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Contamination of Soil and Vegetables by Heavy Metals and the Associated Health Risks in Khartoum North

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Abstract. The concentration of metals in soil and vegetables grown in farms around Khartoum North urban area was determined for estimated contamination of soil, vegetable and health risk. The metals investigated are Al, As, Cu, Fe, Ni, Pb and V, their concentrations are found in soil below WHO permissible limit accept Fe levels 182.57 mg/kg, where permissible limit is 4.25. Metals Al, As, Cu, Fe, Ni, Pb and V content in vegetables range (0.80 – 2.30), (0.07 – 0.18), (0.11 – 0.21), (1.89 – 5.05), (0.06 – 0.08), (0.10 – 2.15) and (0.09 – 0.10) mg/kg respectively. Plant transfer coefficient % (PTC) calculated high metals transmit As 66.52, 55.01 and 52.45 for watercress, purslane, mallow and tomatoes respectively. The PTCs of Cu are 99.77, 86.65, 73.54 and 70.73 for tomatoes, mallow, purslane and okra, while the PTCs of Pb were moderated except purslane 828.46% and watercress 64.23%. The daily intake of metals (DIM) estimated for adult, the values found below the permitted maximum tolerable daily intake PMTDI in most vegetables studied, but it was found that Al consumed in purslane and watercress above PMTDI. The DIMs of As were above PMTDI in all samples, except cucumbers was equal the PMTDI value 0.01 mg/person per day. The DIM of Pb for purslane was estimated to be 0.305 mg/person/day above PMTDI. The health risk index (HRI) values ranged as As 3.40 – 8.689, Cu 0.386 – 0.754, Fe 0.382 – 1.022, Ni 0.404 – 2.154, Pb 0.101 – 6.760 and V 1.480 – 1.621. When HRI<1, the exposed population is safe of metals health risk, while HRI>1 means the exposed population is unsafe of metals health risk.

Keywords: contamination, heavy metals, vegetables, soil, health risk

Introduction

Environmental pollution has exposed humans to various contaminants, which are either inorganic or organic compounds such as metals, metalloid, nonmetals or organic are halogenated and non-halogenated such as aliphatic and aromatic hydrocarbons (FAO and UNEP, 2021) as well as pesticides. Unlike most organic pollutants, heavy metals are not removed from ecosystems by natural processes. Heavy metals are hazardous contaminants in food and the environment and they are non-biodegradable having long biological half-lives (Heidarieh et al., 2013).

Heavy metals generally collective term which applies to the group of metals and metalloids with an atomic density greater than 4 g/cm³. Although it is a loosely defined term (Kachenko & Singh, 2006), it is widely recognized and usually applies to the widespread contaminants of terrestrial and freshwater ecosystems. The major inorganic contaminants are trace elements, radionuclides, and asbestos, where the term “trace elements” refers to a group of ubiquitous elements that normally occur at very low levels in the environment and which can be toxic to organisms. Trace elements include heavy metals (that is, those metals with high atomic mass) such as lead (Pb), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), mercury (Hg), tin (Sn), nickel (Ni) and zinc (Zn). Non-metals that are regarded as trace elements include arsenic (As), antimony (Sb) and selenium (Se). Trace elements can occur in many different forms such as salts, oxides, sulfides, organometallic complexes, or may be present in the form of ions dissolved in soil solution. The partitioning among air, water and soil is driven by chemical processes such as adsorption to particles or pH-dependent dissolution in water (Alloway, 2012). Some trace elements are essential micronutrients for organisms, including; iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), nickel (Ni), boron (B), selenium (Se) and molybdenum (Mo). However, at high concentrations they may be toxic. Among trace elements zinc (Zn), nickel (Ni), cobalt (Co) and copper (Cu) are relatively more toxic to plants, and arsenic (As), cadmium (Cd), lead (Pb), chromium (Cr) and mercury (Hg) are relatively more toxic to higher animals including humans. Also the radioactive elements are source of soil pollution where radionuclides originate either from natural processes such as parent rock weathering and volcanic eruptions or from anthropogenic activities. Radionuclides in the soil are taken up by plants, and thereby becoming available for further redistribution within the food chain (FAO and UNEP, 2021).

Heavy metal ions transfers from soil to plant, it uptake via the roots from contaminated soils and direct deposition of contaminants from the atmosphere onto plant surfaces can lead to plant contamination by heavy metal (Zhuang et al., 2008). Vegetables are essential for human nutrition and health, particularly as source of vitamin C, folic acid, minerals, niacin, thiamine, pyridoxine and dietary fiber, their biochemical role and their antioxidative effects (Siegel et al., 2014). There are different kinds of vegetables, they may be edible roots, stems, leaves, fruits or seeds. Each group contributes to diet in its own way, the plants, vegetables are the excellent sources of minerals, where minerals are very important and essential ingredients of diet required for normal metabolic activities of body tissues.

Vegetables absorb metals from contaminated soils, besides from deposits on the parts of the vegetables exposed to polluted air (Haiyan & Stuanes, 2003). Heavy metals can be readily adsorbed by vegetable roots, and can be accumulated in the edible parts of vegetables at high levels, regardless of the heavy metal concentration in the soil (Jolly et al., 2013). The consumption of vegetables contaminated with heavy metals may pose a risk to the health of humans. Heavy metals are deleterious due to their long biological half-lives, non-biodegradable nature, and their ability to accumulate in different body parts (Heidarieh et al., 2013). The effects of heavy metals contaminant soil and food on human health, as effects on the organs such as lead, manganese, mercury and tin effects on Brain. Cadmium reduced thyroid hormones. lead, mercury and pesticides effects on Heart and cardiovascular system. Arsenic, cadmium, chromium, copper, mercury, and radon effects on Lungs. Chromium, copper and mercury effect on Liver. Cadmium, lead and mercury effects on Kidneys. Arsenic, copper, lead, mercury and tin effects on Intestines. Arsenic and lead effects on Bladder. Antimony, lead and manganese effects on Reproductive system. Cadmium, lead, radium and its decay products effects on Bones and joint. Arsenic and chromium effects on Skin (FAO and UNEP, 2021).

This study was done on farms around urban areas (Khartoum north), the levels of some selected metals, heavy metals and metalloids in soil and vegetables were studied, and measured the contamination of soil, plant transfer factor and determined their associated with human health risk.

Materials and Methods

Chemicals and Reagents

All the chemicals used were of analytical reagent grade and triple distilled water was used for all experiments.

Instrument and Apparatuses

Inductive coupled plasma spectrophotometer (ICP-MS) was used for determination of heavy metals. All glassware's were soaked in 4 M nitric acid HNO_3 for 12 hours, after that washed by deionized water, and triple distilled water.

Sample Collection

The soil and six type of vegetables sample collected from Khartoum North farms. Directly collected from the farms with randomly selections, the vegetables samples include Cucumber (*Cucumis Sativus*), Tomato (*Solanum lycopersicum*), Okra (*Abelmoschus esculentus*), Mallow (*Corchorus olitorius*), Purslane (*Portulaca Oleracea*) and Watercress (*Eruca Sativa*). The surface soils sample collected from the farms which plants growing in it. All the samples were collected in polyethylene bags and were transferred to the laboratory for treated and analysis.

Sample Treatment

The vegetables samples classified in three groups according to consuming part; fruit consumer include cucumber, tomatoes and okra samples, were washed carefully used tap water and distilled water, weighted and were cutting in small parts and putted in glass dish to dry. Second group was leaves consumer include mallow and watercress, samples were washed and leaves were separated and dried. Third group was leaves and steams consumer it was purslane separated from root and washed and cutting in small particles and were putting in glass dish, left it to dry. When sample dried we were milling and kept it close container. We prepared the sample for analysis, digested 1 gram in HNO_3 and HCl acids in ratio 3:1 in cold for 48 hours and heating until clear solution produced, where transferred to 100 cm^3 volumetric flask and diluted to the mark. The soil samples prepared by digested 2 grams in nitric acid and hydrochloric acid in ratio 3:1 with heating to boiling for 30 min after that cooling, diluted, filtered and transferred to 100 cm^3 flask and completed the volume. The samples solution analyzed by using inductive coupled plasma spectrophotometer (ICP), for determination selected metals Al, As, Cu, Fe, Ni, Pb and V.

Plant Transfer Factor

The heavy metal concentrations in the soil and plants samples were determined on the basis of dry weight. The plant concentration factor (PCF) was calculated as a ratio of heavy metals concentration in vegetables and soil, according to following relation.

$$\text{PTF} = \frac{C_{plant}}{C_{soil}} \text{ (Liu et al., 2005)}$$

where C_{plant} and C_{soil} represent the heavy metal concentration in plants and soil on dry weight basis, respectively. Where plant transfer coefficient % (PTC%) is Plant Transfer factor PTF 100 %.

Contamination Factor (CF)

The degree of soil pollution for each metal was measured, by using the following equation;

$$\text{CF} = \frac{\text{C}_{\text{soil}}}{\text{C}_{\text{refe}}}$$

Where C_{soil} is total soil element content (mg kg^{-1}); C_{refe} is reference content in pristine soils (mg kg^{-1}, “world-wide average” (Antoniadis et al., 2019). Reference values for selected; As; 6.83, Cu; 38.9, Ni; 29, Pb; 27 and V; 129 mg kg^{-1} (Kabata-Pendias, 2011), Al and Fe did not report in BG.

Daily Intake of Metals

The daily intake of metals (DIM) was calculated as a product of heavy metals concentration per dry weight vegetable, percentage of fresh green vegetable weight to dry weight (conversion factor), average vegetable daily consumption per person divided on average body weight. Where the daily intake of metals (DIM) was determined by the following equation.

$$\mathrm{DIM} = \frac{C_{\mathrm{metal}} \times C_{\mathrm{factor}} \times D_{\mathrm{intake}}}{B_{\mathrm{average\ weight}}}$$

Where C_{metal} is the heavy metal concentrations in plants (mg kg^{-1}), C_{factor} is conversion factor, D_{intake} is daily intake of vegetables and $B_{average\ weight}$ is average body weight. The conversion factor 0.085 was used to convert fresh green vegetable weight to dry weight (Rattan et al., 2005). The average daily vegetable intakes for adults suggested by WHO guidelines in human diet is 300 to 350 g per person (FAO/WHO, 1989), we used the average daily vegetable intake of Sudanese adults value 100 g per person for calculated. An average weight of person was considered to be 60 kg (FAO/WHO, 1993).

Health Risk Index

The health risk index (HRI) for the consumption of contaminated vegetables were estimated as the ratio of the daily intake of metals to the reference oral dose (RfD) for each metal. The HRI <1 means the exposed population is assumed to be safe.

$$\mathrm{HRI} = \frac{\mathrm{DIM}}{\mathrm{RFD}} \text{ (USEPA, 2002)}$$

Results and Discussion

Heavy Metals Concentration in Soil

The concentration of heavy metals in soil were detected and presented in Table 1, the element determined were including metals, heavy metals and metalloids. Although aluminum is not a heavy metal and unknown as essential metals it makes up about 8% of the surface of the earth and is the third most abundant element. It is readily available for human ingestion through the use of food additives, antacids, buffered aspirin, astringents, nasal sprays and antiperspirants from drinking water (Bakare-Odunola, 2005). The health effects of aluminum are not well defined, but the high concentration of aluminum in body is linked to Alzheimer's and Parkinson's disease. The aluminum (Al) concentration found 102.05 mg/kg, arsenic as metalloid element had concentration 0.23 mg/kg, this value excess WHO permissible limits. The concentration of heavy metals Cu, Fe, Ni, Pb and V were 0.21,182.57,0.23,0.26 and 0.49 mg/kg respectively. we observe iron was higher value than WHO permissible limits.

The contamination factor (CF) was calculated for measuring the degree of soil pollution for each metal, the (CF) of metals As, Cu, Ni, Pb and V were 0.034, 0.005, 0.008, 0.010 and 0.004 respectively, where is observes CF<1 thus refers to low contamination.

Table 1: The metals concentrations in soil

Sample	Metals concentration mg/kg						
	Al	As	Cu	Fe	Ni	Pb	V
Soil	102.05	0.23	0.21	182.57	0.23	0.26	0.49
Permissible limits	-	0.20	40	4.25	1.50	0.20 0.3	1.00

Metals Concentrations in Vegetables

The metals concentration determined in vegetables samples were presented in Table 2 and Figures 1-6. The aluminum concentration was found in range 0.80 – 2.30 mg/kg, the highest value is found in purslane 2.30 mg/kg, where the stems and leaves are consumed, then plant leaves only consumed (mallow and watercress) the low value found in cucumber 0.98 mg/kg and tomatoes 0.80 mg/kg. Arsenic concentration found in range 0.07 – 0.18 mg/kg, had values were less than WHO maximum permissible limits (Codex Alimentarius, 2015). Copper concentration found in range 0.11 – 0.21 mg/kg, this range of copper levels were lowest than maximum permissible limits for FAO/WHO (Codex Alimentarius, 1996). Iron is essential metal, had concentration detected in range 1.89 – 5.05 mg/kg, where is maximum level of it was found in Purslane, the general observation the iron found in high level in vegetables leaves, mallow was contained 3.62 mg/kg and watercress contained 3.50 mg/kg, and found in fruit in order cucumber, okra and tomato, 2.06, 1.95 and 1.89 mg/kg respectively. Nickle found in trace amount in all vegetable samples, where concentrations range 0.06 – 0.08 mg/kg, these concentrations values less than maximum permissible limits. Lead levels determined in vegetables and found range 0.10 – 2.15, accordingly the highest value found was 2.15 mg/kg in purslane it was upper than permissible value, and also found Pb levels in all samples less than permissible value, the lead content in cucumber is considered to be lowest among the detected values. Vanadium levels detected in all vegetable samples had range 0.09 – 0.10 mg/kg, all vanadium concentration values below WHO maximum permissible value.

Table 2: The metals concentrations in vegetables samples

Sample	Metals concentration mg/kg						
	Al	As	Cu	Fe	Ni	Pb	V
Cucumber	0.98	0.07	0.11	2.06	0.07	0.09	0.09
Mallow	1.89	0.13	0.19	3.62	0.08	0.11	0.10
Okra	1.36	0.10	0.15	1.95	0.06	0.09	0.09
Tomato	0.80	0.12	0.21	1.89	0.07	0.10	0.10
Watercress	2.16	0.18	0.11	3.50	0.08	0.17	0.10
Purslane	2.30	0.16	0.16	5.05	0.08	2.15	0.10

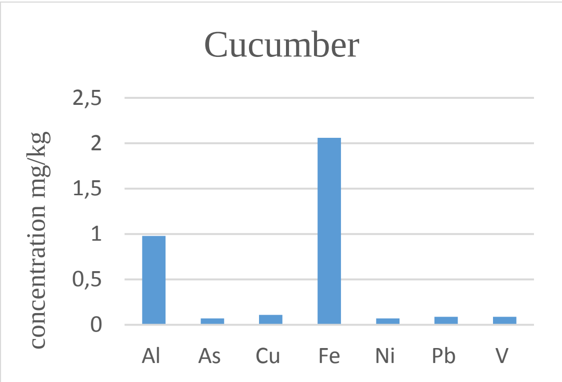

Figure 1: Metals concentration in cucumber

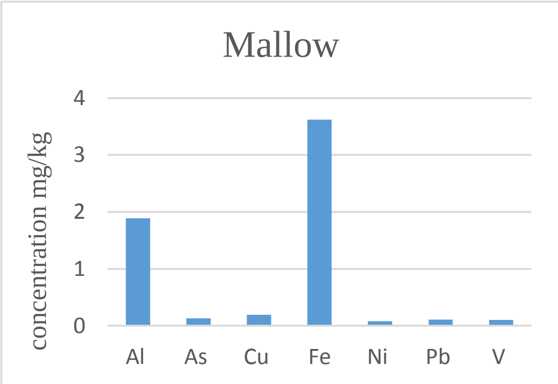

Figure 2: Metals concentration in mallow

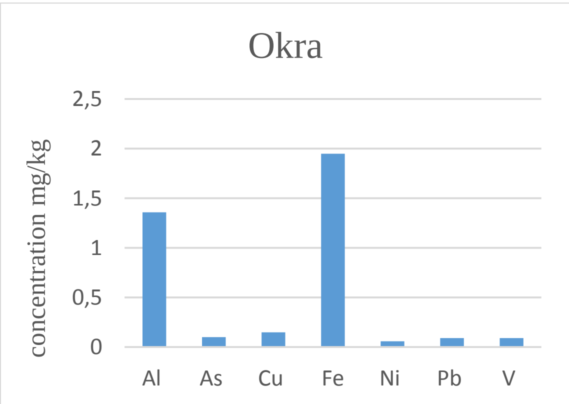

Figure 3: Metals concentration in okra

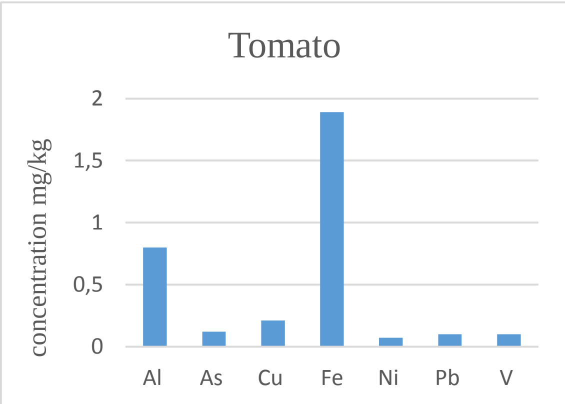

Figure 4: Metals concentration in tomatoes

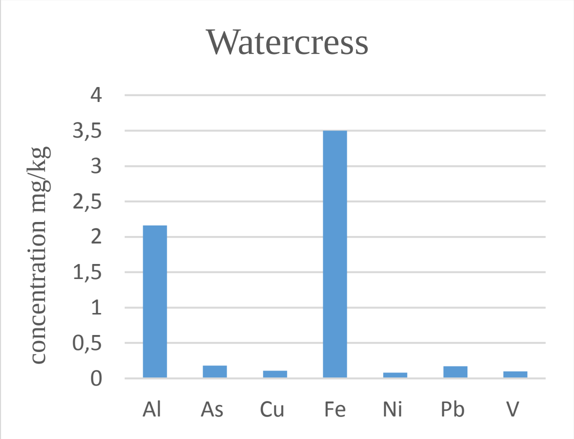

Figure 5: Metals concentration in watercress

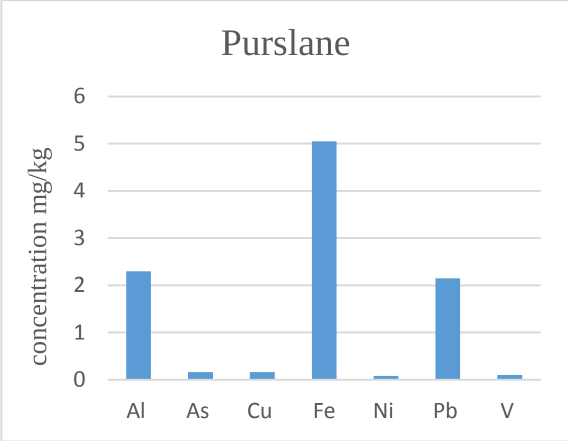

Figure 6: Metals concentration in purslane

Plant Transfer Coefficient

Heavy metals transfer from soil to plant depend on plant physiology, specification of the element in the soil solution, concentration, metals salt dissociates and other factors. Where plant transfer coefficient (PTC) calculated for metals concentration as percentage ratio of plant transfer factors the results shown in Table 3. The PTC of aluminum found in range 0.78% - 2.25%, high transfer rate in purslane and low rate in tomato, generally the PTCs for aluminum are low. Arsenic PTCs were found in high rates at range between 30.70 % for cucumber to 78.46 % for watercress. Therefore, it is assumed that the vegetables that are growing in the soils contained arsenic will absorb more arsenic from the soil and thereby polluted by arsenic. Copper also had high rates of PTC of all vegetables the minimum rate 51.05 % for cucumber and maximum rate 99.77 for tomatoes, however the high rate of copper which was absorbed by plants depended on his chemical behavior in soils. Iron PTC range 1.07 % for okra to 2.76 % for purslane, although iron had high concentration in soil but his PTCs were low, this due to the iron compound in soil and their ability to decompose and saturated the soil solution with iron ions. Nickle had moderate PTCs where range is limited between 24.52 % for okra and 34.41 % for purslane. Plant transfer coefficients of lead had different rates distributed between moderate, high and highest presented with range 33.85 % for cucumber to 828.46 % for purslane. Although its concentration in the soil is low the percentage of transmission to plants is relatively large. it is noticeable that the rate of its absorption in purslane exceeds its presence in the soil, and this confirms the presence of a source of lead in the environment that is absorbed by purslane and most of its sources in urban areas resulting from the combustion of motor fuels and industrial waste. The vanadium PTCs were presented as moderate rate had range 18.72 % to 21.19 %.

Table 3: plant transfer coefficient

Sample	Plant Transfer Coefficient %						
	Al	As	Cu	Fe	Ni	Pb	V
Cucumber	0.96	30.70	51.05	1.13	30.97	33.85	19.34
Mallow	1.85	55.01	86.65	1.98	32.26	43.46	21.19
Okra	1.33	43.92	70.73	1.07	24.52	35.00	18.72
Tomatoes	0.78	52.45	99.77	1.03	27.96	38.08	19.75
Watercress	2.12	78.46	51.52	1.91	34.41	64.23	21.19
Purslane	2.25	66.52	73.54	2.76	34.41	828.46	20.78

Daily Intake of Metals

The estimated daily intake of metals (DIM) for adult is shown in Table 4. The DIM of Al is consumed in purslane and watercress above the permitted maximum tolerable daily intake (PMTDI) endorsed by WHO/FAO of 0.3 mg/person per day, whereas the rest were below permissible limits. The DIM of As is consumed in all vegetables samples were above PMTDI, except cucumbers sample was equal the PMTDI value 0.01 mg/person per day. The DIM of Cu, Fe, Ni and V were below permissible limits, but the DIM of Pb below permissible limits except in purslane was estimated to be 0.305 mg/person/day this value above the PMTDI.

Table 4: The daily intake of metals and health risk index

Sample	Al	As		Cu		Fe		Ni		Pb		V	
	DIM	DIM	HRI	DIM	HRI	DIM	HRI	DIM	HRI	DIM	HRI	DIM	HRI
Cucumber	0.139	0.010	3.400	0.015	0.386	0.292	0.417	0.010	0.510	0.012	3.562	0.013	1.480
Mallow	0.267	0.018	6.092	0.026	0.655	0.512	0.732	0.011	0.531	0.016	4.574	0.015	1.621
Okra	0.193	0.015	4.864	0.021	0.535	0.277	0.395	0.008	0.404	0.013	3.683	0.013	1.432
Tomato	0.113	0.017	5.808	0.030	0.754	0.267	0.382	0.009	0.460	0.014	4.007	0.014	1.511
Watercress	0.307	0.026	8.689	0.016	0.390	0.495	0.707	0.011	0.567	0.024	6.760	0.015	1.621
Purslane	0.325	0.022	7.367	0.022	0.556	0.715	1.022	0.011	2.154	0.305	0.101	0.014	1.590
PMTDI	0.3	0.01		2.00		15.00		0.25		0.21		0.02	

Health Risk Index

The consumption of contaminated vegetables has been pinpointed as one of the major pathways of human exposure to toxic heavy metals. The health risk index (HRI) for all the vegetables estimated were presented in Table 4, where is values ranged as As 3.40 – 8.689, Cu 0.386 – 0.754, Fe 0.382 – 1.022, Ni 0.404 – 2.154, Pb 0.101 – 6.760 and V 1.480 – 1.621. The HRI for Cu his values less than 1 (HRI<1), this means that the exposed population is safe of metals health risk. The HRI for Fe and Ni are safe in all vegetables, except in purslane reported values greater than HRI (HRI > 1) this means the exposed population is unsafe of metals health risk. While As, Pb and V were unsafe the healthy risk, where risk of As and Pb were higher. However, in purslane we note that the Pb is safe.

Conclusion

Most of metals detected in farms soil were below of WHO permissible limits, according to the degree of soil pollution, the contamination of soil was low. The vegetables absorbed metals from soil solution in different ratio depended on chemical behavior of metals and plant physiology. The Cu and V transferred to plant with higher ratio, the absorption of metals by vegetables in order according to the highest percentage were purslane, watercress, mallow, tomatoes, okra and cucumber respectively. The daily intake of metals moderate in all vegetables except purslane highest for Al, As and Pb, where Pb level in purslane upper to soil, accordingly, we assume that Pb has other source in addition the soil, in urban areas it was resulting from air pollution with industrial waste, in addition to car exhausts. The health risk index (HRI) for most estimated metals were safe with the exception of As, Pb and V slightly exceeded the safety limit.

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