Original Article

Determination of Heavy Metals Concentration in Drinking Water of Rural Areas of Divandarreh County, Kurdistan Province: Carcinogenic and Non-carcinogenic Health Risk Assessment

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Abstract

Aims: This study was aimed at the evaluation of heavy metals in the drinking water of the rural area of Divandarreh city and the assessment of carcinogenic and non-carcinogenic health risks**. Materials and Methods:** In the present work, concentration of four heavy metals in drinking water resource in the rural area of Divandarreh County were evaluated. For these aim, the numbers of 29 samples were collected from rural drinking water resources, and the concentration of heavy metals was determined. In addition, carcinogenic and noncarcinogenic risk assessment was conducted in children and adults as target groups. **Results:** The level of Cd was higher than the WHO drinking water Standard. The average amount of target hazard quotient for heavy metals through ingestion in children and adults were in the order of Cd > Cr > Pb > Ni. The total hazard quotient hazard quotients (HQ ing + HQ derm) in children group was higher than the limit set by the USEPA (hazard index = 1.68), indicating probable noncarcinogenic risk to this group through consumption of water. **Conclusion:** Based on the obtained data, the carcinogenic risk for all of the heavy metals were higher than the permissible standard. The obtained data can be useful for managers and the water and wastewater department regarding the improvement of drinking water quality.

Keywords: Carcinogenic risk, dermal contact, divandarreh, Monte–Carlo simulation

Introduction

Water has a vital role in the survival of the ecosystem and all aspects of life.[1-3] In the last few decades, due to urbanization, industrial development, rapid population growth, and an increase in human activities, contamination of water resource have resulted in great concern about human health worldwide.[4] Several contaminants such as pesticides, heavy metals, various organic pollutants, etc., can deteriorate the quality of water.[5] Among the water pollutants, heavy metals attracted a great deal of attention worldwide.[6,7] Some heavy metals, even at low concentrations in drinking water, can cause acute or chronic toxicity and pose significant health hazards to the public.[5,8,9] Drinking water contamination by heavy metals can occur through both natural processes and anthropogenic activities. Concentrations of heavy metals in natural water are dependent on several factors such as hydrology, geochemical properties of the aquifer and local geology, while anthropogenic activities such as industrial and agricultural wastewater discharges, metal smelting, mining, and improper management of municipal and industrial wastes can result in heavy metal contamination in water bodies.[9-11] Exposure of the human body to heavy metals in drinking water can occur via different pathways

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such as direct ingestion, inhalation, and dermal contact.[8] Based on the recently conducted researches, human exposure to heavy metals is a cause of great concern due to the non-biodegradability of heavy metals.[2] Prolong exposure to heavy metals associated with diseases such as hypertension, various kinds of cancers, cardiovascular diseases, abdominal pain, and kidney damage.[2,8,9] Health risk assessment is an approach for the estimation of the total exposure of certain chemicals in humans in a particular area.[5] However, health risk assessment based on water quality can be a challenge as a result of several uncertainties originating from the health risk evaluation process.[12] The problem, becomes more substantial, especially when various toxic contaminants are present in water. However, due to the importance of results obtained through health risk assessment, uncertainties should be taken into account. Monte Carlo simulations is one of the most widely used approaches for probabilistic risk assessment. It can estimate the variability, heterogeneity, and uncertainty in the various factors of the human health risk assessment method.[7,9] Same as many parts of the world, industrialization and rapid growth of economy in Iran has resulted in large-scale contamination of soil and water resource by heavy metals.[5,13] Most parts of Iran have dried and semi-dried climates with very low rainfall. Water scarcity along with the Iran's rapid population growth implies the urgent need for finding water resources with appropriate quality and enough quantity. The main source of water supply in rural areas, small towns, and some cities in Iran are groundwater resources.[5] It is crucial to conduct research to evaluate the level of contamination in drinking water resources in Iran. The results of such evaluation can be helpful to managers and water utilities to provide a better quality of drinking water. The aim of the present study was to evaluate the level of heavy metals in drinking water in the rural area of Divandarreh county. In this study levels of four heavy metals including Chromium (Cr), Cadmium (Cd), Lead (Pb), and Nickel (Ni) in drinking water was determined, moreover carcinogenic and non-carcinogenic health risk of this heavy metal with respect to daily drinking of and dermal pathways was estimated.

Materials and Methods

Study area

The study area located in the Kurdistan province, west of Iran (35° 54′ N, 47° 01′ E). Divandarreh County has a mild climate characterized by warm and dry summers and cold and wet winter. The highest and lowest air temperatures in Divandarreh are 32°C and-20°C, respectively. The average annual rainfall in this city is 174 mm. Divandarreh with about 4203-km^2 area, comprising 15% of the Kurdistan province area. Its average height above sea level is 1850 m. Based on the latest population census in Iran (2016), the urban population of Divandarreh is 36098. The 196 villages and rural areas of Divandarreh County are also home to 43941 people. Figure 1 shows the geographic location of the studied area.

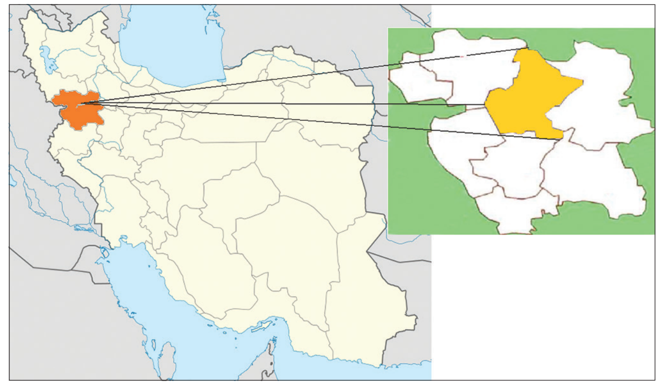

Figure 1: Location of study area

Sampling protocol

In this cross-sectional study, 29 samples were gathered from groundwater resources of rural areas of Divandarreh County. The sampling locations were selected randomly. The polyethylene plastic bottles were used for water sampling from the selected sampling points. Before collecting samples, the bottles were washed with double deionized water containing 10% HNO_3. To prevent further microbial growth, a few drops of 5% HNO_3 were added to the bottles. In the following, all water samples were labeled, stored at 4°C and transported to the laboratory of health faculty, Tehran University of Medical Sciences, Iran, for further laboratory analysis.

Analytical procedures

The concentration of heavy metals (Pb, Cd, Cr, and Ni) in water samples were analyzed using standard methods for the examination of water and wastewater.[14,15] Levels of heavy metal in water samples were determined by an inductively coupled plasma optical emission spectrometry (Model 710 ICP-OES, Agilent Technologies, Santa Clara, California). It is also worth mentioning that the analysis of samples carried out twice, and the average value was reported.

Non-carcinogenic assessment

Health risk assessment is a systematic approach for evaluating the possibility of probable adverse health effects in the exposed population in the polluted area over a determined time period.[16] Generally, health risk assessment is categorized as a carcinogenic and noncarcinogenic health risk. In this study, for estimation of probable carcinogenic and non-carcinogenic health risk due to ingestion and dermal contact of heavy metal in water resource of rural area in Divandarreh county, the hazard quotients (HQ), hazard index (HI), and the Incremental Lifetime Cancer Risk (ILCR) were calculated. Health risk assessment was carried out for children and adults. In this regard, chronic daily intake (CDI) through ingestion and the dermal pathway was calculated using Eq. 1 and Eq. 2, slightly modified from the USEPA protocol.[17]

$$CDI_{Ingestion} = \frac{C_w \times IR_w \times ABS \times EF \times ED}{BW \times AT} \quad (1)$$

$$CDI_{Dermal} = \frac{C_w \times SA \times K_p \times ABS \times ET \times EF \times ED \times CF}{BW \times AT} \quad (2)$$

where, C_w (in mg/L) is the concentration of heavy metals in water, IR_w is the drinking water ingestion rate (IR) (L/day), SA is the exposed skin area (cm^2), K_p is the dermal permeability coefficient for water (Cm/hour), ABS (unit less) is the dermal absorption factor, EF is the exposure frequency (EF) (days/year), ED is the exposure duration (year), ET is the exposure time (ET) (Hour/event), BW is body weight (BW), AT_r is the average resident time (days/year), and CF is the conversion factor (L/cm^3). Table 1 shows the input parameters for the estimation of CDI through oral ingestion and dermal absorption.

The HQ of the noncarcinogenic risk assessment for heavy metals exposure through drinking water and dermal exposure was calculated using Eq. 3.

$$HQ = \frac{CDI}{RfD} \quad (3)$$

where, CDI and RfD are expressed in mg/kg-day. The values of the RfD and cancer slope factor for various metals are shown in Table 2.

For considering of the total non-carcinogenic effects from different metals in the drinking water, a HI was determined, which is the summation of all the calculated HQ values of metals (Eq. 4).

Table 1: Exposure parameters used for the health risk assessment of heavy metals through ingestion and dermal route[18,19]

		Value	
Parameter	**Unit**	**Child**	**Adult**
Daily average intake	L/day	1.25	2.2
Skin surface area	cm^2	7422	18,182
Exposure frequency	Day/year	365	365
Exposure duration	Year	6	30
AT	Days		
For carcinogenic		365 × 70	365 × 70
For non-carcinogenic		365 × ED	365 × ED
Body weight	Kg	16	70
ET	Hour/event	0.54	0.71
Dermal absorption factor (ABS)		0.001	0.001
CF	L/cm^3	0.001	0.001

AT: Average time, ET: Exposure time, CF: Conversion factor

Table 2: Reference dose, dermal permeability co-efficient and cancer slope factor for different metals[5,18,19]

Element	Rdf_{dermal} (mg/L/day)	Rdf_{oral} (mg/L/day)	K_p	CSF (kg/day/mg)
Cd	0.25	0.5	1×10^{-3}	0.38
Pb	0.42	1.4	1×10^{-4}	0.0085
Cr	0.075	3	2×10^{-3}	0.19
Ni	5.4	20	2×10^{-4}	0.84

CSF: Cancer slope factor, Rdf: Reference dose

$$HI = \sum_{i=1}^{n} HQ_i \quad (4)$$

The value of HQ <1 indicates that the adverse effects of exposure cannot be expected, but if HQ >1, it can be assumed that probable adverse effect on human health occurs, which required further study.[20]

Carcinogenic assessment

The carcinogenic risk discusses the possibility of the occurrence of any type of cancer during the whole lifetime regarding exposure to a carcinogenic element. The probable cancer risks from exposure to heavy metal in drinking water can be calculated through the ILCR. The lifetime cancer risk can be determined through (Eq. 5).

$$ILCR = CD1 \times CSF \quad (5)$$

where CSF is the cancer slope factor (µg/kg/day). A risk level of 1×10^{-6} has been recognized as the point of additional cancer risk, specifying 1/1,000,000 chance of getting cancer through consumption of drinking water polluted with toxic metals over the lifetime (70 years). Any amount lower than this level is considered as a safe point for carcinogenic risks.[21] The EPA set the range of 1×10^{-4}–1×10^{-6} as risks borderline. A carcinogenic health risk of a level of 1×10^{-4} is significantly high and creates health hazards.[21,22]

Monte Carlo simulation and sensitivity analysis

In the present work, the risk assessment was conducted via Monte Carlo simulations to minimize the unavoidable uncertainty of calculations. The parameters used in the simulation for each group of people are present in Table 1. The simulation was done by using the presented parameters and employed the risk model for 10,000 iterations. For identifying the input parameters that have a substantial effect on the model output, sensitivity analyses were conducted during Monte Carlo simulations. The Crystal Ball (version 11.1.1.1, Oracle, Inc., USA) was used to perform Monte Carlo simulations and sensitivity analyses.

Results

The concentration of heavy metals in drinking water resources of rural areas in Divandarreh County is depicted in Table 3. The concentration of Cd, Pb, Cr, and Ni ranged from 5.7–7.2 µg/L, 2.2–9.8 µg/L, 16.8–20.6 µg/L, and 6.1–14.5 µg/L, respectively. As shown in Table 3, except Cd, the mean concentration of other heavy metals are lower than the standard set by the WHO. In the present study, the non-carcinogenic risk (HQ) method was applied to estimate the risk to human health of heavy metals in drinking water. The values of HQ for the studied metals such as Cd, Pb, Cr, and Ni for children and adults through drinking and dermal routes are shown in Tables 4 and 5, respectively. The values of HQ_{total} (HQ_{ing} + HQ_{derm}) for Cd, Pb, Cr, and Ni in children were 1.02, 0.15, 0.47, and 0.035, respectively. Moreover, the values of HQ_{total} for the mentioned metals in adults were 0.41, 0.06, 0.19, and 0.144, respectively. Furthermore, the target hazard quotient (THQ) and noncarcinogenic risk (HI) caused

Table 3: Concentration of heavy metals in drinking water resource of study area

Location	Heavy metals concentration (μg/L)			
	Cd	Pb	Cr	Ni
Kani sefid	6.3	2.2	19.1	9.3
Kilekabood	6.3	2.2	18.8	8.3
Kotek	6.4	2.2	18.8	8.1
Choblagh	6.6	9.8	17.8	9.7
Kalakan	7.2	2.2	19.4	7.2
Ebrahimabad	5.7	2.5	18.4	9.1
Golaneh	7	2.2	17.2	9.4
Mohmoodeh	6.4	2.2	19.3	7.3
Shavali	6.3	2.2	17.8	11.5
Gharegaibi	6.7	2.2	19.6	11.7
Nesareh Olia	6.4	2.2	19.5	9.7
Nesareh sofla	7.1	2.2	18.6	9.3
Aghjari	6.3	2.2	19.5	8.9
Dalan	6.5	2.3	18.3	8
Darband	6.5	2.5	17.5	12.8
Ghiasabad	6.3	3.8	17.5	9.8
Shalishal	7	2.4	17.1	7.9
Papaleh	6.3	2.2	17.2	14.5
Abbarik	6.4	2.2	18.2	6.1
Ghochagh	6.9	3.3	19.3	8.8
Gomaie	6.2	3.5	17.8	9.6
Ghalechoga	6.4	2.2	19	8.8
Tegarbari	6.8	2.2	17.7	8.3
Sarghale	6.5	4	18.1	8.8
Zafarabad	6.4	2.2	16.8	8.3
Kanichaie	6.5	2.2	18.1	9.2
Sharifabad	7.1	2.2	20.6	7.2
Zakibaig	6.4	2.2	18.2	9.5
Kanishirin	6.2	2.2	17.6	7.9
Mean	6.5	2.7	18.37	9.13
WHO standard	3	10	50	70

by heavy metals for adults and children through ingestion and dermal contact pathways of drinking water are given in Tables 4 and 5, respectively. The mean values of HI for children and adults through drinking routes were 1.68 and 0.68 and for dermal contact were 1.59E-05 and 1.17E-05, respectively. The result of carcinogenic risk assessment for heavy metals in drinking water for inhabitants of Divandarreh's villages due to ingestion and dermal contacts in adults and children are presented in Figure 2 and Table 6. The values of TCR ($CR_{dermal\ contact} + CR_{ingestion}$) ranged from 1.31E-04-4.65E-04, and its average values for children and adults were 2.46E-04 and 9.54E-03, respectively. Qualitative sensitivity analyses were conducted to recognize the most relevant variables contributing to the results of risk estimates in the model. Figures 3 and 4 show the results of the sensitivity analyses of carcinogenic risk assessment for adults and children, respectively. The BW, EF, drinking water IR, and concentration of heavy metals in drinking water (C) were the most important factors in carcinogenic risk assessment.

Discussion

Contamination of drinking water by heavy metals can cause an adverse health effect. Consumption of the water containing these elements is a common source of exposure in humans. In the present work, carcinogenic and noncarcinogenic health risks posed by heavy metals through ingestion and dermal contact pathway were discussed. The level of four investigated heavy metals shows in Table 3. In general, compared with the nationally and internationally standards for heavy metals, the concentration of Cd in all of the sampling areas exceeded Iran's drinking water standard of 3.0 μg/L.[23] In a study conducted by Rezaei *et al.*, the concentration of heavy metals (Cd and Pb) in the rural area of Dehgolan, were in agreement with theWHO guidelines.[7] Pirsaheb *et al.*,[24] evaluate the concentration of heavy metals in drinking water resources in Kermanshah city. Their results showed that except Aluminum, Iron, and Manganese, the concentrations of all measured metals were lower than the recommended standards by the WHO. It is interesting to note that the presence of mentioned heavy metals in drinking water originated mainly from natural sources, and the contribution of anthropogenic activities can be neglected.

Health risk assessment

Human exposure to hazardous pollutants occurs mainly through direct or indirect ingestion of pollutants, dermal contact, and inhalation of aerosol particles pathway. In the present work, the risk of heavy metals exposure among inhabitants was qualified by the parameter of hazard quart (HQ), which is the comparison of the estimated daily heavy metals intake with the tolerable daily intake.

A brief description of HQ and HIs values for heavy metals (Cd, Cr, Pb, and Ni) in drinking water via ingestion and dermal contacts within adults and children are shown. As can be seen from data, in children group, the HQ for ingestion of water levels for Cd was higher than the USEPA recommended HQ of 1, indicating an adverse effect on this group. However, lower values were observed for Pb, Cr, and Ni in the collected samples. The noncarcinogenic risk from heavy metals due to the ingestion of drinking water is negligible for the adult population. Based on the obtained data, probable adverse health effects cannot be expected in this group of the population due to the drinking of water. Cd is the most toxic heavy metal in the study area; however, special attention should be paid to the children group in the study area. In addition, intensive environmental monitoring, along with medical surveillance, should be taken into consideration.

In general, the HI value for children from exposure to heavy metals was higher than that for adults. The computed hazard index for ingestion for all of the heavy metals in each of the children and adults groups' was 1.68 and 0.68, respectively. Similarly, the calculated values for HI for dermal exposure were1.59E-05 and 1.17E-05, respectively. This indicates a high possibility of unwanted health effects in children. Yong individuals are more susceptible to toxic contaminants. Thus, to attain more comprehensive health information for children living

Table 4: Target hazard quotient and noncarcinogenic risk (Hazard index) posed by heavy metals for adults and children via ingestion of drinking water

Location	THQ of individual heavy metals								∑THQ	
	Cd		Pb		Cr		Ni		HI	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Kani sefid	9.84E-01	3.96E-01	1.23E-01	4.94E-02	4.97E-01	2.00E-01	3.63E-02	1.46E-02	1.64E+00	6.60E-01
Kilekabood	9.84E-01	3.96E-01	1.23E-01	4.94E-02	4.90E-01	1.97E-01	3.24E-02	1.30E-02	1.63E+00	6.55E-01
Kotek	1.00E+00	4.02E-01	1.23E-01	4.94E-02	4.90E-01	1.97E-01	3.16E-02	1.27E-02	1.64E+00	6.61E-01
Choblagh	1.03E+00	4.15E-01	5.47E-01	2.20E-01	4.64E-01	1.86E-01	3.79E-02	1.52E-02	2.08E+00	8.37E-01
Kalakan	1.13E+00	4.53E-01	1.23E-01	4.94E-02	5.05E-01	2.03E-01	2.81E-02	1.13E-02	1.78E+00	7.17E-01
Ebrahimabad	8.91E-01	3.58E-01	1.40E-01	5.61E-02	4.79E-01	1.93E-01	3.55E-02	1.43E-02	1.54E+00	6.21E-01
Golaneh	1.09E+00	4.40E-01	1.23E-01	4.94E-02	4.48E-01	1.80E-01	3.67E-02	1.48E-02	1.70E+00	6.84E-01
Mohmoodeh	1.00E+00	4.02E-01	1.23E-01	4.94E-02	5.03E-01	2.02E-01	2.85E-02	1.15E-02	1.65E+00	6.65E-01
Shavali	9.84E-01	3.96E-01	1.23E-01	4.94E-02	4.64E-01	1.86E-01	4.49E-02	1.81E-02	1.62E+00	6.50E-01
Gharegaibi	1.05E+00	4.21E-01	1.23E-01	4.94E-02	5.10E-01	2.05E-01	4.57E-02	1.84E-02	1.73E+00	6.94E-01
Nesare Olia	1.00E+00	4.02E-01	1.23E-01	4.94E-02	5.08E-01	2.04E-01	3.79E-02	1.52E-02	1.67E+00	6.71E-01
Nesare sofla	1.11E+00	4.46E-01	1.23E-01	4.94E-02	4.84E-01	1.95E-01	3.63E-02	1.46E-02	1.75E+00	7.05E-01
Aghjari	9.84E-01	3.96E-01	1.23E-01	4.94E-02	5.08E-01	2.04E-01	3.48E-02	1.40E-02	1.65E+00	6.64E-01
Dalan	1.02E+00	4.09E-01	1.28E-01	5.16E-02	4.77E-01	1.92E-01	3.13E-02	1.26E-02	1.65E+00	6.64E-01
Darband	1.02E+00	4.09E-01	1.40E-01	5.61E-02	4.56E-01	1.83E-01	5.00E-02	2.01E-02	1.66E+00	6.68E-01
Ghiasabad	9.84E-01	3.96E-01	2.12E-01	8.53E-02	4.56E-01	1.83E-01	3.83E-02	1.54E-02	1.69E+00	6.80E-01
Shalishal	1.09E+00	4.40E-01	1.34E-01	5.39E-02	4.45E-01	1.79E-01	3.09E-02	1.24E-02	1.70E+00	6.85E-01
Papaleh	9.84E-01	3.96E-01	1.23E-01	4.94E-02	4.48E-01	1.80E-01	5.66E-02	2.28E-02	1.61E+00	6.48E-01
Abbarik	1.00E+00	4.02E-01	1.23E-01	4.94E-02	4.74E-01	1.91E-01	2.38E-02	9.59E-03	1.62E+00	6.52E-01
Ghochagh	1.08E+00	4.34E-01	1.84E-01	7.41E-02	5.03E-01	2.02E-01	3.44E-02	1.38E-02	1.80E+00	7.24E-01
Gomaie	9.69E-01	3.90E-01	1.95E-01	7.86E-02	4.64E-01	1.86E-01	3.75E-02	1.51E-02	1.67E+00	6.70E-01
Ghalechoga	1.00E+00	4.02E-01	1.23E-01	4.94E-02	4.95E-01	1.99E-01	3.44E-02	1.38E-02	1.65E+00	6.65E-01
Tegarbari	1.06E+00	4.27E-01	1.23E-01	4.94E-02	4.61E-01	1.85E-01	3.24E-02	1.30E-02	1.68E+00	6.75E-01
Sarghale	1.02E+00	4.09E-01	2.23E-01	8.98E-02	4.71E-01	1.90E-01	3.44E-02	1.38E-02	1.74E+00	7.02E-01
Zafarabad	1.00E+00	4.02E-01	1.23E-01	4.94E-02	4.38E-01	1.76E-01	3.24E-02	1.30E-02	1.59E+00	6.41E-01
Kanichaie	1.02E+00	4.09E-01	1.23E-01	4.94E-02	4.71E-01	1.90E-01	3.59E-02	1.45E-02	1.65E+00	6.62E-01
Sharifabad	1.11E+00	4.46E-01	1.23E-01	4.94E-02	5.36E-01	2.16E-01	2.81E-02	1.13E-02	1.80E+00	7.23E-01
Zakibaig	1.00E+00	4.02E-01	1.23E-01	4.94E-02	4.74E-01	1.91E-01	3.71E-02	1.49E-02	1.63E+00	6.57E-01
Kanishirin	9.69E-01	3.90E-01	1.23E-01	4.94E-02	4.58E-01	1.84E-01	3.09E-02	1.24E-02	1.58E+00	6.36E-01
Mean	1.01	0.4	0.150	0.06	0.48	0.19	0.036	0.014	1.68	0.68

THQ: Target hazard quotient

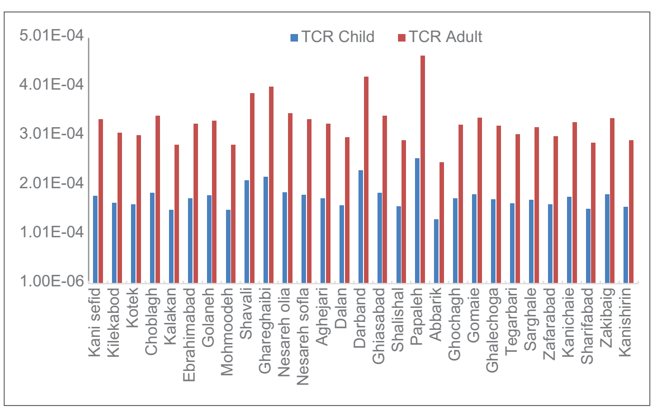

Figure 2: Calculated total carcinogenic risk for drinking water via ingestion and dermal contact by adult and children

in the studied area, more attention should be paid to this group of residents. The calculation of total HQs lead to the conclusion that the contribution of the heavy metals to the noncarcinogenic health hazard due to the ingestion of drinking water in the exposed population was in order of Cd > Cr > Pb > Ni. Giri *et al*. conducted a health risk assessment for metal exposure via groundwater in mining areas of Singhbhum Copper Belt, India. They reported that the concentration of Fe and Mn exceeded the drinking water standards for most of the studied areas. In addition, they found the HQs for the studied metals were below the USEPA recommended HQ of 1 for all the exposed groups except for Mn in case of a child for the pre-and post-monsoon seasons.[20] In another study, Rezaei *et al*. survived health risk assessment related to drinking groundwater in the village areas of Dehgolan. The results of their study showed that the noncarcinogenic risk was below the safe range.[7] In addition, Lu *et al*.[2] evaluated the health risks associated with heavy metals in the drinking water of Swat, northern Pakistan. The results of their study showed that the HRIs of studied heavy metals in drinking water were <1, demonstrating no health hazard to the local individuals. According to the obtained results, there is a high cumulative potential of adverse health effects

Table 5: Target hazard quotient and noncarcinogenic risk (Hazard Index) posed by heavy metals for adults and children via dermal contact of drinking water

Location	THQ of individual heavy metals								∑THQ	
	Cd		Pb		Cr		Ni		HI	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Kani sefid	6.31E-06	4.65E-06	2.62E-06	1.93E-06	6.38E-06	4.70E-06	8.63E-08	6.35E-08	1.54E-05	1.13393E-05
Kilekabood	6.31E-06	4.65E-06	2.62E-06	1.93E-06	6.28E-06	4.62E-06	7.70E-08	5.67E-08	1.53E-05	1.12587E-05
Kotek	6.41E-06	4.72E-06	2.62E-06	1.93E-06	6.28E-06	4.62E-06	7.51E-08	5.53E-08	1.54E-05	1.13311E-05
Choblagh	6.61E-06	4.87E-06	1.17E-05	8.61E-06	5.95E-06	4.38E-06	9.00E-08	6.63E-08	2.43E-05	1.79179E-05
Kalakan	7.21E-06	5.31E-06	2.62E-06	1.93E-06	6.48E-06	4.77E-06	6.68E-08	4.92E-08	1.64E-05	1.20627E-05
Ebrahimabad	5.71E-06	4.20E-06	2.98E-06	2.20E-06	6.15E-06	4.52E-06	8.44E-08	6.22E-08	1.49E-05	1.09867E-05
Golaneh	7.01E-06	5.16E-06	2.62E-06	1.93E-06	5.74E-06	4.23E-06	8.72E-08	6.42E-08	1.55E-05	1.13892E-05
Mohmoodeh	6.41E-06	4.72E-06	2.62E-06	1.93E-06	6.45E-06	4.75E-06	6.77E-08	4.99E-08	1.56E-05	1.14486E-05
Shavali	6.31E-06	4.65E-06	2.62E-06	1.93E-06	5.95E-06	4.38E-06	1.07E-07	7.85E-08	1.50E-05	1.10347E-05
Gharegaibi	6.71E-06	4.94E-06	2.62E-06	1.93E-06	6.55E-06	4.82E-06	1.09E-07	7.99E-08	1.60E-05	1.17737E-05
Nesare Olia	6.41E-06	4.72E-06	2.62E-06	1.93E-06	6.51E-06	4.79E-06	9.00E-08	6.63E-08	1.56E-05	1.15142E-05
Nesare sofla	7.11E-06	5.24E-06	2.62E-06	1.93E-06	6.21E-06	4.57E-06	8.63E-08	6.35E-08	1.60E-05	1.18065E-05
Aghjari	6.31E-06	4.65E-06	2.62E-06	1.93E-06	6.51E-06	4.79E-06	8.26E-08	6.08E-08	1.55E-05	1.1435E-05
Dalan	6.51E-06	4.79E-06	2.74E-06	2.02E-06	6.11E-06	4.50E-06	7.42E-08	5.46E-08	1.54E-05	1.13691E-05
Darband	6.51E-06	4.79E-06	2.98E-06	2.20E-06	5.84E-06	4.30E-06	1.19E-07	8.74E-08	1.55E-05	1.13808E-05
Ghiasabad	6.31E-06	4.65E-06	4.53E-06	3.34E-06	5.84E-06	4.30E-06	9.09E-08	6.69E-08	1.68E-05	1.23544E-05
Shalishal	7.01E-06	5.16E-06	2.86E-06	2.11E-06	5.71E-06	4.20E-06	7.33E-08	5.40E-08	1.57E-05	1.153E-05
Papaleh	6.31E-06	4.65E-06	2.62E-06	1.93E-06	5.74E-06	4.23E-06	1.35E-07	9.90E-08	1.48E-05	1.09077E-05
Abbarik	6.41E-06	4.72E-06	2.62E-06	1.93E-06	6.08E-06	4.48E-06	5.66E-08	4.17E-08	1.52E-05	1.11699E-05
Ghochagh	6.91E-06	5.09E-06	3.94E-06	2.90E-06	6.45E-06	4.75E-06	8.16E-08	6.01E-08	1.74E-05	1.27937E-05
Gomaie	6.21E-06	4.57E-06	4.17E-06	3.07E-06	5.95E-06	4.38E-06	8.91E-08	6.56E-08	1.64E-05	1.20896E-05
Ghalechoga	6.41E-06	4.72E-06	2.62E-06	1.93E-06	6.35E-06	4.67E-06	8.16E-08	6.01E-08	1.55E-05	1.13851E-05
Tegarbari	6.81E-06	5.02E-06	2.62E-06	1.93E-06	5.91E-06	4.35E-06	7.70E-08	5.67E-08	1.54E-05	1.13571E-05
Sarghale	6.51E-06	4.79E-06	4.77E-06	3.51E-06	6.05E-06	4.45E-06	8.16E-08	6.01E-08	1.74E-05	1.28183E-05
Zafarabad	6.41E-06	4.72E-06	2.62E-06	1.93E-06	5.61E-06	4.13E-06	7.70E-08	5.67E-08	1.47E-05	1.08407E-05
Kanichaie	6.51E-06	4.79E-06	2.62E-06	1.93E-06	6.05E-06	4.45E-06	8.54E-08	6.28E-08	1.53E-05	1.12403E-05
Sharifabad	7.11E-06	5.24E-06	2.62E-06	1.93E-06	6.88E-06	5.07E-06	6.68E-08	4.92E-08	1.67E-05	1.2284E-05
Zakibaig	6.41E-06	4.72E-06	2.62E-06	1.93E-06	6.08E-06	4.48E-06	8.81E-08	6.49E-08	1.52E-05	1.11932E-05
Kanishirin	6.21E-06	4.57E-06	2.62E-06	1.93E-06	5.88E-06	4.33E-06	7.33E-08	5.40E-08	1.48E-05	1.08872E-05
Mean	6.53E-06	8.47E-08	3.21E-0	2.36E-06	6.13E-06	4.51E-06	8.47E-08	6.24E-08	1.59E-05	1.17E-05

THQ: Target hazard quotient

through direct ingestion exposure in children, but no cumulative potential for adverse health impact via dermal contact to the water users was seen.

Carcinogen risk assessment

Chronic exposure to heavy metals can be a potential cause for the developing of several types of cancers in humans. As discussed previously, an ILCR above 1×10^{-4} is significantly high and poses health hazards. Based on the obtained data, the level of ILCR was higher than 1×10^{-4} for exposed population. The TCR values for adults through ingestion and dermal intake pathway were 1.34 orders of magnitude higher than the TCR for children. These results specified higher cancer risks for adults than the children. These results are in agreement with those obtained by Haque *et al*.[25] On the other hand, Alidadi *et al*. found that the calculated TCR was higher for children compared to adults, suggesting that children were more susceptible to CR from heavy metals.[21] Our results showed that the carcinogenic risk related to Ni poses the greatest risk to children and adults, reaching 3.98E-03 and 3.00E-03, respectively, on average. With regard to the different exposure pathways, the percentage of dermal exposure was lower than (<1%) ingestion exposure to the TCR, which is in accordance with the other researches.[7,21,26] The result of this study confirmed a potential cancer risk for the exposed population (children and adults) via ingestion and dermal pathway. Based on the obtained results, all the sampling points required further in-depth investigation and development of appropriate control measures to reduce or eliminate carcinogenic heavy metals. Sensitivity analysis was conducted to identify the most important variable on the carcinogenic health risk assessment for adults and children exposed to heavy metals. In children group, in all cases of heavy metals, EF (41.5-45.6%) is the most important variable affecting the carcinogenic risk values. In the case of Cd and Cr, the drinking water IR (21.7%–23.1%) is the most powerful variable effects

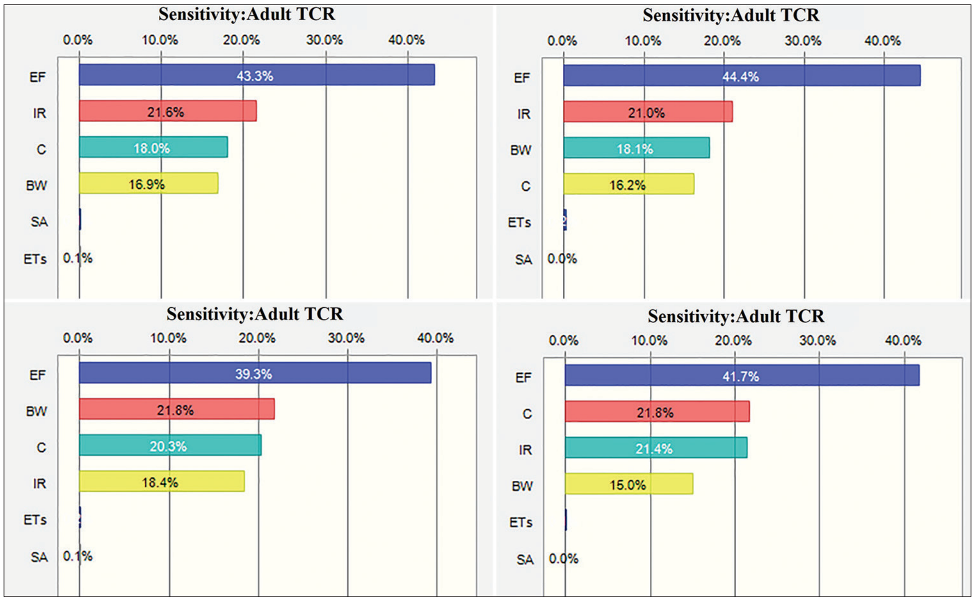

Figure 3: Sensitivity analysis of carcinogenic risk assessment in adults group for heavy metals: Cd (a), Pb (b), Cr (c), and Ni (d)

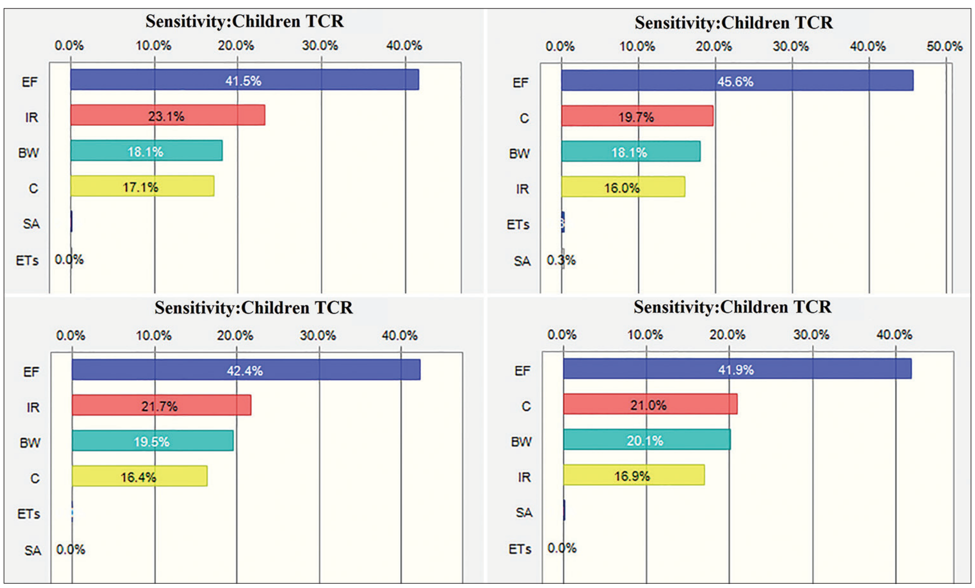

Figure 4: Sensitivity analysis of carcinogenic risk assessment in children group for heavy metals: Cd (a), Pb (b), Cr (c), and Ni (d)

the level of health risk in the children age group. With regard to Pb and Ni, concentration in drinking water (C) (19.7%–21%) is the most influential variable in carcinogenic risk in children. However, similar to the children group, EF for all the heavy metals (39.3%–44.4%) is the greatest variable contributing to carcinogenic risk in adults. Followed by EF, drinking water IR in Cd and Pb, BW in Cr, and concentration in drinking water (C) are the most important variable affecting the amount of carcinogenic health risk in adult age. However, the contribution of dermal exposure in carcinogenic risk can be neglected science skin surface area (SA) and ETs showed very low level (<1%) in the sensitivity analysis.

Uncertainty analysis

Although Monte Carlo simulations were applied to quantify the uncertainty of the estimated health risk, there is some probable uncertainties that may not be considered and could be identified as a limitation for the validity of the risk assessment. For example, some toxicity values such as CSF might have an impressive effect on the estimated risk. However, in this study, it was considered as a constant for all inhabitants, while in reality, CSF can be different for individuals. Furthermore, the rate of drinking water ingestion could vary really because of the effect of climate on water consumption, but it was assumed constant in each of the exposed population. Finally, heavy metals in drinking water are usually considered as the

Table 6: Descriptive statistics of incremental lifetime cancer risk values of carcinogenic risks (through ingestion and dermal combined) for children and adults in the study area

Location	ILCR									
	Cd		Pb		Cr		Ni		∑CR	
	Child	Adult	Child	Adult	Child	Adult	Child	Adult	Child	Adult
Kani sefid	1.61E-05	3.24E-05	1.25E-05	2.52E-05	2.45E-05	4.95E-05	1.40E-04	1.05E-04	1.80E-04	3.35E-04
Kilekabood	1.61E-05	3.24E-05	1.25E-05	2.52E-05	2.41E-05	4.87E-05	1.25E-04	9.40E-05	1.65E-04	3.08E-04
Kotek	1.63E-05	3.29E-05	1.25E-05	2.52E-05	2.41E-05	4.87E-05	1.22E-04	9.18E-05	1.62E-04	3.03E-04
Choblagh	1.68E-05	3.40E-05	5.58E-05	1.12E-04	2.28E-05	4.61E-05	1.46E-04	1.10E-04	1.86E-04	3.43E-04
Kalakan	1.84E-05	3.71E-05	1.25E-05	2.52E-05	2.48E-05	5.02E-05	1.08E-04	8.16E-05	1.51E-04	2.83E-04
Ebrahimabad	1.46E-05	2.93E-05	1.42E-05	2.86E-05	2.36E-05	4.76E-05	1.37E-04	1.03E-04	1.75E-04	3.26E-04
Golaneh	1.79E-05	3.60E-05	1.25E-05	2.52E-05	2.20E-05	4.45E-05	1.41E-04	1.06E-04	1.81E-04	3.32E-04
Mohmoodeh	1.63E-05	3.29E-05	1.25E-05	2.52E-05	2.47E-05	5.00E-05	1.10E-04	8.27E-05	1.51E-04	2.84E-04
Shavali	1.61E-05	3.24E-05	1.25E-05	2.52E-05	2.28E-05	4.61E-05	1.73E-04	1.30E-04	2.12E-04	3.88E-04
Gharegaibi	1.71E-05	3.45E-05	1.25E-05	2.52E-05	2.51E-05	5.07E-05	1.76E-04	1.33E-04	2.18E-04	4.01E-04
Nesare Olia	1.63E-05	3.29E-05	1.25E-05	2.52E-05	2.50E-05	5.05E-05	1.46E-04	1.10E-04	1.87E-04	3.48E-04
Nesare sofla	1.81E-05	3.66E-05	1.25E-05	2.52E-05	2.38E-05	4.82E-05	1.40E-04	1.05E-04	1.82E-04	3.35E-04
Aghjari	1.61E-05	3.24E-05	1.25E-05	2.52E-05	2.50E-05	5.05E-05	1.34E-04	1.01E-04	1.75E-04	3.26E-04
Dalan	1.66E-05	3.35E-05	1.31E-05	2.63E-05	2.34E-05	4.74E-05	1.20E-04	9.06E-05	1.60E-04	2.98E-04
Darband	1.66E-05	3.35E-05	1.42E-05	2.86E-05	2.24E-05	4.53E-05	1.92E-04	1.45E-04	2.31E-04	4.22E-04
Ghiasabad	1.61E-05	3.24E-05	2.16E-05	4.35E-05	2.24E-05	4.53E-05	1.47E-04	1.11E-04	1.86E-04	3.43E-04
Shalishal	1.79E-05	3.60E-05	1.37E-05	2.75E-05	2.19E-05	4.43E-05	1.19E-04	8.95E-05	1.58E-04	2.93E-04
Papaleh	1.61E-05	3.24E-05	1.25E-05	2.52E-05	2.20E-05	4.45E-05	2.18E-04	1.64E-04	2.56E-04	4.65E-04
Abbarik	1.63E-05	3.29E-05	1.25E-05	2.52E-05	2.33E-05	4.71E-05	9.16E-05	6.91E-05	1.31E-04	2.48E-04
Ghochagh	1.76E-05	3.55E-05	1.88E-05	3.78E-05	2.47E-05	5.00E-05	1.32E-04	9.97E-05	1.75E-04	3.25E-04
Gomaie	1.58E-05	3.19E-05	1.99E-05	4.01E-05	2.28E-05	4.61E-05	1.44E-04	1.09E-04	1.83E-04	3.38E-04
Ghalechoga	1.63E-05	3.29E-05	1.25E-05	2.52E-05	2.43E-05	4.92E-05	1.32E-04	9.97E-05	1.73E-04	3.22E-04
Tegarbari	1.74E-05	3.50E-05	1.25E-05	2.52E-05	2.27E-05	4.58E-05	1.25E-04	9.40E-05	1.65E-04	3.05E-04
Sarghale	1.66E-05	3.35E-05	2.28E-05	4.58E-05	2.32E-05	4.69E-05	1.32E-04	9.97E-05	1.72E-04	3.19E-04
Zafarabad	1.63E-05	3.29E-05	1.25E-05	2.52E-05	2.15E-05	4.35E-05	1.25E-04	9.40E-05	1.63E-04	3.00E-04
Kanichaie	1.66E-05	3.35E-05	1.25E-05	2.52E-05	2.32E-05	4.69E-05	1.38E-04	1.04E-04	1.78E-04	3.29E-04
Sharifabad	1.81E-05	3.66E-05	1.25E-05	2.52E-05	2.64E-05	5.33E-05	1.08E-04	8.16E-05	1.53E-04	2.88E-04
Zakibaig	1.63E-05	3.29E-05	1.25E-05	2.52E-05	2.33E-05	4.71E-05	1.43E-04	1.08E-04	1.82E-04	3.37E-04
Kanishirin	1.58E-05	3.19E-05	1.25E-05	2.52E-05	2.25E-05	4.56E-05	1.19E-04	8.95E-05	1.57E-04	2.92E-04
Mean	4.83E-04	9.74E-04	4.45E-06	8.95E-06	6.82E-04	1.38E-03	3.98E-03	3.00E-03	2.46E-04	9.54E-03

ILCR: Incremental lifetime cancer risk

most powerful contributor to daily intake, however other sources of heavy metals, such as foods, and vegetables, can also substantially contribute to daily heavy metal intake. Thus, the level of risk from drinking water in rural areas of Divandarreh may be underestimated.

Conclusion

Consumption of healthy drinking water has a crucial role in human health. In this study, carcinogenic and noncarcinogenic risk of water through ingestion and dermal contact pathways in the rural area of Divandarreh county was survived. In this regard, children and adults were studied as an exposed population. The result of the present work showed that long-term exposure to heavy metals via dermal contact does not increase the probable adverse health effect. The level of computed HI in adults group through the ingestion of drinking water was lower than the US EPA standard, suggesting there is no health risk threat from heavy metals for this group. However, in the children group, the calculated HI was higher than the specified standard by the US EPA, which means the chance of probable noncarcinogenic health risk. Risk assessment showed that the carcinogenic risk from the consumption of drinking water was higher than the safety level of US EPA risk; therefore, lifetime exposure to studied heavy metal concentration poses cancer risks for residents in this study area. It is recommended that water resources be monitored more precisely, and more efforts should be taken into consideration for the reduction of the heavy metal level in drinking water in the rural area of Divandarreh county.

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Conflicts of interest

There are no conflicts of interest.

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