables. Due to the large surface areas of their leaves, the leafy vegetables were often exposed to metal(oid)s by indirect means such as dust and rainwater. Leafy vegetables could absorb higher concentrations than typical plants due to their high growth rates (Khan et al., 2013). The elements accumulation in vegetable samples may be due to chemical fertilizer usage or the discharge of untreated solid and/or fluid waste from factories in the surrounding areas (Alsafran et al., 2021). Toxic levels of these metal(oid)s in the vegetables studied may harm the health of the residents who stay nearby. As a result, vegetables grown in suburban areas are heavily contaminated with these elements, both noncarcinogenic and carcinogenic, harmful to human health. As a result, it is recommended that their contents in this area's food crops be monitored and assessed regularly.

3.2 Principal Components Analysis of Metal(oid)s Concentrations in the Vegetables

In order to interpret their multivariate relationships and to classify their potential sources, the metal(oid) concentration in the vegetables was subjected to the principal component analysis (PCA). The PCA components such as eigenvalue, variance (%), cumulative (%), and PCA biplot of the elements in all vegetables are presented in **Figure 2** and **Supplementary Table S2**. The PCA of the metal(oid) concentrations in the vegetable samples revealed seven principal components (PCs), two of them showed eigenvalues > 1.00, which is considered significantly important. These two principal components (PCs) explained 65.4% of the overall variability (**Figure 2**; **Supplementary Table S2**). PC1 accounted for 40.4% of the overall variability, and data showed a significant positive correlation of PC1 with the following elements; V, Cr, Ni, As, Cd, and Pb. The strongest one was V (0.511), followed by Ni (0.474), and Cd (0.431), which indicates an anthropogenic source, which in part, and could be due to active oil and gas production. Past research has implied that the concentrations of these elements in Qatar vary across the country, which can be attributed to the most active human activities of the surrounding areas (Usman et al., 2019; Al-Thani and Yasseen, 2020; Usman et al., 2020b). In contrast, PC1 exhibited a weak negative linkage with Cu. PC2 accounted for 25% of the overall variability, presented a moderate negative one with Cr and Pb, while a significant association with As (0.561), which may be released from the emissions created by human undertakings (Ying et al., 2016; Zhang et al., 2018).

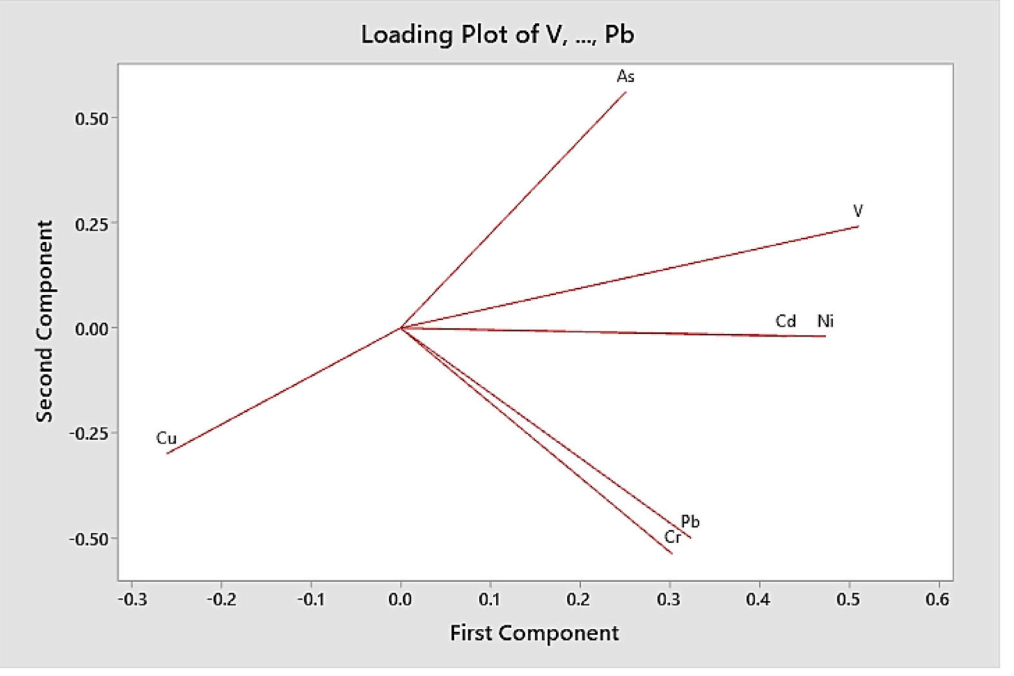

FIGURE 2 | PCA biplot of elemental concentrations in the vegetables samples.

TABLE 2 | Estimated daily intake (mg/day/kg bw) of metal(oid)s for men and women due to the consumption of contaminated vegetables.

		V	Cr	Ni	Cu	As	Cd	Pb	Total EDI_M
Men	Rocca	4.06×10^{-3}	1.52×10^{-3}	4.04×10^{-4}	3.10×10^{-3}	3.50×10^{-3}	2.14×10^{-4}	1.51×10^{-3}	1.43×10^{-2}
	Coraínder	3.78×10^{-3}	1.43×10^{-3}	3.28×10^{-4}	3.63×10^{-3}	4.00×10^{-3}	1.01×10^{-4}	1.19×10^{-3}	1.45×10^{-2}
	Parsley	3.86×10^{-3}	1.49×10^{-3}	5.21×10^{-4}	4.27×10^{-3}	3.94×10^{-3}	1.20×10^{-4}	1.30×10^{-3}	1.55×10^{-2}
	Total EDI_V	1.17×10^{-2}	4.44×10^{-3}	1.25×10^{-3}	1.10×10^{-2}	1.14×10^{-2}	4.36×10^{-4}	3.99×10^{-3}	4.43×10^{-2}
Women	Rocca	4.71×10^{-3}	1.77×10^{-3}	4.69×10^{-4}	3.59×10^{-3}	4.06×10^{-3}	2.48×10^{-4}	1.75×10^{-3}	1.66×10^{-2}
	Coraínder	4.39×10^{-3}	1.66×10^{-3}	3.81×10^{-4}	4.22×10^{-3}	4.65×10^{-3}	1.18×10^{-4}	1.38×10^{-3}	1.68×10^{-2}
	Parsley	4.48×10^{-3}	1.73×10^{-3}	6.04×10^{-4}	4.95×10^{-3}	4.58×10^{-3}	1.39×10^{-4}	1.50×10^{-3}	1.80×10^{-2}
	Total EDI_V	1.36×10^{-2}	5.15×10^{-3}	1.45×10^{-3}	1.28×10^{-2}	1.33×10^{-2}	5.06×10^{-4}	4.64×10^{-3}	5.14×10^{-2}

3.3 Estimated Daily Intake

The dietary exposure approach to vegetable consumption is a valid method for examining a population's diet regarding nutrient, bioactive component, and contaminant intake levels, providing critical information regarding potential nutritional deficiencies or food contamination exposure (WHO, 1985). Because of the increasing awareness of the connection between diet and human health, people are eating more green vegetables than ever before. Food safety and sustainability have become critical issues due to the rapid cultivation and use of green plants (Rahmdel et al., 2018). The metal(oid) mean concentration in each vegetable, and their respective consumption rates were used to calculate the EDI. The results for men and women are presented in **Table 2**. The mean EDI values for men of V, Cr, Ni, Cu, As, Cd, and Pb through the consumption of rocca were 4.06×10^{-3}, 1.52×10^{-3}, 4.04×10^{-4}, 3.10×10^{-3}, 3.50×10^{-3}, 2.14×10^{-4}, and 1.51×10^{-3} mg/day/kg bw, respectively; coriander were 3.78×10^{-3}, 1.43×10^{-3}, 3.28×10^{-4}, 3.63×10^{-3}, 4.00×10^{-3}, 1.01×10^{-4}, and 1.19×10^{-3} mg/day/kg bw, respectively; while the corresponding values in parsley were 3.86×10^{-3}, 1.49×10^{-3}, 5.21×10^{-4}, 4.27×10^{-3}, 3.94×10^{-3}, 1.20×10^{-4}, and 1.30×10^{-3} mg/day/kg bw, respectively (**Table 2**). The EDI of individual metals for men due to the consumption of rocca were in the following order V > As > Cu > Cr > Pb > Ni > Cd; coriander As > V > Cu > Cr > Pb > Ni > Cd; and in parsley Cu > As > V > Cr > Pb > > Ni > Cd. Similarly, for women the EDI values for V, Cr, Ni, Cu, As, Cd, and Pb due to the consumption of rocca were 4.71×10^{-3}, 1.77×10^{-3}, 4.69×10^{-4}, 3.59×10^{-3}, 4.06×10^{-3}, 2.48×10^{-4}, and 1.75×10^{-3} mg/day/kg bw, respectively; coriander were 4.39×10^{-3}, 1.66×10^{-3}, 3.81×10^{-4}, 4.22×10^{-3}, 4.65×10^{-3}, 1.18×10^{-4}, and 1.38×10^{-3} mg/day/kg bw, respectively; and in parsley were 4.48×10^{-3}, 1.73×10^{-3}, 6.04×10^{-4}, 4.95×10^{-3}, 4.58×10^{-3}, 1.39×10^{-4},and 1.50 $\times 10^{-3}$ mg/day/kg bw, respectively (**Table 2**). The EDI of individual metals for women as a result of consumption of rocca were in the following order V > As > Cu > Cr > Pb > Ni > Cd; coriander As > V

TABLE 3 | THQ and HI for men and women through the consumption of rocca, coriander, and parsley from the study areas.

	Metals	V	Cr	Ni	Cu	As	Cd	Pb	Hazard index (HI)
Men	Rocca	0.58	0.51	0.13	1.03	1.17	0.07	0.50	3.99
	Coriander	0.54	0.48	0.11	1.21	1.33	0.03	0.40	4.10
	Parsley	0.55	0.50	0.17	1.42	1.31	0.04	0.43	4.43
Women	Rocca	0.67	0.59	0.16	1.20	1.35	0.08	0.58	4.64
	Coriander	0.63	0.55	0.13	1.41	1.55	0.04	0.46	4.76
	Parsley	0.64	0.58	0.20	1.65	1.53	0.05	0.50	5.14

> Cu > Cr > Pb > Ni > Cd; and in parsley Cu > As > V > Cr > Pb > Ni > Ni > Cd. The total EDI values for all metal(oid)s of interest as a result of rocca, coriander, and parsley consumption for men were found to be 1.43×10^{-2}, 1.45×10^{-3}, and 1.55×10^{-2} mg/day/kg bw, respectively, while for women, the values were found to be 1.66×10^{-2}, 1.68×10^{-2} and 1.80×10^{-2} mg/day/kg bw, respectively (**Table 2**).

3.4 Health Risk Assessment

3.4.1 Non-Carcinogenic Risk

The routes of exposure to the target species are used to detect the health risk of a pollutant because estimating the exposure level is highly crucial. There are many paths by which people get exposed to potential toxic metal(oid)s, and ingestion of vegetables contaminated with such elements could damage human health.

3.4.1.1 Target Hazard Quotient

The THQ was computed to estimate the health risk of metal(oid)s ingestion by vegetable consumption both for male and female inhabitants of the study area, and data obtained are depicted in **Table 3**. The THQ, which is the ratio of a pollutant's calculated dosage to a reference dose level, is being used to assess the health risks of adult populations from contaminated leafy vegetables. If THQ > 1, the exposed population is expected to be affected. The THQs of Cu and As were found to be greater than unity in all vegetables. In men, the THQ values of Cu and As ranged from 1.03 to 1.42, 1.17 to 1.44, respectively, whereas in women, it varied from 1.20 to 1.65, 1.35 to 1.55, respectively (**Table 3**), reflecting the serious potential health risks associated with the consumption of rocca, coriander, and parsley. In a similar study involving coriander and lettuce, Baghaie and Fereydoni (2019) reported higher THQ levels than standard values. THQs for the other elements such as V, Cr, Ni, Cd, and Pb studied were found to be less than 1. As a result, there is no reason to be concerned about the continuous consumption of vegetables posing a health risk. The risk-level sequence of THQ followed a decreasing order for rocca, coriander, and parsley As > Cu > V > Cr > Pb > Ni > Cd; As > Cu > V > Cr > Pb > Ni > Cd; and Cu > As > V > Cr > Pb > Ni > Cd. Contrastingly, separate studies found higher THQ than the standard for Cd and Pb (Baghaie and Fereydoni, 2019), and Cd, Pb, and Cr (Quispe et al., 2021) in coriander. Both men and women had the same risk sequence, but women had higher THQ values in both cases.

3.4.1.2 Hazard Index

The HI, which indicates the effects of all elements concurrently, was used to assess their health risks. **Table 3** shows the HI of the studied metal(oid)s due to vegetable consumption for both men and women. For men, the HI of rocca, coriander, and parsley was 3.99, 4.10, and 4.43, respectively, while for women, it was 4.64, 4.76, and 5.14, respectively, indicating that the level of noncarcinogenic adverse health effect is alarmingly high (**Table 3**). For men, compared to the THQs resulting from rocca, coriander, and parsley consumption, it can be seen that As accounts for 29.32% of the HI attributable to rocca intake followed by Cu (25.81%), V (14.54%), Cr (12.78%), Pb (12.53%), Ni (3.26%), and Cd (1.75%); As accounts for 32.44% of the HI due to the consumption of coriander followed by Cu (29.51%), V (13.17%), Cr (11.71%), Pb (9.76%), Ni (2.68%), and Cd (0.73%); in contrast, Cu accounted for the highest contribution (32.12%) to HI values attributed to parsley consumption followed by As (29.64%), V (12.45%), Cr (11.31%), Pb (9.73%), Ni (3.85%), and Cd (0.90%) (**Figure 3A**). Similarly, for women, the highest contribution to HI values as a result of consumption of rocca was accounted by As (29.15%) followed by Cu, V, Cr, Pb, Ni, and Cd, which accounts for 25.92, 14.47, 12.75, 12.53, 3.46, and 1.72%, respectively. As a result of consumption of coriander, As accounted highest contribution (32.50%) to HI values followed by Cu, V, Cr, Pb, Ni, and Cd, which accounts for 29.56, 13.21, 11.53, 9.64, 2.72, and 0.84%, respectively, while, due to consumption of parsley, Cu accounted highest contribution (32.04%) to HI values followed by As, V, Cr, Pb, Ni, and Cd which accounts for 29.71, 12.43, 11.26, 9.71, 3.88, and 0.97%, respectively (**Figure 3B**). Our HI results agree with the findings of other studies involving coriander (Quispe et al., 2021) and other leafy vegetables (Hussain and Qureshi, 2020). In the latter study, the combined HI values for Cu, Zn, Cd, Cr, and Pb due to lettuce and carrot consumption were found to be significantly higher than standard limits at 12.8 and 9.21. This indicates that the health of residents in the current study area is at risk, and therefore appropriate actions are required to reduce the metal(oid) levels and protect the residential population from potential health risks.

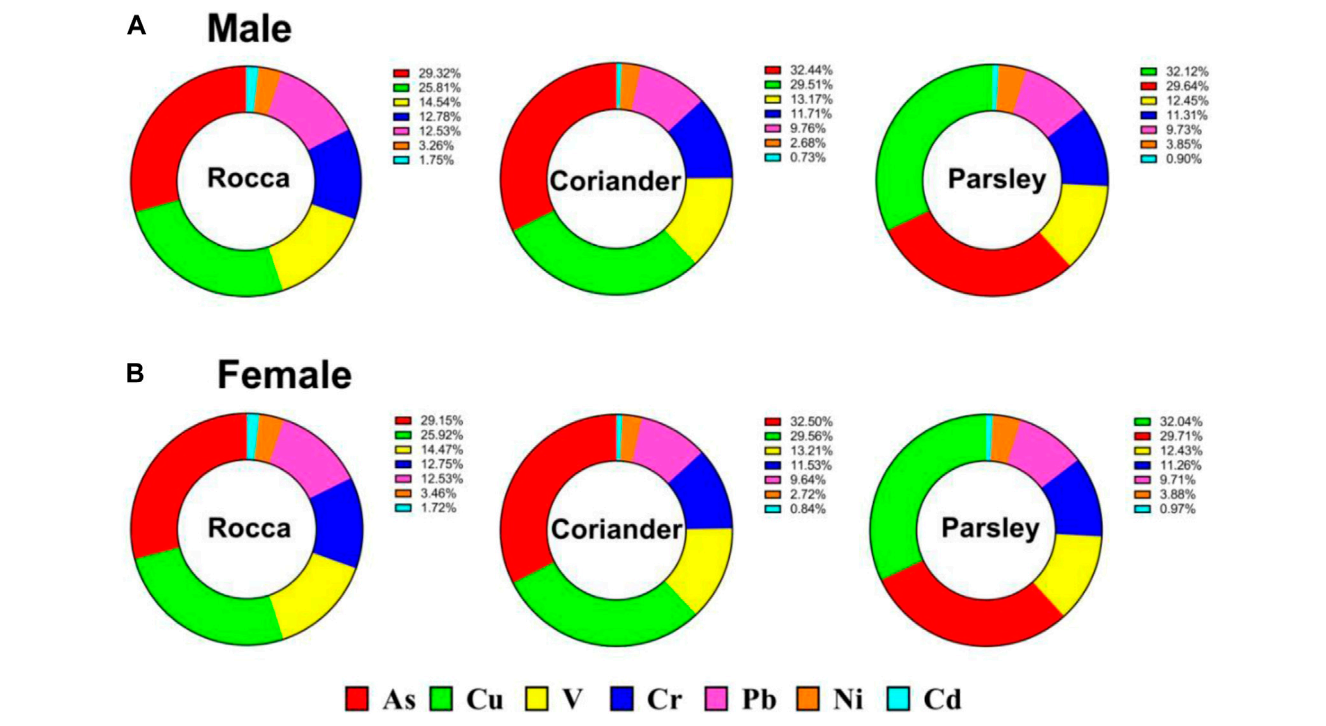

FIGURE 3 | Comparison of health risks caused by the different metal(oid)s according to HI among adult population. **(A)** Men and **(B)** women.

TABLE 4 | CR and TCR for men and women through the consumption of rocca, coriander, and parsley in the study area.

	Metals	Cr	Ni	As	Cd	Pb	TCR
Men	Rocca	7.61×10^{-4}	6.87×10^{-4}	5.24×10^{-3}	8.13×10^{-5}	1.28×10^{-5}	6.78×10^{-3}
	Coriander	7.16×10^{-4}	5.57×10^{-4}	6.01×10^{-3}	3.85×10^{-5}	1.01×10^{-5}	7.33×10^{-3}
	Parsley	7.44×10^{-4}	8.85×10^{-4}	5.91×10^{-3}	4.57×10^{-5}	1.10×10^{-5}	7.60×10^{-3}
Women	Rocca	8.83×10^{-4}	7.98×10^{-4}	6.09×10^{-3}	9.44×10^{-5}	1.49×10^{-5}	7.88×10^{-3}
	Coriander	8.31×10^{-4}	6.47×10^{-4}	6.97×10^{-3}	4.47×10^{-5}	1.17×10^{-5}	8.51×10^{-3}
	Parsley	8.63×10^{-4}	1.03×10^{-3}	6.86×10^{-3}	5.30×10^{-5}	1.28×10^{-5}	8.82×10^{-3}

3.4.2 Carcinogenic Risk

Since these elements may promote both noncarcinogenic and carcinogenic effects based on exposure levels, the carcinogenic risks (CR) and cumulative carcinogenic risk (TCR) derived from Cr, Ni, As, Pb, and Cd intake by leafy vegetable consumption were estimated, and the results are presented in **Table 4**. In men, the CR values of Cr, Ni, and As ranged from 7.16×10^{-4} to 7.61×10^{-4}, 5.57×10^{-4} to 8.85×10^{-4}, and 5.24×10^{-3} to 6.01×10^{-3}, respectively. In women, it varied from 8.31×10^{-4} to 8.83×10^{-4}, 6.47×10^{-4} to 1.03×10^{-3}, and 6.09×10^{-3} to 6.97×10^{-3}, respectively, in all vegetables (**Table 4**). Given that the CR values for Cr, Ni, and As exceeded the threshold value ($CR > 10^{-4}$), these elements potentially pose cancer risk to the adult population through the consumption of the studied vegetables (rocca, coriander, and parsley). While the CR values for Pb and Cd were found to be less than the threshold value ($CR > 10^{-4}$), indicating that the adult population in the studied areas are not at any cancer risk due to Pb and Cd exposure from rocca, coriander, and parsley consumption. **Table 4** shows the TCR of the elements examined due to the vegetable consumption for both men and women. For men, the TCR of rocca, coriander, and parsley was 6.87×10^{-3}, 7.33×10^{-3}, and 7.60×10^{-3}, while for women, it was 7.88×10^{-3}, 8.51×10^{-3}, and 8.82×10^{-3} respectively. In a study involving coriander and other crops, Bian et al. (2016) found a significantly higher CR and TCR than the acceptable level and concluded that As, Cd, and Cr poses cancer risks in the study area. In a separate study, Khezerlou et al. (2020) reported the CR value of As in salad to be higher than the acceptable risk limit, and concluded that consuming salad grown in the area puts the resident population at a high potential cancer risk. Additionally, in another study, Gebeyehu and Bayissa (2020) assessed and found higher than recommended TCR values for As, Cd, and Ni in other vegetables, indicating that exposure to the elements potentially poses adverse cancer risks. Together, our results indicate that the consumption of rocca, coriander, and parsley grown in agricultural farms in Qatar and poses a possible cancer risk to the adult population due to the prevalence of Cr, Ni, and As.

4 CONCLUSION

- Certain elements are essential components of the human diet. However, because of their tendency of accumulating toxic elements, their content in leafy vegetables must be determined and assessed for potential health risks to humans.
- The study results indicated that the mean concentration of V, Cr, As, Cd, and Pb in rocca, coriander, and parsley were alarmingly higher than the recommended values proposed by the WHO/FAO.
- The THQs of Cu and As were greater than unity in all vegetables, while THQs for the other elements such as V, Cr, Ni, Cd, and Pb were less than 1 in both men and women.
- The combined noncarcinogenic effects of all studied elements due to the consumption of rocca, coriander, and parsley to adult populations based on the HI exceeded 1, indicating risks to human health.
- Since the CR levels of Cr, Ni, and As are above the threshold value ($CR > 10^{-4}$), these values are known to pose cancer risk to both men and women, who consume rocca, coriander, and parsley, in the study region and its periphery.
- Collectively, the outcome suggests that local populations are potentially exposed to the toxic effects of the studied metal(oid)s, particularly Cr, Ni, and As by consuming leafy vegetables grown in open irrigated farms. To protect the country's population from long-term potential health risks, it is vital to take adequate measures to minimize the pollution level of elements, particularly As, Cr, and Ni.
- Our findings support the need for close monitoring of potential toxic metal(oid) concentrations in Qatar produce. Accordingly, the development of innovative strategies to limit the bioavailability of the elements in cultivated lands will be helpful. Further study on the elements' gastrointestinal bio-accessibilities is required to fully understand their long-term effects on human health.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

MA: Conceptualization, Methodology, Writing—review and editing, Resources, Supervision, Project administration. KU: Conceptualization, Methodology, Formal analysis, Writing—original draft, Writing—review and editing. MR: Formal analysis, Writing—review and editing. TA: Methodology, Formal Analysis, Writing—review and editing, HA: Conceptualization, Resources, Writing—review and editing, Supervision, Project administration.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2021.742269/full#supplementary-material

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