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RESEARCH ARTICLE

Human health risk assessment of trace elements in drinking tap water in Zahedan city, Iran

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Abstract

Daily intake of elements through the consumption of drinking water, due to its detrimental effects, is accounted for an important concern. Although the health risk assessment of heavy metals in different water sources has extensively carried out in various studies, the effect of age and the concentration of all trace elements in drinking tap water have neglected. Therefore, this study was conducted to evaluate the concentrations of heavy metals, e.g., As, Cd, Cr, Ni, Pb, B, Al, Hg, Mn, Zn, Cu, Fe, Se and Ba in the drinking tap water of Zahedan city and to estimate their non-carcinogenic and carcinogenic effects. Moreover, this is the first research in Iran that has also been dedicated to complete investigation on daily intakes of trace elements in tap water. A total of 155 samples of drinking water were randomly taken from the tap water and were analyzed using ICP-OES device. The estimation of the carcinogenic and non-carcinogenic risks of analyzed elements was carried out based on the guidelines of the U.S EPA. The hazard index (HI) values for children and adult age groups were 9.84E-01 and 4.22E-01, respectively. The cumulative Excess Lifetime Cancer Risk (ELCR) for carcinogenic trace elements was in range of tolerable carcinogenic risk 10^{-6} to10^{-4} and for all carcinogenic elements were in the order of Pb > Cd > Cr. It also detected that the total carcinogenic risks of the Cd, As and Cr in water samples through the ingestion route are at the levels of "low risk" and "low-medium risk".

Keywords Tap water · Trace elements · Risk assessment

Introduction

Access to safe drinking water is accounted for as an indispensable part of a healthy life and one of the main human needs. Although over the last decades, the access to safe drinking water has increased in almost every part of the world, nearly one billion people still do not have access to safe drinking water and more than 2.5 billion people do not have access to proper sanitation [24].

Safe drinking water should not contain the harmful levels of contaminants, e.g., bacteria, viruses, heavy metals and toxic organic substances [3]. However, the drinking waters can be contaminated by the toxic trace elements through the industrial activities and inappropriate wastes disposal, and the exhaustion of the distribution network and the home network [2, 7]. Another source of the trace elements found in tap waters is the corrosion of household plumbing systems. Different factors such as pipe material and internal protective lining of the pipe are effective on the corrosion of pipe. The corrosion typically occurs over time and leads to release the elements into the water when water contacts with the metal coating [1]. Substantial concentrations of trace elements may be identified after the stagnation of the water in distribution systems, particularly during night-time [15]. On the other hand, the hygiene and superior management of the water during its

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treatment, storage and distribution have a remarkable effect on the quality of tap water [3].

Excessive intake of essential trace elements observed in potable water, especially cadmium, chromium, arsenic, and lead, has considerable biological toxicity and is dangerous to human health [25]. Cadmium mainly accumulates in the human hepatic system and kidneys, disturbing estrogen secretion, and is also carcinogenic [19]. Chronic intakes of heavy metals have damaging effects on human beings and other animals. For example, Cr, Cu and Zn can cause non-carcinogenic hazardous such as neurologic involvement, headache and liver disease, when they exceed their safe threshold values. Acute and chronic arsenic exposure could also cause numerous human health problems. These included dermal, respiratory, cardiovascular, gastrointestinal, hematological, hepatic, renal, neurological, developmental, reproductive, immunological, genotoxic, mutagenetic, and carcinogenic effects (such as liver cancer) [13, 14, 20].

Ingestion of drinking water containing significant amounts of metals may result in adverse health effects varying from shortness of breath to several types of cancers [15]. The determination of the levels of these trace elements has recently become one of the imperative subjects for health researchers due to the persistence of some trace elements and the detrimental effect of these elements at the concentration higher than allowable levels; thus, monitoring and determining these elements in drinking waters is essential and important for health and safety assessment of human [4, 11, 21].

In the quantitative assessment of the potential risks, the human health risk assessments are commonly utilized to identify whether the exposure to any concentrations of a chemical can lead to increasing the occurrence of a conflicting consequence on human health [26]. The human health risk assessment has been distinguished as a suitable method for estimation of the potential health risks in humans resulted from the exposure to the trace elements and the results and information obtained from it can help the decision-makers to establish the comprehensive regulations and policies to protect the population's health [9, 26].

In spite of all measures which are currently performed to supply the drinking water with the high quality in Zahedan, there is the possibility to enter the trace elements into the drinking water during transfer and storage and to threaten the human health by these elements. Accordingly, the regional-scale risk assessments seem to be necessary and useful for the total population at risk [25].

Materials and methods

Study area description

Zahedan, the capital of Sistan and Baluchistan province, is located in one of the aridest areas of Iran, close to the border with Pakistan (Fig. 1) [17]. Zahedan has a population more than 800,000 and is considered as a moderately urbanized area with several small industries. The urban water system in Zahedan is struggling with several problems which are as follows: Water demand and the population growth, limited water resources and old water distribution network. Therefore, this cross-sectional study was implemented to appraise the health risk assessment of the exposure to trace elements in drinking water from Zahedan city [23].

Sampling

According to water distribution system and population distribution, we used random sampling methods and collected samples of the tap drinking water [25]. A total of 155 samples of tap drinking water were randomly taken from different locations. Sampling points were selected so that can cover the whole of the city. At each sampling point, one sample was taken and maintained in 1 L volume polyethylene's bottles. Prior to sampling, these bottles were washed with double distilled water and nitric acid in a ratio of 1:1. The pH of the samples was reduced to values less than 2 using pure nitric acid to decrease the possibility of absorption of trace elements in sampling bottles. The acidified samples were kept in the refrigerator at 4 °C. The concentrations of As, Cd, Cr, Ni, Pb, B, Al, Hg, Mn, Zn, Cu, Fe, Se and Ba were determined using the inductively coupled plasma-optical emission spectrometry (ICP-OES). The ICP-OES (Perkin-Elmer, Optima2100DV) was calibrated with a certified standard solution (Merck ICP Multi- element standard solution XIII). After utilizing the device for analyzing every 10 samples, it, was checked in terms of its calibration state using a standard solution and it was recalibrated, if the standard deviation has been increased to values higher than 10% (Table 1).

Human health risk assessment

Health risk assessment is a process that consists of four steps: hazard identification, dose-response assessment, exposure assessment and risk characterization (24). Heavy metals can enter the body through several pathways, including dermal contact, ingestion, and inhalation but in comparison to oral intake all others are negligible [22, 27]. In the present study, eq. 1 was applied to compute the exposure dosage [9, 18, 24]:

$$: \mathrm{ADDing} = \frac{\mathrm{C} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (1)$$

The carcinogenic and non-carcinogenic risks are habitually specified based on the instructions in the risk assessment guidance of the U.S EPA [9]. In order to assess the potential non-

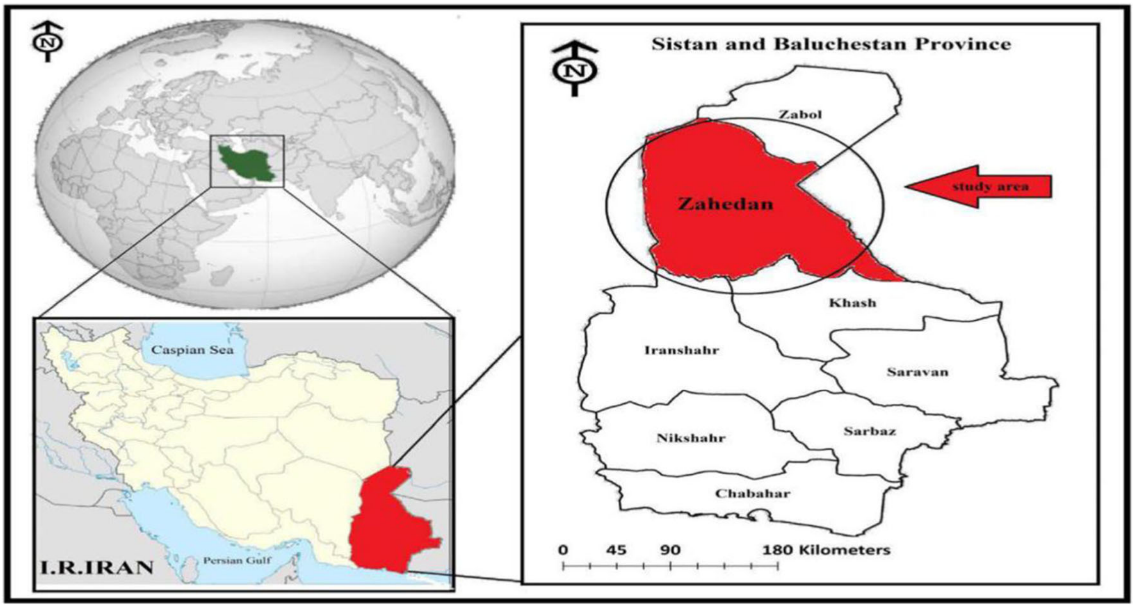

Fig. 1 The map of the study area

carcinogenic risks, the hazard quotient (HQ) is determined via the eq. 2: [9, 19, 26]

$$HQi = \frac{ADDi}{RfDi} \quad (2)$$

where ADDi and RfD represent the average daily dose and the oral reference dose of metal elements in a given condition (mg kg^{-1} day^{-1}), respectively; these values were acquired from the US EPA's integrated risk information system [8, 9].

When several heavy metals are considered and studied, the integrated non-carcinogenic risk outlined by hazard index (HI) (Eq. 3) was used; it is the sum of the HQs related to the studied trace elements. The HI values higher than 1 are indicative of a definite degree of adverse effects on human health, but the values less than 1 is representative of the lack of harm [8].

$$HI = \sum_{i=1}^{n} HQi \quad (3)$$

The Excess Lifetime Cancer Risk (ELCR) of chemical contaminants is typically computed using e equations (Eq.4): [9]

$$ELCR = ADDi \times SFi \quad (4)$$

Where SF indicates the carcinogenic slope factor (mg kg^{-1} day^{-1}) and ELCR value is the cancer-developing probability caused by the exposure of different type of carcinogenic chemicals during the lifetime of a general population. When several heavy metals are considered, the cumulative carcinogenic risk (total ELCR) is utilized; this value is obtained by calculating the sum of the ELCR values related to the studied carcinogenic chemicals. Total ELCR is determined using the following Equation (Eq.5):

Table 1 The parameters of exposure assessment

Parameter	Meaning	unit	Value		
			noncancer		cancer
			adult	child	
ADDi(ingestion)	Average Daily Rose	mg/ kg. day			
C	Concentration of trace	mg/L			
IR	Ingestion Rate	L/day	2	1	2
EF	Exposure Frequency	days/year	365	365	365
ED	Exposure Duration	years	30	6	70
BW	Body Weight	kg	70	15	70
AT	Average Time	days	ED × 365	ED × 365	70 × 365

Table 2 Excess lifetime cancer risk (ELCR) levels based on the Delphi method [13]

Grade I	Extremely low risk	<E-06	Completely accept
Grade II	Low risk	E-06, E-05	Not willing to care about the risk
Grade III	Low-medium risk	E-05,5E-05	Do not mind about the risk
Grade IV	Medium risk	5E-05, E-4	Care about the risk
Grade V	Medium-high risk	E-04,5E-04	Care about the risk and willing to invest
Grade VI	High risk	5E-04, E-03	Pay attention to the risk and take action to solve it
Grade VII	Extremely high risk	>E-03	Reject the risk and must solve it

$$\text{Total ELCR} = \sum_{i=1}^{n} \text{Risk} \quad (5)$$

In consonance with the USEPA's guidance, the range of acceptable or tolerable carcinogenic risk is 10^{-6} to 10^{-4}. Substantially, the ELCR values less than 10^{-6} indicate that the cancer risk is considered negligible; however, based on the most of international regulatory agencies, the cancer risk is considered to be unacceptable for ELCR values higher than 10^{-4}. In order to provide more clarity and intelligibility in evaluation of the results, some researchers state ELCR according to the risk classification in which the ELCR is classified into 7 levels based on the Delphi method (Table 2).

Statistical analysis

In this study, all statistical analysis such as average, standard deviation, analysis of data and human health risk assessment were estimated by using the Excel and SPSS software.

Table 3 Heavy metal concentrations (mg/L) in each tap water

Element	min	max	average	SD	MCL EPA	MCL WHO
As	0.002	0.003	0.0025	4.33E-19	0.01	0.01
Cd	0.003	0.004	0.0035	4E-19	0.005	0.003
Cr	0.001	0.002	0.0015	4E-19	0.1	0.05
Ni	0.004	0.006	0.005	8.8E-04		0.07
Pb	0.0022	0.005	0.003	1E-03	0.015	0.01
B	0.142	1.441	0.46	4.2E-01		2.4
Al	0.014	0.072	0.05	1.9E-02	0.2	0.1
Hg	0.001	0.001	0.001	4E-19	0.002	0.006
Mn	0.001	0.036	0.004	9.43E-03		0.4
Zn	0.022	0.097	0.04	1.9E-02		
Cu	0.003	0.011	0.01	2.6E-03	1.3	2
Fe	0.009	0.298	0.06	7.6E-02		
Se	0.001	0.001	0.001	4E-19	0.05	0.04
Ba	0.001	0.026	0.02	7.5E-03	2	1.3
pH	6.6	7.8	7.15	3.4E-01	6.5–8.5	6.5–8.5

Results and discussion

In the present study, the pH values varied from 6.6 to 7.8 and were within the permissible limit set by water standard of Iran, US-EPA and WHO [16]. The pH has been specified to be one of the main factors influencing the water quality [6]. The pH parameter has no direct health effects on human; however, due to its effects on water quality parameters, e.g., elements solubility and pathogen survival, it can indirectly affect human health. However, the bitter taste of the drinking water is attributed to the high range of pH [10, 22].

In Table 3, the total concentrations of studied metals in the 155 water samples and their maximum permissible limits set by the USEPA and WHO are presented. Generally, Table 3 indicates that all of the water samples contain metal elements such as As, Cd, Cr, Ni, Pb, B, Al, Hg, Mn, Zn, Cu, Fe, Se and Ba. The ranking order of mean concentrations of these elements in all analyzed samples were as follows: Hg(0.001) = Se(0.001) < Cr(0.0015) < As(0.0025) < Pb(0.003) < Cd(0.0035) < Mn(0.004) < Ni(0.005) < Cu(0.01) < Ba(0.02) < Zn(0.04) < Al(0.05) < Fe(0.06) < B(0.46) [5, 12, 25].

The mean concentrations of total trace elements in this study were observed to be much lower than the maximum allowed concentrations advised by the USEPA and WHO for drinking water (Table 3). Thus, based on these criteria, the consumption of drinking water in the distribution network and tap water in Zahedan is safe and is lack of health risks. However, many researchers believe that the estimation of adverse health effects associated with trace elements, according to the trace element concentrations, is not sufficient and it should be assessed by other indices [10].

Therefore, in this study, the determination of the non-carcinogenic and carcinogenic effects of trace elements was done using the hazard quotient (HQ) and Excess Lifetime Cancer Risk (ELCR).

Table 4 summarizes the estimated HQ of trace elements for two age groups of the population (children and adults) which consume the drinking water in the study area. Based on Table 4, all HQ values of the trace elements were less than 1 and were in the order of Hg(2.22E-01) = As(2.22E-01) > B(1.53E-01) > Se(1.33E-1) = Cd(1.33E-01) > Pb(5.71E-02) > Cr(2.22E-02) > Cu(1.03E-02) > Zn(8.00E-03) >

Table 4 Non-carcinogenic risk of trace elements in tap water

Trace elements	C(mg/L)	RfD (mg/kg.d)	ADD		HQ	
			Child	Adult	Child	Adult
As	1.00E-03	3.00E-04	6.67E-05	2.86E-05	2.22E-01	9.52E-02
Cd	1.00E-03	5.00E-04	6.67E-05	2.86E-05	1.33E-01	5.71E-02
Cr	1.00E-03	3.00E-03	6.67E-05	2.86E-05	2.22E-02	9.52E-03
Ni	1.60E-03	2.00E-02	-1.07E-04	4.57E-05	5.33E-03	2.29E-03
Pb	3.00E-03	3.50E-03	2.00E-04	8.57E-05	5.71E-02	2.45E-02
B	4.60E-01	2.00E-01	3.07E-02	1.31E-02	1.53E-01	6.57E-02
Al	4.60E-02	1.00E-00	3.06E-03	1.31E-03	3.06E-03	1.31E-03
Hg	1.00E-03	3.00E-04	6.67E-05	2.86E-05	2.22E-01	9.52E-02
Mn	4.50E-03	1.40E-01	3.00E-04	1.29E-04	2.14E-03	9.18E-04
Zn	3.60E-02	3.00E-01	2.40E-03	1.03E-03	8.00E-03	3.43E-03
Cu	6.20E-03	4.00E-02	4.13E-04	1.77E-04	1.03E-02	4.43E-03
Fe	5.50E-02	7.00E-01	3.67E-03	1.57E-03	5.23E-3	2.24E-3
Se	1.00E-02	5.00E-03	6.67E-04	2.86E-04	1.33E-1	5.71E-2
Ba	1.80E-02	2.00E-01	1.20E-04	5.14E-04	6.00E-3	2.57E-3
HI = ΣHQi					9.84E-01	4.22E-01

Ba(6.00E-3) > Ni(5.33E-03) > Fe(5.23E-3) > Al(3.06E-03) > Mn(2.14E-03) for children and Hg(9.52E-02) = As(9.52E-02) > B(6.57E-02) > Se(5.71E-2) = Cd(5.71E-2) > Pb(2.42E-02) > Cr(9.52E-03) > Cu(4.43E-03) > Zn(3.43E-03) > Ba(2.57E-3) > Ni(2.29E-03) > Fe(2.24E-3) > Al(1.31E-03) > Mn(9.18E-04) for adults. Accordingly, the human health risk assessment of all measured trace elements clarified that the HQ values have an acceptable level of non-carcinogenic adverse health risk [25].

Table 4 also shows that HI values for children and adult age groups were 9.84E-01 and 4.22E-01, respectively. These HI values less than 1 illustrate that the drinking water of the distribution system in Zahedan, according to the non-carcinogenic risk, is safe for human consumption. In this study area, the HI values for children were found to be greater than the values for adult; this reveals the greater susceptibility of children and greater risk associated with drinking of the contaminated water for them because of their increased daily drinking water intake.

In general, the results of this study indicated that there is no noticeable non-carcinogenic risk for the analyzed trace elements, but the routine monitoring is necessary due to possibility of unpredictable contamination in the future.

Table 5 represents the estimated ELCR values of carcinogenic trace elements in two age groups population (children and adults) in the study area. Table 5 shows that the carcinogenic risk of trace elements has a descending order as follows: Cd(1.09E-05) > As(4.28E-05) > Cr(5.43E-06).

The carcinogenic risk of Cd was achieved to be 1.09E−05 in terms of per capita; based on this, the chance of cancer is 1 per 100,000. As can be observed, the estimated carcinogenic risk is in the accepted range of E−04 to E−06. According to the presented grades in Table 5, carcinogenic risk of Cd belongs to Grade III (Low-medium risk) [18].

The carcinogenic risk of as was 4.28 E−05 which it implies that 4 persons per 100,000 are at risk for cancerous diseases. It also observed that the estimated carcinogenic risk of As is related to the Grade III (Low-medium risk) and is within the accepted range of E−04 to E−06. Moreover, the carcinogenic risk of Cr was 5.43 E−06 that it means that 5 persons per 1,000,000 are at risk for cancer. According to the risk levels in Table 5, the carcinogenic risk of Cr belongs to Grade II (Low risk) [26].

Table 5 carcinogenic risk of trace elements in tap water

Trace elements	Carcinogenic risk	Risk Grades		Range of Risk Value
As	4.28E-05	Grade III	Low-medium risk	E-05,5E-05
Cd	1.09E-05	Grade III	Low-medium risk	E-05,5E-05
Cr	5.43E-06	Grade II	Low risk	E-06,E-05
Total ELCR	5.91E-05			

Conclusion

This study was accomplished to appraise the potential health risks of drinking water in Zahedan city. The concentrations of As, Cd, Cr, Ni, Pb, B, Al, Hg, Mn, Zn, Cu, Fe, Se and Ba were in the attainment of drinking water standards and were also lower than the maximum allowed concentrations advised by the USEPA and WHO.

In addition, It was found that the non-carcinogenic risks of ingestion of metal elements existed in Zahedan drinking water is no noticeable. Moreover, it was detected that total carcinogenic risks associated with carcinogenic heavy metal, e.g., Cd, As and Cr in drinking water through the ingestion route was at the levels of "low risk" and "low-medium risk". Eventually, it is proposed that a complete assessment towards all pathways/routes exposure and the associated risks should be implemented.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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