Assessment of potentially toxic elements in vegetables cultivated in urban and peri-urban sites in the Kurdistan region of Iraq and implications for human health

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Abstract

Vegetable fields in and around urban areas in the Kurdistan region of Iraq may have higher than background concentrations of potentially toxic elements (PTEs) from contamination sources including municipal waste disposal and waste water used for irrigation. The purpose of this study was to assess PTE concentrations in soils and the edible parts of field-grown vegetables to quantify potential health risks to the local population. In this survey, 174 soils and 26 different vegetable and fruit types were sampled from 15 areas around Sulaymaniyah and Halabja cities. Sampling was undertaken from fields in urban, peri-urban and rural locations including sites close to areas of waste disposal.

The soils are calcareous (pH 7.67 - 8.21) and classified as silty loam, sandy or silty clay with organic matter content between 6.62 and 11.4%. Concentrations of PTEs were typically higher in waste disposal areas compared with urban, peri-urban and rural areas. Pollution load indices (PLI) suggested that agricultural soils near waste disposal sites were contaminated with some trace elements. Potentially toxic element concentrations in vegetables were highly variable. Higher total concentrations of PTEs were measured in vegetables from the waste areas with decreasing concentrations in urban, peri-urban and rural areas. Risks to human health were assessed using hazard quotients (HQ). Vegetable consumption poses no risk for adults whereas children might be exposed to Ni, As and Cd. Although HQs suggest elevated risk for children from consumption of some vegetables, these risks are likely to be lower when realistic dietary consumption levels are considered.

Introduction

Urban agriculture is a primary source of income and nutrition for some populations and, used strategically, can increase urban sustainability, particularly in developing countries. Expansion of urban areas can result in considerable alteration of the natural environment, affecting water quality and quantity and increasing the accumulation of waste materials. In developed countries, urban and peri-urban agriculture (UPA) may be practiced in specific areas, including allotments and community vegetable gardens, while in developing countries UPA is mainly practiced in informal areas such as, rear and front gardens, road verges and on waste ground. UPA can be important for food production, strengthening communities, and helping to reduce both socio-economic and environmental problems. It can also pose health risks if cultivation takes place on sites contaminated with potentially toxic elements (PTEs) and organic contaminants (Alloway, 2004, Clark et al., 2006). Exposure pathways include direct ingestion, dermal contact and inhalation (Wang et al., 2011, Gebrekidan et al., 2013). In countries where water is scarce, wastewater (sometimes diluted by freshwater sources) is often used for irrigation.

Vegetables play an important role in providing essential dietary nutrients. However, vegetables and crops grown in urban and peri-urban areas generally contain higher concentrations of PTEs and other pollutants compared with crops and vegetables grown in rural areas (Gupta et al., 2019). Although some trace metals act as micro-nutrients to maintain normal body function, exposure to elements such as Cr, Cu, As and Zn can result in neurologic disorders, headaches, renal and liver diseases when they exceed safe limits (Lin et al., 2013). There is also evidence that long-term exposure to low doses of some PTEs may increase the incidence of cancer. Itoh et al. (2014) found that dietary Cd intake through ingestion of contaminated rice and other vegetables was directly related to the incidence of postmenopausal breast cancer. Increased risk of lung cancer has been observed as a result of occupational exposure to mists and dusts containing hexavalent chromium (Liu et al., 2013). Zhao et al. (2014) report a statistically significant correlation between top soil Pb concentration and gastric cancer, and between Hg in grain and liver cancer. In the Sulaymaniyah province of northern Iraq it is estimated that fresh fruits, grains and vegetables are grown in as many as 2000 locations including rural, urban and peri-urban areas, some of which are contaminated with PTEs and other substances. The produce grown at these sites is sold as a component of daily meals eaten by more than 500,000 urban residents.

The objective of this study was to provide a first comprehensive survey of soil, water and vegetation concentrations of major and trace elements in Sulaymaniyah province and to establish whether elevated concentrations are present in food crops that might pose a risk to human health. Soil, water and produce samples were collected from sites across the province from agricultural fields in urban, peri-urban and rural areas and close to sites of municipal waste disposal.

Materials and methods

Sampling

The Kurdistan region of Iraq is mountainous with calcareous soils. It borders Syria to the west, Iran to the east and Turkey to the north. The climate is semi-arid continental with hot and dry summers (35-48˚C) and cold and wet winters (7-13˚C). Soil and water samples were initially collected from areas located in or around the cities of Sulaymaniyah, Halabja, Kalar, Sirwan and Khurmal (Table 1, Figure 1). Subsequently, paired plant and soil samples were collected around the cities of Sulaymaniyah and Halabja where cultivation for subsistence and/or commercial consumption is practiced.

Composite top soil (1-15 cm) samples (c.1 kg) were collected to be representative of different fields within each sampling area. Each sample was collected using a clean stainless steel trowel and placed in a plastic bag for transport to the laboratory before being air dried. Water pH and electrical conductivity (EC) were measured in the field at the time of sampling. Water samples for trace element analysis were immediately filtered (< 0.45 µm) before being preserved by acidification to 2% $HNO_{3.}$ Plant samples were placed in paper bags and transported to the laboratory on the day of sampling.

Sample Processing

Dry soil samples were gently disaggregated using a pestle and mortar and sieved to obtain the <2 mm fraction. Soil pH was determined using 5 g of <2 mm sieved, air-dried soil after suspension in 12.5 mL of distilled water and shaking at 40 rpm for 30 minutes. Measurements were made using a Hanna pH-209 pH meter with combined glass electrode (Ag/AgCl; PHE 1004) calibrated at pH 7.0 and 4.01, allowing 5 minutes for the reading to stabilize. Loss on ignition (%LOI) was used to estimate the percentage of organic matter in the samples. A known weight of <2 mm oven-dried soil in a pre-weighed ceramic crucible was placed in a muffle furnace (Gallenkamp) overnight at 550ºC, to combust organic matter. The crucibles and combusted soil were then placed in a desiccator to cool before weighing and calculation of %LOI. A portion of <2 mm sieved and homogenised soil was finely ground using an agate ball mill (Retsch Model PM400, Germany) before digestion with 70% hydrofluoric acid, nitric acid and perchloric acid (Trace Element Grade (TEG), Fisher Scientific, UK) in a teflon-coated graphite block digester (Analysco, UK) using PFA digestion vessels. The digested samples were diluted to 50 mL using MilliQ water and stored in PTFE bottles (5% HNO_3) pending elemental analysis. All digests were diluted 1:10 with MilliQ water immediately prior to analysis.

The fresh weight (FW) of plant samples was recorded as soon as possible after sampling before approximately half of each sample was washed with tap water and then thoroughly rinsed in distilled water to remove surface soil contamination. The remaining plant material was left unwashed. Washed and unwashed portions were oven dried at 70°C for 72 h and re-weighed to determine dry weight (DW).

Samples were finely ground in an ultra-centrifugal mill (Retsch Model ZM200, Germany) fitted with a 0.5 mm titanium screen. Ground material (200 mg) was digested in pressurised PFA vessels in 6.0 mL of 70% Trace Analysis Grade (TAG, Thermo-Fisher Scientific, UK) HNO_3 with microwave heating (Anton Paar 'Multiwave'). Digested samples were diluted to 20 mL using MilliQ water and stored pending elemental analysis. Immediately before analysis, samples were diluted 1:10 with MilliQ water.

Elemental Analysis

Elemental analysis was undertaken using an ICP-MS (Model X-Series II, Thermo-Fisher Scientific) operated in 'collision cell mode' (7% hydrogen in helium) to reduce polyatomic interferences. Samples were introduced from an autosampler (Cetac ASX-520) through a concentric glass venturi nebuliser (flowrate c. 0.8 mL min^{-1}). Internal standards were introduced to the sample stream via a T-piece and included Rh (20 ng mL^{-1}) and Ir (10 ng mL^{-1}) in 2% TAG HNO_3. External multi-element calibration standards (Claritas-PPT grade CLMS-2, Certiprep/Fisher) were used for calibration. Sample processing was undertaken using Plasma lab software (version 2.5.4; Thermo-Fisher Scientific) configured to employ separate calibration blocks and internal cross-calibration where required.

Quality Control

Quality control was assessed by digestion of NIST Standard Reference Material (SRM 2711 Montana soil) and (SRM 1573a tomato leaf) alongside soil and plant samples to confirm data quality. Recoveries (%) were within the acceptable range of uncertainty for each element.

Pollution load index (PLI)

To assess the degree of contamination around sampling sites a pollution load index (PLI) was calculated (Jorfi et al., 2017) according to:

$$PLI = \sqrt[n]{(CF_1 \times CF_2 \times CF_3 \times CF_n} \qquad (1)$$

Where CF_n is the concentration factor for an individual element, defined as C_s/C_b where C_s was the concentration of the element in the sample compared to the background, C_b. Values of C_b were the mean concentrations of individual PTEs observed in samples from rural areas. PLI ≤1 indicates PTE loads close the rural baseline while PLI >1 indicates PTE contamination.

Assessment of Soil Contamination of Plant Samples

Unwashed plant samples were assessed for extraneous soil contamination using the approach of Mwesigye et al (2016). The percentage of soil contamination was estimated for each element by comparison with soil and plant vanadium (V) concentrations:

$$P(\%) = \frac{(V_p \times M_s) \times 100}{V_s \times M_p} \qquad (2)$$

where P (%) is the percentage contamination of the plant with soil particles for a given element (M), V_p and V_s are the vanadium concentrations in the plant and soil samples, respectively, and M_p and M_s are the concentrations of a given element in the plant and soil samples, respectively. This approach provides an approximate percentage of plant contamination with soil particles based on the assumption that there is no systematic uptake of V by the plant. Although a labile form of V can be present in calcareous soil (HVO_4^{2-}), vanadate ($VO^{3-}{}_4$) ions are unlikely to be taken up by plants (Joy et al., 2015).

Risk assessment from PTEs in vegetables

Hazard quotients to assess risks to human health from consumption of locally grown produce were calculated using the USEPA approach (USEPA, 2000):

$$HQ_M = \frac{ADD_M}{RfD} \qquad (3)$$

where HQ_M is the hazard quotient for a given element, RfD (mg kg^{-1} d^{-1}) is the reference dose, defined as the maximum tolerable daily ingestion of an element that has no adverse health impact. ADD_M (mg kg^{-1} d^{-1}) is the average daily intake of the element:

$$ADD_M = \frac{(DI \times C_{FW})}{W_B} \qquad (4)$$

where DI represents the daily intake of fruit and vegetables (kg d^{-1}), C_{FW} is the concentration of an element in the edible plant material (mg kg^{-1} FW) and W_B is human body weight (kg). Assumed daily intakes (DI) were 0.342 kg d^{-1} FW for adults and 0.232 kg d^{-1} FW for children with body weights of 70 and 16.2 kg, respectively (Hamad et al., 2014). Reference doses were 0.003, 0.012, 0.04, 0.3, 0.0003, 0.00036 and

0.0035 mg kg^{-1} day^{-1} for Cr, Ni, Cu, Zn, As, Cd and Pb, respectively (WHO, 1982; US EPA Iris Database, 2009; Environment Agency, 2009a, Environment Agency, 2009b).

Statistical analysis

Descriptive statistics are presented as means, medians, standard errors, differences between means, minima and maxima. A two way ANOVA was used to analyse concentration differences between sampling sites. Pearson correlation coefficients and linear regressions were calculated to determine the relationships between total trace elements in soil and edible parts of vegetables. The data were statistically analysed using the statistical packages SPSS 17.0 and MINITAB 16.0. A probability (p) <0.05 was considered to be statistically significant when testing null hypotheses.

Result and discussion

Soil characterization

Soil properties are given in Table 2. Soil pH typically ranged from 7.67 to 8.21 confirming the calcareous nature of the soils which have previously been classified as silty loams, sandy and silty clays (Rashid, 2010). The highest pH values were recorded at sites irrigated with groundwater, springs and drilled wells in the Anab area of Halabja. Long-term irrigation with waste water has been suggested to decrease soil pH and to increase the organic matter of top soils (Rattan et al., 2005, Xu et al., 2010) although this pH difference probably reflects the underlying geology and variation in soil type. The lowest soil organic matter (SOM) (6.62 and 6.8% LOI) was recorded in fields irrigated with clean water and diluted waste water in the Kalar river side and Anab area; the highest SOM (11.4% LOI) was in fields near the municipal waste disposal site in Sulaymaniyah city, which is irrigated with diluted domestic waste water. Major element chemistry reflects the calcareous geology of the area; calcium is the dominant cation present at significantly greater concentrations (45900 – 127000 mg kg^{-1}) than other cations. Studies in areas of calcareous geology have shown similar major element profiles (Iqbal and Shah, 2011, Nazif et al., 2015).

No local environmental standards exist for trace elements in soils in Iraq therefore concentrations were compared to UK Soil Guideline Values (SGV), European and WHO guidelines (EU/WHO) (Table 2). Large standard deviations for some elements demonstrate heterogeneity between soils within the same sampling area. Total concentrations of individual elements also varied significantly ($p<0.01$) between study areas suggesting localized contamination sources. Figure 2 shows trace elements in the Halabja area compared based on land use (waste, urban, peri-urban and rural areas). Data for Sulaymaniyah City and other sites are given in Figures S1 & S2. Concentrations of Cu, Zn, Cd and Pb were significantly greater and more variable in areas subject to waste disposal compared with other urban or rural areas. No obvious increase was observed for Cr, Ni and As at waste disposal areas. The lowest concentrations of all elements were recorded in the rural areas. Waste disposal and urban activity therefore appears to be increasing the concentrations of some PTEs in nearby agricultural soils.

Concentrations of Cr were frequently above SGVs and EU/WHO guidelines in most soil samples, including those collected in waste disposal area, but all fell within the typical range reported for calcareous soils of 5 -150 mg kg^{-1} (Kabata-Pendias and Mukherjee, 2007). Soils from Anab (n=9) had significantly lower Cr concentrations which may reflect lower geological backgrounds concentrations. Chromium concentrations were similar to those in a study conducted in Damascus (Syria) by Möller et al. (2005) who observed that the main sources of Cr in soils at their sampling sites were geogenic as concentrations were close to "pedogeochemical" background values.

Nickel concentrations varied from c.75 mg kg^{-1} in the waste area in Halabja (n=3) to c.185 mg kg^{-1} at Kalar Riverside (peri-urban area, n=11) with all samples exceeding typical concentrations for calcareous soils of 5-20 mg kg^{-1} (Kabata-Pendias and Mukherjee, 2007). Concentrations also all exceeded the EU standard of 50 mg kg^{-1}. Although greater than typical concentrations in calcareous soils elevated Ni concentrations were observed by Habib et al. (2012) who investigated the trace element content of 25 calcareous soil samples in Baghdad city (Iraq). They reported Ni concentrations ranging between 105 - 210 mg kg^{-1}, similar to those observed in this study, which may suggest that geogenic Ni concentrations in Iraqi soils are greater than in most calcareous soils. Copper and Zn concentrations were lower than the permitted UK sludge limits for agricultural soil (50 and 300 mg kg^{-1}) and EU standards (100 and 300 mg kg^{-1}), respectively, except at the waste disposal site in Halabja (Figure 2) where higher mean concentrations were recorded (263 and 773 mg kg^{-1}, respectively). Mean concentrations of As, Cd and Pb were below SGVs and EU limits except for Cd and Pb in the waste disposal area of Halabja. Concentrations of these elements in rural areas were generally lower than those in urban, peri-urban and waste.

Pollution load indices were used to assess overall trace elemental contamination in the study areas. Values for Sulaymaniyah and Halabja and soils from other sites are shown in Figure 3. The PLI values in Halabja city were higher than for Sulaymaniyah city under all land uses but especially at the waste disposal area which was clearly more polluted than the other sampling areas. Values of PLI in Sulaymaniyah city are centred around 'safe' limits except for soils collected around the waste area. Both cities had greater PLI values than for soils collected in other areas of the province. Overall the data also indicate some PTE contamination at waste disposal sites in both cities and in agricultural fields near waste disposal sites. Urban and peri-urban areas also had slightly elevated soil PTE concentrations compared with rural sites.

Trace element concentrations in fresh and waste waters

Physico-chemical properties of water samples are given in Table 3. All samples are within the safe pH range recommended for irrigation waters (pH 6-9). The EC of the waters was typically in the range 500-600 µS cm^{-1} with the exception of waste water in the Halabja area (c. 950 µS cm^{-1}). Trace element (e.g. Co, Ni, Cu) concentrations are slightly greater in the waste waters compared to the fresh waters but are well below the maximum concentrations recommended for irrigation water (Ayers, 1994) indicating that the use of these waters for irrigation purposes is not likely to result in elevated toxic element concentrations in the soils or plants.

Accumulation of trace elements in vegetables

The mean concentrations of PTEs in 26 types of unwashed and washed fruits and vegetables are presented in Table 4. A significant variation between PTEs in all sample types was clear ($p<0.05$). The greatest concentrations of Al, V, Cr, Fe, Ni, Se, Cd, Pb and U were 4653, 9.43, 14.7, 3392, 10.6, 0.196, 0.892, 1.91 and 0.062 mg kg^{-1} (dry weight), respectively, in unwashed radish leaves while the highest concentration of Mn was 1745 mg kg^{-1} in vine leaves. Cobalt was highest (2.88 mg kg^{-1}) in washed cress, Cu was highest (17.0 mg kg^{-1}) in unwashed tarragon and Zn was highest (53.0 mg kg^{-1}) in unwashed okra. These concentrations are likely due to external contamination of the samples with soil particles although some trace element uptake by plants is possible.

Mean concentrations of PTEs determined in washed and unwashed vegetable samples are compared in Figure 4. This suggests that, with a few exceptions, there is little difference between PTE concentrations in washed and unwashed samples. The greatest deviation from the 1:1 line was found for Zn, suggesting a contribution from particles containing only Zn, especially at greater total concentrations. Many authors have reported that washing vegetables plays an important role in minimizing trace element concentrations in produce grown in and around cities and near road verges (Qadir et al., 2000, Itanna, 2002, Sharma et al., 2008, Nabulo et al., 2010, Ali and Al-Qahtani, 2012, Kumar, 2013) but washing has not reduced trace element concentrations here and therefore concentrations likely reflect the trace element concentrations of the vegetables as consumed.

Mean concentrations in the most commonly consumed vegetables such as eggplant, pepper, okra, tomato, cowpea and chard are presented in Figure 4, grouped according to land use. Most of the vegetables can be consumed raw but some are cooked before eating, which may alter the PTE concentrations. Greatest concentrations were typically observed in vegetables grown in or around waste disposal sites with progressively reduced concentrations in urban, peri-urban and rural areas.

Concentrations of Cr were all well below the FAO/WHO ‘safe limit’ of 2.3 mg kg^{-1} FW based (FAO/WHO, 2001). Nickel and Cu in all vegetable types, in both cities, were greater than UK recommended values of 0.2

and 0.5 mg kg^{-1} FW, respectively (UK Food Standard Agency, 2009) with the exception of Ni in eggplant, tomato and cucumber. Nickel and Cu concentrations in this study are similar concentrations in the edible parts of vegetables observed in a Libyan study (Elbagermi et al., 2013). Concentrations of As, Cd and Pb also exceeded UK and FAO/WHO standards in selected fruits and vegetables (Figure 5). Arsenic concentrations in the vegetable samples exceeded the UK limit of 0.005 mg kg^{-1} FW in the waste area and also exceeded this limit in other land use areas for okra, cucumber and chard. Concentrations of As were however lower than values reported by Nazemi (2012) in vegetables grown in long term waste water irrigated fields in Iran. Cadmium concentrations exceeded UK limits for many vegetables for all land uses. Cadmium concentrations in okra in the waste and peri-urban areas were also higher than EU standards for non-leafy vegetables of 0.05 mg kg^{-1} FW (European Commission, 2004). Greatest Cd accumulation was observed in a sample of celery (0.11 mg kg^{-1} FW) and the lowest in samples of cowpea (0.002 mg kg^{-1} FW). Yang et al. (2009) undertook a field trial to investigate Cd accumulation in leek, pak choi, carrot, radish, tomato and cucumber grown on Cd-contaminated soils. They found that Cd concentrations varied from 0.01 to 0.1 mg kg^{-1} FW, which is a similar range to that observed in this study. In general, Pb concentrations were significantly above the UK limit of 0.01 mg kg^{-1} FW in chard collected in all areas of Sulaymaniyah and Halabja cities. Lower concentrations of trace elements were typically detected in fruits compared with leafy vegetables, which is in agreement with other studies. For example, Gebrekidan et al. (2013) observed higher accumulation of Ni and Cd in chard and lettuce compared with fruits of tomato and green pepper.

Ranges of element concentrations within and between vegetable types indicate that trace element accumulation varies between different species of plants and/or among different plants of the same species (Säumel et al., 2012, Xu et al., 2013). For example in an assessment of exposure risks associated with urban horticulture in the city of Berlin, Säumel et al. (2012) observed that leafy vegetables had greater concentrations of Cu, Zn, Ni compared to fruits, stem and root vegetables. Leaf type and morphology is likely to play a significant role in determining the extent of trapping of soil particles and the ability to remove these particles with washing.

Soil contamination of vegetable samples

The extent of soil contamination of the vegetables samples was estimated from Equation 2. Strong correlations between V and Fe in plants indicated contamination of vegetables with soil particles (Figure 6, r = 0.97 and 0.93 for leafy vegetables and fruits, respectively). The greatest contamination by soil particles was in the unwashed leafy vegetables (leek, celery, purslane, spring onion, tarragon and chard), Table 5. For example mean proportions of Cr and Co derived from soil particles in washed samples were >40% for purslane and tarragon, >60% in leek, celery and chard, and >80% in spring onion. Nickel concentrations attributable to soil particles were typically >30% in washed vegetables. Washing was therefore insufficient to remove all adhering soil particles for many vegetables but probably reflects concentrations a consumer might be exposed to after washing vegetables in the home.

Health risk assessment

Non-carcinogenic risk from consumption of vegetables was assessed according to Equation 3. Element-specific HQs were calculated for the most commonly-consumed leaf and fruit vegetables (eggplant, cowpea, okra, tomato, cucumber and chard) sampled from waste, urban, peri-urban and rural areas for both adults and children. Results for children are presented in Figure 7. Hazard quotients exceeded 1.0 for one or more element in pepper, okra, cowpea and chard in samples collected across all land use types. This suggests that consumption of these vegetables regularly and in large amounts may exposure children to risk. Calculated HQs for adults were typically below 1.0 with the exception of Cd in okra and chard from urban areas, Ni in cowpea (excluding rural sites) and Cr chard from waste disposal areas (Figure S3) suggesting that some specific combinations of metals and crop types may be potentially problematic.

Element-specific HQs were calculated for seven commonly-consumed vegetables assuming an equal dietary contribution from each vegetable. Results for land use types for both adults and children are shown in Figure 8. A clear influence of municipal waste and urban pollution on the agricultural fields was observed with HQs typically greater than for peri-urban and rural areas. HQs calculated for adults for this mixture of commonly consumed vegetables were all < 1.0 suggesting no risk. Values for children suggested a slight risk from Ni and Cd for city dwellers and possible risks from Cr, Ni, As and Cd if the vegetables were grown close to waste disposal sites. To refine these findings further a full dietary survey would be required to understand the relative contributions of specific vegetable types and other foods to the diets of adults and children in the Kurdistan region of Iraq.

Conclusions

Soil contamination as a consequence of municipal waste disposal and urban activities in Sulaymaniyah and Halabja cities has been clearly identified as a source of PTEs to surrounding areas. Vegetable crops grown close to waste areas and urban fields contained higher concentrations of PTEs than crops grown in peri-urban and rural areas. For vegetables in rural areas, most PTEs were found to be below accepted regulatory limits. A significant proportion of PTE content of vegetables appeared to be derived from soil dust rather than systemic uptake despite washing of samples. Consumption of vegetables grown close to municipal waste disposal sites may pose a potential health risk to children but this requires confirmation following a comprehensive dietary survey that includes other food types.

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Table 1: Sampling site locations and descriptions.

City	Area	GPS	Total no. sites	Classification	Plant samples	Water samples	Description
Sulaymaniyah	Waste site	35°28'47.51"N 45°25'28.36"E	5	Waste	Y		Municipal waste disposal site located on the outskirts of the city close to agricultural fields. Leachates from the site flows across the surrounding fields. Waste disposed includes, glass, metals, batteries, plastics and organic material.
	Tanjaro	35°480154"N 45°420719"E	11	Peri-urban	Y		Located c. 10 km from Sulaymaniyah city centre. Most vegetables grown in this area are sold in Sulaymaniyah grocery markets. The Tanjaro river is the main source of irrigation water. Domestic waste water channels from the city flow in to this river.
	Kana sura	35.540020"N 45.391216"E	8	Urban	Y		Located in a built-up area, waste water channel flows through the site that is used to grow vegetables.
	Kani goma	35.541090°N 45.370417"E	6	Peri-urban	Y		Close to the conurbation. A waste water channel from Sulaymaniyah city runs through this site. Numerous orchards exist and farmers grow vegetables between the trees.
	Industrial	35.486328"N 45.428052"E	27	Waste	N	4	Located to the south of Sulaymaniyah close to the municipal waste disposal site with a wide range of agricultural produce. Small scale industry e.g. metal workshops and scrap dealers are nearby. Domestic waste water discharges into the Tanjaro river.
Halabja	Kani kolka	35.187476"N 45.987567"E	13	Urban	Y		Located between domestic houses and a hospital. A waste water channel from Halabja city runs through this site and is used as a source of irrigation.
	Kani spi	35.204790"N 45.978693"E	5	Peri-urban	Y		Close to the city. Two waste water channels from Halabja run through the site and are used for irrigation.
	Anab	35.206296°N 46.008673"E	9	Rural	Y		A village c.10 miles east of Halabja. Situated on a wide plain mostly used for growing wheat and barley, but vegetables are also grown in this area. The main source of irrigation is spring and ground water.
	Northwest	35.190031"N 45.979305"E	9	Peri-urban	N	0	Northwest of Halabja. Agricultural fields surrounding waste site
	Waste area	35°12'28.08"N, 45°56'57.65"E	3	Waste	N	0	Northwest of Halabja. Waste disposal site in close proximity to agricultural fields
	North	35°11'25.75"N, 45°59'13.34"E	24	Urban	N	7	North of Halabja, waste water channel collect discharge from industrial and domestic areas including the hospital.
Kalar	Grdagozina	34°35'02.44"N, 45°16'55.18"E	11	Peri-urban	N	4	Southwest of Kalar in a residential area. Agricultural area irrigated with fresh water.
	Riverside	34°36'21.63"N, 45°19'04.63"E	11	Peri-urban	N	4	Agricultural area in the south of Kalar, irrigated with water from the Sirwan river.
Sirwan		35°15'12.74"N, 45°51'31.72"E	24	Peri-urban	N	4	Agricultural fields frequently flooded by the river which receives a combination of waste and fresh water.
Khurmal		35°18'15.83"N, 46° 1'29.88"E	8	Peri-urban	N	3	Northwest of the city in an area where pomegranate orchards predominate. Irrigation is freshwater in some locations and sewerage in others

Table 2: Mean soil pH and major and trace element concentrations (mg kg^{-1}) for each locality. Bold values indicate where concentrations exceed Soil Guideline Values (SGV), UK Ministry of Agriculture Fisheries and Food Sludge limits (MAFF) or European Union standards (EU).

Sites		pH	%LOI	Na	Mg	K	Ca	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Cd	Cs	Ba	Pb	U
Sulamanyah																								
Waste area	Mean	7.92	11.4	2946	13927	7819	119821	31241	75.2	**129**	817	57647	17.6	**127**	**84.8**	262	8.17	0.236	268	0.467	2.05	234	35.8	0.99
	±SD	*0.141*	*1.53*	*71.6*	*374*	*123*	*1945*	*1150*	*0.99*	*3.75*	*12.8*	*907*	*0.33*	*2.27*	*25.3*	*70.3*	*0.311*	*0.008*	*3.57*	*0.099*	*0.08*	*4.72*	*3.54*	*0.03*
Tanjaro	Mean	8.07	7.60	2563	18270	8710	117120	37772	80.3	**136**	624	34946	18.6	**156**	30.1	78.2	4.23	0.259	267	0.313	2.60	219	12.3	1.07
	±SD	*0.101*	*1.29*	*58.7*	*377*	*165*	*2371*	*817*	*1.54*	*3.36*	*12.6*	*687*	*0.354*	*3.02*	*0.746*	*2.17*	*0.156*	*0.004*	*5.489*	*0.021*	*0.059*	*4.45*	*0.36*	*0.027*
Kana sura	Mean	7.86	8.89	3118	18757	12112	85447	51430	107	**141**	802	44417	21.03	**147**	34.4	94.5	8.59	0.253	188	0.423	3.66	285	14.8	1.26
	±SD	*0.129*	*1.37*	*237*	*1418*	*1000*	*3590*	*4035*	*8.37*	*10.8*	*63.8*	*3410*	*1.598*	*11.2*	*2.80*	*12.1*	*0.723*	*-*	*10.9*	*0.064*	*0.301*	*23.6*	*1.41*	*0.102*
Kani goma	Mean	8.18	7.37	3034	18538	10045	117282	37837	76.4	**107**	624	31923	14.8	**109**	25.9	71.0	6.16	0.218	253	0.302	2.53	217	12.4	1.15
	±SD	*0.137*	*1.17*	*106*	*658*	*302*	*3464*	*1500*	*2.558*	*3.189*	*18.8*	*978*	*0.465*	***3.19***	*0.943*	*2.40*	*0.316*	*-*	*7.42*	*0.026*	*0.10*	*6.28*	*0.332*	*0.037*
Industrial	Mean	8.08	8.81	2510	14700	7600	110000	32200	74.2	**114**	590	25000	16.2	**125**	29.0	111	4.74	0.90	286	0.32	2.64	229	12.1	1.13
	±SD	*1.89*	*0.26*	*270*	*2710*	*1340*	*18800*	*4649*	*5.52*	*24.3*	*96.1*	*3090*	*2.51*	*35.8*	*3.01*	*94.4*	*0.516*	*0.083*	*40.0*	*0.10*	*0.40*	*23.1*	*4.31*	*0.05*
Halabjah																								
Kani kolka	Mean	7.67	11.1	3614	20552	9580	45883	23422	96.1	**113**	719	34326	18.9	**132**	38.7	149	11.8	0.486	150	0.578	4.09	353	21.6	1.23
	±SD	*0.319*	*1.74*	*212*	*503*	*2746*	*3403*	*8608*	*5.62*	*5.79*	*181*	*1785*	*0.998*	*7.06*	*1.98*	*10.7*	*0.777*	*0.006*	*7.925*	*0.048*	*0.238*	*16.5*	*1.27*	*0.082*
Kani spi	Mean	7.69	9.56	2570	16194	12754	61800	51939	112	**132**	951	44770	20.2	**138**	35.0	122	12.2	0.441	162	0.560	4.27	352	18.8	1.56
	±SD	*0.209*	*1.69*	*29*	*171*	*120*	*60*	*541*	*1.217*	*1.827*	*8.12*	*396*	*0.224*	*1.53*	*0.349*	*2.87*	*0.390*	*0.005*	*1.380*	*0.021*	*0.057*	*2.81*	*0.166*	*0.019*
Anab	Mean	8.20	6.80	2128	14798	6608	85972	29507	57.6	77.3	623	25210	12.6	**81.0**	29.0	84.6	7.57	0.435	161	0.296	2.88	422	15.2	0.87
	±SD	*0.117*	*0.385*	*76.5*	*500*	*1207*	*3653*	*1768*	*1.87*	*2.36*	*19.3*	*789*	*0.398*	*2.70*	*0.98*	*3.64*	*0.321*	*0.026*	*6.024*	*0.022*	*0.089*	*15.4*	*0.47*	*0.031*
Northwest	Mean	8.11	11.1	2940	14800	11200	76500	47000	92.7	**114**	726	29400	17.9	**117**	30.8	87.0	10.4	0.94	174	0.422	3.99	390	13.1	1.42
	±SD	*0.16*	*0.78*	*557*	*3120*	*1840*	*34500*	*9890*	*14.7*	*18.5*	*120*	*5000*	*3.05*	*22.4*	*4.03*	*9.38*	*1.48*	*0.12*	*47.3*	*0.03*	*0.77*	*40.4*	*2.25*	*0.12*
Waste area	Mean	8.10	13.7	4620	10300	9390	129000	31100	62.3	**134**	651	26800	12.5	**74.9**	**263**	**773**	9.61	0.76	323	**4.19**	2.45	511	**161**	1.20
	±SD	*0.17*	*2.55*	*1640*	*1070*	*1700*	*21700*	*3550*	*7.90*	*36.4*	*89.2*	*4300*	*1.41*	*11.2*	*155*	*192*	*2.48*	*0.06*	*43.5*	*1.66*	*0.33*	*126*	*17.4*	*0.04*
North	Mean	8.04	11.0	2550	12500	11500	48800	41300	109	**128**	879	35000	20.2	**134**	37.0	112	13.5	1.38	144	0.57	3.42	358	15.5	1.72
	±SD	*1.74*	*0.16*	*173*	*1170*	*533*	*8310*	*3090*	*5.43*	*5.85*	*42.2*	*1200*	*0.94*	*7.11*	*2.27*	*35.9*	*1.16*	*0.06*	*18.4*	*0.05*	*0.54*	*17.1*	*3.35*	*0.05*
Kalar																								
Grdagozina	Mean	8.01	8.76	3530	15300	8530	111000	31800	67.1	81.3	539	22016	12.3	**145**	22.0	78.9	6.43	0.926	381	0.23	2.47	248	44.4	1.19
	±SD	*1.66*	*0.16*	*704*	*2020*	*1000*	*16800*	*3720*	*5.02*	*5.66*	*49.2*	*2380*	*1.25*	*13.3*	*1.74*	*6.94*	*0.48*	*0.23*	*31.4*	*0.02*	*0.30*	*18.5*	*3.82*	*0.15*
Riverside	Mean	8.21	6.62	6290	19500	10600	11600	42000	85.6	106	563	27738	14.5	**185**	26.3	123	5.90	1.17	323	0.24	2.81	230	63.0	1.16
	±SD	*2.20*	*0.09*	*1830*	*1690*	*658*	*6270*	*3080*	*3.61*	*6.39*	*35.7*	*1790*	*1.39*	*10.7*	*5.48*	*53.8*	*0.61*	*0.05*	*14.6*	*0.09*	*0.44*	*9.54*	*10.8*	*0.15*
Sirwan																								
Riverside	Mean	8.15	8.55	2350	13900	8260	96300	34000	76.0	**103**	548	23800	15.8	**129**	27.8	75.0	5.70	0.69	244	0.34	2.83	238	21.7	1.23
	±SD	*1.62*	*0.08*	*526*	*2122*	*1760*	*23100*	*7230*	*11.5*	*16.0*	*93.2*	*4230*	*2.48*	*26.3*	*4.51*	*13.9*	*1.31*	*0.110*	*54.3*	*0.04*	*0.64*	*47.2*	*11.5*	*0.14*
Khurmal																								
Orchards	Mean	7.94	9.23	2790	10513	8770	1270000	36500	73.1	80.5	614	28107	15.1	**86.1**	29.5	97.2	13.5	1.47	115	0.36	3.45	185	17.1	1.17
	±SD	*1.54*	*0.16*	*186*	*1830*	*1700*	*49400*	*8670*	*14.8*	*18.5*	*226*	*5540*	*3.54*	*22.4*	*4.77*	*15.5*	*1.94*	*0.17*	*10.8*	*0.03*	*0.63*	*51.0*	*3.91*	*0.13*
SGV[a]/MAFF[b]										130[a]				250[a]	50[b]	300[b]	43[a]			1.80[a]			450[a]	
EU[c]										100				50	100	300				3.00			100	

[a]Soil Guideline Values (SGVs) Environment Agency, 2009b, [b]Cu and Zn (MAFF, 1998), [c] (European Union, 2006)

Table 3: Water properties and mean elemental concentrations (µg L^{-1}) in fresh and waste waters used for irrigation.

Sites		pH	EC	Na	Mg	K	Ca	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Cd	Cs	Ba	Pb	U
Sulaymaniyah	Fresh	7.70	557	2460	10100	1560	59700	28.3	5.86	2.35	20.4	31.5	0.25	4.16	1.27	37.1	0.85	1.08	481	0.02	0.01	86.3	0.076	1.02
	Waste	8.00	652	23500	8220	5780	56300	13.8	7.82	2.30	276	26.7	1.51	10.0	1.25	20.8	2.79	0.37	400	0.02	0.01	73.8	0.15	0.44
Halabja	Fresh	7.70	604	3830	11200	890	72900	20.1	3.74	2.49	13.2	26.6	0.13	2.58	0.79	65.0	0.51	0.91	528	0.04	0.00	125	0.23	0.98
	Waste	8.00	946	66800	7200	10110	58800	40.5	2.53	3.07	124	57.5	0.62	5.78	2.66	60.8	1.06	0.73	364	0.07	0.05	106	0.87	0.44
Kalar	Fresh	7.80	603	15500	15200	900	65400	11.2	7.99	3.92	0.90	10.6	0.03	0.85	0.34	15.1	0.39	0.58	1400	0.01	0.00	57.1	0.07	1.82
	Waste	7.70	453	10400	9690	1860	50300	56.1	3.00	2.94	6.76	82.5	0.14	2.91	0.81	19.9	1.19	0.48	607	0.02	0.01	74.5	0.24	0.48
Sirwan	Fresh	7.80	520	15000	13700	950	60900	21.9	8.80	1.02	2.03	18.9	0.04	1.23	0.60	15.5	0.40	0.49	1320	0.02	0.01	50.3	0.14	1.60
	Waste	7.90	620	12600	12600	2160	74000	11.4	5.56	1.59	37.6	19.4	0.39	4.11	0.65	17.4	1.85	0.56	584	0.02	0.01	94.2	0.09	0.64
Khurmal	Fresh	8.20	427	4470	6010	910	58000	13.0	1.38	5.52	1.34	33.0	0.06	4.00	4.02	27.5	5.87	0.16	234	0.08	0.05	32.2	1.36	0.34
	Waste	7.80	505	24500	3880	4490	49700	18.2	1.21	6.86	70.4	49.4	0.36	4.91	1.47	37.9	0.66	0.18	138	0.03	0.02	28.1	0.30	0.24
*FAO/WHO**								*5000*	*100*	*100*	*200*	*5000*	*50*	*200*	*200*	*2000*	*100*		*20*	*10*			*5000*	

** Recommended maximum concentration in irrigation water applied at a rate of 10, 000 m3 ha-1 yr-1, FAO/WHO,* http://www.fao.org/3/T0234E/T0234E06.htm,

Table 4: Mean trace element concentrations (µg kg^{-1} FW) in edible plants. Data are given to three significant figures.

Sample	n		µg/kg FW	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Mo	Cd	Cs	Ba	Pb	U
Pepper	14	Unwashed	Mean:	6330	20.2	88.8	3380	18700	59.7	679	2490	5080	3.90	11.9	2070	148	23.5	1.65	943	9.51	0.56
			SD:	*1040*	*3.32*	*10.5*	*102*	*2750*	*5.44*	*73.6*	*70.6*	*114*	*0.587*	*2.21*	*176*	*10.0*	*1.60*	*0.244*	*68*	*1.01*	*0.115*
	2	Washed	Mean:	4090	9.27	77.3	3230	14500	54.3	640	2280	4880	3.70	11.0	1720	97.5	22.2	0.423	915	9.55	1.15
			SD:	*301*	*0.569*	*5.39*	*85.2*	*2.64*	*1.40*	*44.5*	*24.1*	*110*	*0.413*	*0.388*	*138*	*4.29*	*0.574*	*0.0246*	*101*	*0.685*	*0.202*
Okra	16	Unwashed	Mean:	18700	41.7	187	14000	25500	95.1	1070	3580	18000	10.6	11.5	20500	228	60.6	6.98	9600	24.1	1.21
			SD:	*1890*	*4.29*	*11.4*	*911*	*1510*	*8.42*	*63.8*	*77.3*	*287*	*1.53*	*1.23*	*825*	*8.44*	*3.95*	*0.638*	*1030*	*1.77*	*0.156*
	3	Washed	Mean:	5630	8.89	149	17400	15000	40.1	849	3660	18400	11.6	12.9	22100	154	60.3	5.86	16100	17.6	1.28
			SD:	*279*	*0.406*	*15.1*	*1150*	*304*	*1.00*	*45.4*	*46.4*	*234*	*1.85*	*1.40*	*398*	*11.0*	*6.38*	*0.267*	*1190*	*1.18*	*0.152*
Tomato	10	Unwashed	Mean:	20300	6.98	37.3	1840	6380	24.5	156	1120	3100	0.691	10.8	620	125	21.2	1.33	495	5.40	0.091
			SD:	*3790*	*0.618*	*1.46*	*50.4*	*315*	*0.905*	*6.99*	*27.8*	*65.1*	*0.182*	*0.86*	*25.6*	*3.95*	*0.933*	*0.136*	*40.3*	*0.533*	*0.024*
	5	Washed	Mean:	17400	6.98	38.6	1870	4990	22.7	151	1110	3050	0.639	11.3	604	114	19.2	2.34	509	5.81	0.461
			SD:	*3950*	*0.977*	*2.16*	*40.8*	*205*	*0.550*	*5.63*	*12.9*	*38.6*	*0.326*	*1.26*	*29.2*	*1.73*	*0.545*	*0.241*	*23.1*	*0.518*	*0.068*
Cow pea	16	Unwashed	Mean:	10400	29.4	163	20900	28100	56.5	2760	4750	18500	5.08	48.8	9410	2210	4.31	2.51	2790	20.4	1.30
			SD:	*1780*	*6.06*	*22.4*	*2930*	*2280*	*4.76*	*169*	*165*	*764*	*2.25*	*10.4*	*1115*	*237*	*0.744*	*0.427*	*520*	*3.63*	*0.436*
	2	Washed	Mean:	4370	9.59	143	36000	24100	51.5	2690	4570	18000	4.05	31.6	7290	1430	5.86	2.77	3560	15.3	1.69
			SD:	*261*	*0.970*	*2.10*	*161*	*1560*	*0.401*	*47.7*	*23.8*	*190*	*0.0936*	*6.27*	*77.8*	*135*	*1.63*	*0.212*	*585*	*3.20*	*0.794*
Cucumber	7	Unwashed	Mean:	4390	13.8	62.0	1670	8270	16.8	299	1120	5140	24.4	12.4	2470	168	5.68	1.12	1150	9.14	0.304
			SD:	*981*	*3.26*	*11.4*	*56.5*	*949*	*1.29*	*19.0*	*39.0*	*157*	*3.34*	*2.81*	*157*	*10.7*	*1.00*	*0.205*	*213*	*2.19*	*0.123*
	2	Washed	Mean:	5390	17.7	61.4	1570	8620	15.3	279	1120	5110	24.8	14.1	2630	167	5.52	0.871	1620	9.91	0.892
			SD:	*1560*	*5.48*	*13.2*	*31.7*	*1300*	*0.774*	*7.41*	*44.2*	*17.5*	*2.58*	*3.36*	*70.8*	*7.14*	*0.619*	*0.119*	*441*	*2.02*	*0.334*
Leek	6	Unwashed	Mean:	114000	229	425	12200	87100	76.8	658	2830	12500	50.4	43.5	26100	873	43.1	10.1	7810	98.0	3.57
			SD:	*10800*	*18.4*	*29.9*	*811*	*3880*	*6.47*	*29.6*	*81.4*	*766*	*3.58*	*5.42*	*1150*	*230*	*2.72*	*0.848*	*430*	*14.1*	*0.352*
	6	Washed	Mean:	89700	211	417	12100	86700	70.0	640	2980	12700	43.4	44.6	26100	872	40.3	9.18	7710	93.1	3.14
			SD:	*10500*	*24.7*	*50.7*	*767*	*7900*	*5.64*	*47.9*	*68.4*	*534*	*1.28*	*5.72*	*1380*	*216*	*3.14*	*0.906*	*472*	*16.5*	*0.336*
Celery	7	Unwashed	Mean:	253000	621	1070	35000	178000	166	1700	3650	16200	83.4	65.9	56100	1380	61.4	20.9	20600	211	8.34
			SD:	*39800*	*83.5*	*116*	*2240*	*25100*	*18.3*	*149*	*148*	*1176*	*10.7*	*14.1*	*4730*	*377*	*5.73*	*3.52*	*1230*	*28.7*	*1.24*
	4	Washed	Mean:	210000	519	976	31700	127000	135	1530	3410	16200	76.2	76.8	56500	2460	70.0	18.2	23600	170	6.69
			SD:	*39200*	*85.2*	*81.6*	*1050*	*21000*	*16.6*	*88.2*	*111*	*1191*	*10.2*	*14.3*	*5920*	*554*	*8.97*	*3.42*	*1430*	*24.3*	*1.43*
Parsley	3	Unwashed	Mean:	236000	586	1250	33700	246000	214	2410	4280	18500	94.1	51.3	47600	1240	29.3	21.4	26000	194	9.43
			SD:	*63000*	*146*	*335*	*5420*	*54000*	*62.0*	*571*	*406*	*1796*	*34.7*	*25.0*	*5680*	*656*	*13.0*	*5.35*	*1680*	*39.8*	*4.49*
	2	Washed	Mean:	173000	355	1200	27200	150000	144	2250	4150	18000	64.5	20.8	50400	484	14.0	15.3	23000	195	5.92
			SD:	*340*	*75.4*	*169*	*3440*	*30500*	*1.70*	*148*	*305*	*1312*	*7.54*	*7.48*	*6100*	*51.5*	*3.80*	*0.800*	*551*	*56.4*	*0.741*
Pursulane	15	Unwashed	Mean:	60600	137	333	6180	56600	63.4	937	1980	6940	21.0	5.53	18600	147	25.6	5.95	28200	48.7	2.00
			SD:	*10100*	*20.9*	*47.0*	*486*	*7580*	*8.91*	*62.1*	*118*	*480*	*2.98*	*0.543*	*560*	*14.5*	*2.32*	*0.785*	*1640*	*5.06*	*0.273*
	3	Washed	Mean:	67800	155	319	6100	46200	58.0	875	2120	7810	22.4	5.54	20500	233	20.1	5.57	30700	61.2	2.72
			SD:	*8740*	*19.5*	*40.5*	*176*	*5770*	*2.81*	*13.9*	*40.5*	*630*	*1.54*	*0.834*	*727*	*29.4*	*0.868*	*0.771*	*1440*	*7.49*	*0.271*
Vine Leaves	2	Unwashed	Mean:	209000	507	961	94100	157000	153	1310	5680	10300	73.5	25.2	29000	486	13.2	25.2	9370	194	6.42
			SD:	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
	2	Washed	Mean:	162000	289	1280	68900	132000	89.6	737	7200	10600	47.4	27.2	22000	324	16.2	18.9	6860	152	7.09
			SD:	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
Spring onion	2	Unwashed	Mean:	92700	183	295	7880	69300	53.0	593	1330	9080	27.0	29.7	14900	573	50.1	7.60	4290	39.8	1.40
			SD:	*1830*	*3.90*	*5.49*	*39.5*	*1200*	*0.784*	*0.765*	*0.0586*	*86.7*	*0.403*	*0.486*	*23.1*	*1.44*	*0.535*	*0.155*	*22.8*	*0.728*	*0.0435*
	1	Washed		29900		130	6600	29400	26.9	294	1470	7120	16.3	25.1	15000	708	59.5	2.75	4890	24.7	1.47

cont’d

Sample	**n**		**µg/kg fw**	**Al**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Sr**	**Mo**	**Cd**	**Cs**	**Ba**	**Pb**	**U**
Tarragon	2	Unwashed	Mean:	168000	399	822	52700	173000	148	3030	10100	31000	75.9	67.2	36300	305	372	23.9	11500	184	4.56
			SD:	*830*	*3.50*	*5.32*	*244*	*1380*	*0.201*	*30.9*	*2.73*	*225*	*0.169*	*2.10*	*107*	*4.35*	*10.6*	*0.54*	*122*	*2.99*	*0.069*
	2	Washed	Mean:	108000	259	683	48200	113000	116	2500	9430	28400	47.3	55.5	33600	322	310	15.4	10400	131	3.44
			SD:	*231*	*1.64*	*3.78*	*666*	*627*	*0.0874*	*29.0*	*22.7*	*29.2*	*0.847*	*1.62*	*37.5*	*7.21*	*8.38*	*0.278*	*72.2*	*0.271*	*0.0322*
Chard	10	Unwashed	Mean:	131000	312	549	36500	123000	111	775	2770	5890	41.1	18.8	22100	201	66.3	12.3	23300	132	4.21
			SD:	*14700*	*28.4*	*45*	*3920*	*10400*	*7.57*	*47.6*	*102*	*261*	*3.16*	*3.26*	*1640*	*14.6*	*5.07*	*1.23*	*1046*	*10.3*	*0.392*
	9	Washed	Mean:	10200	172	520	32700	70300	76.1	466	2790	6340	22.8	27.0	21800	211	58.7	6.99	21100	106	3.20
			SD:	*8190*	*19.4*	*57.6*	*4080*	*5990*	*4.16*	*30.7*	*104*	*277*	*2.21*	*7.66*	*1630*	*13.7*	*3.97*	*0.727*	*1020*	*11.1*	*0.417*
Radish leaves	2	Unwashed	Mean:	1450000	2930	4590	56700	106000	750	3290	2540	15500	365	60.9	44700	1690	278	118	16700	593	19.4
			SD:	*16600*	*32.1*	*51.3*	*331*	*13200*	*7.41*	*28.2*	*18.0*	*14.1*	*3.10*	*0.571*	*183*	*18.0*	*1.60*	*1.32*	*79.7*	*4.68*	*0.181*
		Washed		178000	368	583	32600	88400	184	5370	1060	15900	93.5	73.2	29700	2570	164	14.1	8800	154	4.62
Cress	1	Unwashed		86900	398	449	15200	102000	283	1350	979	7100	65.2	5.93	16000	212	56.6	4.88	7370	102	5.56
		Washed		126000	601	499	15100	151000	411	1390	984	7260	71.2	6.65	20200	285	51.1	7.21	7000	108	9.02
Mint	1	Unwashed		183000	427	799	26100	106000	135	1200	4270	9120	53.8	22.8	27400	656	5.67	15.6	13300	145	5.27
Dill	1	Unwashed		56200	179	1100	14900	78700	80.1	1500	2860	12600	70.0	43.5	40800	486	38.5	5.37	7560	219	3.64
		Washed		109000	361	923	26700	136000	126	1450	3170	13100	72.1	38.2	47800	633	38.9	6.72	7510	173	7.82
Quince	4	Unwashed	Mean:	8130	17.8	227	716	14800	31.2	300	501	5340	4.87	3.90	1790	508	12.0	1.58	1800	19	2.71
			SD:	*250*	*0.480*	*5.58*	*9.59*	*773*	*1.18*	*2.42*	*9.49*	*244*	*0.90*	*0.191*	*33.9*	*52.7*	*0.177*	*0.085*	*26.5*	*0.93*	*0.369*
Pomegranate	14	Peeled	Mean:	112000	18.8	90.2	2170	6300	9.23	274	1700	3250	0.000	4.70	627	77.6	3.48	4.74	311	12.6	1.27
			SD:	*9770*	*1.01*	*6.68*	*35.7*	*325*	*1.04*	*27.8*	*36.6*	*55.0*	*0.399*	*0.444*	*141*	*6.19*	*0.326*	*0.306*	*29.8*	*0.779*	*0.279*
Fig	11	Unwashed	Mean:	13500	13.7	108	1760	9280	29.4	729	1300	2720	0.57	2.54	4730	111	5.51	2.11	2570	9.76	0.376
			SD:	*1850*	*1.54*	*23.0*	*137*	*739*	*3.79*	*44.9*	*87.6*	*110*	*0.765*	*0.319*	*312*	*12.7*	*0.80*	*0.354*	*478*	*0.77*	*0.124*
Eggplant	11	Unwashed	Mean:	2240	5.32	50.8	2770	6000	9.7	133	1750	3870	2.49	9.28	1451	152	16.1	0.715	762	5.72	0.329
			SD:	*175*	*0.640*	*3.13*	*97.2*	*285*	*0.53*	*4.46*	*32.0*	*102*	*0.782*	*1.68*	*138*	*9.89*	*1.67*	*0.0744*	*63.8*	*0.451*	*0.068*
Courgette	4	Unwashed	Mean:	5620	12.3	44.4	1300	7950	20.6	350	964	2620	1.14	4.24	700	95	2.65	0.523	322	5.80	0.296
			SD:	*1120*	*2.59*	*8.12*	*108*	*1310*	*5.09*	*44.9*	*55.7*	*78.3*	*0.335*	*0.60*	*26.7*	*14.3*	*0.381*	*0.038*	*72.6*	*0.723*	*0.074*
Water Melon	4	Peeled	Mean:	12600	5.06	33.9	479	2790	5.64	217	428	1640	3.41	6.39	1670	41.1	8.60	0.549	258	5.42	0.388
			SD:	*1490*	*0.294*	*0.85*	*27.1*	*87.5*	*0.0847*	*18.1*	*34.8*	*116*	*0.427*	*0.67*	*95.2*	*1.25*	*0.528*	*0.021*	*16.7*	*0.295*	*0.033*
Melon	3	Peeled	Mean:	28900	8.34	30.5	251	2150	5.73	119	145	626	4.20	3.20	1050	29.6	7.49	0.374	174	8.34	0.402
			SD:	*998*	*0.130*	*0.61*	*3.24*	*43.7*	*0.142*	*5.10*	*2.48*	*7.88*	*0.116*	*0.204*	*29.0*	*0.148*	*0.368*	*0.00766*	*3.78*	*0.0948*	*0.016*
Onion	2	Peeled	Mean:	8650	10.0	67.1	1770	6630	11.2	432	1430	4400	2.69	13.2	3490	41.6	13.1	0.365	997	11.1	0.595
			SD:	*1470*	*0.328*	*7.83*	*81.1*	*228*	*1.82*	*14.5*	*188*	*519*	*0.80*	*1.98*	*134*	*13.7*	*2.36*	*0.049*	*94.7*	*0.91*	*0.034*

Table 5: Percentage of elements in edible plant tissue arising from soil dust.

				Cr	Co	Ni	Cu	Zn	Se	Cd	Ba	Pb
Plant		**n**		**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Pepper	Unwashed	13	Mean:	33.4	7.64	3.99	0.37	0.62	1.48	0.53	8.83	49.3
			SD:	*28.16*	*6.92*	*2.46*	*0.40*	*0.89*	*1.94*	*0.77*	*8.31*	*48.96*
	Washed	2	Mean:	17.0	3.52	2.05	0.16	0.26	0.38	0.25	5.21	21.8
			SD:	*12.2*	*1.75*	*0.09*	*0.05*	*0.10*	*0.02*	*0.06*	*4.49*	*13.4*
Okra	Unwashed	16	Mean:	31.2	11.6	6.20	0.58	0.44	2.41	0.38	2.50	37.8
			SD:	*16.28*	*13.40*	*5.38*	*0.83*	*0.87*	*2.42*	*0.39*	*2.62*	*29.50*
	Washed	3	Mean:	9.89	4.41	1.52	0.10	0.07	0.60	0.12	0.31	12.3
			SD:	*5.10*	*0.66*	*0.17*	*0.02*	*0.02*	*0.39*	*0.07*	*0.14*	*5.19*
Tomato	Unwashed	10	Mean:	26.2	6.61	7.01	0.34	0.45	0.54	0.21	11.4	40.2
			SD:	*17.6*	*5.42*	*5.63*	*0.33*	*0.56*	*0.58*	*0.20*	*15.0*	*36.8*
	Washed	5	Mean:	25.7	8.80	8.10	0.72	0.99	0.85	0.32	17.2	46.9
			SD:	*26.6*	*13.02*	*8.83*	*1.32*	*1.87*	*1.62*	*0.51*	*30.3*	*60.9*
Cow Pea	Unwashed	16	Mean:	25.9	12.5	1.79	0.33	0.30	0.65	4.01	6.07	39.2
			SD:	*17.2*	*12.6*	*1.86*	*0.50*	*0.58*	*1.07*	*4.11*	*6.47*	*47.7*
	Washed	2	Mean:	8.6	3.84	0.49	0.09	0.08	0.26	1.86	1.74	19.2
			SD:	*3.28*	*1.47*	*0.17*	*0.02*	*0.03*	*0.26*	*1.65*	*1.19*	*11.4*
Cucumber	Unwashed	7	Mean:	33.1	19.0	7.68	1.58	0.82	0.73	2.14	7.38	44.6
			SD:	20.3	18.3	8.01	3.22	1.54	0.64	2.89	9.44	39.7
	Washed	2	Mean:	53.8	32.4	13.4	4.62	2.32	1.19	4.56	16.0	115
			SD:	*55.5*	*39.3*	*16.9*	*6.32*	*3.17*	*1.56*	*6.16*	*21.5*	*142*
Leek	Unwashed	6	Mean:	66.5	60.7	48.8	3.06	2.04	2.62	2.94	9.03	47.3
			SD:	9.2	20.4	18.0	1.65	1.29	1.26	1.72	2.70	20.6
	Washed	6	Mean:	63.2	58.5	44.5	2.67	1.73	2.47	2.84	8.14	44.4
			SD:	9.9	23.0	17.2	1.88	1.02	2.20	1.86	3.16	18.5
Celery	Unwashed	7	Mean:	70.7	70.9	50.1	6.13	4.25	5.84	5.41	9.06	52.8
			SD:	9.7	15.2	20.6	3.88	3.71	5.31	3.53	3.89	21.4
	Washed	4	Mean:	63.1	70.6	43.7	5.39	3.70	4.82	4.34	7.03	53.4
			SD:	27.7	25.7	25.5	3.55	3.23	5.58	2.94	4.20	17.9
Parsley	Unwashed	3	Mean:	62.0	54.8	33.6	4.25	2.58	6.96	12.60	6.02	46.1
			SD:	*4.5*	*12.2*	*3.4*	*0.84*	*0.65*	*7.05*	*9.95*	*2.47*	*15.2*
	Washed	2	Mean:	44.9	49.1	24.9	3.18	1.69	5.33	9.72	4.09	28.0
			SD:	*33.2*	*25.4*	*17.2*	*2.33*	*0.84*	*0.88*	*0.54*	*1.87*	*2.1*
Pursulane	Unwashed	15	Mean:	62.5	45.9	22.5	4.42	2.98	9.75	2.80	1.70	54.2
			SD:	*29.0*	*24.5*	*15.8*	*6.96*	*3.26*	*8.60*	*2.62*	*1.71*	*46.7*
	Washed	3	Mean:	80.3	60.6	34.2	14.2	6.24	12.37	7.01	2.16	108
			SD:	*32.7*	*45.3*	*31.1*	*20.6*	*6.88*	*10.65*	*7.63*	*1.91*	*103*
Vine Leaves	Unwashed	2	Mean:	63.4	65.2	54.0	3.71	9.19	12.52	23.1	25.1	61.8
			SD:	*5.0*	*8.4*	*1.4*	*0.08*	*4.44*	*6.71*	*8.6*	*19.2*	*3.3*
	Washed	2	Mean:	39.3	62.6	54.1	1.73	5.27	6.21	10.5	15.8	47.1
			SD:	*25.2*	*12.5*	*2.2*	*0.99*	*3.53*	*2.42*	*4.7*	*8.8*	*8.1*
Spring Onion	Unwashed	2		72.8	62.2	41.8	5.37	2.12	3.85	2.75	13.8	72.8
			SD:	*8.82*	*20.9*	*32.5*	*4.75*	*1.50*	*4.36*	*2.99*	*10.1*	*21.2*
	Washed	1		104	82.4	53.2	3.10	1.99	1.89	1.18	8.23	81.8
Tarragon	Unwashed	2	Mean:	54.9	51.4	17.7	1.53	1.52	3.20	0.75	11.9	38.9
			SD:	*9.3*	*4.2*	*1.7*	*0.11*	*0.28*	*0.80*	*0.28*	*3.1*	*7.5*
	Washed	2	Mean:	42.7	42.6	14.0	1.06	1.07	2.50	0.58	8.44	34.5
			SD:	*4.1*	*3.2*	*2.4*	*0.01*	*0.03*	*0.63*	*0.23*	*1.24*	*3.5*
Chard	Unwashed	10	Mean:	83.8	61.6	61.1	9.27	8.57	11.82	2.74	4.27	60.9
			SD:	*29.6*	*25.4*	*21.7*	*17.06*	*11.23*	*11.17*	*2.12*	*1.96*	*46.8*
	Washed	9	Mean:	68.3	50.4	55.6	9.09	6.61	6.18	2.25	3.16	51.2
			SD:	*50.9*	*31.1*	*26.4*	*21.80*	*12.38*	*6.31*	*3.41*	*3.14*	*56.8*
Radish Leaves	Unwashed	2	Mean:	77.1	64.5	95.8	33.0	19.2	35.07	3.60	40.3	60.8
			SD:	*5.5*	*19.4*	*52.8*	*22.9*	*21.2*	*45.35*	*1.98*	*34.1*	*32.6*
	Washed	1		65.7	36.8	8.7	12.7	2.53	2.81	1.42	13.2	40.3
Cress	Unwashed	1		114	25.9	38.8	12.9	4.41	15.97	2.50	14.3	53.2
	Washed	1		155	26.9	57.1	19.3	6.50	21.47	4.18	22.7	75.7
Radish	Washed	3	Mean:	64.9	32.3	32.3	10.7	5.73	4.55	1.34	13.6	57.6
			SD:	*20.5*	*41.8*	*41.2*	*13.2*	*8.79*	*6.05*	*1.32*	*15.9*	*9.9*
Mint	Unwashed	1		64.8	62.8	49.3	4.09	7.72	9.89	45.6	11.8	69.0

cont'd

				Cr	Co	Ni	Cu	Zn	Se	Cd	Ba	Pb
Plant		**n**		**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Dill	Unwashed	1		20.9	41.2	15.7	1.98	1.11	0.98	1.66	6.27	11.1
	Washed	1		50.3	52.5	32.8	3.60	2.16	2.24	3.29	12.7	28.3
Quince	Unwashed	4	Mean:	11.3	12.8	8.4	1.61	1.17	4.43	0.84	5.42	33.4
			SD:	*6.4*	*3.7*	*2.6*	*0.44*	*0.73*	*2.84*	*0.28*	*4.57*	*24.9*
Pomegranate	Peeled	14	Mean:	41.4	54.7	13.9	0.53	0.96	3.39	7.75	41.0	46.7
			SD:	*40.9*	*39.1*	*10.9*	*0.38*	*0.57*	*2.58*	*10.23*	*28.4*	*38.0*
Fig	Unwashed	11	Mean:	22.9	11.3	2.6	0.48	0.63	3.28	1.66	2.98	31.4
			SD:	*9.9*	*5.5*	*1.1*	*0.27*	*0.24*	*2.43*	*1.08*	*2.00*	*17.0*
Eggplant	Unwashed	11	Mean:	12.9	13.0	6.0	0.19	0.32	0.85	0.19	3.71	30.0
			SD:	*10.0*	*13.5*	*4.9*	*0.32*	*0.62*	*1.09*	*0.13*	*3.13*	*43.3*
Courgette	Unwashed	4	Mean:	38.8	13.2	4.99	0.58	0.51	1.49	2.17	19.9	39.2
			SD:	*26.5*	*6.9*	*3.34*	*0.61*	*0.43*	*1.51*	*1.66*	*15.1*	*37.1*
Water Melon	Peeled	4	Mean:	31.2	24.5	8.9	3.86	2.05	1.11	0.73	13.4	37.7
			SD:	*26.7*	*20.7*	*9.0*	*6.54*	*3.50*	*1.41*	*1.04*	*19.1*	*50.4*
Melon	Peeled	3	Mean:	53.6	38.9	16.3	5.79	3.15	2.33	1.08	15.8	39.6
			SD:	*20.2*	*16.3*	*9.1*	*5.80*	*3.27*	*2.97*	*0.96*	*7.7*	*44.0*
Onion	Peeled	2	Mean:	25.1	26.3	4.27	0.303	0.307	0.441	0.434	3.25	19.6
			SD:	*6.95*	*18.6*	*1.49*	*0.102*	*0.015*	*0.401*	*0.174*	*0.339*	*15.4*

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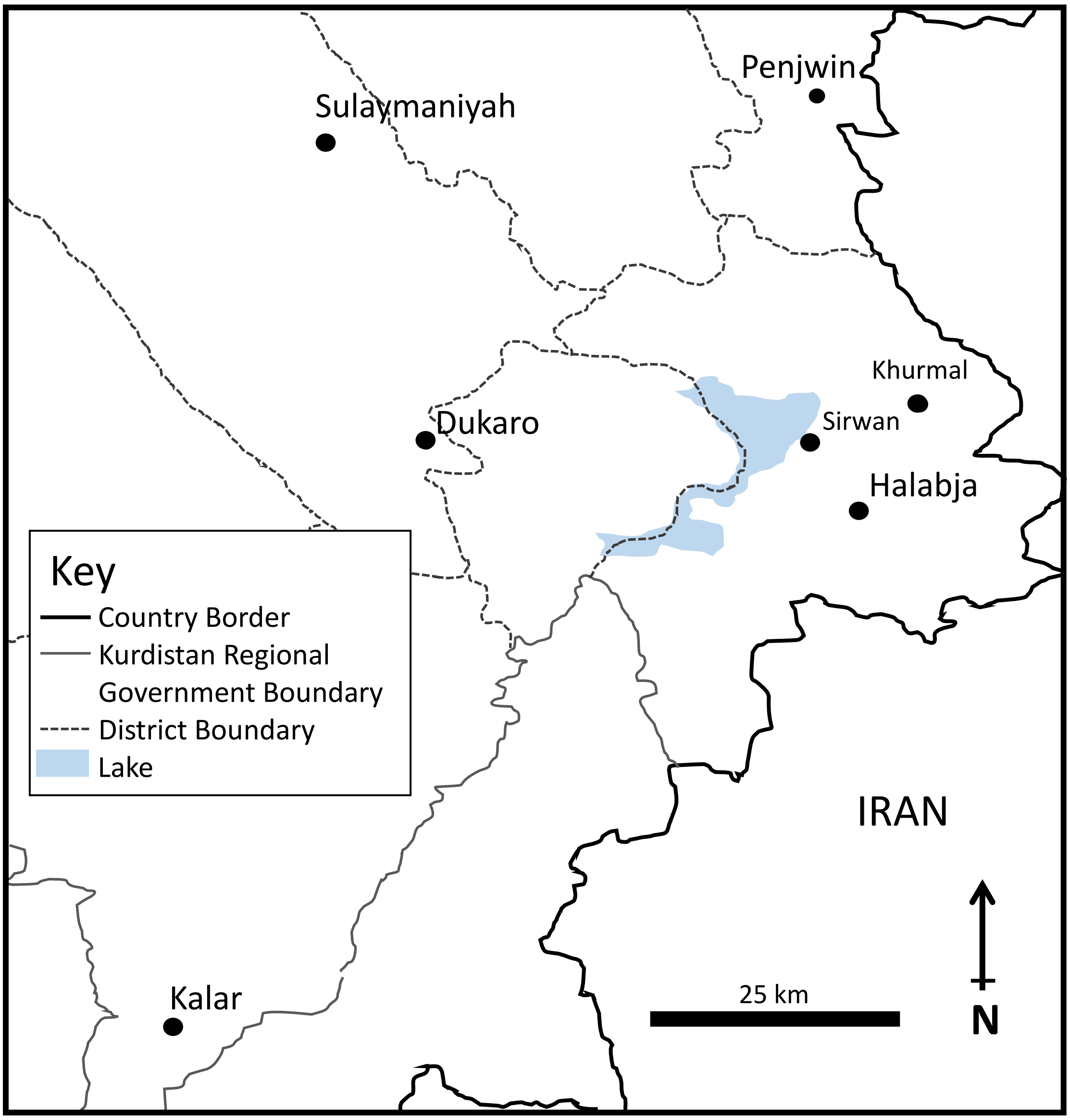

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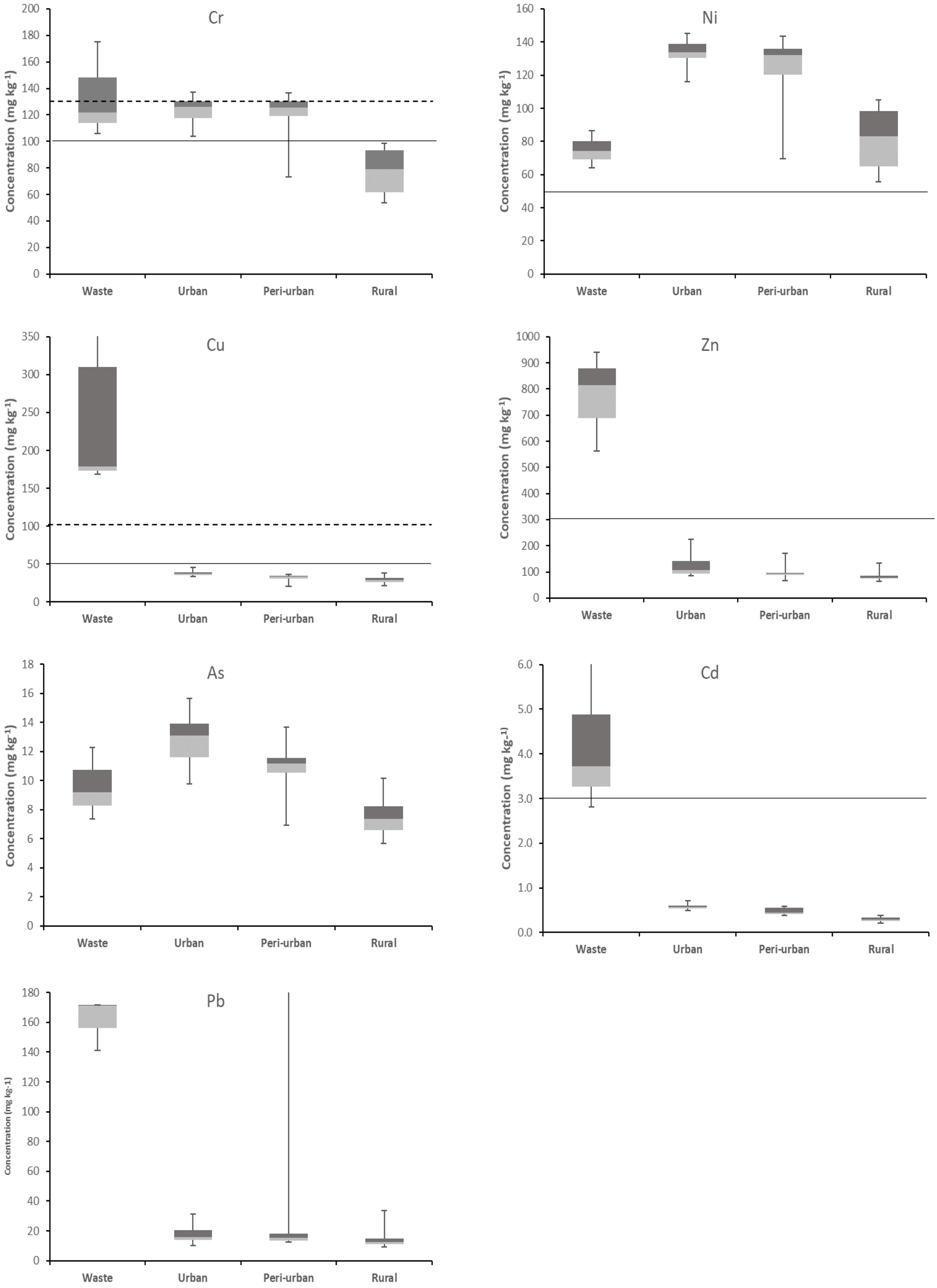

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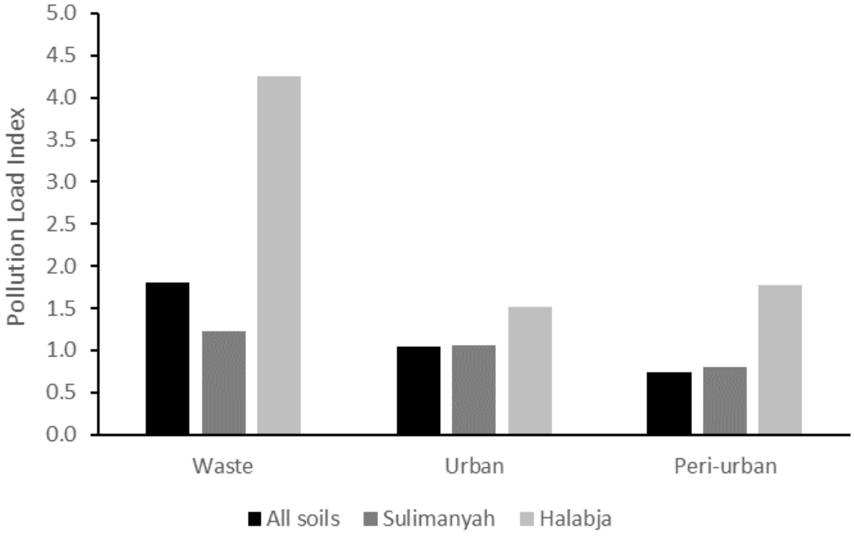

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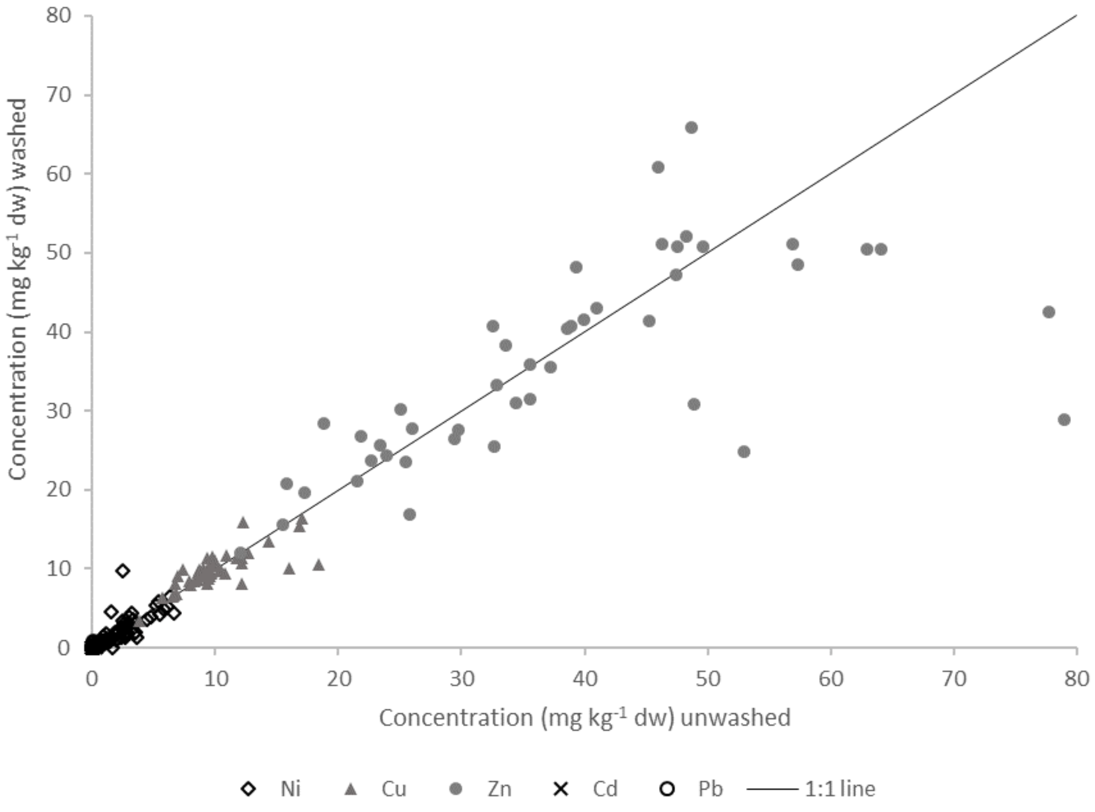

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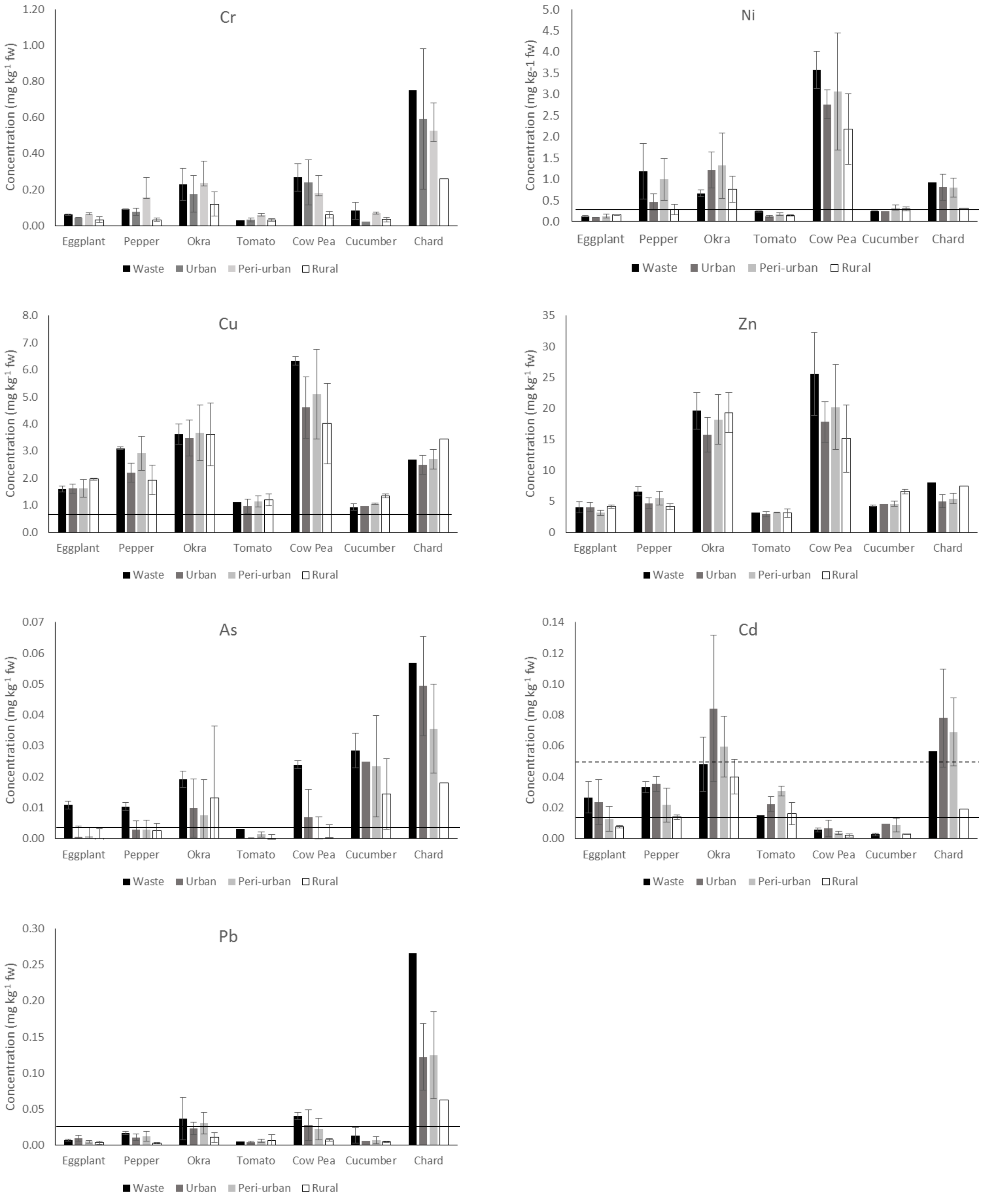

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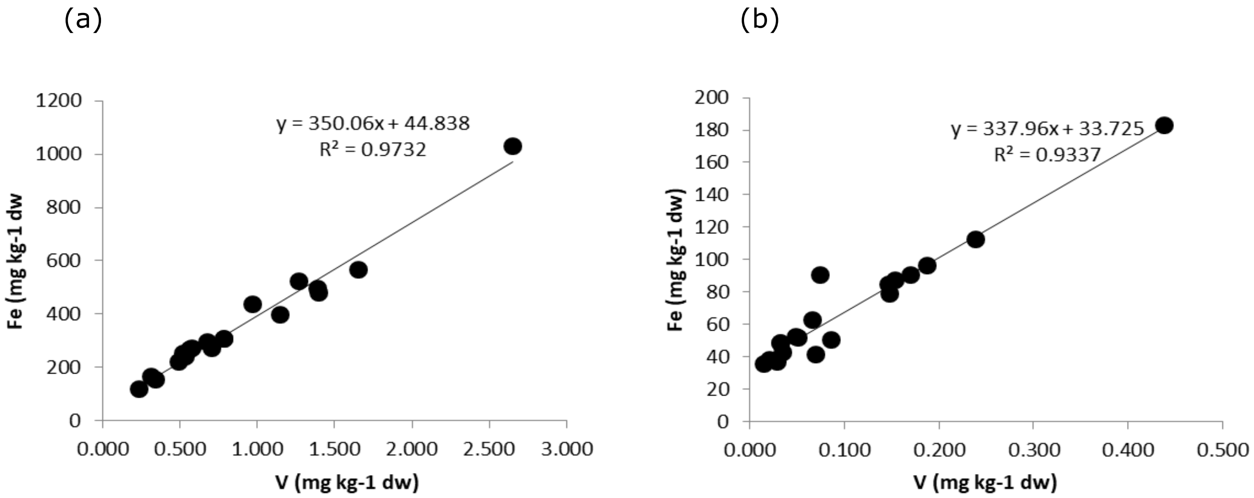

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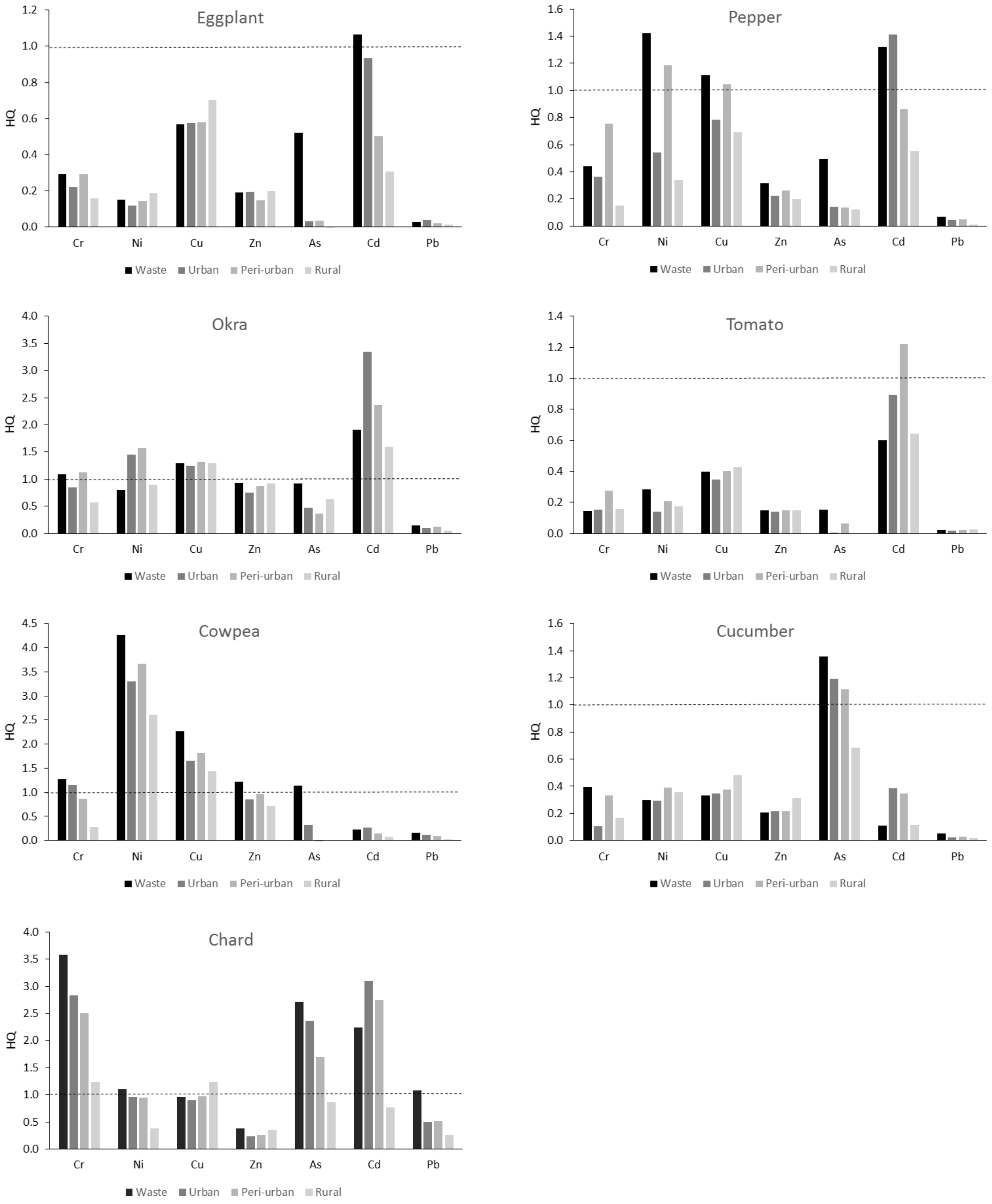

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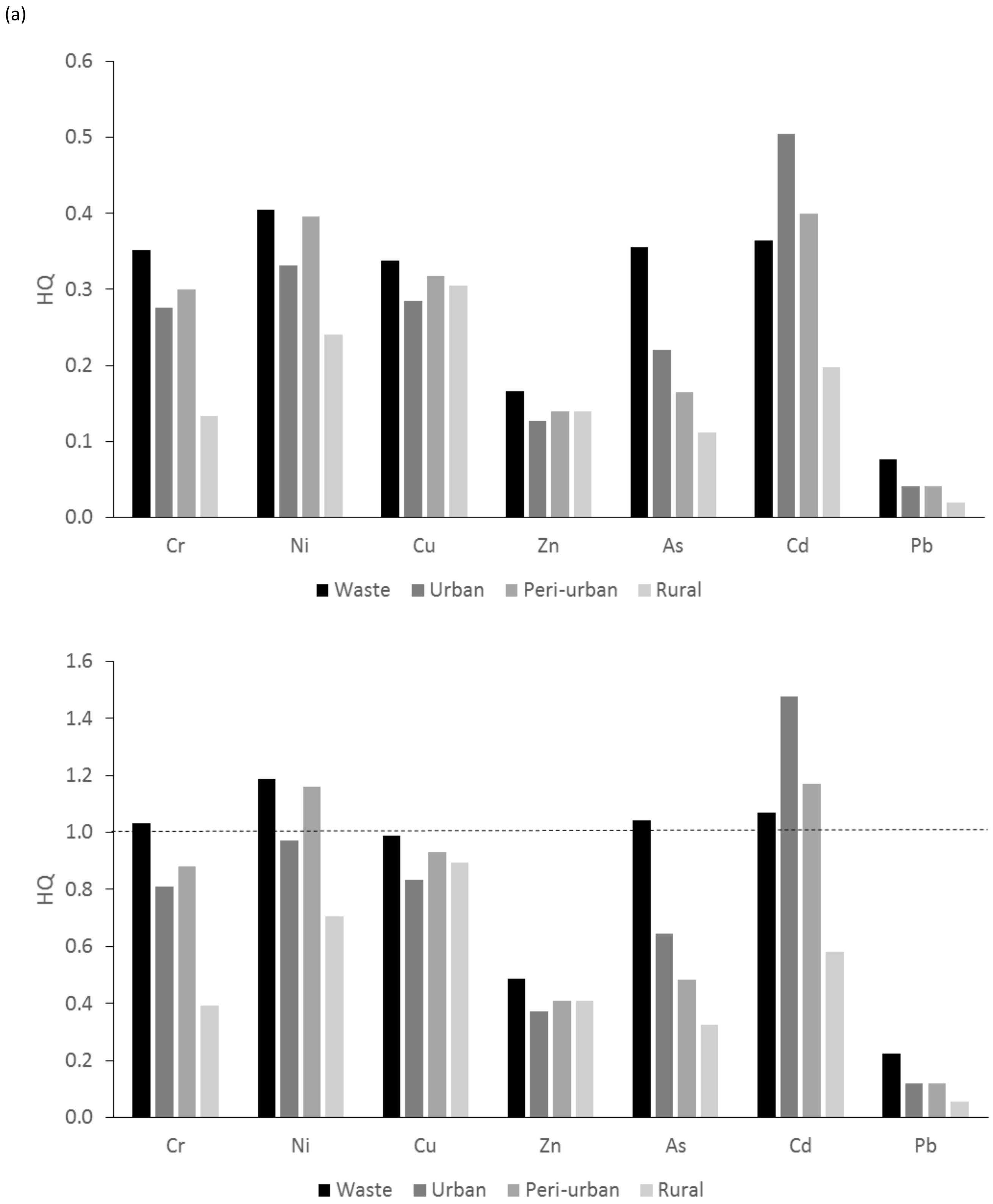

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Supplementary Information

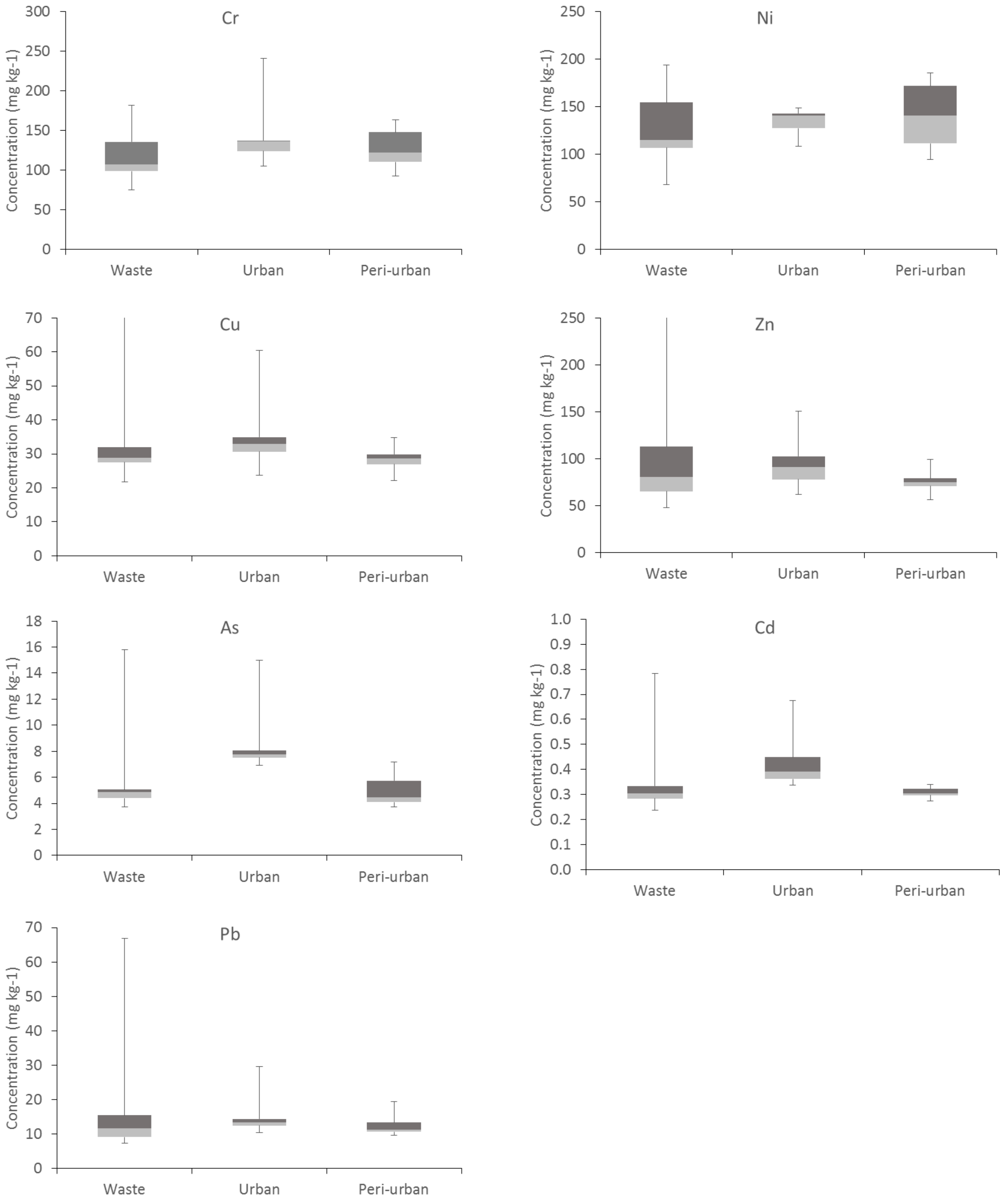

Figure S1: Mean concentrations of Cr, Ni, Cu, Zn, As, Cd and Pb for all land uses in Sulaymaniyah city. Grey boxes denote the data between the 25th and 50th percentile and black boxes the data falling between the 25th and 75th percentile. Maximum and minimum values and shown by the upper and lower error bars respectively. Solid line and dashed lines denote SGV and EU/WHO standards respectively.

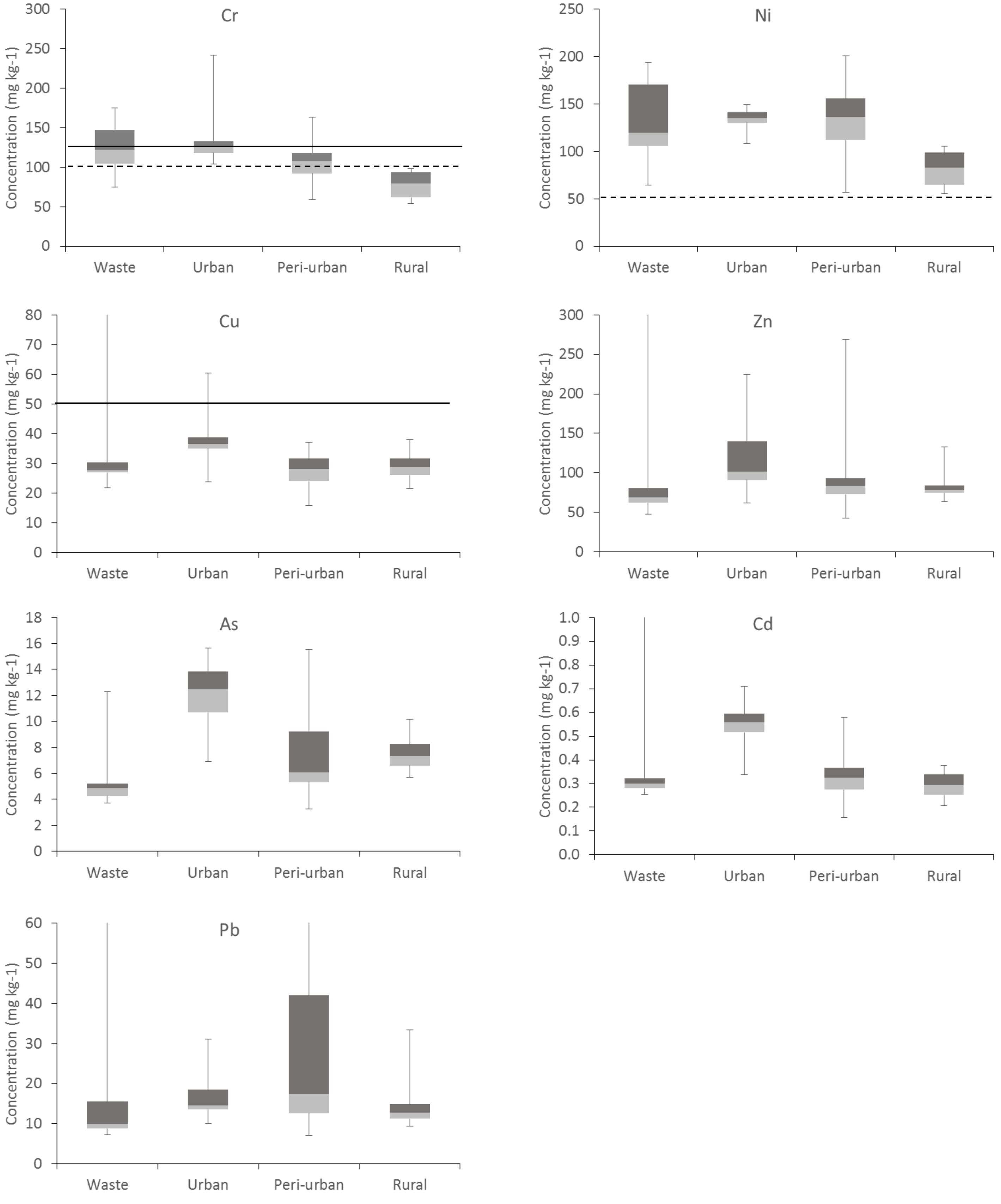

Figure S2: Mean concentrations of Cr, Ni, Cu, Zn, As, Cd and Pb for all land uses for all sites. Grey boxes denote the data between the 25th and 50th percentile and black boxes the data falling between the 25th and 75th percentile. Maximum and minimum values and shown by the upper and lower error bars respectively. Solid line and dashed lines denote SGV and EU/WHO standards respectively.

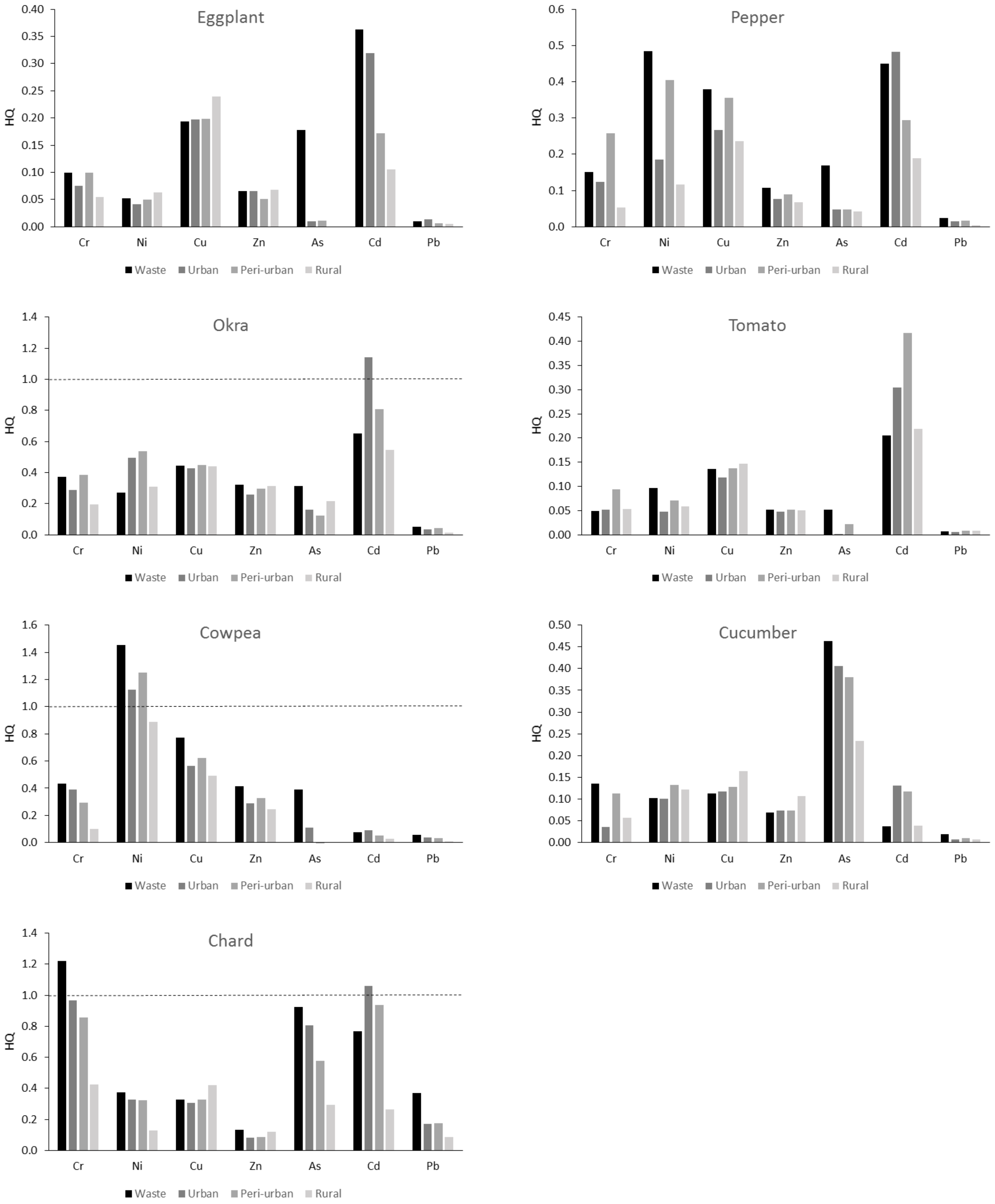

Figure S3: Mean hazard quotients (HQ) for adults.