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RESEARCH ARTICLE

Association between heavy metals and metabolic syndrome in drinking water and surface soil: case-control study in Iran

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Abstract

Although obesity is a major risk factor for metabolic syndrome (MetS), not all obese people develop MetS that is directly related to obesity. This suggests that the risk of MetS is influenced by other genetic or environmental agents such as heavy metals. The aim of this study was to investigate the relationship between heavy metals in drinking water and surface soil, and its relationship with the incidence of MetS. To determine the sampling points of drinking water and surface soil, from the location of 150 people selected for inclusion in the study, 16 points were selected randomly for heavy metal concentration analysis. Results were indicated that mean concentrations of V, Mn, Ni, As, Cd, and Sr in drinking water of MetS group were higher than control group. The concentration of heavy metals in drinking water, except for Mn and Sr, did not show a significant difference between case and control groups. The results of this study showed that concentration of heavy metals in drinking water and surface soil was positively associated with the incidence of MetS.

Keywords Drinking water · Surface soil · Metabolic syndrome · Hoveyzeh

Introduction

Apart from changes in habits and lifestyles, exposure to heavy metals is increasing due to urbanization (Asaduzzaman et al. 2017). Most heavy metals in the body cannot be metabolized and disrupt the normal function of cells (Asaduzzaman et al. 2017; Rhee et al. 2013; Yoo 2014).

Heavy metals may cause MetS (Rhee et al. 2013). While lifestyle and genetic factors largely determine the risk of developing this syndrome, evidence suggests that environmental factors, including heavy metals, are associated with an increased risk of MetS. However, obesity is a major risk factor for MetS, but not all obese people develop MetS, indicating that risk of developing MetS is influenced by other genetic or environmental factors. Recently, environmental research has shifted from examining the effects of single chemical on human health to the "biology of exposure" approach to examining the effects of low to moderate chronic exposure versus acute exposure. This method considers several factors that may play key role in creating final phenotype. In this regard, it has been shown that exposure to toxic substances, such as heavy metals, affects various aspects of metabolism (Ghaedrahmat et al. 2021; Padilla et al. 2010).

Heavy metals are elements that have an atomic mass greater than 55.8 g mol^{-1} or in other words have a specific gravity greater than 35 g cm^{-3} (Bánfalvi 2011). Among all pollutants, heavy metals have attracted attention of environmental chemists due to their toxic nature. Heavy metals such as arsenic (As), lead (Pb), cadmium (Cd), nickel (Ni), mercury (Hg), chromium (Cr), cobalt (Co), zinc (Zn), and selenium (Se) are highly toxic. Heavy metals are usually present in small amounts in natural waters, but many of them are toxic even at very low concentrations (Guo et al. 2019; Herawati et al.

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2000; Ma et al. 2020; Nazarpour et al. 2018; Tian et al. 2020; Tong et al. 2020). Currently, increasing amounts of heavy metals in water resources have received more attention, especially since a large number of industries are discharging their metal effluents into fresh water without any sufficient treatment (Karimian et al. 2021; Salomons et al. 2012).

Heavy metals until not metabolized in the body and accumulate in soft tissues are not toxic. Heavy metals maybe enter the human body through food, water, soil, and air as a result of agricultural, manufacturing, pharmaceutical, industrial, or residential practices (He et al. 2005; Salomons et al. 2012; Soltani-Gerdefaramarzi et al. 2021). Therefore, two main sources of heavy metals for entering in human body are drinking water and soil, and in this study, these two sources are monitored. The aim of this study was to investigate the relationship between heavy metals in drinking water and surface soil of individuals studied in a cohort of Hoveyzeh and its relationship with MetS.

Material and methods

Study subject

The data was used in this case-control study from PERSIAN cohort center of Hoveyzeh. Two groups of healthy individuals (control) and individuals with MetS (case) were randomly selected according to list of patients with MetS at cohort center of Hoveyzeh. Individuals are diagnosed with MetS when they meet three of following five criteria: blood pressure >130/85 mm Hg, fasting blood glucose >5.6mmol L^{-1}, serum triglyceride level >1.7mmol L^{-1}, high-density lipoprotein (HDL-C) level <1.0 mmol L^{-1} in men and <1.3 in women, and waist circumference >102cm in men and >88cm in women.

Data collection and analysis

To determine the sampling points of drinking water and surface soil from location of 150 individuals selected for inclusion in the study, 16 points were selected according to systematic sampling for drinking water and surface soil. To analyze the drinking water sample, 100 ml of water sample was placed in a fluorescein container and 1 ml of high purity nitric acid (98%) was added to it. Then, the solution was heated for 2 h. After cooling, the solution was transferred to the plastic container and 100 ml of deionized water was added to it and analyzed by ICP-MS [83]. The amounts of limit of detection (LOD) for heavy metal concentration such as V, Ni, As, Cd, Sb, Hg, and Pb are 1, 0, 1, 0, 1, 2, 2, and 2 μg L^{-1}, respectively. The amounts of limit of quantification (LOQ) for metals V, Ni, As, Cd, Sb, Hg, and Pb are 3.3, 0.3, 3.3, 0.3, 3.3, 6.7, and 6.7 μg L^{-1}, respectively.

For acidic digestion of surface soil samples, 0.2 g of soil sample was weighed in the Teflon container. For simultaneous extraction of large quantities of metals in the soil, 6 ml of nitric acid, 2 ml of hydrochloric acid, and 2 ml of hydrofluoric acid were used. The solution was digested by microwave digester (CEM, MARS6, USA). The solution was heated to 120 °C for 8 min. Then, the temperature was raised to 150 °C and set aside for 5 min. After 5 min, the temperature increases to 190 °C and allows to cool for 35 min. After cooling, 2 ml of hydrogen peroxide was added to digested mixture and then transferred to heating block at 140 °C until 1 ml of solution remained. Finally, the solution was transferred to 50-ml volumetric vessel. To measure the metals, digested solution was diluted at the ratio of 10:1 with nitric acid (2%). The heavy metal measurements were performed by ICP-MS [84]. The amounts of LOD for heavy metals such as V, Ni, As, Cd, Sb, Hg, and Pb are 10, 1, 10, 1, 10, 20, 20, and 10 μg L^{-1}, respectively. The amounts of LOQ in this method for V, Ni, As, Cd, Sb, Hg, and Pb metals are 33, 3, 33, 3, 33, 67, 67, 33 μg L^{-1}, respectively.

Statistical analysis

Statistical analysis was performed using Excel and SPSS 26 software. To analyze the data, first, descriptive statistical methods were used. The normality of quantitative data distribution was evaluated by Kolmogorov-Smirnov test. Chi-square test was used to determine the relationship between qualitative variables. For quantitative comparison between the two groups, the Man-Whitney nonparametric test was used. Spearman nonparametric correlation test was used to investigate correlation between heavy metals. Also, multivariate statistical analysis including principal component analysis and cluster analysis were used to determine source of metals. The significance level of all tests was considered less than 0.05 and 0.01.

Result and discussion

Heavy metals in surface soil

Results of descriptive statistics of aluminum (Al), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), mercury (Hg), lead (Pb), strontium (Sr), and antimony (Sb) are given in Table 1. The mean concentrations of V, CO, Cr, Mn, Fe, Sb, Hg, Ni, and Sr in MetS group were higher than control group. The results of Mann-Whitney analysis showed that concentration of heavy metals in surface soil did not show a significant difference between case and control groups (Table 1). The concentration of Fe was the highest concentrations among heavy metals in surface soil, with mean

Table 1 Heavy metal concentration in surface soil in two groups with MetS and without MetS

Heavy metal (mg kg^{-1})	Case (n=8)				Control (n=8)				p value	VC	Background value[1]
	Minimum	Maximum	Mean	Std. deviation	Minimum	Maximum	Mean	Std. deviation			
Al	88.00	12,382.00	7310.25	3758.07	4786.00	13,953.00	7523.50	2931.31	0.60	0.44	82000
V	0.70	41.30	28.61	13.02	14.70	47.60	30.18	10.24	0.785	0.38	36.25
Cr	3.50	67.90	45.58	20.17	45.50	77.00	58.45	11.77	0.20	0.33	42
Mn	2.10	625.80	384.56	180.89	241.50	617.40	399.78	124.43	0.793	0.38	412.4
Fe	159.00	13,987.00	9879.50	4420.08	8030.00	16,077.00	11,520.37	2406.78	0.529	0.33	3.5
Co	−0.70	13.30	7.43	4.314	3.50	13.30	7.26	3.32	0.752	0.5	6.9
Ni	2.80	78.40	52.32	25.64	26.60	88.90	49.17	20.09	0.494	0.44	18
Cu	23.10	67.90	51.97	15.25	42.70	1483.30	248.85	500.78	0.462	2.38	14
Zn	7.00	218.40	105.26	69.92	41.30	707.00	199.67	227.25	0.636	1.11	62
As	0.00	12.60	3.93	4.48	0.70	10.50	4.02	3.90	0.915	1.01	4.7
Cd	0.00	0.91	0.61	0.29	0.52	3.50	1.12	1.00	0.462	0.88	0.2
Sb	0.00	4.20	1.83	1.39	0.70	2.80	1.48	0.87	0.587	0.68	0.62
Hg	0.53	511.70	120.48	221.65	0.45	1.76	0.80	0.43	0.115	2.7	0.03
Pb	1.40	22.40	14.08	6.97	7.00	282.80	61.86	96.51	0.430	1.85	25.02
Sr	4.90	819.00	541.18	264.97	389.90	763.70	590.80	134.69	1.00	0.36	110

concentration of 9879 mg kg^{-1}, followed by Al (7310 mg kg^{-1}), Sr (540 mg kg^{-1}), Mn (384 mg kg^{-1}), Hg (120 mg kg^{-1}), and Zn (105 mg kg^{-1}).

Indoor dust was expected to have high concentration of Fe, as it is the most abundant constituent of the earth's crust (Hunt et al. 2012). Differences in Fe concentration in indoor surface soil samples from different locations may be due to entry of soil dust into indoor environment by human activity as well as wind from outside (Al-Rajhi et al. 1996).

The concentration of heavy metals in surface soil varies depending on type of local human activity and its location. In previous studies, the highest concentration of Pb (639.10 μg G^{-1}) was reported in Riyadh, Saudi Arabia due to heavy traffic and Pb fuel consumption. High concentrations of Pb were also reported in surface soil of classroom in another study (Tahir et al. 2007).

In previous studies, high concentrations of Pb have been reported in domestic dust collected from urban areas with heavy traffic and rapid industrialization. The vehicle emissions have also become a major source of heavy metals in indoor dust, as shown in previous studies (Hassan 2012; Tahir et al. 2007). The results of these studies are not consistent with the present study.

However, another study reported the highest concentrations of Zn in dust collected in offices and homes in Istanbul were 1970 μg G^{-1} and 832 μg G^{-1}, respectively. This may be due to dust and building ventilation, which can cause different concentrations of heavy metals in indoor dust (Nigeria 2012). The results of this study are consistent with the present study. Also reported that wind-induced dust from surface soil and road dust are main sources of heavy metals in domestic dust (Al-Rajhi et al. 1996). In addition, most studies have shown that industrial areas have the highest concentrations of heavy metals (Hassan 2012; Tahir et al. 2007). In another study, high concentrations of Al, Fe, and Zn were reported at the entrance of a house. This may be due to the entry of indoor dust (Hassan 2012). The results of this study are consistent with the present study.

Spearman correlation analysis for heavy metals in surface soil

Due to the fact that in this study, heavy metal concentration data in surface soil did not have a normal distribution, Spearman correlation test was used to investigate correlation between heavy metal concentration in surface soil. The results of spearman correlation coefficients are presented in Table 2. As can be seen in Table 2, at $p< 0.01$, Al has positive correlation with V, Mn, Co, Fe, and Ni concentration ($r> 0.6$). The Fe concentration is positively correlated with Co and Ni; also, Co and Ni concentrations are positively correlated. The Cr concentration is positively correlated with Fe, Cu, and Zn concentrations. The Cu concentration also has a positive correlation with Zn, Cd, and Pb concentrations. The Zn and Pb metals also have a positive correlation (r=0.87). The Cd and Pb concentrations also have a positive correlation (r=0.87). At $p< 0.05$, Fe concentration has a significant positive correlation with Cu and Zn concentrations. Also, Al and Cr concentrations (r = 0.51), Cr and Ni (r = 0.52), and Cd and Zn concentrations (r = 0.62) have a significant positive correlation.

Table 2 Spearman correlation coefficients for heavy metal concentrations in surface soil

	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Cd	Sb	Hg	Pb	Sr
Al	1.000														
V	0.82**	1.00													
Cr	0.51*	0.37	1.00												
Mn	0.95**	0.81**	0.44	1.00											
Fe	0.79**	0.68**	0.71**	0.82**	1.00										
Co	0.96**	0.89**	0.46	0.95**	0.75**	1.00									
Ni	0.97**	0.78**	0.52*	0.92**	0.77**	0.93**	1.00								
Cu	0.25	0.04	0.69**	0.29	0.53*	0.22	0.28	1.00							
Zn	0.22	0.11	0.67**	0.24	0.52*	0.20	0.21	0.94**	1.00						
As	−0.03	0.07	−0.22	−0.02	−0.02	−0.01	−0.08	−0.27	−0.21	1.00					
Cd	0.27	0.02	0.48	0.32	0.43	0.20	0.31	0.75**	0.62*	0.07	1.00				
Sb	−0.33	−0.29	−0.09	−0.37	0.18	−0.36	−0.27	0.14	0.21	0.26	0.20	1.00			
Hg	0.36	−0.04	0.28	0.25	0.18	0.26	0.41	0.01	−0.05	0.14	0.23	0.09	1.00		
Pb	0.06	−0.11	0.61*	0.08	0.40	0.009	0.03	0.85**	0.87**	−0.13	0.67**	0.39	−.003	1.00	
Sr	0.036	0.44	0.15	0.39	0.20	0.41	0.32	−0.16	−0.09	−0.06	−0.21	0.22	0.20	−0.08	1.00

* correlation is significant at the 0.05 level (2-tailled)

** correlation is significant at the 0.01 level (2-tailled)

The correlation analysis was used to determine the potential sources of pollution. The correlation between heavy metals was examined based on Spearman correlation coefficient. The high correlation between heavy metals in soil may indicate that source of these metals is probably same. The elements with weak correlation are originated from different geochemical sources.

Therefore, it can be concluded that changes in concentration of these metals will affect concentration of other metals. In this regard, previous studies were reported that high correlation coefficient between metals indicates the same source of these metals (Karimi et al. 2020; Li et al. 2019). Based on correlation between metals and considering that Fe and Al have the highest concentration in the surface soil in this study, heavy metals in surface soil are mostly from natural source.

Principal component analysis for heavy metals in surface soil

The results of principal components test are given in Table 3. Based on result, four components were extracted which accounted for 81.83% of total variance. Table 3 shows the rotating factor matrix for studied metals. Interpreting factor loads without rotation is not easy, so the factors were rotated to increase their interpretability. According to results, it can be seen that the first factor describes 45.97%, the second factor describes 15.75%, the third factor describes 12.69%, and the fourth factor describes 9.69% of total variance. So the first factor is positively and significantly related to Al, V, Mn, Co, Ni, Cr, Fe and Sr concentration. The second factor related with Cu and Zn concentration, the third factor related with As and Cd concentration and the fourthfactor related with Cd and Pb concentration.

Multivariate statistical methods such as principal component analysis and cluster analysis are powerful tools for determining effective sources of pollution. These techniques are used to differentiate between different natural sources that

Table 3 Principal component analysis and eigenvalue

Heavy metals	Rotated factor matrix			
	Factor 1	Factor 2	Factor 3	Factor 4
Al	0.975	−0.001	0.038	0.022
V	0.953	−0.123	0.053	−0.149
Cr	0.746	0.421	0.118	0.431
Mn	0.977	−0.095	−0.017	0.013
Fe	0.933	0.074	0.097	0.202
Co	0.973	−0.045	−0.025	−0.105
Ni	0.955	−0.094	0.036	0.030
Cu	−0.180	0.918	−0.102	−0.043
Zn	0.028	0.970	−0.047	0.063
As	0.032	−0.148	0.872	−0.187
Cd	0.217	−0.129	−0.121	0.683
Sb	−0.264	−0.121	0.681	0.323
Hg	0.295	0.030	0.788	−0.137
Pb	−0.206	0.532	0.023	0.729
Sr	0.700	−0.200	−0.036	0.106
Variance (%)	45.97	15.75	12.69	9.56
Cumulative (%)	45.97	61.55	74.24	81.83
Eigenvalues	6.86	2.36	1.9	1.43

cause changes in soil composition and to identify sources of pollution that affect amount of metals in the soil (Marec et al. 2008). In this regard, principal component analysis was used in order to derive concentration of heavy metals in soil samples. This analysis has been used in various studies to determine the source of metal concentrations in soil (Maull et al. 2012).

The result of principal component analysis was consistent with the results of Spearman correlation in the present study. On the other hand, the results of cluster analysis (Fig. 1) confirm the results of principal component analysis and Spearman correlation. The shorter distance between these elements was indicated high correlation and same source of metals.

Although human activities are also effective in increasing the concentration of these metals, a significant portion of these metals can enter the soil through natural resources during geochemical processes. Also, the heavy metals including Pb, Zn, and V concentrations have human and geological sources. The concentrations of heavy metals in this study were compared with other cities in previous study (Table 4). The concentrations of heavy metals in indoor dust in the present study were less than domestic dust samples reported in most previous studies in different parts of the world. The lowest concentrations of heavy metals were obtained in areas with low traffic and away from industrial areas, which are consistent with the present study.

According to results of statistical analysis and grouping and high correlation between some metals, different parts of vehicle are involved in emission of heavy metals, so that, in previous studies, it has been reported that vehicles are an important source of soil pollution (Aslam et al. 2013; Saeedi et al. 2009). The use of oxide in the form of vulcanization in tires and antioxidants in oil is effective in the release of this element from cars (Elnazer et al. 2015). Corrosion of guardrails and traffic signs also release Zn to roadside soils (Botsou et al. 2016). The Cu alloys are used in mechanical parts and radiators due to their desirable quality, such as corrosion resistance and strength, which emit Cu to the environment. The brake pads are the most important source of Cu emissions to roadside soils (Johansson et al. 2009) so that based on study conducted in Sweden, it was found that 84% of total Cu emissions is due to brake pad wear, and the amounts of emissions for Zn, Ni, Pb, and Cr were obtained 50, 16, 10, and 2%, respectively (Johansson et al. 2009).

The Pb is released from tetraethyl lead $(CH_3CH_2)_4$ Pb in gasoline, bearing wear, and resin wear. On the other hand, car exhaust, tires, engine oil leaks, and greases (Duong and Lee 2011) have been introduced as the most important ways for emission of Pb (Root 2000). The Ni and Cr are released through combustion of fossil fuels such as diesel in heavy vehicles (Al-Awadhi and Aldhafiri 2016), engine oils, lubricating oils (Khan and Awan 2014), and their leakage into roadside soils (Johansson et al. 2009).

Cluster analysis of heavy metals in surface soil

The cluster analysis was used to classify heavy metals in surface soil. The results of cluster analysis can be seen as a dendrogram according to Figure 1. Different clusters were observed in dendrogram for heavy metals. Cluster 1 including V, Ni, Cr, Co, Cu, Zn, Pb, Hg, Sr, Mn, Ar, and Cd. Cluster 2 including Al, and cluster 3 including Fe.

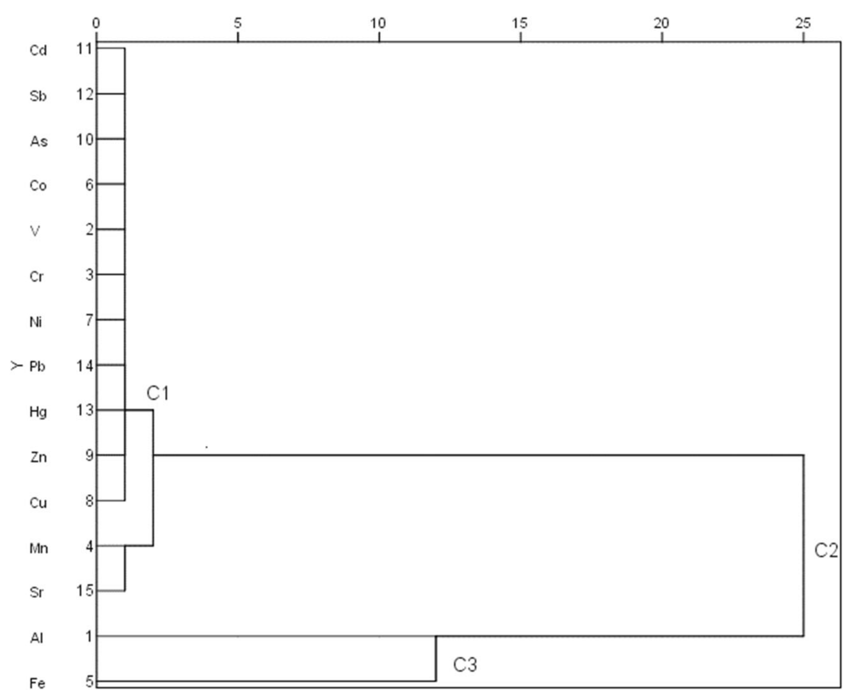

Fig. 1 Cluster analysis to determine source of heavy metals in surface soil

Table 4 Concentration of heavy metals in drinking water of houses in two groups with MetS and without MetS

Heavy metals (μg/l)	Case (n=8)				Control (n=8)				p value
	Minimum	Maximum	Mean	Std. deviation	Minimum	Maximum	Mean	Std. deviation	
Al	0	12.40	3.98	3.88	0.40	305.80	40.65	107.18	0.75
V	1	2	1.41	0.30	0.70	1.50	1.16	0.32	0.18
Cr	3.80	7.90	5.62	1.32	3.60	12.90	6.70	3.04	0.79
Mn	2.10	7.90	5.42	2.40	1.40	4	2.56	1.03	0.02
Fe	3.90	13.10	5.93	2.98	3.90	107.40	17.96	36.16	0.95
Co	0.50	0.07	0.63	0.09	1.10	9.90	5.35	2.51	0.17
Ni	1.30	5.80	4.38	1.33	0.50	8.10	2.48	2.82	0.34
Cu	3.20	5.30	3.76	0.74	3.10	7.30	4.50	1.76	0.75
Zn	4.20	35.20	16.50	11.92	7.60	60.50	28.53	19.23	0.20
As	0.40	0.63	0.50	0.07	0.11	0.55	0.44	0.13	0.49
Cd	0.13	0.21	0.19	0.02	0.01	0.16	0.07	0.05	0.05
Sb	0.10	0.22	0.13	0.03	0.08	0.29	0.16	0.07	0.71
Hg	0.05	0.34	0.17	0.10	0.03	0.38	0.17	0.13	0.83
Pb	0.01	0.34	0.09	0.10	0.18	0.70	0.27	0.17	0.91
Sr	2391	5157	3185.62	968.21	224	2982	2449.50	929.71	0.91

The coefficient of variation (CV) was demonstrated in Table 1. The CV ratio up to 0.4 indicates natural source, and less than 0.4 indicates anthropogenic source of heavy metals (Yongming et al. 2006; Yuan et al. 2014). According to results, it can be said that heavy metals including Al, Co, Ni, Cu, Zn, As, Cd, Hg, Pb, Sr, and Sb concentrations are mostly originated from natural sources. Therefore, Ni, Cu, Zn, As, Cd, Hg, Pb, Sr, and Sb concentrations, which are in same clusters, were originated from natural sources.

Concentration of heavy metals in drinking water

Results of descriptive statistics of Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Cd, Hg, Pb, Sr, and Sb concentrations are given in Table 4. The mean concentrations of V, Mn, Ni, As, Cd, and Sr in MetS group were higher than control group. The results of Mann-Whitney analysis showed that concentration of heavy metals in drinking water, except for Mn (p = 0.02) and Sr (p = 0.05), did not show significant difference between case and control groups. The concentration of Sr was the highest concentration (3185 mg L^{-1}) in drinking water. The concentration of heavy metals in drinking water was compared with national standards and WHO and EPA guidelines. The concentration of all heavy metals in drinking water is higher than national standard and WHO and EPA guidelines (Fig. 2).

The heavy metal concentration in water supply through various ways is one of the most worrying environmental problems for human beings. The stability of heavy metals, entrance in the food chain, and their cumulative effect cause acute and chronic consequences (disruption of enzymes, dangerous poisoning, etc.) in humans and other organisms (Klenow et al. 2009).

The study of metal concentration in this study showed that Sr concentration was the highest and Pb was the lowest concentration in drinking water. The drinking water distribution system is subject to corrosion and accumulation of sediments and crusts. Both corrosion and sediments in drinking water distribution systems act as reaction cavities for metal ions such as Pb, Cu, As, V, and Sr. These cavities can be periodically removed as a result of physical, hydraulic, or chemical disturbances in unstable water, allowing contaminants to remove from water and creating potential health hazards (Dong et al. 2003).

The concentration of Pb was higher than national standards and WHO guideline. The Pb disrupts the nervous system of children and causes anemia, seizures, and even death. Today, the use of Pb in water pipes is prohibited, but some old pipes still contain Pb compounds. The previous study have shown that Pb contamination in drinking water can be due to corrosion of piping system with lead pipes, corrosion of copper pipes containing lead, and corrosion of valves or brass fittings containing Pb (Miranzadeh et al. 2011). The Crown and Calderon study has showed that intrusion of heavy metals such as Pb and Cu in drinking water of urban distribution network is considered as important percentage of drinking water pollution (Craun and Calderon 2001).

The average concentration of Cr in this study was higher than national and international standard. Chromium may pose a risk to different age groups due to its potential for

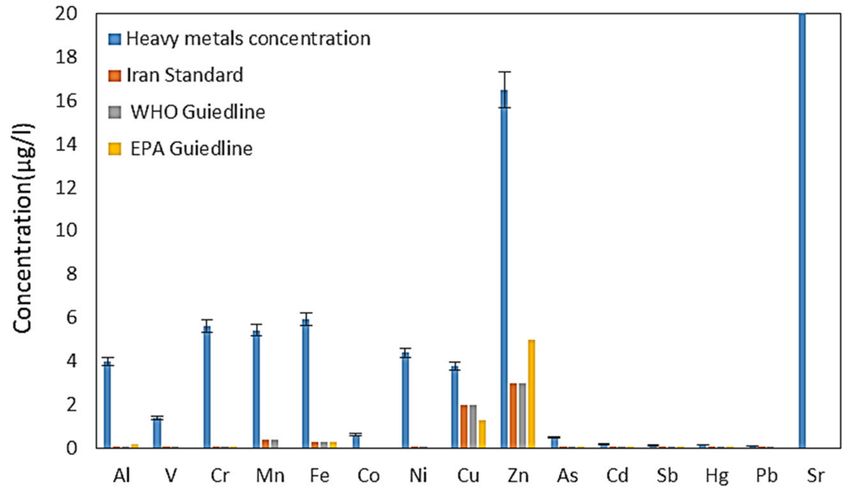

Fig. 2 Comparison of heavy metal concentrations in drinking water with national and international standards

pathogenicity and possibility of turning all forms of chromium to most dangerous form of chromium (VI), even in lower than standard amounts (Smith and Steinmaus 2009). Chromates are often used in leather industry, building paints, and some building materials (Sutton 2010).

The concentrations of Zn in drinking water are higher than other heavy metals. The Zn concentration of drinking water in this study was higher than national standards and WHO and EPA guidelines. Deficiency of this mineral can lead to disturbances in blood sugar balance, slowing down the metabolism, impaired sense of smell and taste, and impaired cell division and DNA synthesis; so, it is a necessary element for the body, and its concentration is higher than other metals (Sutton 2010).

In cross-sectional study in Pakistan, the concentrations of Cd, Cr, Ni, and Pb were higher than WHO and EPA limits; and the concentrations of Mn, Zn, and Cu were within limits (Geneva 2008). In the present study, the concentrations of heavy metals were higher than WHO and EPA limits. There is no limit for Co concentrations in national and international drinking water standards. The concentrations of Cd are low in water sources, and among the ways the metal enters water sources are environmental pollutants such as unsanitary disposal of sewage, waste, excessive use of chemical fertilizers, and burning of fossil fuels (Kaplan et al. 2011).

The results of another study also showed that concentration of heavy metals was lower than standard, and it would not pose a risk to health of consumers (Miranzadeh et al. 2011). Another study has investigated concentration of Pb and Cr in drinking water and reported that concentration of Pb was higher than standard in some areas due to old texture and wear of water pipes (Alidadi et al. 2014). Also, results of studies on concentration of heavy metals in water distribution network of Ardabil, Hamedan, and Birjand showed that concentration of metals in water of these cities was less than standard, which is consistent with results of this study (Alighadr et al. 2007).

Conclusion

The aim of this study was to establish association between heavy metals in drinking water and surface soil and MetS. The mean concentrations of V, Mn, Ni, As, Cd, and Sr of drinking water in the MetS group were higher than the control group. The concentration of heavy metals in drinking water, except for Mn and Sr, did not show a significant difference between the case and control groups. Future work is also needed to investigate the precise functional mechanism of heavy metals that may exacerbate the diagnostic components of MetS and subsequent MetS.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Zeinab Ghaedrahmat, Bahman Cheraghian, Neamat Jaafarzadeh, Afshin Takdastan, Hajieh Bibi Shahbazian, and Mehdi Ahmadi. The first draft of the manuscript was written by Zeinab Ghaedrahmat, and all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

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