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REVIEW PAPER

Investigation of heavy metals in drinking water: A systematic review in Iran

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ABSTRACT

Toxic elements (heavy metals) generally include a wide range of elements such as cadmium, lead, arsenic, etc. which have a significant impact on water pollution, especially human drinking water. The main purpose of this study is to investigate the effect of these metals on the level of drinking water pollution in Iran. This research is a systematic review article, conducted by searching the Scholar, SID, Science Direct, PubMed, and MAGIRAN databases for related published papers from 2000 to 2019. Several keywords have been searched including heavy metals, drinking water, water pollution index, urban water supply network, and GIS. Searching the database, 812 articles have been found, out of which 190 articles were picked out by reviewing their titles and abstracts, and finally, 50 articles were selected by reading the entire text. Out of these 50 articles, 25 articles were selected for review due to their high conceptual relationship with this study. According to the results, in 54.17% of the studies, the concentration of heavy metals was higher than the standards of Iran and WHO. The concentration of Chromium, Arsenic, Cadmium, Lead, Copper, Iron and Manganese, in 18.75, 30, 16.66, 33.33, 7.69, 33.33 and 25% of the articles were higher than the permissible limits, respectively. In general, natural factors such as geology and human factors such as the effects of effluent, waste, metal and worn water supply networks cause drinking water pollution.

Keywords: Toxic elements, Water pollution, Carcinogens drinking water

Introduction

In the present era, with the growth of the industry and economy, and production of various kinds of compounds and chemicals, made for the well-being and comfort of humankind using natural resources, various pollutants are inadvertently introduced into nature, such as heavy metals. These pollutants have caused problems for both human health and the environment.[1] Humans are permanently and temporarily exposed to 35 toxic metals, among which, 23 of them are heavy metals. Some of them are naturally present in the environment and the diet in small amounts and are not harmful to human health. However, due to human activities, their concentration in the environment increases and endangers human health after entering the food chain.[1] Although the presence of some of these elements is partially necessary for the human food chain and living organisms, excessive concentrations of these elements can cause various adverse effects. Due to the cumulative properties of heavy metals in the body such as biodegradability, resistance to biodegradation, and strong tendency of their cations to sulfur, the activity of vital enzymes in the living organisms can be disrupted, and the probability of cancer and short-term and long-term genetic effects increases. Various

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activities have been carried out to remove these metals by chemical, physical, and biological methods and advanced oxidation processes in water and wastewater sources. Heavy metals such as lead, zinc, chromium, arsenic, and cadmium enter the human body through contaminated drinking water, air, and food. Then, they gradually deposit and accumulate in adipose tissue, muscles, bones, and joints. Heavy metals cause enzymes to break down and lose their enzymatic strength. These metals accumulate in ecological systems and their concentration gradually increases, resulting in adverse effects on living organs.[2] According to epidemiological studies, there is a link between heavy metals and health issues such as tooth decay, heart disease, kidney and nerve disorders, and various forms of cancer. These metals, in larger quantities, can cause morphological disorders, growth retardation, increased mortality, and genetic effects in humans.[3] In recent years, the importance of controlling the level of environmental pollution in natural waterways and drinking water has created a growing tendency to study and measure the sources of heavy metals and to find ways to prevent them from entering water resources. The presence of heavy metals in drinking water networks may be natural and its source may be the geology of the area or the impacts of human activity such as lead pollution due to the use of galvanized pipes in the municipal water supply network.[4] Due to the observed contamination of heavy metals affected by the age and deterioration of the water supply network, measuring and monitoring the concentrations of potentially toxic heavy metals in water resources is essential. According to the American Water Association, the share of urban water distribution networks in drinking water pollution to heavy metals is estimated about 29%, and the main source of concentration of these toxic metals in Iran has been reported in urban water distribution networks.[5] More than 90% of houses in the older parts of the city have metal water pipes containing lead in the water supply network. Adding lead to the alloy of water pipes reduces their brittleness due to pressure in the basement. Exhausted urban water supply networks and their metal fittings have been identified as the most important source of contamination of drinking water to heavy metals.[6]

In most cities of Iran, metal pipes have been used for the water supply network, and there is a possibility of their wear due to their long-term use. There are also other natural or anthropogenic sources of heavy metals contamination of drinking water in Iran. Due to the harmful and dangerous effects of heavy metals on human health, monitoring and investigation of heavy metal pollution in drinking water sources is important and necessary. Therefore, this study aimed to identify the most important sources of pollution to heavy metals and the types of these contaminants in Iran with a systematic review of related researches.

Materials and Methods

To review the researches conducted in Iran from 2000 to 2019, articles were searched in Persian databases using Scholar, SID, MAGIRAN and the international database, Google Scholar, Science Direct and PubMed. Since search engines on international sites such as PubMed are faster than Persian search engines, the search process is done through advanced search and screenwriting. Advanced search of Persian sites was used to find the desired results. The use of more general keywords reduces the likelihood of missing relevant articles and, in turn, increases the chances of unrelated articles being added, which can be identified and deleted during the content review phase. articles related to the objectives of the study were identified using keywords such as heavy metals, drinking water, water pollution index, urban water supply network, and geographic information system (GIS) related to water pollution.

Structured review of studies related to drinking water pollution to heavy metals in Iran: Identification of research gaps

In this study, according to Fig. 1, a total of 812 articles were searched by 2019, out of which, 297 articles in Science Direct database, 293 articles in Scholar database, 200 articles in MAGIRAN database, 12 articles in SID database, and 10 articles on the PubMed website were found. Screening of studies was performed based on the amount of water pollution to heavy metals. In the screening stage, all articles that did not have a thematic relationship in terms of text, abstract, or keyword were deleted. After reviewing 812 articles, 622 articles were excluded from the study for the above reasons. A total of the remaining 190 articles were reviewed in terms of content, and finally, 50 almost relevant articles were reviewed to analyze the information required from these studies, such as the location of the study, the type of pollution, the effects of heavy metal pollution, and the year of publication. To investigate the concentration of heavy metals in drinking water, the standard limits of these metals were used, which are shown in Table 1.

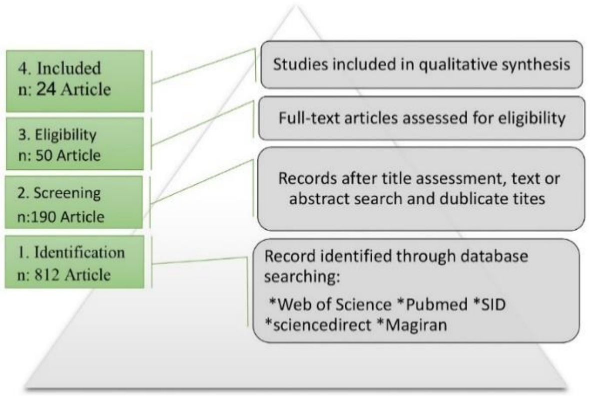

Fig. 1. Search strategy

Table 1. Permissible concentration of toxic elements in drinking water (WHO/IRAN)

Metals	WHO standard values (mg/L)	Iranian standard values (mg/L)
Ba	0.3	0.7
Mn	0.05	0.4
Ni	0.02	0.07
Hg	0.001	0.006
As	0.05	0.01
Cr	0.05	0.05
Pb	0.05	0.01
Cd	0.005	0.003
Zn	5	3
Fe	-	-

Results and Discussion

At first, several articles completely related to our goal were collected. Then the most repetitive keywords for the systematic search were selected. Finally, using Strategy Search, 50 articles related to these keywords (heavy metals, drinking water, water pollution index, urban water supply network, and GIS) and the purpose of this research, which was published from 2000 to 2019, were selected. The most relevant articles were selected based on the purpose of the research, by conducting detailed reviews and analysis in terms of content. Then, the articles were classified into three categories: 1) with high relevance (24 articles), 2) with moderate relevance (15 articles) and 3) with low relevance (11 articles). Since the number of candidate articles is large, only articles with a high degree of conceptual relevance were selected for a coherent and accurate review to identify the influencing factors as well as the concentration of heavy metals in drinking water (Table 2).

Table 2. Selected articles

Researcher	Source	Year	Study City	Heavy metals	The main results	Concentration of elements in water (mg/L)
Kamarehei *et al.*[7]	Ground water	2009	Boroujerd	As, Ba, Cd, Hg, Pb, Cr	Concentrations of these toxic elements were less than the allowable threshold.	Average concentration: Cd: 0.0014 Pb: 0.005 Cr: 0.0002 Hg: 0.0077 As: 0.0 Ba: 0.3222
Miranzadeh *et al.*[8]	Ground water	2010	Kashan	Cr, Cu, Zn, Pb, Ag, Co, Ni, Cd	Concentrations of these toxic elements were less than the allowable threshold.	Average concentration: Cr: 0.036 Cu: 0.76 Zn: 1.67 Pb: 0.028 Ag: 0.013

						Co: 0.037 Ni: 0.051 Cd: 0.004
Karbasi *et al.*[1]	Ground water	2010	AleShatr	As, Pb, Cr, Hg, Zn, Cd	Concentrations of these toxic elements were less than the allowable threshold.	Average concentration: As: 0.0033 Pb: 0.0788 Cr: 0.01 Hg/Zn/Cd: 0
Shahriari *et al.*[4]	Ground water	2010	Birjand	Cr, Cu	Cr concentration was higher than the allowable threshold.	Average concentration: Cu in the well: 0.0046 Cu in the home: 0 Cr in the well: 0.091 Cr in the home: 0.051
Alidadi *et al.*[9]	Ground water	2011	Mashhad	Cr, Cd, Pb	Pb concentration was higher than the allowable threshold.	Cr/Cd concentration below the standard Pb concentration above the standard.
Hosseinpour Feizi *et al.*[10]	Surface water and ground water	2011	Azarbaijan sharghi	As	Different concentrations in different regions	Out of 210 samples, the concentration of As in 41 samples was higher than the allowable limit.
Rajaei *et al.*[11]	Ground water	2012	Aliabad Katoul	As, Zn, Pb, Cd, Cr	Concentrations of these toxic elements were less than the allowable threshold.	Average concentrations in autumn and spring, respectively: Zn: 0.0143 & 0.0045 Pb: 0.006 & 0.0066 Cr: 0.0025 & 0.0023 As: 0.0022 & 0.0009 Cd: 0.00 & 0.00
Paraham *et al.*[12]	Ground water	2012	Gachsaran	Ba, Se, Hg, Ag, Cd, Cr, As, Pb, Cu, Zn	Concentrations of these toxic elements were less than the allowable threshold.	Average concentration: As: 0.0054 Cd: 0.0005 Zn: 0.559 Pb: 0.0018 Cu: 0.0082 Cr: 0.016 Ba: 0.38 Se: 0.005 Hg: 0.001 Ag: 0.0005
Shams Khorramabadi *et al.*[13]	Ground water	2013	Noorabad Lorestan	Cu, Pb, Zn, Cd, Fe, Mn	Concentrations of these toxic elements were less than the allowable threshold.	Concentrations of toxic elements in the drinking water distribution network also increased in winter.
Ahmadizadeh Fini *et al.*[14]	Ground water	2014	Bandar Abbas	Cd, Pb, Zn	The concentration of Cd in 13 samples (52%) and Pb in 4 samples (16%) was higher than the allowable threshold.	Average concentration: Cd: 0.0054 Pb: 0.020 Zn: 0.07
Tabandeh *et al.*[2]	Ground water	2015	Noorabad Lorestan	Cu, Pb, Zn	Pb concentration in 1 sample out of 9 samples was higher than the allowable limit.	The concentration of metals in winter is higher than in spring
Mansouri *et al.*[15]	Ground water	2015	Sanandaj	Pb, Cd, Cr, Cu	Concentrations of these toxic elements were less than the allowable threshold	Average concentration: Cd: 0.0004 Pb: 0.0011 Cr: 0.03 Cu: 0.3
Malakootian *et al.*[16]	Ground water	2015	Bardsir Plain	As, Cu, Pb, Cd, Fe	The concentration of As in 50% of the samples was higher than the allowable limit.	Average concentration: Pb: 0.004 Cu: 0.12 Cd: 0.008 Fe: 1.6 As: 2.1

SobhanArdakani[17]	Ground water	2016	Hamedan	As, Zn, Pb, Cd, Cr, Cu, Mn	Concentrations of these toxic elements were less than the allowable threshold	Concentrations in spring and summer, respectively: As: 0.058 & 0.068 Zn: 0.302 & 0.345 Pb: 0.056 & 0.048 Cd: 0.002 & 0.002 Cr: 0.0004 &0.0004 Cu: 0.321 & 0.265 Mn: 0.036 & 0.045
Aghavali *et al.*[18]	Ground water	2016	Ardestan	Pb, Cd, As	Pb concentration in 13 samples and As concentration in 3 samples out of 14 samples were higher than the allowable limit.	Average concentration: Pb: 0.524 Cd: - As: 0.078
Roudbari[19]	Ground water	2016	Semnan	As, Cd, Pb, Hg, Cr	Concentrations of these toxic elements were less than the allowable threshold	Toxic element concentrations were measured at 7 points between 2001 and 2015.
Mirzabeygi *et al.*[20]	Ground water	2016	Torbat Heidarie	Pb, Cd, Cr	Cr concentration in 11 samples out of 41 samples was higher than the allowable limit.	Cd: 0.005 Cr: 0.335 Pb: 0.018
Saraskanroud *et al.*[21]	Surface and ground water	2016	Khorramabad	Cr, Zn, Ba, Co, Al, Pb, Cd, Ni	Cr concentration in one sample was higher than the allowable limit	The concentration of elements had different distributions.
Nejatijahromi *et al.*[3]	Ground water	2017	Varamin	Cu, Pb, Zn, Cr, Cd, Co, Mn, Fe	The average concentration of Cd in both seasons and the average concentration of Pb in wet season is higher than the allowable limit.	Average concentrations in wet and dry seasons, respectively: Cu: 0.0475 & 0.0292 Cd: 0.08 & 0.0574 Mn: 0.0759 & 0.0671 Pb: 0.1248 & 0.059 Fe: 0.8892 & 0.57 Zn: 0.1078 & 0.0742 Co: 0.5752 & 0.1276 Cr: 0.0595 & 0.0345
Kolahkaj *et al.*[22]	Ground water	2017	Khuzestan	As	Concentration below the allowable limit.	Average concentration: As: 0.008
Valaei *et al.*[23]	Ground water	2017	Karaj	Cr, Cu, Pb, Mn, Zn	Mn concentration in 18 samples and Cu concentration in 8 samples out of 58 samples were above the allowable limit.	Maximum concentration of toxic elements: Cr: - Mn: 1.87 Zn: 0.45 Cu: 2.99 Pb: 0.001
Amanloo *et al.*[6]	Surface water and ground water	2019	Zanjan	Pb, Zn, Cu, Cd	Cd and Pb concentrations respectively 5.2 and 6.3 percent of the samples exceeded the limit allowed.	Average concentration: Zn: 1.6 Cd: 0.0068 Pb: 0.0261 Cu: 0.078
Ghaderpoori *et al.*[24]	Ground water	2018	Khorramabad	Zn, Pb, Cd, Cr, Cu	Concentrations of these toxic elements were less than the allowable threshold.	Average concentrations: Zn: 0.471 Pb: 0.032 Cd: 0.0042 Cr: 0.0508 Cu: 0.0679
Nahid and Moslehi [5]	Surface water	2008	Tehran	Cr, Zn, Ni, Cu, Pb	Pb concentration can be controlled by reverse osmosis.	Pb concentration was higher than allowed.

In 24 reviewed articles, the concentrations of Chromium (Cr), Arsenic (As), Barium (Ba), Cadmium (Cd), Mercury (Hg), Lead (Pb), Copper (Cu), Zinc (Zn), Silver (Ag), Cobalt

(Co), Nickel (Ni), Selenium (Se), Iron (Fe), Manganese (Mn), and Aluminum (Al) have been studied. The sum of articles focusing on each of these heavy metals as well as the number of articles that reported excessive concentrations of each, based on the standards are presented in Table 1. 13 out of 24 reviewed articles, equivalent to 54% of them, contained reports of toxic elements exceeding their permissible limit, which are presented in Table 3.

Table 3. Statistics of different types of toxic elements examined in the articles

	Names of toxic elements														
	Cr	As	Ba	Cd	Hg	Pb	Cu	Zn	Ag	Co	Ni	Se	Fe	Mn	Al
Total number of articles	16	10	3	18	4	21	13	14	2	3	3	1	3	4	1
Number of articles where the concentration is below the allowed limit.	13	7	3	15	4	14	12	14	2	3	3	1	2	3	1
Number of articles in which the concentration is higher than the allowed limit.	3	3	0	3	0	7	1	0	0	0	0	0	1	1	0
Percentage of articles in which the concentration is higher than allowed.	18.75	30	0	16.66	0	33.33	7.69	0	0	0	0	0	33.33	25	0

In the study of Shahriari *et al.*, measurements have been conducted based on which the concentration of Chromium exceeded the allowable level (more than 0.05). Geological reasons related to the Cretaceous sediments, which include ophiolites and coloured compounds were the main reason for this pollution.[4] In the research of Alidadi *et al.*, the concentration of lead measured was less than the standard amount only in April, but in other months exceeded the standard level. The high concentration of Pb was due to the use of an old and worn-out water supply system.[9] In the research of Hosseinpour Feizi *et al.*, drinking water has been contaminated with metals like arsenic, nitrate, etc. Since contamination occurs especially when sulfide oxidation is performed, one of the most important causes of arsenic contamination is identified to be geological factors. Other causes of arsenic pollution include geothermal, mining, and other human activities.[10] In the study of Ahmadizadeh Fini *et al.*, the concentration of Cd in 13 samples (52%) and lead in 4 samples (16%) was higher than the allowable threshold. The increase in Cd concentration in drinking water is due to excessive use of chemical pesticides and fertilizers containing phosphorus in agriculture.[14] In the research of Tabandeh *et al.*, the concentration of Pb in 1 out of 9 samples was higher than the allowable limit. In this study, factors such as municipal wastewater, agricultural activities and atmospheric sediments have been identified as having the ability to affect the concentration of toxic elements.[2] In the research of Malakootian *et al.*, the arsenic concentration was higher than the permissible level in 50% of the samples. The high concentration of arsenic is due to Geogenic resources.[16] In the study of Aghavali, *et al.*, the concentration of Pb in 13 samples and arsenic concentration in 3 samples out of 14 samples was higher than the allowable limit. In this article, one of the most important reasons for the increase of these toxic elements identified as geological conditions as well as the use of chemical pesticides in agriculture.[18] In the study of Mirzabeygi *et al.*, the concentration of Cr in 11 samples out of 41 samples was higher than the allowable limit. The reason for the increase in the concentration of these toxic elements can be due to geological conditions and mining activities.[20] In the study of Saraskanroud *et al.*, the concentration of Cr in a sample was higher than the allowable limit. The increase in Cr content has a geological origin.[21] In the study of Nejatijahromi *et al.*, the mean Cd concentration in the wet and dry seasons and also the mean Pb concentration in the wet season were higher than the allowable limit.

One of the effective reasons for increasing the concentration of toxic elements in this area is water returned from agriculture, industrial-domestic wastewater, as well as the quality of effluent transferred from Tehran to this plain.[3] In the study of Valaei *et al*., investigating 58 samples, the concentration of Mn in 18 samples and the concentration of Cu in 8 samples were higher than the allowable limit. The most important reasons that can increase the concentration of toxic elements in this area are factors such as waste disposal sites, industries in the plain, geological features and the type of water supply network.[23] In the study of Amanloo *et al*., the concentrations of Cd and Pb exceeded the permissible limits of 5.2 and 6.3% of the samples, respectively. In this study, the most important factor in increasing the concentration of these toxic elements was the use of worn galvanized pipes.[6] In the study of Nahid and Moslehi, it was shown that the concentration of Pb can be controlled by reverse osmosis. Most of the contamination enters the drinking water due to the deterioration of the piping system. The length of the path in which water transfers can be also effective in this regard. Also, it has been shown that if sampling is done in the early morning hours, the samples will contain more Pb.[5] In all reviewed articles, toxic elements with concentrations higher than the allowable thresholds were Mn, As, Cr, Cu, Cd, Pb, and Zn; they are presented in Table 4.

Table 4. Most important parameters and most polluted points

City		Toxic elements						
		Mn	As	Cr	Cu	Cd	Pb	Zn
Karaj		1.87	-	-	2.99	-	0.001	0.45
Birjand		-	-	0.0916	0.0046	-	-	-
Ahvaz		30.6	-	-	168	0.97	8.48	3180
Rey		1.363	-	2.813	0.335	0.03	0.5	1.3341
Zanjan		-	-	-	7.80	0.68	2.61	160.17
Alashtar		-	0.0033	0.01	-	-	0.0788	-
Torbat heydarie		-	-	33.5	-	0.59	1.8	-
Bandar Abbas		-	-	-	-	0.0054	0.020	0.07
Mashhad	Spring	-		10.37	-	1.08	3.98	-
	Summer	-	-	17.11	-	0.52	9.38	-
Noorabad	Fall	-	-	-	-	-	0.501	-
	Winter	-	-	-	-	-	0.501	-

Based on the results and also because safe water goes through steps along the route from supply sources to the place of consumption, within them may suffer from some cases of pollution such as heavy metal elements. Therefore, it is necessary to study and analyze the amount and concentration of these elements to define healthy drinking water. According to the values examined in the table 2, among all the studies, most of them pointed out that drinking water is not polluted and the concentration of heavy metals is standard. On the other hand, most studies have pointed to the pollution caused by Pb metal contamination, the main reason for which is the old and worn texture of the water pipes, which increases the concentration of heavy metals and it is necessary to take appropriate measures to solve this problem. Cr concentrations vary depending on the soil texture of the area and the amount of leakage which itself depends on the quality of the water pipes and their corrosion. The more carefully the water distribution networks are reconstructed, the lower the concentration of heavy metals in the water, and the less impact it will have on human health. Also, studies conducted in the wet and dried seasons show that the concentration of elements in the wet season has decreased compared to the dried season. The increase in the concentration of Ba in drinking water is due to the discharge of sewage from the excavation of the mine, the refinery, and the erosion of natural sediments.

The increase in the concentration of Zn in drinking water is due to the use of galvanized pipes to transfer drinking water. In other words, the presence of Zn can be attributed to industrial pollution. The presence of CO_2 and CL gases, SO_4 in water causes corrosion and destruction of the inner surface of the pipes, which has side effects. High concentrations of Cd due to environmental pollution has many reasons, including the entry of sewage or the use of chemical fertilizers in agriculture and the entry of drinking water resources. In most studies, drinking water pollution has been due to the presence of the elements Pb and Cd. The main reasons for this are the wear and tear of the water supply networks, the lack of a plan for the water supply network and reconstructions, the non-compliance with the standard conditions of wastewater disposal and transfer waste from various complexes.

Conclusion

In general, in most of the reviewed articles (in 54.17% of them), the concentration of toxic elements was higher than the allowable limit. The most important reasons for these pollutions were the characteristics of geology and water supply network, but factors such as mismanagement of waste, wastewater, and the distribution system of industries were also influential.

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