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Evaluating Heavy Metals Contamination in Soil, Water and Vegetables Cultivated in Three Areas of Ad-Dawadmi Governorate, Kingdom of Saudi Arabia

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Abstract: Irrigation of croplands with untreated wastewater and industrial waste has caused contamination of soils and bioaccumulation of toxic metals in edible parts plants, threatening human health**.** The concentrations of seven different heavy metals (Cu, Fe, Zn, Ni, Cd, Pb, and Hg) were investigated in the soil, water and the root, fruits and leaf of carrot (*Daucus carota*), cucumber (*Cucumis sativus*) and parsley (*Petroselinum crispum*), collected from three regions; Arjaa, Sajir and Ad-Dawadmi, in Ad-Dawadmi Governorate, Western Riyadh, Kingdom of Saudi Arabia (KSA). The heavy metal contents of the samples were determined after digestion of samples using nitric acid, using Inductively-Coupled Plasma-Mass Spectrometry (ICP-MS). The plant translocation factors (TF) were calculated throughout this study. The results revealed that the concentrations of Cu, Fe, Zn and Ni in all vegetable samples from the three regions were found under the maximum permissible concentration of WHO and FAO Maximum Levels, 73, 425, 99 and 67 [(µg/g) mg/kg], respectively. Concentrations of Cd and Pb in the edible vegetable samples harvested from the Arjaa and Sajir regions are higher than their permissible limits by WHO, 0.36, 0.21; 1.29, and 1.68 with respect to 0.2, 0.3, respectively. Moreover, Hg was not detected in all investigated samples of vegetables, soil and water. Water samples collected from Sajir and Ad-Dawadmi and the soil samples collected from Sajir exceed the standard level of Zn (180, 157 and 103 µg/g respectively). The concentrations of Cd and Pb in the soil and water from the three regions exceed their respective permissible limits. Increased bioaccumulation of certain heavy metals can be a risk factor for consumers in the studied areas. Detailed studies are required to further assess threats of heavy metal contamination in the region.

Keywords: Ad-Dawadmi, Environmental pollution, Heavy metals contamination, soil contamination, toxic metals, vegetable contamination, Kingdom of Saudi Arabia.

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1. Introduction

Irrigation of croplands with untreated wastewater and application of industrial waste has caused contamination of soils. Crops grown on these contaminated soils cause bioaccumulation of toxic metals in edible plant parts, which transfer to other trophic levels, ultimately to humans, posing a serious risk to human health (Albdaiwi et al., 2022; Noor et al., 2023; Scanlon et al., 2023). Heavy metals are a group

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of chemical elements including metals and metalloids, having a specific gravity of 4 g/cm^3 (Jayakuma et al., 2021), and atomic weight ranges from 63 to 200 Dalton. They can be highly toxic or poisonous to living organisms even at very low concentrations. Generally, these elements do not occur in living organisms and can cause illness (Singh et al., 2023; Velarde et al., 2023).

Heavy metals exist naturally in parent rocks. These rocks are introduced into the environment by natural processes and human activities (Li et al., 2023; Madhav et al., 2023; Nivetha et al., 2023). Anthropogenic activities, such as industrial processes (mining, smelting, various manufacturing processes, incineration, power generation, landfills), agricultural practices (application of fertilizers, manures, pesticides, herbicides fungicides, wastewater, etc), improper waste disposal, emissions from automobiles, land development activities trigger accumulation of heavy metals in the agricultural ecosystems and overall (Jayakuma et al., 2021; Li et al., 2019; Sarhan et al., 2021).

Heavy metal pollution exposure can have serious implications for humans, plants, animals and microbes (Elahi et al., 2018; Farid et al., 2018; Manzoor et al., 2022). Moreover, it can also contaminate soil and water, hindering crop production and animal rearing. It is important to properly manage waste and industrial processes to prevent heavy metal pollution (Sarhan et al., 2021). Chronic health troubles because of exposition to small intensity of heavy metals from natural sources or anthropogenic have become a very important scientific issue globally (Adnan et al., 2022). Uncontrollable vegetables grown in polluted soil can pose serious threats to consumers. Such metals are not able to be degradable and can accumulate in the human body, causing many health problems; one of the major health problems is the different types of cancers (Rehman et al., 2018).

Heavy metals, for instance, lead (Pb) and cadmium (Cd), are the leading environmental pollutants (Zhao et al., 2013; Wen et al., 2022). Even though zinc and copper are essential micronutrients, their existence in the environment in higher concentrations can also be a threat to different plants and humans (Kaur and Garg. 2021; Uchimiya et al., 2020). Pb and Cd have no critical biological functions and are highly noxious to humans (Clemens and Ma, 2016; Collin et al., 2022; Ismael et al., 2018; Qin et al., 2020). The most affected people with heavy metal toxicity are sensitive aged-persons for example pregnant women, the elderly and young children (Alengebawy et al., 2021; Clemens and Ma, 2016). Heavy metal toxicity can cause serious health issues, malfunctioning of the nervous system and could alter blood contents, and damage lungs, kidneys, liver and other fundamental organs (Clemens and Ma, 2016). Consuming food with higher levels of Pb and Cd can critically exhaust the body's storage of iron, vitamin C and other vital nutrients, causing decreased immunological resistance, intra-uterine development retardation, impaired psycho-social disabilities coupled with malnutrition (Khan et al., 2016; Mohammadi et al., 2018; Mumtaz et al., 2020; Anuoluwa et al., 2021).

The problems of heavy metal contamination of vegetables in the KSA and their accumulation on the vegetables have been reported earlier (Ahmad and Al-Qahtani, 2012; Al Jassir et al., 2005; Arif et al., 2011; Nassar et al., 2018, Khaled et al., 2019). However, the work that has been achieved was concentrated on the problems of heavy metal accumulation on vegetables cultivated in industrial areas or vegetables sold from markets. The Governorate of Ad-Dawadmi northwest Riyadh city, KSA, is a hyperarid area. Water availability is further threatened by changing climatic conditions (Gomaa et al., 2022; Gomaa et al., 2023). Various crops are grown, moreover, livestock and poultry farms are widely distributed all over the area (Al-Zaidi et al., 2011), Main source of irrigation water is the underground water aquifer (Gomaa et al., 2022; Gomaa et al., 2023)

There is no industry, however, a high quantity of heavy metals concentration was observed (Gomaa et al., 2022). Therefore, this study was designed to determine heavy metal concentration loaded in vegetables grown in three farms in Ad-Dawadmi Governorate and to propose future possible improvement measures to reduce the impact associated with the health status of the people and to compare the contamination level of heavy metals in vegetables grown in the three farm regions with the levels that recommended by the international organizations, FAO and WHO. Systematic studies are lacking in the literature to investigate these areas of the KSA for heavy metal contamination in vegetables.

2. Materials and Methods

2.1. Study Area and Geologic History

This study was carried out at three locations of Ad-Dawadmi Governorate, Kingdom of Saudi Arabia (KSA), i.e., Ad Dawadimi town, Arjaa and Sajir (Fig. 1). The area is located northwest of Riyadh Principality, at the highest elevation of the Najd plateau, central KSA.

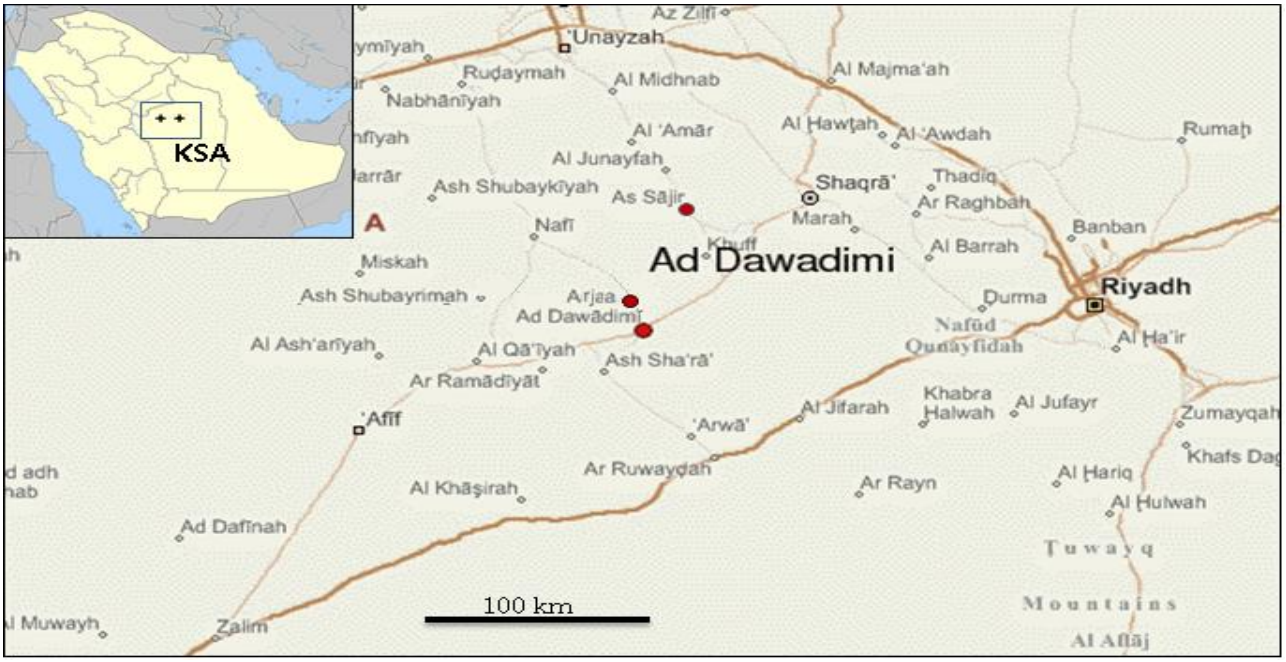

Fig. 1. Location Map of the study areas (Ad-Dawadmi, Arjaa and As Sajir) of Ad-Dawadmi Governorate, Kingdom of Saudi Arabia

The region covers an area of about 30,000 km^2 with a latitude between 24° 49’ N and a longitude between 44° 13’ E (Hassan et al., 2016). The meteorological data indicated that the annual average rainfall is about 21.4 mm, the summer average temperature is about 41°C and in winter reaches 11°C, and relative humidity ranges between 10 -38%.

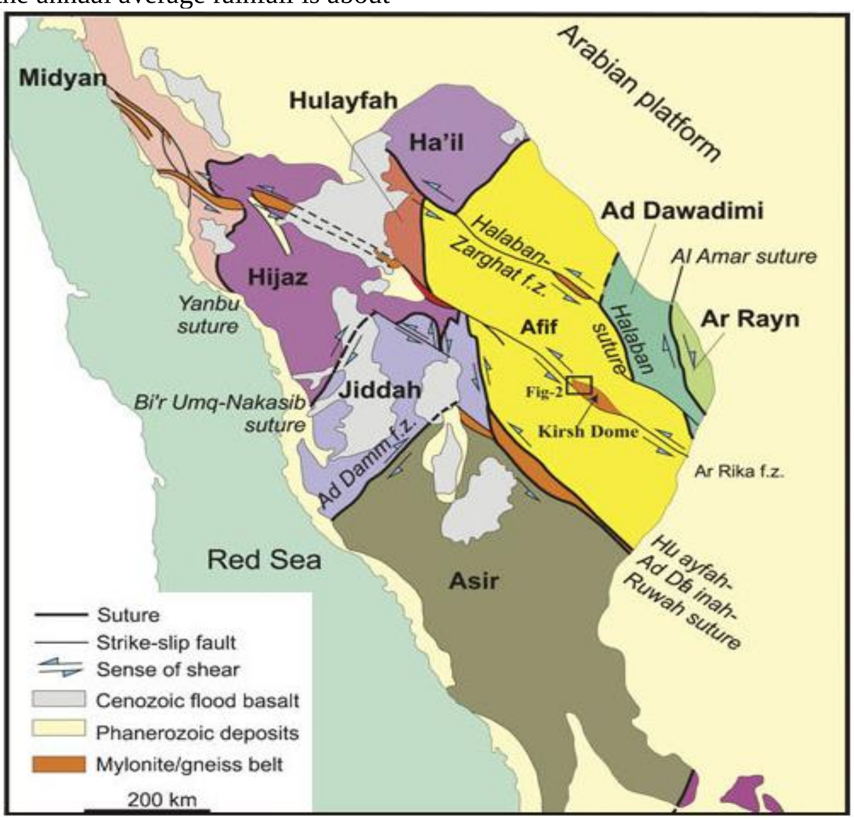

Fig. 2. Terrane map of the Arabian Shield showing the main segments of the Najd fault system and their associated gneissic domains (Johnson, 2006).

The geology of Ad-Dawadmi area is represented by crystalline rocks of the Arabian Shield (Fig. 2) which disappear beneath superficial sediments with some outcrops of different heights scattered in and around the area. The highest altitude in Ad-Dawadmi area is Jabal Al-Nir in the extreme west (about 1307 meters), and in the onward northeast and the lowest plains height is about 660 m. The depths of sedimentary strata are shallow extending between 1.0 and 7.0 m, descending from the west to the east and superimposing with crystalline rocks (El-Didy, 1997). The area is considered part of the Arabian Shield at the east-central boundary, with the Paleozoic sediments, composed of Precambrian granitic rock complexes coupled to two basic complexes and folded meta-sediments strata (Amin and Mesaed, 2023; Gomaa et al., 2022; Gomaa et al., 2023).

2.2. Sampling and Pre-Treatment

Plant samples of harvested fresh vegetables consumed by people were collected from three different farms at Ad-Dawadmi, Arjaa, and Sajir, and these samples were classified into, leafy vegetables (parsley), roots (carrot) and fruits (cucumber) (Table 1). The collected plant samples were kept in containers with treatment and site codes and kept in the laboratory until analyses. Soil (0-25 cm depths) and water samples (three samples) were collected from the same sites and location points where the plant specimens were collected. Individual healthy specimens of each plant sample were selected for chemical analysis. The collected plant species were taxonomically identified.

2.3. Heavy Metal Determination

Soil and water pH were determined using a pH meter. The water and soil collected specimens were digested using HNO_3 Conc.: H_2O_2 (2:1) for the estimation of total heavy metal contents.

Filtration of the treated solutions was carried out using filter paper (Whatman No. 42) and the Inductively-Coupled Plasma-Mass Spectrometry (ICP-MS) was used to analyze collected filtrates for the presence of Cu, Fe, Zn, Ni, Cd, Pb, and Hg. The plant specimens were washed with running tap water and then distilled water to eliminate any soil or debris particles on the outer surfaces of the plants. Subsequently, samples were oven-dried for 72 h at 60^{o} C until constant weight. Samples (0.5 g) were used for digestion using HNO_3Conc.: H_2O_2 (2:1) ratio and heated at boiling water bath. The volume of the obtained digested samples was diluted with distilled water to 25 mL. Filtration of the treated solutions was carried out using filter paper (Whatman No. 42) (Khan et al., 2013). Inductively-Coupled Plasma-Mass Spectrometry (ICP-MS) was used to estimate the amounts of heavy metals in the extracts. To avoid inaccuracy, the results were taken in triplicate. Analytical-grade chemicals were used in this study.

Calibration using standard solutions was made for all elements under estimations. A standard solution (was obtained from Ultra Scientific USA). Using Thermo Scientific- iCAP-Q -Mass Spectrometer model, heavy metal concentrations were recorded against standard solutions. This is achieved by ionizing the sample using an inductively coupled plasma part and then mass spectrometer. The determination of elements using ICP-MS ranges from 7 to 250 atomic mass.

2.4. Metal translocation factor

The transfer of heavy metal from the soil to the plant samples was recorded as a translocation factor (TF). TF was calculated (Cui et al., 2005; Khan et al., 2010) as:

$$TF= \frac{\text{Metal concentration in the vegetable}}{\text{Metal concentration in the soil sample}}$$

The heavy metal concentrations of the soils and vegetables under investigation were evaluated, in proportion to dry weight. If the TF ratio is greater than one, then the plant accumulates metals, TF ratio=1 indicates no absorption of heavy metals by plants, and if the TF ratio is less than one indicates a negligible amount of heavy metals absorption (Olowoyo et al., 2010).

3. Results and Discussion

3.1. Heavy Metals Concentrations in Vegetables

In this study trace minerals concentrations such as Cu, Fe, Ni, and Zn and three toxic metals Cd, Hg and Pb were determined in some cultivated vegetables from three regions in Ad-Dawadmi Governorate, KSA, using Inductively-Coupled Plasma-Mass Spectrometry (ICP-MS).

Table 1. Description of plant species and their parts used in this study.

Vegetable	Scientific Name	Family	Part used
Carrot	*Daucus carota*	Apiaceae	Roots
Cucumber	*Cucumis sativus*	Cucurbitacaeae	Fruits
Parsley	*Petroselinum crispum*	Apiaceae	Leaves

Table 2. Concentrations of heavy metals (µg /g dry weight) in Vegetables, Soil and Water collected from the three areas of Ad-Dawadmi Governorate, Kingdom of Saudi Arabia

Study Areas	Samples	Cu (µg /g)	Fe (µg /g)	Zn (µg /g)	Ni (µg /g)	Cd (µg /g)	Pb(µg /g)
Arjaa	Carrot	3.96±1.81	50.83±4.17	86.83±13.82	2.7±0.23	0.13±0.40	0.96±0.58
	Cucumber	4.31±2.13	35.34±3.13	97.38±7.19	3.04±0.12	0.26±0.00	1.06±0.11
	Parsley	5.6±0.78	54.74±5.28	57.11±17.16	3.98±0.31	0.11±0.01	0.49±0.12
	Soil	5.64±0.01	390.29±13.66	62.92±3.33	10.73±0.04	0.13±0.01	2.57±0.63
	water	0.95±0.01	95.51±9.8	42.65±3.70	2.89±0.12	0.26±0.13	1.88±0.43
Sajir	Carrot	5.72±1.50	54.03±4.22	44.88±16.39	1.78±0.28	0.21±0.05	1.68±0.44
	Cucumber	5.73±0.55	44.52±4.04	18.97±12.18	1.87±0.16	0.19±0.02	1.15±0.19
	Parsley	6.15±0.74	51.64±2.98	74.60±21.48	3.31±0.22	0.16±0.03	0.61±0.11
	Soil	1.8±0.03	180.19±8.9	103.13±5.70	5.02±1.2	0.24±0.02	2.48±0.10
	Water	0.22±0.01	23.99±0.42	180.97±9.67	1.46±0.63	0.15±0.01	1.14±0.81
Ad-Dawadmi	Carrot	5.98±2.89	40.30±6.35	30.18±0.06	2.34±0.11	0.17±0.03	0.72±0.20
	Cucumber	2.95±0.41	39.59±7.87	55.88±35.00	1.8±0.11	0.17±0.02	0.70±0.08
	Parsley	2.73±0.08	40.33±2.86	49.00±15.07	2.63±0.17	0.20±0.05	0.94±0.79
	Soil	3.03±0.01	165.18±2.3	91.60±0.26	5.49± 0.03	0.21± 0.01	1.94±0.01
	Water	0.35±0.01	24.73±1.10	157.3±7.6	1.46±0.02	0.09± 0.01	1.42±0.02
***FAO/WHO**		73	425	99	67	0.2	0.3

(*FAO/WHO, 2001)

Concentrations of Cu, Fe, Ni and Zn in all vegetable samples from the three regions were found within the maximum permissible concentration (Table 2) 73, 425, 99 and 67 µg/g (mg/kg), respectively. Cadmium values showed mild concentrations against permissible limits by FAO/WHO, 0.2; the lowest value (0.11 µg/g) was recorded from parsley harvested from Arjaa region (Table 2). However, a high Cd concentration was noticed in cucumber (0.26 µg/g) from the same area. The mean concentration levels of Pb in all vegetables of the three regions were detected higher than the permissible limits by FAO/WHO, 0.3 (Table 2); and thus, might be a threat to the consumers.

In this study, Hg was not detected in all samples, vegetables, soil and water. In other words, it might be under an immeasurable level. Plants' heavy metals contents are affected by some aspects such as rainfall (or water of irrigation), climate, the availability of heavy metals concentration in the area, the soil origin, and finally plants' status or features during harvesting time (Albdaiwi et al., 2022; Atta et al., 2023). Absorption of mineral nutrients and water is mostly carried out through the plant roots, the direct interaction between the roots, and the surrounding soils which might contain heavy metals, allows the tissues of the plant to absorb different heavy metals within this mineral nutrition (Smical et al., 2008). Later, after the entry of heavy metals inside the roots, they might be either reserved in the storage tissues of the roots or translocated through stems to the other organs of the plant species. Therefore, edible or nonedible parts of the plants could accumulate different concentrations of heavy metals (Arora et al., 2008). The absorption of Pb and Cd by vegetables in the study areas needs much more investigation.

3.2. Heavy metals in soils and waters

The concentrations of Cu, Fe, Zn, and Ni in all soil and water samples from the three regions were found under the maximum permissible concentration (Table 2), except the samples of water from Sajir and Ad-Dawadmi water and soil from Sajir exceeded the standard level of Zn (180, 157 and 103 µg/g respectively). The concentrations of Pb in the soil and water from the three regions exceed their respective permissible limits (Table 2).

Regarding Cd concentration levels from the three regions were found under the maximum permissible concentration only the water sample from Arjaa and the soil sample (Sajir region) were considered above the level of FAO/WHO standards of Cd. Groundwater pollution and higher concentrations of heavy metals (Pb, Cd and Zn) in the three studied areas can be attributed to chemical weathering.

Lead is a critical body poison when cumulative inside the plant body system. It will get inside the plant through air, water and soil and is unable to be removed by rinsing the surfaces of fruits and vegetables (Divrikli et al., 2003). The high concentrations of Pb in these plants are probably attributed to Pb pollutants in irrigation water and/or soil.

Table 3. Translocation Factor values of heavy metals for selected vegetables collected from the three areas of Ad-Dawadmi Governorate, Central Saudi Arabia

Study areas	Vegetable	Cu	Fe	Zn	Ni	Cd	Pb
Arjaa	Carrot	0.7	0.13	1.38	0.25	1	0.3
	Cucumber	0.76	0.09	1.55	0.28	2.02	0.41
	Parsley	0.99	0.14	0.9	0.37	0.85	0.19
Sajir	Carrot	3.18	0.3	0.43	0.35	0.88	0.68
	Cucumber	3.18	0.25	0.18	0.37	0.79	0.46
	Parsley	3.42	0.29	0.72	0.66	0.67	0.25
Ad Dawadmi	Carrot	1.97	0.24	0.33	0.43	0.81	0.37
	Cucumber	0.96	1.65	0.31	1.24	1.17	0.61
	Parsley	1.51	0.22	0.48	0.52	0.83	0.38

3.3. Translocation Factor

Copper exhibited a high translocation factor in almost all samples (TF was more than 1). TF of Fe was recorded as more than 1; for the cucumber collected from Ad-Dawadmi, while Zn was marked as;1.55, and 1.38 µg/g for cucumber and carrot harvested from Arjaa, respectively.

A higher Cd translocation factor was observed for cucumber fruits from the Arjaa area (2.02 µg/g). The soils of the three areas had alkaline pH, despite the high concentrations of Pb in the soil samples, their transfer factor values were low in the given alkaline values. The TF was less than 1 for other metals (Table 3). high TF values may denote that heavy metals are weakly bonded to the soils or efficiently absorbed by vegetables. A Strong bond between heavy metals and colloidal particles in soils may lower TF values.

These results indicated that Cu antagonist Fe, Zn and Cd translocation. Yoon et al., (2006) reported that the mobility of metal may be affected by many factors; soil properties (chemical and physical) and environmental factors. The differences in heavy metals concentration detected in vegetables throughout this study may be due to the solubility of heavy metals in the soil solutions (Cordeiro et al., 2013).

Studied areas lack industrial activities, therefore, the heavy metal pollution can be attributed to geological contamination resulting from the weathering of heavy metal-rich parent rocks and/or human activities (Nazzal et al., 2016). Mineral uptake by plants is influenced by several factors, including their abundance in the soil, water and soil contamination, and proximity of sampling sites to the roads or other sources of pollution (Khan et al., 2015). However, the heavy metals detected in the plants might derive from the soil and/or the irrigation groundwater (Manwani et al., 2023). Obaid et al., (2023) also reported increased levels of heavy matter accumulation in soil, water and plant parts in Afghanistan, when treated with wastewater.

The moderate concentration of Cd is probably because of using a fertilizer that contains Cd or because the area of agriculture is watered with sewage water or both reasons. The high concentrations of Pb in the plant, soil and water need great awareness it conceivably creates real health complications (Natasha et al., 2022; Kumar et al., 2020; Zulfiqar et al., 2019). Our findings are in agreement with the previous reports from different areas of central KSA, by Al Jassir et al., (2005), who detected higher levels of Cd and Pb in some vegetable species collected from central KSA.

4. Conclusion

Results presented in this study revealed considerable variations in heavy metal concentration were observed in studied vegetables, soil and water samples analyzed. The high concentrations of heavy metals in the samples investigated could fully or partially be referred to as the bedrock texture of the area of the study. The capability of vegetables to mount up metals was emphasized. This study denoted that heavy metals (Zn, Cu, Ni and Fe) were under the permissible standard levels of FAO/WHO level, while Pb and Cd were above the standard level in most plant specimens under the study. One of the obvious results of the present study, the translocation factor of toxic metals by the edible plant samples in the study areas may enhance and consequently be considered a hazard agent for the consumption of these vegetables. To reduce the threats of harmful heavy metals detected, it is better to use nonedible wild plants accumulating pollutants before using soil or land for cultivating vegetables, i.e., phytoremediation. Other studies to confirm these findings might be of great importance.

List of Abbreviations: Cd: Cadmium; Cu: Copper; FAO: Food and Agriculture Organization; Fe Ferrous; Hg: HNO3 Conc.: Concentrated Nitric acid; H2O2: Hydrogen peroxide; Mercury; ICP-MS: Inductively-Coupled Plasma-Mass Spectrometry; mg/kg-: milligram per kilogram: mL: milliliter; µg/g: microgram per gram; Ni: Nickel; Pb: Lead; TF: Translocation Factor; WHO: World health organization; Zn: Zinc.

Competing Interest Statement: The authors have declared that they have no competing interests and there is no conflict of interest exists.

Author's Contribution: I. E. M. designed the study. I. E. M. and K. Z. G. collected the samples and conducted the experiments. while I. E. M and M. S. A. wrote the manuscript. All the authors read and approved the final manuscript.

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