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Spatial distribution and potential health risks of heavy metal(loid)s present in drinking water resources of Iran

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ABSTRACT

Drinking water contaminated by heavy metal(loid)s (HMs) can pose several health risks to humans. The present study was aimed to investigate the spatial distribution as well as possible health risks associated with HMs in drinking water resources in Iran using a literature review. International and national databases searched carefully and a number of 57 articles were found to be eligible for this review. Descriptive statistics were provided for HMs and their spatial distribution and related health risks. The results of estimated hazard quotients (HQ_{Oral}) and excess lifetime cancer risk ($ELCR_{Oral}$) for HMs in drinking water resources revealed high risk of non-carcinogenic and carcinogenic effects for all population groups. The maximum HQ values for subjected HMs were found by following order: As > Co > Hg > Cr > Se > Pb > Cu > Cd > Zn > Ni > Mn > Fe > Ba and the maximum ELCR values for investigated HMs were as follows: Cd > As > Ni > Cr. According to the results of this study strict measures need to be implemented at the national scale to minimize the contamination of drinking waters with toxic HMs.

Keywords: Drinking water; Health risk assessment; Heavy metal(loid)s; Iran; Spatial distribution

1. Introduction

The term of heavy metal(loid)s (HMs) refers to those metals and metalloids having an atomic weight ranged from 63.5 to 200.6 g/mol with a density more than 5 g/cm [1]. Generally, these elements are not degradable naturally and have not a unified distribution on the earth [2]. Some of the HMs such as Fe, Co, Zn, Cu, Mn and Se at trace amounts are necessary for the growth of microorganisms, animals and human beings; however, Cd, Pb, As, Cr and Hg pose

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hazardous effects on the living organisms even at low levels [3,4–6]. The toxic HMs such as As tends to accumulate in different tissues leading to adverse effects on human health [7]. It has been demonstrated that high As exposure can increase the risk of getting different cancers such as skin, lung, bladder, prostate and probably kidney as well as colorectal, thus has been classified as a carcinogenic agent and categorized in Group 1 of the hazardous substances by the IARC [8–10]. Similarly, long time exposure to Pb can result in health problems in both children and adults ranged from changes in body metabolism to convulsion, coma, losing sensitive organs such as kidneys and eventually death [11]. Cd is another toxic metal which is known to be carcinogenic for humans by IARC and categorized in Group 1 of the hazardous substances. Furthermore, the relationship of this metal with increased risk of lung, kidney and prostate cancers has been studied widely [10,12,13]. Cr^{+6} is also categorized in Group 1 (carcinogenic agent) of the hazardous substances and its role in lung and nose cancer as well as the loss of nasal cavity sinuses has been demonstrated so far [10,14]. In addition, intake of excess amounts of Zn, can lead to different health-related problems including digestive disorders, headache, dysfunction or malfunction of the body's immune system, changes in the lipoprotein and cholesterol level and specially may disrupt the interactions between iron and zinc in the body [15]. In the case of Mn, scientific reports have revealed that the exposure with high concentration of this metal may be associated with decreased intelligence quotient (IQ) as well as increased behavioral problems in children [16–18]. Ni is known as an absolute carcinogenic agent for humans (categorized in Group 1 of hazardous agent by the IARC) and its entrance into the body can cause problems in metabolism, inflammation, oxidative stress, cellular reproduction and most importantly can increase the risk of getting cancers in lung, nose and nasal cavities [10,19]. Furthermore, a meaningful correlation was demonstrated between the concentration of Ba in drinking water and the mortality rate due to atherosclerosis and cardiovascular diseases [20,21]. The uptake of mineral mercury through drinking water was also related with renal disorders and increased risk of getting Alzheimer [22,23]. Although, the selenium is among the essential micronutrients, the USEPA has suggested that the exposure to higher concentrations of selenium could cause some adverse health problems such as effects on hair and nail color, damage to the peripheral nervous system, fatigue and sensitivity, alopecia, nail scrub, and damage to the kidneys and blood circulation [24]. According to the abovementioned properties, these toxic HMs have been considered as environmental health hazard and are included among the top 10 most dangerous factors/agents in the list of hazardous substances by the Agency of Toxic Substances and Diseases Registry for soil, air and water pollution [25,26].

Iran is a developing country located in the Middle East which has dry and semi-arid climate. There are critical concerns about the quality of drinking water supplies and resources in Iran [27]. In recent decades, due to exploitation of water resources, in particular groundwater resources, along with the lack of proper management measures have led to the water scarcity phenomenon in the country. Moreover, lack of adequate precipitation has an adverse impact on the water scarcity [28]. The official statistics revealed that 75% of the populations of Iran are living in the small and large cities; however, the remaining 25% are living in rural areas. In the case of large cities, the drinking water resources are mainly treated with conventional water treatment systems but groundwater directly or with primary treatment measures enter into the drinking water distribution network of the small towns and villages [29]. Due to the high costs of water management, in many cases water resources are left untreated. In this regard, different surveys on water resources exhibited that most of these sources have been polluted by chemical or biological contaminants. Thus, the main problems in the field of drinking water in Iran include the lack of access to safe water, the lack or shortness of water and wastewater treatment plants, the lack of special wastewater treatment systems in industrial centers, and substantial defects in the management of waste disposal [30].

The groundwater resources have provided the main part of drinking water supplies in most of the regions in Iran; therefore, investigating the quality of groundwater resources, especially in terms of contamination with HMs has significant importance [31]. However, up to now only a limited number of studies investigated the level of contamination of drinking water sources with HMs in Iran. Therefore comprehensive assessments are needed at national level. In the present study, we systematically reviewed the previous studies to evaluate the concentration of HMs in drinking water resources and assess their related health risks on the national scale. Therefore the main objectives of this study were to: (1) review the studies on drinking water sources in Iran; (2) determine the spatial distribution of HMs in water resources in Iran and (3) determine health risks associated with the intake of HMs-contaminated water.

2. Materials and methods

2.1. Search strategy

In the present work, we aimed to review the previous publications regarding the presence of HMs in drinking water sources of Iran via a systematic literature review. The international and Iranian national databases including Google Scholar, Pubmed, Scopus, Web of Science, Magiran, Iran Medex of Science, Iran doc and SID (Scientific Information Database) were searched carefully. The searches were performed using appropriate keywords including "concentration", "heavy metals", "drinking water", "groundwater", "surface water" and "Iran". The combination of abovementioned terms was also used in both English and Persian languages to find available publications after Jan 1, 2005 up to February 9, 2018. Altogether, 970 articles were found initially and then the inappropriate articles or the publications with inaccessible full texts were omitted from the study. The suitable documents were selected based on the inclusion criteria and assessed by two expert researchers independently.

2.2. Inclusion and exclusion criteria and data extraction

Initially, a checklist comprised of seven questions was applied in order to evaluate the quality of the selected studies which have been conducted in terms of the presence of HMs in drinking water resources in Iran. The subjected questions (Q.1), the way of identifying sampling source (Q.2 to Q.5), utilized experimental methods (Q.6) and the methods by which the results of the studies were evaluated to determine the final quality of the studies (Q.7) are presented in Table S1. To minimize the bias, the name of the authors and the location of the selected studies were omitted during the initial refining process. As mentioned previously, the full texts of the studies were used to evaluate their quality based on the abovementioned checklist, and then a score was ascribed to each document. The publications were sorted as high quality (22–35), middle quality (14–21) and low quality (13 and below). The documents categorized in the "low/weak quality" group were further excluded from the study. Finally, 57 studies were found to be appropriate to include in the present study. The refining process utilized in the present study is presented in Table S2.

2.3. Comparison with the standards

A list of HMs investigated in the present study is provided in Table S3. The concentrations of subjected HMs in drinking water were compared with those permitted levels recommended by the World Health Organization (WHO) and the National Standard of Iran for the Drinking Water [32,33].

2.4. Spatial distributions and health risk assessments

Spatial distributions of HMs were carried out using Arc Map software (Ver. 10.3). Human beings may be potentially exposed to HMs through three different oral, dermal and inhalation routes. In the present study, we only considered the oral exposure route by intake of drinking water. The chronic daily intake for each of the HMs via oral exposure to contaminated water is calculated by following equation [22].

$$CDI_{Oral} = \frac{C \times IR \times ED \times EF}{BW \times AT} \quad (1)$$

In this equation, C stands for the concentration of each heavy metal in water (mg/L), IR is the water ingestion rate (L/d), ED refers to the exposure duration for different age groups, EF stands for the exposure frequency, BW is the body weight and AT refers to the average life time for each age group, that the units and values are seen in Table 1.

The non-carcinogenic risks of HMs via oral exposure were estimated based on the methods recommended by the USEPA and by Eq. (2). As mentioned previously, the possible exposure to HMs was only considered by the consumption of drinking water, thus other possible exposures through food ingestion (25%), soil ingestion (25%) and other ingestions (25%) were omitted. Finally, the estimated HQ values were compared with a source contribution factor of drinking water (0.25). The HQ > 0.25 represents a possible non-carcinogenic risk for human health [22].

$$HQ_{Oral} = \frac{CDI_{Oral}}{RfD_{Oral}} \quad (2)$$

where RfD (oral) is the oral reference dose for each of the HMs calculated by USEPA [22]. The excess lifetime cancer risk (ELCR) related to each HM via oral exposure was calculated using Eq. (3). The ELCR value $> 10^{-6}$ indicates the potential carcinogenic risk for the humans [12].

$$ELCR_{Oral} = CDI_{Oral} \times SF \quad (3)$$

Here, the SF is the cancer slope factor for Cd, Cr, As and Ni through oral exposure that was set up to be 15, 0.5, 1.5 and 0.91, respectively according to the USEPA [22].

3. Results and discussion

3.1. Spatial distribution of the studies investigated the presence of HMs in drinking water resources in Iran

In order to illustrate the spatial distribution of the subjected HMs in drinking water resources in Iran, the location of the selected studies was spotted in the present study. The distribution of the included studies throughout the country is shown in Fig. 1. According to this figure, it is obvious that the distribution of the study locations is highly matched with the population density map of Iran. As seen, the central part of Iran is almost devoided of residential areas which is due to the existence of two large deserts (Dasht-e Kavir and Dasht-e Lut deserts). It has to be mentioned that in the selected 57 studies at least one of the investigated HMs (Zn, Cu, Fe, Mn, Cd, Cr, Ni, Pb, As, Co, Ba, Se and Hg) have been assessed. Furthermore, the kind of sampling resources, the number of samples and the concentration of each HM are presented in Table S4.

3.2. Descriptive statistics of the investigated HMs

The descriptive statistics related to the investigated HMs in drinking water resources are provided in Table 2.

Table 1
Baseline characteristics of parameters included in the health risk assessment

	Infant	Toddler	Child	Teen	Adult
Age	0–6 months	7 months–4 years	5–11 years	12–19 years	≥ 20 years
Exposure duration (years)	0.5	4	11	19	70
Exposure frequency (d)	365	365	365	365	365
Body weight (kg)	8.2	16.5	32.9	59.7	70.7
Average life Time (d)	182	1,460	4,015	6,935	25,550

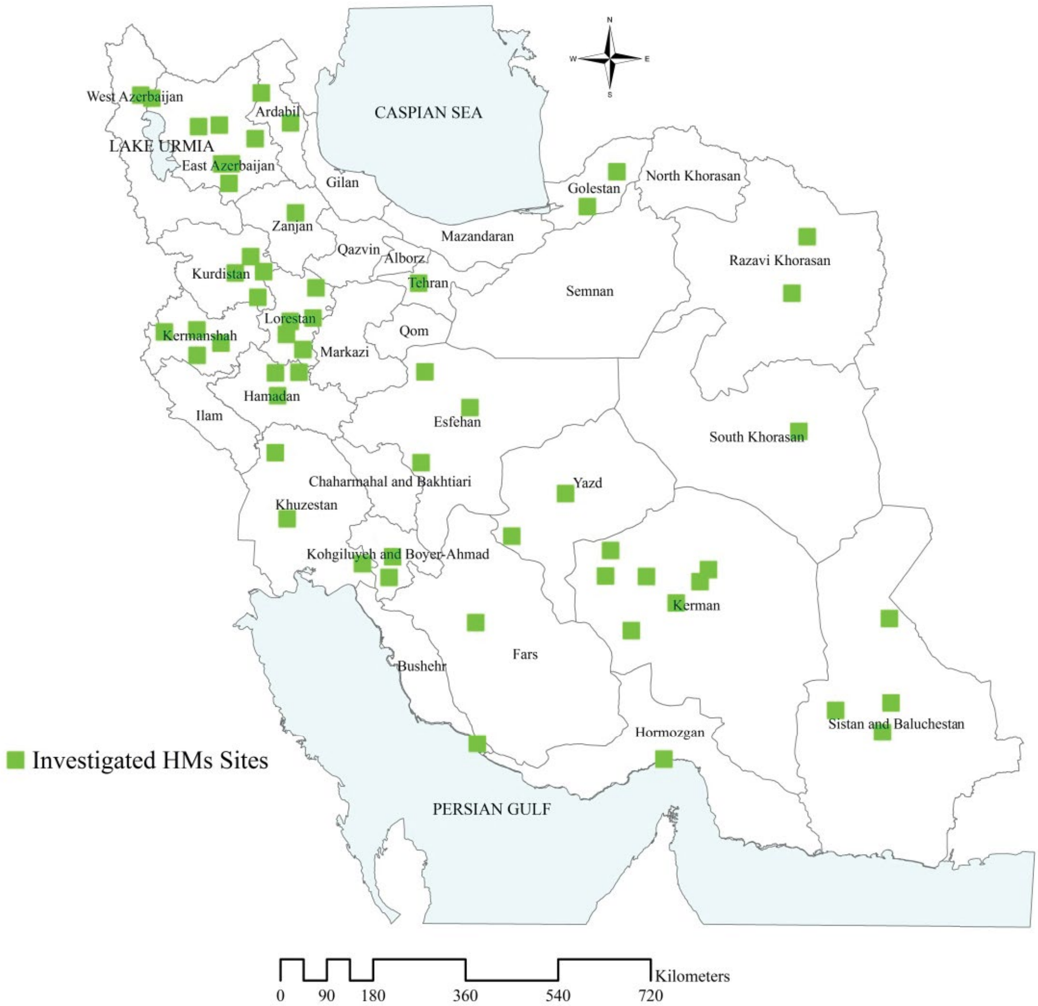

Fig. 1. Spatial distribution of the study sites throughout Iran in which the presence of HMs in drinking water resources have been investigated.

Table 2
Descriptive statistics provided for the investigted HMs (μg/L), *n* (sample size), Min. (minimium), Max. (maximum), Mean (arithmetic), S.D. (standard deviation), S.E. (standard error), U.B. (upper bound), L.B. (lower bound)

HMs	*n*	Min.	Max.	Mean	S.D.	S.E.	U.B.	L.B.
Zn	1,197	0.01	5,937	389.2	73.8	2.133	393.38	385.02
Cu	1,154	0.01	7,618	171.5	34.3	1.010	173.48	169.52
Fe	962	0.01	4,800	293.4	28.9	0.932	295.23	291.57
Mn	968	0.01	550	98.6	21.3	0.685	99.94	97.26
Cd	2,008	0.001	60	3.84	0.71	0.016	3.87	3.81
Cr	2,074	0.001	280	15.8	2.31	0.051	15.90	15.70
Ni	768	0.001	182	14.83	2.06	0.074	14.98	14.68
Pb	2,285	0.001	900	21.6	3.49	0.073	21.74	21.46
As	1,725	0.001	2,490	33.37	4.19	0.101	23.57	23.17
Co	571	0.003	204	14.8	3.11	0.130	15.06	14.54
Ba	281	0.001	1,300	28.6	5.16	0.308	29.20	28.00
Se	494	0.001	490	41.3	19.6	0.882	43.03	39.57
Hg	474	0.001	96	3.16	0.78	0.036	3.23	3.09

Comparing these results with the WHO and NSIDW standards, it can be concluded that the mean concentration of Cd, Cr, As and Se remarkably exceeded the limited levels [32,33]. Moreover, the number of studies in which the concentration of HMs has been reported to be higher than WHO standards are illustrated in Fig. 2.

3.3. Spatial distribution of the investigated HMs in drinking water resources throughout Iran

The spatial distribution patterns of the investigated HMs in water resources throughout Iran are shown in Figs. 3a–3j.

3.3.1. As

According to our results, about 70% of the studies that included in the present study have reported As concentrations above the WHO and NSIDW standards (Fig. 2). We found that the amount of As in the western provinces of Iran is extremely higher than those recommended national and international standard limits for drinking water resources. The maximum concentrations of the As were found to be reported in Kurdistan province (1,737 μg/L) and East Azerbaijan province (2,490 μg/L) [34,35] which is presented in Table S1. Previous epidemiologic studies have reported skin lesions among the residents of these regions, which can be a result of the elevated concentrations of As in the drinking water sources of these areas. Moreover, it has been shown that most of the residents in the village of Qopuz located in the West Azerbaijan Province were severely suffering from chronic arsenicosis. It is believed that this may be attributed to the high concentration of arsenic in drinking water resources of this region. Several studies have been shown that the ground water resources in this area are highly contaminated with the mineral arsenic due to the geological structure of this region [36–38]. Altogether, the As was found at highest concentration in the northwestern (West Azarbaijan and Kurdistan Provinces), and central part of Iran (Kerman Province). The pollution trend indicated that these areas may be potentially contaminated by As originated from natural soil or mining activities [39–41].

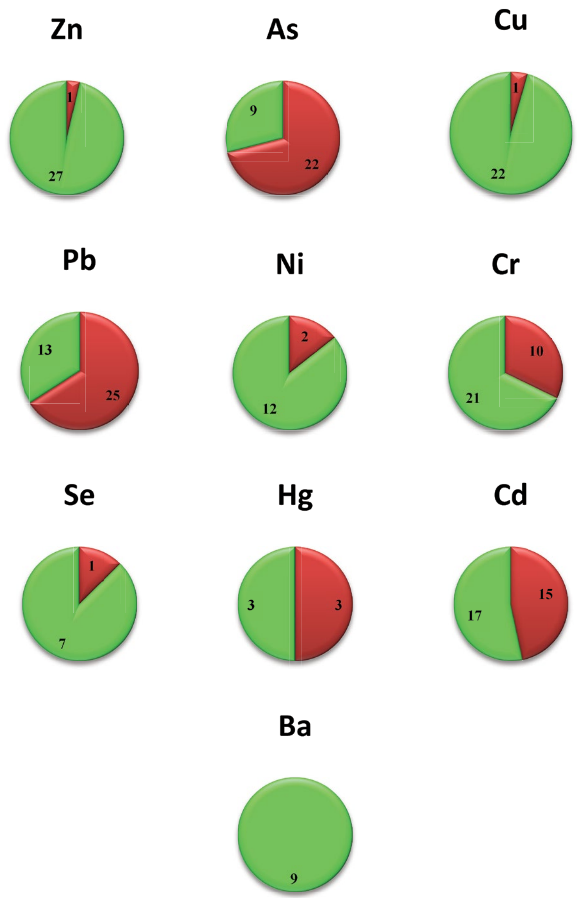

Fig. 2. Number of the studies in which the concentration of HMs has been reported to be higher than WHO standards (N Less than standard – N More than standard).

3.3.2. Pb

Previous studies have been shown that the concentration of Pb in water resources of Kerman, Anar plain, Bandar Abbas and Aleshtar was higher than the suggested levels by NSIDW. Since the samples were mainly collected from the groundwater resources in these studies, the high concentration of Pb can be attributed to the background geological and soil structure of these regions [42–45]. In a research by Ehya and Marbouti [46] in Behbahan, the maximum concentration of Pb in groundwater resources was reached to 840 μg/L and they suggested that this is related to the entry of industrial and urban wastewaters to the feeding layers of drinking water resources. Moreover, Alinejad et al. [47] investigated the water resources in Kohgiluyeh and Boyer-Ahmad and have found the highest concentration of 1,553 μg/L Pb in this area and assumed that this can be related to human activities.

3.3.3. Cd

The Cd was investigated in 32 out of 57 selected studies and its concentration ranged from 0.001 to 60 μg/L (Table S4). The highest concentration of the Cd was found in the water resources of the urban areas. The possible source of this element can be related to the plastic and dyeing industries located in these areas [48]. In addition, the results of studies conducted on the groundwater resources in Bandar Abbas, Zanjan, Sistan and Baluchestan, Andimeshk, Behbahan and Qorveh, revealed that the concentrations of Cd in these regions were higher than the standard level (Table S4). In Zanjan and Behbahan, the high concentration of Cd in drinking water resources was attributed to the industrial activities as well as the leakage of industrial and urban wastewaters to the water resources [49]. According to the results, the distribution patterns of Cd and Cr are somehow similar, indicating that these metals may be originated from same sources such as several anthropogenic pollutions [4,50–53].

3.3.4. Cr

The highest concentrations of the Cr were observed in the regions of Khoy and Zurabad plain which can be due to the

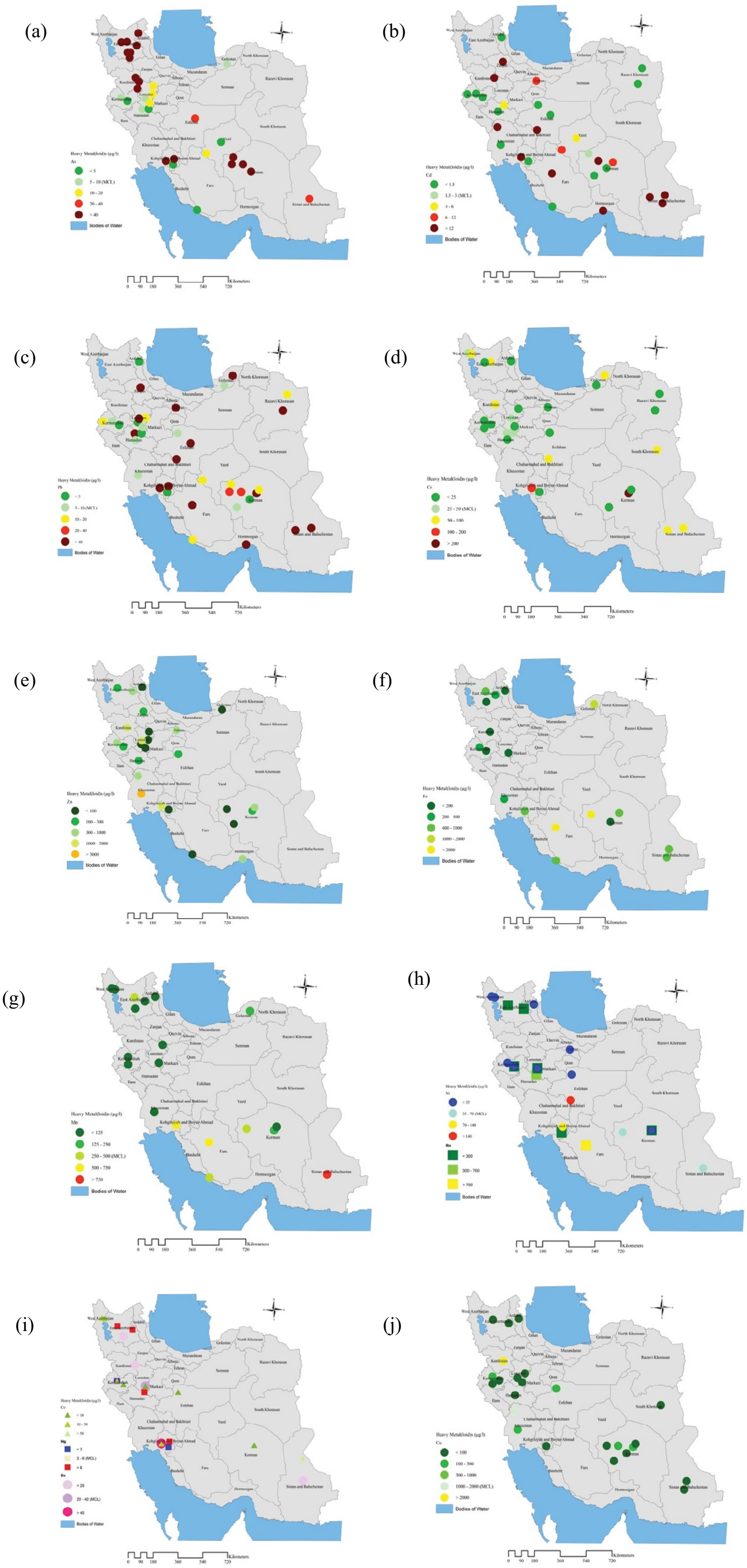

Fig. 3. Spatial distribution maps related to the maximum concentration of HMs in drinking water resources throughout Iran. (a) As, (b) Cd, (c) Pb, (d) Cr, (e) Zn, (f) Fe, (g) Mn, (h) Ni and Ba, (i) Co, Hg and Se, (j) Cu.

geological structure of these areas [54]. In another study conducted by Shahriyari et al. in Birjand, they found that 68% of the samples collected from the drinking water wells and 51% of the total samples taken from the water distribution network were contaminated with higher concentration of Cr exceeded the drinking water standards of Iran. Regarding the absence of a particular industry or mining activity in this area, these pollutions have been related to the geological structure of the region [55]. Furthermore, Hassanzadeh et al. [45] investigated in the groundwater resources of Kerman province and have shown that the concentration of Cr was extremely high in this area. Considering the lack of correlation with other available metals and ions, they believed that this pollution can be resulted from the uncontrolled disposal of raw wastewaters in the areas downward of the water resources [45]. Cr concentrations higher than the permitted values recommended by NSIDW have also been reported in the other regions (Fig. 3d).

3.3.5. *Zn*

According to our findings, only in one of the 57 selected studies, the concentration of Zn (5,937 μg/L) was found to be higher than the WHO standards. In this study, it has been shown that in 27.27% of the collected samples from drinking water resources, the concentration of Zn was higher than the permitted standard level and the average concentration of Zn has been reported to be 3,180 μg/L. This result demonstrates the high corrosiveness of urban water and confers the possible corrosion of the galvanized pipes, which were used in water distribution network [56].

3.3.6. *Ni and Ba*

The maximum concentration of Ni (182 μg/L) was reported from Isfahan province. The high amount of Ni in this area was attributed to the adjacent iron-melting factory and the downward urban wastewater sewage drainage system [57]. In a survey performed on the 50 water resources around Shiraz to identify the concentration of Ba, the maximum concentration of Ba reached was 1,300 μg/L. It is believed that the high concentration of barium in these samples may be related to the soil texture of this area [48]. Fig. 3h displays the spatial distribution of Ni and Ba across the Iran.

3.3.7. *Fe and Mn*

The spatial distribution of the Fe and Mn in the drinking water resources throughout Iran is illustrated in Figs. 3f and g. The analysis of the samples obtained from 140 drinking water cisterns in the rural areas of Golestan province showed that the concentration of Fe in 12% of those samples was higher than the NSIDW permitted level. According to the previous investigations, the main reason for the excess amount of Fe in these cisterns may be resulted from the materials utilized in the roof covering [28]. Moreover, the maximum concentration of Fe and Mn in 50 samples of drinking water resources around Shiraz was found to be 4,800 and 550 μg/L, respectively. Since these metals are presented at high amounts and are distributed consistently, same source of the soil and rocks may be corresponded to their distribution in the region. However, in other cases the increased levels of Fe or Mn in drinking water sources can be associated with human activities [48]. In another study Ehya and Marbouti [46] have found that the concentration of Fe and Mn in groundwater resources in Behbahan city was higher than the NSIDW and reached 900 and 510 μg/L, respectively. Further investigations revealed that the high concentration of Fe and Mn may be due to the leakage of urban and industrial sewage systems to the drinking water layers [46]. Barzegar et al. [58] studied the water wells around Ajichi River in Tabriz and have found high concentrations of Fe and Mn in these resources which reached to 965 and 425 μg/Lat the highest levels. In addition, the principal component analysis has shown that high concentrations of Fe and Mn in this area are related to the geological and volcanic structure of the study region [58]. The results of the study conducted by Kermani et al. [59] in Miduk district in Yazd province showed that the concentration of Fe and Mn in a number of samples was higher than NSIDW permitted levels. The maximum concentrations of these elements have found to be 2,530 and 460 μg/L, respectively. The authors suggested that the high amount of these metals may be due to geological structure of the region as well as the adjacency of water resources with the main mines [59]. Gholamalizadeh et al. [60] investigated the water resources available in the Chah Nimeh number 1 in Sistan and Baluchestan province in term of Fe and Mn concentrations and have found that the average concentration of these metals in water resources was 449 and 514 μg/L, respectively. Comparing with the NSIDW permitted levels, it is obvious that the concentrations of iron and manganese were higher than the standard levels and this may be related to the natural depositions [60]. Moreover, Hassanzadeh et al. [45] have also shown that the concentration of Mn was higher than the permitted level in groundwater resources in Kerman. According to the correlation coefficients with the other elements including lead and cadmium, they assumed that higher amount of Mn could be due to the pollutions made by human activities [45]. Also, the high concentration of Fe in water resources in Kerman province was demonstrated by Atapour [61]. Several investigations assumed that the high amount of Fe can be due to the existence of high amount of mineral iron in the region. Furthermore, the highest concentration of Fe in drinking water resources was not exceeded the permitted level established by WHO. Altogether, the maximum concentration of Fe was higher than acceptable level (300 μg/L) in drinking water resources in 10 out of the 57 selected studies (Table S4).

3.3.8. *Hg, Co and Se*

The concentration of mercury, cobalt and selenium throughout Iran is illustrated in Fig. 3i. The study of the water resources of Kohgiluyeh and Boyer-Ahmad have shown that the concentration of Hg was much higher than the NSIDW permitted level and reached to 96 μg/Lat the maximum level. Researchers have assumed that the high amount of Hg may be related to the geological structure of the region [47]. Ehya and Marbouti [46] have also shown that the amount of selenium was higher in all investigated drinking water resource of Behbahan city compared with NSIDW standards which reached to 490 μg/L at the maximum level. The main reason for high amount of selenium in this region was attributed to the leakages from urban and industrial wastewater system to the drinking water layers. The maximum observed concentration of cobalt in water resource of Behbahan city was 50 μg/L [46]. The concentration of selenium in drinking water resources in Ahangaran, Bijar and Qorveh was observed to be two times higher than the maximum permitted level for drinking water [62,41]. Moreover, Rajaie et al. [63] have shown that the maximum level of selenium in the drinking water samples obtained from water resources in Sistan and Baluchestan province was reached up to 17.9 μg/L. According to the correlations between the metals investigated in abovementioned study, the higher concentration of selenium potentially may be related to the geological structure of the region [63]. Khodadadi et al. [54] also investigated the concentration of cobalt in drinking water resources in Khoy and Zurabad plain and have found the maximum levels of 13.8 and 14.2 μg/L, respectively. In a study conducted by Atashi et al. [64], the drinking water wells located in Zahedan city were investigated and have found that the concentration of Cobalt was higher than WHO guidelines in all cases with the maximum concentration of 204 μg/L. Further studies assumed that different factors such as industrial and urban wastewater systems had the main effects on the elevated concentration of cobalt, thus the wells located in downtown may contain more amount of cobalt compared with others [64]. The concentration of Hg in water resources of Borujerd was studied by Kamarehei et al. [65], and the maximum amount of 11 μg/L was observed in this region. The high concentration of Hg could be related to human activities or leakages of wastewater to the water resources [65]. Furthermore, Pourakbar et al. [27] evaluated the concentration of Hg in 25 rural sites in Saraab city and have found that only in one of the sampling sites its concentration was higher than the national standard and reached 8.4 μg/L. Regarding the absence of industries in this region, the presence of Hg was attributed to the natural sources [27]. Moreover, Barzegar et al. [58] have conducted a study to investigate the conditions of water resources in 18 rural sites in Tabriz. They found that the concentration of Hg in one of the resources was somehow higher than the national maximum permitted level and was 6.5 μg/L. In this regard, several studies indicated that the concentration of Hg in this area can be due to the soil texture and the existing mining sites [58].

3.3.9. Cu

The reported concentrations of Cu across the country are presented in Fig. 3j. The concentration of cupper was investigated in water resources of the rural communities in Qorveh. It was found that the concentration of Cu exceeded the permitted standard level in some sites of the region and reached to 7,618 μg/Lat the maximum level. The high concentration of Cu was assumed to be related to the geological structure of this area [66]. However, other studies have shown Cu concentration under the limited level established by NSIDW (Table S3).

Several studies were also performed in different countries worldwide. In this regard, Berisha and Goessler [67] investigated the concentration of Ni, As and Ur in groundwater resources in Kosovo. Based on their results, the concentration of arsenic, nickel and uranium in 3.1%, 2.1% and 7.3% of the tested samples exceeded the permitted levels established by WHO. They assumed that the elevated amount of these metals in water resources, particularly in deep wells may be related to the geological texture of the region [67]. Moreover, Nezar et al. [68] examined the drinking water wells around Mecca in Saudi Arabia in term of the HMs concentrations. They observed that the concentration of arsenic, selenium and mercury exceeded the standard levels established by WHO and was 50, 42 and 1.2 μg/L, respectively, at the maximum concentration. Since there was no any special industry in the region or wastewater treatment system, the presence of such metals in water resources can be related to the geological texture of the study area [68]. However, previous studies have been shown that the high concentration of some of the HMs in water resources such as barium and strontium may be originated from the medical industries, despite the geological texture of the region. In addition, the high concentration of HMs including iron, nickel, lead and zinc in water resources can be due to the adjacency of the industries and possible entry of industrial wastewaters to drinking water resources [69].

3.4. Health risks assessment of HMs-contaminated drinking water resources

The health risk assessments of HMs-contaminated drinking water resources in Iran were done using hazard quotients (HQ_{Oral}) for 13 HMs and excess lifetime cancer risk ($ELCR_{Oral}$) for 4 potentially toxic elements and the obtained minimum, maximum and mean values are presented in Tables 3 and 4. Our findings showed that the HQ_{Oral} values for 11 out of the subjected 13 HMs were higher than 0.25, which indicate that they pose non-carcinogenic risks for human beings. The trend of non-carcinogenic health risks was decreased in the order of As > Co > Hg > Cr > Pb > Cu > Se > Cd > Zn > Ni > F e > Ba > Mn in all groups. Among this HMs, the non-carcinogenic health risks related to As, Co, Hg, Cr and Pb are remarkably higher than the others metals. Arsenic has a HQ_{Oral} of 303.6, 301.8, 201.8, 139 and 176 for infant, toddler, child, teen and adult groups, respectively. Thus, As lonely pose higher health risks compared with the other HMs together. In accordance with the results obtained in the present study, previous studies also have demonstrated extreme As contamination in drinking water resources in different parts of Iran which is associated with significant and serious health problems [35,39–41,70]. Regardless of the arsenic, the HQ_{oral} values obtained for subjected HMs via intake of drinking water showed no risk of non-carcinogenic effects for any age group; however, the health risks were higher for the groups with lower age compared with the adults. According to the mean HQ values obtained for each of the HMs, non-carcinogenic risks can occur for As, Co, Hg and Cr, respectively (Figs. 4a and b).

Generally, ingestion route is one of the most important exposure pathways by which the HMs enter the human body. In the case of carcinogenic risk, our results showed the maximum risk of 1.366×10^{-1} for As via water intake for infant group. These results indicated a high carcinogenic risk for humans. Regardless of As, the ELCR values for Cd, Cr and Ni via oral exposure was found to be higher than the acceptable range (Table 4), suggesting that exposure to these elements

Table 3
Hazard quotients (HQ_{oral}) of HMs in drinking water for different age groups considering the min., max. and mean value of HMs

		HMs												
Groups	HQ_{Oral}	Zn	Cu	Fe	Mn	Cd	Cr	Ni	Pb	As	Co	Ba	Se	Hg
Infant	Min.	1.22E-06	9.15E-06	5.23E-07	2.61E-06	3.66E-04	3.66E-04	1.83E-05	1.02E-04	1.22E-03	3.66E-04	1.83E-07	7.32E-06	2.29E-04
	Max.	7.24E-01	6.97E+00	2.51E-01	1.44E-01	2.20E+00	1.02E+01	3.33E-01	9.15E+00	3.04E+02	2.49E+01	2.38E-01	3.59E+00	2.20E+01
	Mean	4.75E-02	1.57E-01	1.53E-02	2.58E-02	1.40E-01	5.78E-01	2.71E-02	2.20E-01	4.07E+00	1.80E+00	5.23E-03	3.02E-01	7.23E-01
Toddler	Min.	1.21E-06	9.09E-06	5.19E-07	2.60E-06	3.64E-04	3.64E-04	1.82E-05	1.01E-04	1.21E-03	3.64E-04	1.82E-07	7.27E-06	2.27E-04
	Max.	7.20E-01	6.93E+00	2.49E-01	1.43E-01	2.18E+00	1.02E+01	3.31E-01	9.09E+00	3.02E+02	2.47E+01	2.36E-01	3.56E+00	2.18E+01
	Mean	4.72E-02	1.56E-01	1.52E-02	2.56E-02	1.40E-01	5.75E-01	2.70E-02	2.18E-01	4.04E+00	1.79E+00	5.20E-03	3.00E-01	7.18E-01
Child	Min.	8.11E-07	6.08E-06	3.47E-07	1.74E-06	2.43E-04	2.43E-04	1.22E-05	6.75E-05	8.11E-04	2.43E-04	1.22E-07	4.86E-06	1.52E-04
	Max.	4.81E-01	4.63E+00	1.67E-01	9.55E-02	1.46E+00	6.81E+00	2.21E-01	6.08E+00	2.02E+02	1.65E+01	1.58E-01	2.38E+00	1.46E+01
	Mean	3.15E-02	1.04E-01	1.02E-02	1.71E-02	9.34E-02	3.84E-01	1.80E-02	1.46E-01	2.70E+00	1.20E+00	3.48E-03	2.01E-01	4.80E-01
Teen	Min.	5.58E-07	4.19E-06	2.39E-07	1.20E-06	1.68E-04	1.68E-04	8.38E-06	4.65E-05	5.58E-04	1.68E-04	8.38E-08	3.35E-06	1.05E-04
	Max.	3.31E-01	3.19E+00	1.15E-01	6.58E-02	1.01E+00	4.69E+00	1.52E-01	4.19E+00	1.39E+02	1.14E+01	1.09E-01	1.64E+00	1.01E+01
	Mean	2.17E-02	7.18E-02	7.02E-03	1.18E-02	6.43E-02	2.65E-01	1.24E-02	1.01E-01	1.86E+00	8.26E-01	2.40E-03	1.38E-01	3.31E-01
Adult	Min.	7.07E-07	5.30E-06	3.03E-07	1.52E-06	2.12E-04	2.12E-04	1.06E-05	5.89E-05	7.07E-04	2.12E-04	1.06E-07	4.24E-06	1.33E-04
	Max.	4.20E-01	4.04E+00	1.45E-01	8.34E-02	1.27E+00	5.94E+00	1.93E-01	5.30E+00	1.76E+02	1.44E+01	1.38E-01	2.08E+00	1.27E+01
	Mean	2.75E-02	9.10E-02	8.89E-03	1.49E-02	8.15E-02	3.35E-01	1.57E-02	1.27E-01	2.36E+00	1.05E+00	3.03E-03	1.75E-01	4.19E-01

in drinking water in Iran pose remarkable carcinogenic risks to human groups. The maximum $ELCR_{Oral}$ values for these HMs were decreased in the order of As > Cd > Ni > Cr in all age groups. The result of carcinogenic risk assessment revealed that the investigated HMs pose more threats to infant, toddler, child, adult and teen, respectively. The ELCR values with the 95% confidence interval showed that the carcinogenic effects are unlike to any age group but the level of the carcinogenic risks were found to be higher for infants compared with the other age groups. However, based on the ELCR results obtained for Cd, As, Ni and Cr, it can be concluded that the concentration of these metals has potential carcinogenic risk for consumers (Figs. 5a and b).

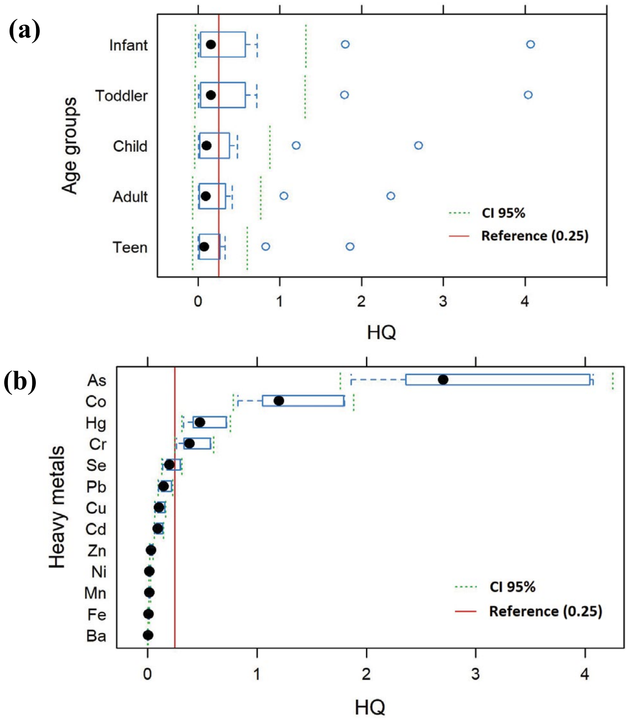

Fig. 4. Estimated HQ values and the potential non-carcinogenic effects posed to the consumers by (a) age categories and (b) type of HMs.

As presented in Table 4, the maximum non-carcinogenic risk value in drinking water resources of Iran for most of the HMs is above the acceptable levels. Altogether, based on the mean HQ_{Oral} values obtained for HMs, As and Co have non-carcinogenic risk for human health in all age groups. The HQ_{Oral} values of all HMs were decreased in the order of children groups > adult groups. The estimated carcinogenic risk value of As for different population groups was much higher than those values obtained for other investigated HMs. According to our findings, it is obvious that the infant, toddler and child groups are at a higher risk of non-carcinogenic and carcinogenic effects than teen and adults due to the exposure to HMs via drinking water ingestion. The reason for the subject that higher HQ and ELCR values were obtained for children than that for adults can because that children have longer exposure duration than adults [71].

4. Conclusion

The present research was conducted to systematically review the scientific documents and articles about the conditions of HMs in drinking water resources throughout Iran. Based on the results, it can be inferred that the distribution pattern of some heavy metals in drinking water resources is not consistent in different parts of the country. Accordingly, the maximum concentration of As was found in the northwestern parts of the country, especially in Kurdistan and East Azerbaijan provinces which is mainly related to the geological texture of these regions. Moreover, higher amount of As was reported in central part of the country in Kerman province which is attributed to the mining activities in this area. Furthermore, a correlation was observed between Fe

Table 4
Excess lifetime cancer risk ($ELCR_{Oral}$) of Cd, Cr, Ni and As via drinking water for different age groups considering the min., max. and mean value

Groups	CR_{Oral}	Cd	Cr	Ni	As
Infant	Min.	5.488E-06	1.829E-07	3.329E-07	5.488E-07
	Max.	3.293E-02	5.122E-03	6.059E-03	1.366E-01
	Mean	2.107E-03	2.890E-04	4.937E-04	1.831E-03
Toddler	Min.	5.455E-06	1.818E-07	3.309E-07	5.455E-07
	Max.	3.273E-02	5.091E-03	6.023E-03	1.358E-01
	Mean	2.095E-03	2.873E-04	4.907E-04	1.820E-03
Child	Min.	3.647E-06	1.216E-07	2.213E-07	3.647E-07
	Max.	2.188E-02	3.404E-03	4.027E-03	9.082E-02
	Mean	1.401E-03	1.921E-04	3.282E-04	1.217E-03
Teen	Min.	2.513E-06	8.375E-08	1.524E-07	2.513E-07
	Max.	1.508E-02	2.345E-03	2.774E-03	6.256E-02
	Mean	9.648E-04	1.323E-04	2.261E-04	8.384E-04
Adult	Min.	3.182E-06	1.061E-07	1.931E-07	3.182E-07
	Max.	1.909E-02	2.970E-03	3.514E-03	7.924E-02
	Mean	1.222E-03	1.676E-04	2.863E-04	1.062E-03

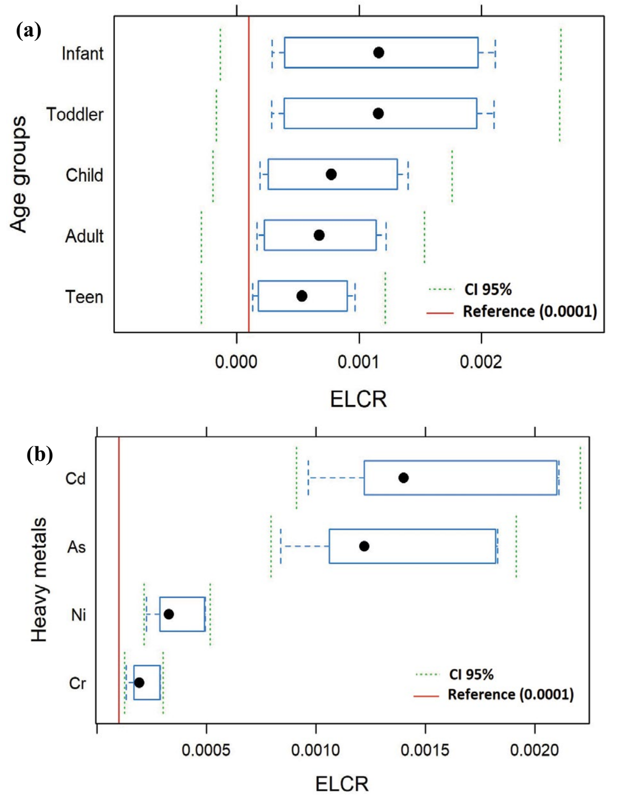

Fig. 5. Estimated potential carcinogenic effects for drinking water consumers by (a) age categories and (b) type of HMs.

and Mn in the water resources in different study areas. Our results demonstrated that the concentration of some heavy metals including Cu, Fe, Mn, Cd, Cr, Ni, Pb, As, Co, Ba, Se and Hg in some sampling sites was extremely higher than the NSIDW and the WHO standards. The result of maximum HQ_{Oral} and $ELCR_{Oral}$ values obtained for HMs showed very high non-carcinogenic and carcinogenic risks for all population groups. The highest health risk was found to be related to As which is widely present in drinking water resources throughout Iran. Regarding the results of the present study strict measures need to be adopted at the national scale in order to prevent exposure with the toxic HMs via drinking water intake as well as leakage of chemical substances to drinking water resources.

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Symbols

ELCR — Excess Lifetime Cancer Risk
HMs — Heavy Metal(loid)s
HQ — Hazard Quotients
IARC — International Agency for Research on Cancer
IQ — Intelligence Quotient
SID — Scientific Information Database
USEPA — United States Environmental Protection Agency
WHO — World Health Organization

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Supplementary information

Table S1
Approach of giving scores to the documents

Number	Question	Article number			
		Linguistic term	Weak	Middle	Strong
		Value	1	3	5
1	Has the purpose of the study been clearly identified?				
2	Has the location and time limit been identified correctly?				
3	Has the sampling method and the method of measuring the samples been done correctly?				
4	Has the number of samples been identified correctly and is it indicative of the total condition of the sampling location?				
5	Has the method of identifying the volume of the sample been done in a standard way?				
6	Is the method of identifying the concentration of HMs standard?				
7	Has the data analysis been done correctly?				
Final score					

Table S2
Process of searching and documents refining

	Google Scholar	Magiran, Iran Medex, Iran doc	Web of Science	Pubmed, Scopus	SID	
Number of articles	241	223	86	327	93	
Deleting the articles based on the title.	119	137	57	238	64	
Deleting article based on abstracts.	83	27	22	53	16	
Deleting repetitive articles.						83
Adding articles using reference articles.						2
Complete articles assessed based on the text.						73
Articles that did not get the criterion based on the assessment to get into this study.						16
Complete articles that could get into the study.						57

Table S3
WHO guideline and NSIDW for some heavy metal(loid)s

Heavy Metal(loid)s	WHO MCLs (μg/L)	NSIDW MCLs (μg/L)
Zinc (Zn)	3,000	–
Copper (Cu)	2,000	2,000
Iron (Fe)	–	–
Manganese (Mn)	500	400
Cadmium (Cd)	3	3
Chromium (Cr)	50	50
Nickel (Ni)	70	70
Lead (Pb)	10	10
Arsenic (As)	10	10
Cobalt (Co)	–	–
Barium (Ba)	1,300	700
Selenium (Se)	40	10
Mercury (Hg)	6	6

MCLs: maximum concentration levels.

Table S4
Sampling sites and the concentration range or (arithmetic mean) of HMs (μg/L)

N	Sampling site	Sample type[a]	Sample size	Zn	Cu	Fe	Mn	Cd
1	Ardabil 1	R, W	20	0.07–0.7	0.01–0.9	0.01–0.3	0.01–0.4	0.001–0.002
2	Bijar-Kurdistan	W, S	44					
3	Aleshtar-Lorestan	W	20					
4	Borujerd-Lorestan	W	54					(1.4)
5	Bandar Abbas	W	25	0–337 (70)				1–13 (5.4)
6	Tuyserkan-Hamadan	W	24	(6.3)	(12.49)			
7	Sistan and Baluchestan 1	W, R	15	(19.2)		(449)	(514)	(10.7)
8	Khoy plain-West Azerbaijan	W, S	30				7–24.9 (12.52)	
9	Zurabad plain- West Azerbaijan	W, S	12				14.2–51.6 (34.78)	
10	Anar plain-Kerman	W	21					0.06–2.63
11	Qahavand plain-Hamedan	W	20	2.88–32.5 (13.72)	1.55–15.68 (9.21)			
12	Razan plain-Hamedan	W	20	10.49–78.54 (30.28)			1.81–9.02 (3.69)	
13	Rafsanjan-Kerman	W, S, Q	48		53–248			1.5–17
14	Zanjan	W	17	17–285 (58.5)				2–30 (5.9)
15	Sirjan plain-Kerman	W	40	(0.08)	(26.74)			ND
16	Sistan and Baluchestan 2	R	48		3–92.8	94.8–539.1		1.5–29.3
17	Charuymaq- East Azerbaijan	W, S	210					
18	Hashtrud- East Azerbaijan	W, S	200					
19	Shiraz	W, S	50			0–4800	0–550	0–60
20	Asaluyeh-Bushehr	W	9	0.4–37.8		28.3–446	0.2–344	0.1–1
21	Aliabad-e Katul- Golestan	W	36	(14.3)				(0.01)
22	Qorveh- Kurdistan	W, S	105					

Cr	Ni	Pb	As	Co	Ba	Se	Hg	Reference
0.01–0.03	0.001–0.03	0.001–0.04						[S1]
			0–447					[S2]
(10)		(78.8)	(3.3)					[S3]
(0.2)		(5)	(7.7)		(322.2)		(1.1)	[S4]
		2–164						[S5]
		(20)						
		(1.85)	(3.99)					[S6]
								[S7]
3–30	8.4–13.2			8.2–13.8				[S8]
(15.21)	(10.45)			(9.98)				
17–60	8.4–17.9			9–14.2				[S9]
(37.35)	(12.36)			(11.63)				
		1–20	10–96					[S10]
		0.05–11.92	2.92–13.67					[S11]
		(2.36)	(7.49)					
0.02–0.104			1.92–11.83					[S12]
(0.044)			(5.86)					
		3.6–20.42	0–43.6					[S13]
		5–50						[S14]
		(13.9)						
(0.5)		(2.842)						[S15]
3.1–92.1	1–39.1	4.4–57.7	0.47–22.4			1–17.9		[S16]
			0–637					[S17]
			0–1,136					[S18]
		0–60			0–1,300			[S19]
		0.3–15	0.2–2					[S20]
(2.5)		(6.6)	(2.2)					[S21]
			17–1,737					[S22]

(Continued)

Table S4 *Continued*

N	Sampling site	Sample typea	Sample size	Zn	Cu	Fe	Mn	Cd
23	Qopuz- East Azerbaijan	S	4			46–102	1–2	
24	Kashan	N	35	(182.2)	(71)			(0.38)
25	Kermanshah 1	W, S	31	2.4–147.3	0.029–4.87	7.9–16.8		0.001–0.015
26	Gachsaran	N	11	(55.9)	(0.82)			(0.05)
27	Mashhad	N	158					(1.1)
28	Miduk- Yazd	W, S, Q	27	10–50	35–70	100–2,530	10–460	
29	Yazd	N	20					(5.35)
30	Ahvaz	N	76	700–5,937 (3,180)	10–608 (168)	112–478 (257)	25–76 (31.6)	0.1–4.6 (0.97)
31	Birjand	W, N	67		(46)			
32	Zarrin Shahr - Isfahan	W	18					26–60
33	Sarab-Ardabil	W, S	25	2–823	24–37	15–273	1–25	ND
34	Kerman 1	W	43	0.5–172 (35)	1–150 (13)		1–132 (26)	1–12 (6)
35	Golestan	R	140			0–1,300	0–150	
36	Ahangaran- Lorestan	W, S	28	3.5–44.3	1.2–16.5	0.02–0.23	0.84–28.09	
37	Andimeshk- Khuzestan	W	42	108–494	10–1,090			1–14
38	Bardsir- Kerman	W, S, Q	46		1–12	33–160		0.02–0.8
39	Behbahan- Khuzestan	W	30	0–1,560		0–900	0–510	0–20
40	Bijar and Qorveh- Kurdistan	W, S	28					0–13.63
41	Kerman 2	W, S, Q	50	31.5–369.5	17.1–42.7	75–482	0.6–3.6	
42	Kermanshah 2	W, S, N	320	0–320.5	0.1–145.7	1.6–347	0–113.3	0–1.5
43	Aji Chay- East Azerbaijan	W	18	1–48		20–965	5–425	
44	Tabriz	S, Q	32	<2–131.1	28.8–49.8			
45	Zahedan	W	10					
46	Ardestan- Isfahan	W	14					ND
47	Abarkuh-Yazd	W	37					0.06–7.2 (0.8)
48	Ardabil 2	N	163					
49	Qaleh Shahin- Kermanshah	W	20					0.11–1.49 (0.77)
50	Kohgiluyeh and Boyer-Ahmad	N	32					
51	Sistan and Baluchestan 3	W	493					ND-20 (2.76)
52	Eslamshahr-Tehran	W	92	3–367				0.22–10
53	Torbat-e Heydarieh- Razavi Khorasan	W	41					0–0.9 (0.59)
54	Qorveh 2- Kurdistan	W	25	24–1,572	15–7,618	25–96		
55	Hamadan	N	41	423–2,495 (1,457.6)				
56	Kermanshah 3	N	51		0–0.501 (.07)		0–0.72 (0.24)	
57	Khorramabad	N	45	7.41–104.77 (47.01)	0.1–39.31 (6.79)			0–1.48 (0.42)

[a]Sample type (reservoir (R), well (W), spring (S), qanat (Q), water distribution network (N)).
*ND = Not detectable.

Cr	Ni	Pb	As	Co	Ba	Se	Hg	Reference
			386–2,490			7–7.5		[S23]
(4.2)	(5.02)	(2.86)		(3.9)				[S24]
0.006–0.076	0.345–1.9	0.016–0.83	0–0.017	0.057–0.58	1.035–13			[S25]
(1.66)		(0.18)	(0.54)		(38)	(0.5)	(0.1)	[S26]
(12.1)		(14.6)						[S27]
	5–60	5–35	5–60					[S28]
			(2.88)					[S29]
		3.7–24.3						[S30]
		(8.48)						
(90)								[S31]
36–58	100–182	45–88						[S32]
ND	ND	ND	1–358	ND	3–101	ND	1–8.6	[S33]
1–280		10–120						[S34]
(28)		(45)						
1–100		1–900						[S35]
0.001–0.01	0.15–7.9	1.2–8.6	0.38–16.4	0.1–0.5	3.29–144.3	0.8–20.2		[S36]
								[S37]
		1–4	3–210					[S38]
20–130		0–840	0–90	20–50		10–490		[S39]
			0–1,500			0–19		[S40]
3.9—20.9	5.7–26.1	7.5–11.3		0–0.75	26.4–30.2			[S41]
0–15.2	0–13	0–8.76	0–9.3	0–48		0–2	0–1	[S42]
5–59			3–150					[S43]
21.4–23.9			<1–69.1		5–105		<1–6.5	[S44]
				172–204				[S45]
		6.4–68	1.7–31.9					[S46]
		0.88–16.43	0.38–12.72					[S47]
		(2.56)	(2.53)					
			0–99					[S48]
			(15.6)					
		0.47–12.7						[S49]
		(9.52)						
	0–124	0–1553	0–42				0–96	[S50]
	(39.15)	(657.45)	(10.13)				(26.27)	
ND-79.3		ND-72.5						[S51]
(13.6)		(20.1)						
0–12.2	1.4–29.8	0–103						[S52]
0–8		0–109						[S53]
(1.8)		(33.5)						
57–92								[S54]
0.185–34.395		3.55–65.7						[S55]
(8.3)		(15.3)						
0.04–0.16								[S56]
(0.044)								
0.39–10.76		0.35–8.27						[S57]
(5.08)		(3.2)						

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