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Review of Heavy Metal Concentrations in Iranian Water Resources

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A B S T R A C T

Urbanization, industrial development, mining, and agriculture all contribute to the pollution of the environment. Water resources are considered to be a vital part of the environment and are especially impacted by pollution from heavy metals. Because of the detrimental effects of heavy metal contamination on public health, the present study reviews previous research on Iranian water resources in terms of concentrations of heavy metals in the last 20 years. This study will be the first step toward managing and solving this critical public health concern. This study is a systematic review that aims to investigate the concentrations of heavy metals in Iranian surface and groundwater resources. Iranian and non-Iranian databases, including Iran Medex, SID, Google Scholar, Scopus, and ISI Web of knowledge, were reviewed for papers over the last 20 years from 1992 to 2012. Thirty-nine relevant papers were analyzed. Most studies reported the concentrations of heavy metals to be above the standard level. In groundwater resources, concentrations of Pb and Cd are above medium level, whereas in surface water resources, concentrations of Pb, Cd, Ni, Cr, and Fe are above the standard level. Accordingly, the increase in heavy metal concentrations is due to the pollution of mining and related industries, and also the excessive use of pesticides in agricultural land, and so on. Regarding high the concentration of heavy metals in several areas, particularly around industrial and agricultural sites, the government should administer strict environmental regulations to reduce the concentrations of these metals in order to protect the environment and public health from damage; otherwise, irreparable damages will occur to the environment and public health.

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Introduction

Urbanization, industrial and agricultural development, and mining have polluted the environment [1]. Heavy metals are major pollutants that pose a particular threat to the environment [2]. These metals are released through various industries such as dyeing, metalworking, battery production, textiles, printing, horticulture, metallurgy. If the wastewater of these industries is not treated properly, heavy metal concentrations in surface water and groundwater will increase [3], making the water resources non-potable. Hence, significant expenses are justified to reuse and re-treat these resources [4].

Heavy metals are inorganic compounds with a density greater than 6 g/cm and a weight 4 to 5 times greater than water [4,5]. They are placed between groups 3 and 16 in Mendeleev's periodic table.

In addition, heavy metals have a high affinity for humic acids, organic clays, and oxides coated with organic matter [6,7]. They are persistent and viable in the environment, can accumulate in plants and organisms, lead to various enzyme dysfunctions in human organs, and cause various cancers and acute and chronic toxicity [8]. Studies have shown that in many countries, especially developing ones, the concentrations of metals in surface and ground water resources are growing fast because of a lack of awareness of environmental legislations and regulations [9]. Iran, as a developing country, is exposed to this threatening concern. Groundwater pollution is an impairment of water quality by chemicals, heat, or bacteria to a degree that does not necessarily create public health hazards, but adversely affects water for domestic, agricultural, municipal, or industrial use [10-12]. In several parts of the country, heavy metal concentrations in surface water and ground water exceed standards prescribed by the national authorities and WHO [13,14]. For example, it is reported that in 1992, 2006, and 2008, the concentrations of cadmium, zinc, and arsenic in water resources were above the standard level [14-16].

Considering the importance of detecting contaminants in water and because of the environmental and public health risks associated with these contaminants, the aim of the present study is to review previous studies about the concentration of heavy metals in groundwater and surface water resources in Iran in a 20-year period. Thus, integrated and coherent data in this field will enable us to take the first step in managing practices to resolve the health concerns associated with heavy-metal pollution. These data will provide some information by which we can decide if the reviewed water resources are healthy or not. Finally, this review provides some recommendations to resolve the water resources problems. Because this study is a review and not a survey, no section on funding was included.

Materials and Methods

In this study, both local databases, such as Iran Medex, Irandoc, and SID, as well as international databases, such as Google Scholar, Scopus, ISI Web of Knowledge, were used. In addition, the scientific databases of the WHO (Medicus/WHO/EMR), the Directory of Open Access Journals, Elsevier, and PubMed were examined. Simple searches were conducted using terms such as "heavy metal," "groundwater," "water resources," and "surface water." Papers were collected with publication dates ranging from 1992 to 2012. Note that "heavy metal" was our main research term in this study. Secondary search terms were "ground water," "surface water," and "water resources." **Fig. 1** summarizes the study selection process.

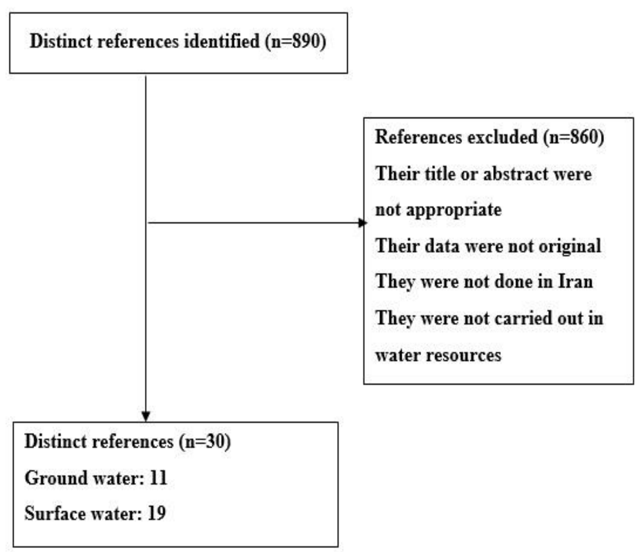

Figure 1. Selection process used in the systematic review of studies on heavy metals in water resources.

Reliable and valid resources and papers were collected to conduct this review study, and some associate professors and full-time professors of Environmental Health Engineering have evaluated the study for the same. Therefore, it can be concluded that the research validity and reliability is not under question so that in review papers the validity and reliability is not calculated by making the use of regular formula.

Results

The results of different studies on the concentration of heavy metals in surface and ground water resources in different parts of Iran are categorized in **Tables 1** and **2**.

Arsenic (As)

A total of ten studies were identified for inclusion in the review. This review study, on the whole, provided a total of 15 citations. Five studies met the inclusion criteria. No unpublished irrelevant studies were obtained. The literature presented here is shown in **Table 2**. Arsenic, which is a rare element in the Earth's crust, is a carcinogen metalloid. It is found in surface water bordering stone quarries. This metalloid also enters the environment through the excessive use of pesticides and insecticides [41,42]. Inorganic arsenic compounds are more toxic than the organic compounds [43,44]. Arsenic contamination of drinking water has been reported in several parts of the world [45]. The Iran and WHO standard for arsenic in drinking water is 0.01 mg/L [46]. Regarding the investigated papers, the minimum amount of arsenic concentration was 0.00097 mg/L in Ali Abad Katul, while the maximum amount of Arsenic concentration was 0.032 mg/L in the southern part of the Sarcheme Cooper Mine of Kerman. According to the standards, apart from a study conducted by Pirsaheb and colleagues, the concentration of arsenic is above the standards specified by WHO and Iran [14,38,39].

Chromium (Cr)

A total of ten studies were identified for inclusion in the review. This review study, on the whole, provided a total of 18 citations. Sixteen studies met the inclusion criteria regarding chromium concentration in ground and surface water resources.

No unpublished irrelevant studies were obtained. The literature presented here is shown in **Tables 1** and **2**. Chromium enters into the environment as a result of activities such as alloy preparation ,chrome plating, corrosion inhibiting compounds, textiles, printing, photography, tanning, and the like [41].

According to a WHO report, about 93%–98% of chromium enters into the body through food and 1.9% 7% of it enters into the body through water [38]. The Iranian and the WHO standard for chromium is 0.05 mg/L [46].

In this study, the minimum amount of chromium concentration recorded was on Mobarakeh surface waters (0 mg/L), and the maximum amount was measured in Shahnama in Shahrud (780 mg/L), which was used for floriculture irrigation [23,24]. In studies of surface water, at Anzali Wetland, Karun River, Gomishan Wetland, Shahrud, Shiraz KhoshRud, and Gavkhoni Wetlands, chromium concentration levels were observed to be above the standard level [21,22,24,27,31,33].

The studies conducted in eight cases report that the minimum chromium concentration was in Ali Abad Katul (0.0023 mg/L) and the maximum concentrations in groundwater was in Hamedan (0.107 mg/L) [16,38]. In studies conducted in Sistan–Baluchestan, Kerman, and Hamedan, the chromium concentration level was above the standards [14,16,36].

The sources of pollution in water samples in Sistan–Baluchestan and Kerman were, respectively, related industrial wastewater discharges and proximity to the copper mines of Sarcheshmeh [14,36].

Cadmium (Cd)

A total of ten studies were identified for inclusion in the review. This review study, on the whole, provided a total of 13 citations. Twelve studies met the inclusion criteria regarding cadmium concentration in ground and surface water resources.

No unpublished irrelevant studies were obtained. The literature presented here is shown in **Tables 1** and **2**. Cadmium has some side effects on humans including liver and lung damage, hypertension, kidney failure, birth defects, carcinogenesis, and mutagenesis. Cadmium in the soil and water is absorbed by crops and it may enter into the food chain [38,41].

The designated standard for cadmium should be 0.003 mg/L, which is based on the WHO and Iranian standards [46]. In the present study, 12 studies were examined regarding cadmium concentration in surface water. The minimum amount of cadmium concentration in surface water was 0.0002 mg/L in Mobarakeh city, and the maximum amount of cadmium concentration in surface water was 4.850 mg/L in Shahrud. In ten reviewed studies, cadmium concentration was above the WHO and Iranian standards [16,22,25,31].

Table 1: Heavy metal concentrations in Iran surface water resources (µg/l).

Row	Place	Season[¥]	Fe	Co	Zn	Cr	Pb	Ni	Mn	Cu	Cd	Year	Reference
1	South West of Iran	-	-	-	-	-	0.12-0.63*	-	-	-	-	2011	Hoseini *et al* [17]
2	Gamasiab Hamdan	-	19	-	13	-	12*	11	-	11	-	2010	Babaee *et al* [18]
3	Golestan Gorganrud	S	56	1.17	-	1.53	-	1.01	79	1.17	-	2009	Bagheri *et al* [19]
4	Golestan	S	-	-	-	-	-	2-299*	-	0.1-172.9	-	2009	Bagheri *et al* [20]
5	Gomishan pond & Gorgan bay	W	-	-	93	73.9*	154*	-	-	-	101*	2009	Hasanpour *et al* [21]
6	Anzali pond	-	-	15.9	85.3	85.2*	18*	51.6*	-	34.7	3.20*	2008	Ghazban *et al* [22]
7	Mpbarake	S	-	-	-	0-2.26	-	40-80*	-	0-0.7	0.2-1.3	2008	Noruzi *et al* [23]
8	Shahrud	A	-	-	347990*	780*	7550*	-	-	-	4850*	2008	Nazemi *et al* [24]
9	Zanjan	W	-	-	58.5	-	13.9*	-	-	-	5.9*	2007	Mohamadian *et al* [25]
10	Ahwaz	-	257	-	3180	-	8.48	-	30.6	168	0.97	2007	Savari *et al* [26]
11	Khaoshkrud	S A	*	-	1700*	190*	70*	80 *	250*	30	30*	2005 & 2007	Salati *et al* [27]
12	Gavkhuni wetland	-	-	-	75	54*	1140*	480*	58	760	730*	2002-2006	Dastjerdi *et al*[28]
13	Rudshur Kerman	W	10980*	-	688	-	116*	-	-	771	26*	2005	Karbasi *et al* [29]
14	Anzali pond	A	-	-	110	-	-	-	-	-	-	2004 & 2005	Ardalan *et al* [30]
15	Esfehan	W Su	-	-	standard	-	100*	-	-	standard	-	2002	Sertaj *et al* [31]
16	Siahrud	W	300*	-	32	-	142*	-	-	1	5*	2001 & 2002	Charkhabi *et al* [32]
		S	837*	-	18	-	103*	4	228*	-	1		
		Su	144*	-	123	-	45	1	272*	3	2		
		A	243*	-	183	-	76*	4	114*	0	-		
		W	122*	-	-	-	43	35	57	1	10*		
17	Tajan	S	465*	27.9	62.8	-	24.9	13.2*	35	5.8	12.1*	2001	Saeedi *et al* [13]
		Su	1767*	22.1	66.7	-	58.5*	28.5*	74.5	29.3	80.3*		
		A	985*	22.9	58.6	-	41.3	22.3*	63.1	24.9	62.5*		
		W	391.5*	23.1	49.8	-	20.3	10.9*	28.5	4.5	9.7*		
18	Karun	W	-	-	-	1.7-18*	-	69.3-110.7*	-	5.5-70.3	-	1996	Diagomanolin *et al*[33]
		Su	-	-	-	0.7-9.8*	-	41-60.7*	-	0.5-28.7	-		
19	Hamdan	-	-	-	-	107*	514*	-	-	-	118*	2005	Karimpour *et al* [16]

[¥]W =Winter, A =Autumn , Su = Summer, S= Spring

*More than standard levels

Table 2: Heavy metal concentrations in Iran ground water resources (µg/l).

Row	Place	Season[¥]	Fe	Co	As	Zn	Cr	Pb	Ni	Mn	Cu	Se	Cd	Year	Reference
1	Kermanshah	-	37.07	0.21	0.99	15.88	4.79	1.28	1.88	2.07	4.91	0.18	0.06	2011	Pirsaheb *etal*[34]
2	Kashan	S Su A	-	3.74	-	167.8	3.66	2.78	5.1	-	76.5	-	0.45	2010	Mizanzade *etal*[35]
3	Sistan&Baluchestan	S	-	-	-	-	*	*	*	-	-	-	*	2010	Rajaee *etal*[36]
4	Kerman	W	-	-	-	-	*	*	-	*	-	-	*	2010	Hasanzade *etal*[37]
5	Aliabad Katul	A		-	2.2	14.43	2.5	6.11	-	-	-	-	0	2009-2010	Rajaee *etal*[38]
		S			0.9	5	2.3	6.61	-	-	-	-	0		
6	Anar plain Kerman	S	-	-	17.6*	-	-	11.76*	-	-	-	-	0.3	2009	Dehghani *etal*[39]
7	Bardscan	S	509*	-	-	107	40	-	-	-	99	-	12*	2008	Abedini *etal*[40]
8	Kerman	North Mine	220.7*	-	15.4	15.4	-	10	15.4*	19.6*	55.3	10	-	2008	Kermani *etal*[10]
		South Mine	374.2*		32	34	-	26.4	38.9*	72.8*	56	24.6	-		
9	Zanjan	W	-	-	-	58.5	-	13.9	*	-	-	-	5.9*	2007	Mohamadian *etal*[15]
10	Ardebil		92	-	-	470	14	۵۲	7.7*	168	410*	-	1.2	2005-2006	Alighadr *etal*[2]
			93	-	-	339	15	0.6	4.3*	42	414*	-	0.6		
11	Hamdan	-	-	-	-	-	107*	514*	-	-	-	-	118*	1994	Karimpour *etal*[16]

¥W=Winter, A =Autumn , Su = Summer, S= Spring
*More than standard levels

The maximum level of cadmium concentration was in Shahroud and in the Gavkhoni wetland [24,31]. In some studies on groundwater, the minimum amount of cadmium concentration in groundwater was 0.000 mg/L, and the maximum amount of cadmium concentration in groundwater was reported 0.118 mg/L in Hamadan province. Furthermore, in 5 cases, the concentration was higher than the standard level [14,16,25,36].

Zinc (Zn)

A total of 11 studies were identified for inclusion in the review. This review study, on the whole, provided a total of 14 citations. Twenty five studies met the inclusion criteria regarding zinc concentration in ground and surface water resources. No unpublished irrelevant studies were obtained. The literature presented here is shown in **Tables 1** and **2**. In addition to natural factors, this metal enters into potable water tanks through tank corrosion, galvanized pipes, and brass connectors [41,42].

The Iranian and the WHO standard for zinc is 3 mg/L. In 13 studies, zinc concentrations were measured in the surface waters [13,18,22,25,31]. The minimum amount of zinc concentration measured in surface water was 0.005 mg/L in the Anzali Wetland in spring and the maximum amount of zinc concentration in surface water was 347.99 mg/L in Shahrud [24]. It was reported that zinc concentrations in surface waters were above the standard level in Shahrud and Ahvaz [24,26]. The minimum amount of zinc concentration in groundwater was 0 mg/L in Ali Abad Katul in the spring [38], and the maximum amount of Zinc concentration in groundwater was 0.47 mg/L in Ardebil in low-water seasons [2].

Selenium (Se)

A total of five studies were identified for inclusion in the review. This review study, on the whole, provided a total of six citations. Three studies met the inclusion criteria regarding selenium concentration in ground water resources. No unpublished irrelevant studies were obtained. The literature presented here is presented in **Table 2**. Selenium poisoning in humans occurs through contaminated food and water [47]. Symptoms of selenium poisoning are vomiting, diarrhea, loss of hair and nails, and neurological disorders [48].

The standard concentration of selenium is 0.01 mg/L according to Iranian and WHO standards. In the present study, with regards to the positive role of selenium in human health, only in two studies were the levels of selenium measured in groundwater. The minimum amount of selenium concentration in groundwater was 0.00018 mg/L in Kermanshah, and the maximum amount of selenium concentration in groundwater was 0.0246 mg/L in South Mine [14,34,4].

Cobalt (Co)

A total of four studies were identified for inclusion in the review. This review study, on the whole, provided a total of 7 citations. Five studies met the inclusion criteria regarding cobalt concentration in ground and surface water resources. No unpublished irrelevant studies were obtained. The literature presented here is shown in **Tables 1** and **2**. The International Agency of Research in America has introduced cobalt as a cause of cancer [49].

No standard for cobalt is defined by Iran and the WHO. In the three studies, it is shown that the minimum amount of cobalt concentration was 0.00117 mg/L for Gorgan Rud in Golestan Province [20], and the maximum amount of cobalt concentration was 0.279 mg/L for Tajan River in Mazandaran Province [13,20,22].

Nickel (Ni)

A total of eight studies were identified for inclusion in the review. This review study, on the whole, provided a total of 11 citations. Sixteen studies met the inclusion criteria regarding nickel concentration in ground and surface water resources. No unpublished irrelevant studies were obtained. The literature presented here is shown in **Tables 1** and **2**. Nickel is a hard, silvery-white element used in the construction of steel and other alloys. The most common effects of nickel on health are reactions to allergens [50]. Furthermore, studies show that nickel causes many problems such as respiratory cancers (larynx, nose and lungs), abnormalities like osteoporosis, disorientation of taste in mammalian embryos, headache, dizziness, seizures, sinus cancer, and dysfunction in the nervous system and heart [51].

The WHO and Iranian standard set for nickel concentration is 0.02 mg/L for. The papers reviewed measured nickel concentrations between 0.001 mg/L for Gorgan Rud of in Golestan Province and Siah Rud in Gilan Province [20,32] and 0.48 mg/L in the Gavkhuni wetland, which in six cases was above the standard level [13,20,22,23,31,33].

In four studies on groundwater, the minimum amount of nickel concentration was 0.00188 mg/L for Kermanshah Province [34], and the maximum amount of nickel concentration was 0.389 mg/L in the southern part of a copper mine in Kerman province [14]. In Sistan–Baluchestan and the southern part of a copper mine in Kerman province, two cases were reported to be above the standard level [14,36].

Iron and Manganese (Fe and Mg)

Iron is an essential mineral material for proper functioning of the body and physical health. Having an iron deficiency in the blood causes anemia, which is common during food shortages [52].

Generally, the body needs 4-5 grams of iron, while excessive iron consumption causes accumulation in target organs. Eating more than 30 mg of iron per kg leads to poisoning, and consumption of more than 250 to 300 mg of iron per kg causes death [8]. Oxygen-free water, a characteristic of groundwater, results in a regenerative environment and increases the solubility of iron and manganese. Therefore, after the movement of water to the surface, oxygen would be re-dissolved which results in the precipitation of iron and manganese [53]. One the problems of iron and manganese in water resources is an unpleasant smell and taste as well as colored spots on health services and clothing (corrosion of pipes). A positive effect of manganese has been observed in patients suffering from epilepsy.

The WHO and Iranian standard is 0.3 mg/L for iron. Six studies have been conducted to measure iron concentration in surface waters [13,14,16,19,26,32,54] in which the minimum amount of iron concentration in surface water was 0.019 mg/L in the Gamasiab River of the Hamedan Province [16], and the maximum amount of iron concentration was 10.980 mg/L in the Tajan River in Mazandaran Province; moreover, four studies were conducted on groundwater where the concentrations ranged from 0.037 mg/L in Kermanshah Province [34] to 0.509 mg/L for Bardaskan in Khorasan Province [40].

The WHO and Iranian standard for manganese concentration in water is 0.5 mg/L. In the current study, six studies examined the concentration of manganese in surface water; the concentration ranged between 0.0285 mg/L in the Tajan River of Mazandaran Province [13] and 0.25 mg/L in Shiraz Province Khaoshk Rud [27]. In all these studies, the manganese concentration was not above the standard. Moreover, four studies were performed on groundwater in which the manganese concentration ranged between 0.00207 mg/L (34) and 0.167 mg/L [2].

Lead (Pb)

The main source of lead can be found in drinking water contaminated by old plumbing containing lead [36]. It is estimated that 10%–20% of lead infections are because of the consumption of contaminated drinking water. Lead poisoning is more common for children because of their high sensitivity. The consequences of lead contamination are as follows: learning and behavioral disorders, lower IQ in children, damage to organs such as the liver, kidneys, the heart and the nervous system; blood and immune system damage; tumors; and many cancers [55]. Lead is deposited in a similar manner to calcium and is accumulated primarily in the human skeletal structure. Additionally, it has a high tendency to combine with the red blood cells [51,56].

The WHO and Iranian standard is 0.01 mg/L for lead concentration [46]. Fourteen studies have been conducted on surface waters [13,16,17,18,22,25,26,31]. Among them, the minimum amount of lead concentration was found to be 0.012 mg/L in the Gamasiab River of the Hamedan Province [18], and the maximum amount of lead concentration was measured to be 7.50 mg/L in Shahrud [24].

Thirteen cases among the all studies reported higher concentrations than the standard. In ten groundwater studies, the minimum amount of lead concentration was 0.0006 mg/L in Ardebil in wet seasons [2], and the maximum amount of lead concentration was 0.514 mg/L in the Hamedan Province [16]. Some concentrations have been reported to be above the standard level in Sistan–Baluchistan, Kerman, the Sarcheshmeh copper mine of Kerman, Zanjan (close to a lead and zinc factory), Ardabil, Hamedan and the Dashte Anar lead mine [2,14,16,25,36,38,39].

Copper (Cu)

Copper is naturally found in the environment but industrial effluents and agricultural activities has caused it to be more widely distributed [57].This metal is found in several foods, water and air; and an acceptable amount of it is essential to animals and humans health. One of the useful features of copper is to eliminate health threatening viruses including micro-organisms in drinking water [57]. However, copper over-consumption can cause many health problems in humans including a flu-like illness called metal fever [57]. The WHO and Iranian standards for copper concentrations in drinking water are respectively 2 and 1 mg/L. In 13 cases of studies on surface waters, copper concentrations was measured between 0 mg/L in Mobarakeh, Esfahan [31] and 0.168 mg/L in Ahvaz surface waters. In none of the studies were the copper concentrations above the standard [26].

In five studies investigating copper in groundwater, the minimum concentration was measured in Kermanshah (0.0049 mg/L) and the maximum concentration was obtained in Ahvaz (0.414 mg/L); in none of the cases were copper concentrations over the standard [2,14,16,35,40].

Mercury (Hg)

Mercury is a rare element in the earth’s crust. The greatest amount of the mercury enters into the environment as the result of the following human activities: coal-burning in power plants; household heating systems; incineration devices; and mercury, gold, copper, zinc and silver mining. High concentrations of mercury are considered a serious threat to human health, and the different forms of mercury have many toxic impacts on public health. It can be absorbed through inhalation, ingestion, and through skin contact. Mercury vapor mainly affects the central nervous system, but the main damages of mercury are directed to kidney and liver. Exposure to small amounts of mercury is considered a serious threat for infant health at both embryonic and birth stages [56].

International studies have shown that direct contact to mercury vapor causes nausea, vomiting, diarrhea, abdominal pain, hematuria, conjunctivitis, bronchitis, pneumonia, pulmonary edema, metal vapor fever, infertility, cardiac dysfunction, Alzheimer’s disease, neural and behavioral problems, impaired kidney function, neuro-psychotics disorders, damaging effects on the central and peripheral nervous systems, visual effects, oral problems, acute respiratory failure, dermatitis, negative effects on the fetus reproduction and genetic toxicity [58].

The most dangerous form of mercury is methyl mercury. The use of methyl mercury as a fungicide to protect seeds resulted in a substantial reduction in the number of birds that had consumed these seeds. The first case suffering from Minamata disease was discovered in the Minamata Bay in Japan in 1950 and the disease was caused by the consumption of mercury-contaminated rice. This disease has many neurological complications in humans including disruption of senses, Alzheimer's disease in old ages, and in severe cases, it leads to death [58].

Despite many problems caused by mercury, only in one of the studies, conducted by Pirsaheb and colleagues, the groundwater mercury concentration was 0.084 µg/L [34], whereas the WHO and Iran standard for mercury in drinking waters is 0.001 mg/L [46]. Because of the significance impacts of this metal on human health, it is recommended that more studies have to be conducted on groundwater and surface waters in different parts of Iran to investigate mercury concentration in risky areas. In **Tables 1** and **2**, respectively, the average concentrations of heavy metals in surface and groundwater resources are presented.

Discussion

The relationship between heavy metal concentrations and different seasons

In some studies, in different years, the relationship between seasons and concentrations of heavy metals in water resources has been considered and different results are obtained. In studies conducted by Alighadr, Ardalan, Charkhabi and Saeedi inArdebil, Anzali Wetland, Siahrud and Tajan River, respectively, levels of iron, zinc, lead, nickel, manganese and cadmium in warm and low-water seasons were more [13,15,22,32]; whereas, in studies conducted by Charkhabi, Diago, Saeedi and Alighadr in Siahrud, Karun, Tajan and Ardebil, respectively, the levels of some heavy metals such as iron, cobalt, chromium, nickel and copper in wet seasons have a maximum value [2,13,32,33].

In a study conducted by Saeedi on the Tajan River, concentrations of heavy metals (other than cobalt) were highest in summer [13] because of the severe reduction of Debbie, effluent pollutants and agricultural runoffs from the use of fertilizers and pesticides on croplands. In this case, cobalt was an exception because the origins of cobalt production are mainly through soil erosion and sediment, which occurs mostly in wet seasons like winter and spring. The results of a study that was conducted in Aliabad stated that the concentration of heavy metals, except lead, in autumn was the highest. The use of insecticides and pesticides results in an increase in heavy metals in autumn and winter in water resources in the area [38].

In another study conducted by the Manueline about Karun River, the concentrations of chromium (118.3), nickel (110.7) and copper (70.3) µg/l were at their maxima in the winter. Manueline states that because of the melting of snow of the Koohrang Mountains in spring, water volume increases, and this could be the reason of the dilution of the concentration of heavy metals in the river [33].

In a study on water resources, concentrations of metals, including iron, copper and chromium were measured to be 93, 414 and 15 µg/l, respectively, and were higher in the wet seasons. The concentrations of a number of other elements, including Pb, Ni, Mn and Cd were measured at 52, 7.7, 168 and 1.2 mg/L, which were the maximum in hot and low-water seasons [2].

Heavy metal concentrations in waters close to polluted sources

According to studies, we observed that the concentration of heavy metals in waters close to sources of contamination is higher. In a study conducted by Kermani in water sources close to the Miduk Mine, the concentrations of lead and selenium were measured at 26.4 and 24.6 µg/l, which are higher than the WHO standard [14]. Mohammadian also showed that lead and cadmium concentrations in water wells close to the Zanjan lead and zinc factories are 50% higher than the WHO standards [25]. In addition, another study published by the WHO states that the concentration of lead, zinc, and cadmium in water sources close to lead and zinc factories shows an increasing use after approximately one decade [56]. Vahid Dastjerdi argued that the concentration of all heavy metals in Gavkhoni wetland has increased in 1385, compared with the concentrations in the years 1381–1383. The main reasons for the increase of pollution are industrial and agricultural activities [31]. In a study conducted by Saeedi, heavy metal concentrations in the Tajan River are more than the standard level because of its proximity to the city, the Mazandaran Wood and Paper Factory, and the use of fertilizers and pesticides for agriculture [13]. The study conducted by

Manueline indicates that the Karun River is polluted by heavy metals including chromium, nickel and copper with concentration levels of 118.3, 110.7 and 70.3 µg/l, respectively, due to their proximity to industrial areas [33].

In the study conducted by Karbasi, concentrations of iron, lead, and cadmium were reported to be high because of the mining and agricultural activities in the studied area [54]. In a study conducted by Dehghani, it was found that lead concentration had an average of 14.4 µg/L and arsenic concentration averaged 30.3 µg/l and was above the national standard. He mentioned that the origins of such contaminations are the villages, road traffic, agriculture (pistachio farming), mines, and industries such as brick and pottery [39]. A study conducted by Charkhabi asserts that heavy metal pollution in Gilan Siahrud is due to urban development and agricultural activities. According to statistics of Gilan province in 1998, about 1.4 million cubic meters of sewage were discharged to the river [32].

As in previous years, because of the discharge of sewage by Iranian poplin, textile, and Pars Khazar factories, 2 million fish died in the river [59]. In addition to the impacts of agricultural activities and the use of fertilizers, iron, zinc and phosphate play a major role in the increase in the concentrations of heavy metals such as cadmium [32].

Study Limitations

- In this study, the concentration of heavy metals in surface and ground waters in all regions of Iran was not considered.
- It seems that there is no standard and balanced distribution of heavy metals in Iran.
- Sampling period in some areas was incomplete.
- In some areas, the study focused on either surface water or ground water but not both.
- In some areas, the authors failed to investigate all heavy metals at the same time.

Conclusion

This study shows that in many parts of Iran, the concentrations of heavy metals are high in surface or groundwater resources. Industrial, agricultural, and mining activities have major roles in increasing the concentrations of such metals.

Among the metals in groundwater, lead and cadmium concentrations exceeded environmental standards; whereas in surface waters, lead, cadmium, chromium, nickel, and iron were higher than their standards. The main reasons for such high concentrations are as follows: biological treatment and absorption of the metals by soil. According to the reviewed studies, the sources of lead, cadmium, nickel, chromium, and iron contamination were human activities, industries, mining, and the use of pesticides in agriculture.

Thus, regarding the undesirable effects of heavy metals on the environment and human health, the government is advised to reduce these negative effects by applying new laws and stricter environmental regulations. In addition, the government should implement short-term and long-term educational programs; otherwise, irreparable damage to the environment and public health will occur.

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