University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

Study of Contaminants in Iranian Drinking Water and their Health Outcomes: A Review

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Article Info

Article type:
Research Article

Article history:
Received: 22 Mar 2023
Revised: 5 May 2023
Accepted: 30 Jun 2023

Keywords:
Drinking water contamination
Carcinogenic risk
Nitrate
Heavy metal
Health Impacts

ABSTRACT

Contamination of ground and surface water resources with Nitrate (NO_3), Fluoride (F), Trihalomethanes (THMs), radon, and heavy metals is the most important global concern due to its possible health risks to people. This study reviews the drinking water contaminants and their health outcomes examined in Iran. A review search was conducted using Scopus, Web of Knowledge, PubMed, and Embase databases for associated released articles from 2014 to 2023, resulting in 86 articles relevant to the objective of this study.
According to the results of this review, different emerging contaminants were found in potable water, including THMs, NO_3, F, radon and heavy elements (i.e., As, Pb, Ni, Cd, Zn, Cu, and Cr). Health outcomes of exposure to radon, F, NO3, THMs, and heavy metals in potable water have been expressed in various epidemiological research studies. More than 65% of the studies reported hazard index (HI) or hazard quotient (HQ) of heavy elements to be greater than one in potable water in Iran for infants, children, teenagers, and adults. Children and infants are at higher health risk than adults in these areas.
The level of Arsenic, Cadmium, Lead, Nickel, Zinc, and Chromium, in 26, 26, 17.39, 13.04, 8.69, and 4.3% of the papers was more than the allowable limits, respectively. Various groups of emerging pollutants have been found in potable water in Iran, while epidemiological research studies on their health outcomes are still insufficient.

Cite this article: Fadaei, A. (2023). Study of Contaminants in Iranian Drinking Water and their Health Outcomes: A Review. *Pollution*, 9 (4), 1450-1474.
https://doi.org/10.22059/POLL.2023.356999.1839

DOI: https://doi.org/10.22059/POLL.2023.356999.1839

INTRODUCTION

Potable water may be polluted with heavy elements such as cadmium (Cd), arsenic (As), lead (Pb), copper (Cu), mercury (Hg), nitrate(NO_3), fluoride(F), Trihalomethanes (THMs), and radioactive compounds (Keramati *et al.* 2018). The health risk from these compounds in potable water have not been calculated. The compounds hazard quotient (HQ) or non-carcinogenic risk, hazard index (HI), and carcinogenic risk (CR) metrics were applied to calculate the heavy elements potential hazard. Some of heavy metals are hazardous. Heavy metals risk assessment involves the recognition and quantification of the risks related to the use of chemical materials by considering their possible effects on the users of these chemicals via different exposure pathways (Essien *et al.* 2022). The most important objectives of risk assessment is recognizing the hazards associated with each chemical, assessing the level of exposure to harmful or toxic chemicals, evaluating the hazards related to the adverse or toxic chemicals, and estimating the possible adverse effects of exposure to these chemicals (Qasemi *et al.* 2018c).

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Based on the current studies, about 80% of diseases and more than 33% of deaths in under development nations are caused by the use of polluted water (Daud *et al.* 2017). Based on

studies carried out in various districts of Iran like Shiraz, Gonabad, and Bajestan, the level of nitrate in potable water resources is more than the Iran standard(Maleki and Jari 2021). Source of contaminant in the ground and surface waters is related with petroleum industry, mine wastes, municipal wastewater, agricultural activities, and solid waste disposal(Radfarda *et al.* 2019).

There is wide difference in F levels in the natural waters of various districts of Iran with levels upper and lesser than the optimal span suggested by WHO and Iran standard limit(Dehghani *et al.* 2019). Arsenic (As) is a carcinogenic constituent in the groundwater, resulting from both human made and natural resources. Arsenic pollution of water has become a severe public health matter in several nations of Asia such as Myanmar, Bangladesh, China, Pakistan, Vietnam, India, and Iran (Qu *et al.* 2018, Shams *et al.* 2022).The WHO standard for Hg, Pb, As, Ni, Cd and Cr in potable water is 0.001, 0.05, 0.05,0.02, 0.005 and 0.05 mg/L, respectively (WHO 2011). Owing to the adverse and hazardous effects of heavy metals, THMs, NO_3, F, and radon on human health, surveillance and study of these pollutants in potable water sources is significant and essential. These contaminants cause a limitation in using water by people. Therefore, the removal techniques are essential to remove these contaminants. Techniques are used to treat water are physical, chemical, and biological methods(Abdulkhaleq Alalwan *et al.* 2022, Mohammed Ali *et al.* 2022). There are limited studies regarding contaminants of drinking water and health outcomes in Iran. The existing studies are only related to the risk assessment and exposure to contamination through potable water in Iran. The purpose of this review is to study of contaminants in Iranian drinking water and their health outcomes.

OVERVIEW OF RADON, NITRATE, FLUORIDE, HEAVY METALS AND THMs

Radon

Radon is one of the carcinogenic radioactive gases. Radon causes radioactive risk to the public through digestion and respiration(Suresh *et al.* 2020). Uranium and thorium exist in small values in most rocks, soil, and water. Radon gas diffused from rocks and soil can go to air, ground, and surface waters (Sharma *et al.* 2017) Radon causes lung cancer, gastric cancer, and other cancers(Malakootian *et al.* 2014b). Most radon values are within the standard value of 100 Bq/L-11.1 Bq/L suggested by WHO and EPA standard limit(WHO 2011). Based on studies carried out in various districts of Iran like Ramsar, Dehshir - Baft, and Kerman Province, the level of Radon in potable water resources is lower than the Iran standard (Malakootian *et al.* 2014b).

Nitrate

Nitrate is one of the most widespread pollutants in groundwater resources worldwide, and its attendance can intensely prevent safe drinking water accessibility; high nitrate values lead to restricted confidence on such sources (Fadaei and Sadeghi 2014, Wagh *et al.* 2020). Nitrate transpires groundwater through various sources, such as the employment of synthetic nitrogen fertilizers and manure, septic tank outlets, pesticides, sewage pits, absorption wells, wastewater outlets, decay of dead beasts and plants, and unsuitable waste disposal (Lee *et al.* 2020). Nitrate elevated levels in potable water can lead to infant methemoglobinemia and may be related to the incidence of spontaneous abortion and unproductivity difficulties. NO_3 is the precursor in the shape of nitrosamines (strong carcinogens), increasing the risk of different types of cancer, including nasopharynx, stomach, pancreas, esophagus, colorectal, and brain cancers (Mohammadpour *et al.* 2022). Various epidemiological studies of different human populations have revealed a relation between stomach cancer and NO_3 in potable water (Picetti *et al.* 2022). Based on the WHO guidelines and Iran standards for potable water quality, the

NO_3 level in potable water to preserve the health of the prone subpopulation, bottle-fed infants, is 50 mg/L in the shape of NO_3^-(Cotruvo 2017).The levels of nitrate in drinking water for Ilam city, Behbahan city, Robat-Karim city and Semnan city were 8.13±5.4, 15.05, 2.1and7.27±5.1, respectively(Kalteh *et al.* 2022).

Fluoride

Fluoride is one of the water elements that are essential in low levels but dangerous at high levels. Fluoride is vital in a little quantity for mineralization of bone and teeth. Higher intake of fluoride causes decay of teeth enamel called fluorosis and other damages, such as digestive disorders, harm to the endocrine, thyroid, and liver, and loss of growth and intelligence(Rezaei *et al.* 2019a, Fadaei 2021). The optimal level of fluoride in potable water for public good health determined by the WHO is between 0.5 and 1.5 mg/L at a temperature ranging from 12 to 25°C (WHO 2011). Fluoride enters into water sources from natural and industrial resources. The concentration of fluoride in potable water in Yazd and Dayyer were 0.64±0.25 and1.29 to 3.1 mg/L, respectively(Keshavarz *et al.* 2015, Yousefi *et al.* 2019a).

Heavy metals

Heavy metals in potable water are recognized to be poisonous and a severe menace to human health according to witness from several areas of the globe(Fadaei 2022). Even though some heavy elements (e.g., Cu, Mn, and Cr) are necessary for humans, their excessive levels may be toxic. Besides, other metals (e.g., Cd, Hg, As, and Pb) are greatly toxic at very little levels with no known advantages for human health. The aforementioned heavy metals cannot be removed from aqueous media and are often recovered through physicochemical and biological methods and pose harmful risks to human health and aquatic environments. Identifying the heavy metals content of groundwater is the essential purpose to find out the sources, fate, and possible health risks of heavy metals(Liu and Ma 2020). The EPA set the range of 1×10^{-4} to1×10^{-6} as risks boundary. A carcinogenic health risk of a value of 1×10^{-4} is considerably elevated and generates health hazards (Radfard *et al.* 2018b).

Trihalomethanes

The most important THMs are bromodichloromethane ($CHCl_2Br$), chloroform ($CHCl_3$), dibromochloromethane ($CHClBr_2$), and bromoform ($CHBr_3$)(Nadali *et al.* 2019). THMs formation is affected by various factors, such as pH, UV-ray absorbance at a wavelength of 254 nm (UV-254), alkalinity, chlorine dose, water temperature, dissolved organic carbon (DOC), and contact time of water. THMs have health effects, including spontaneous abortion, birth defects, low birth weight, intrauterine growth retardation, prematurity, and even cancers. The exposure to and uptake of THMs can be oral, dermal or can occur by inhalation (Sriboonnak *et al.* 2021).The USEPA states that the highest allowable levels of THMs in usable water is 80 µg/L(USEPA 2012).Various studies have been monitored the level of THMs in potable water supply and stated different span of level include Ardabil (11.89 ± 6.64 to 101.97 ± 58.51 µg/L) and Tehran (0.81to 9.00 µg/L)(Sadeghi *et al.* 2019).

METHODS

This study provides a review of the current literature providing a comprehensive review during the period between 2011 and 2022. The last systematic search was conducted from Apr 2022 to Feb, 2023. This study is mainly focused on contaminants and their health outcomes. Databases like Google Scholar, Science Direct, PubMed, Cochrane, Scopus, and Web of Science were employed to retrieve various articles on the topic. Keywords, such as “drinking water”, “Nitrate”, “Radon”, “Trihalomethanes”, “Heavy metals,” “Fluoride”, “Health risk assessment”, “non-carcinogenic risk”, “carcinogenic risk”, and “ground water” were used to retrieve proper articles. The exclusion criteria were unavailability of full text of the article, review studies, book reviews, guidelines, letters-to-editors, protocols, theses, papers submitted to conferences, white papers, etc. A total of 300 peer reviewed publications were accessed according to the relation of titles to the research. These were further screened to 150 after reading through their abstracts. In the present study, AM.F systematically checked (2 times) title-abstract and full text to avoid bias. The data related to the contamination type, location, level, health outcomes, source, and references were then extracted. After screening the full text of the articles, 86 were used for this study, excluding the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reference(Moher *et al.* 2009).To estimate the contaminants and potential carcinogenic and non-cancer health risk caused via ingestion and dermal absorption of contaminants in the water of Iran, Hazard Quotients (HQ), Hazard Index (HI). Eq. 1 and Eq. 2 taken from the Environmental Protection Agency (EPA) were applied to determine HQ and HI, respectively, where ADD and RfD represent the average daily dose and the oral reference dose of contaminants are expressed in mg/kg-day(Dashtizadeh *et al.* 2019).

$$\mathrm{HQ}=\frac{ADD}{RfD} \tag{1}$$

$$\mathrm{HI}=\sum_{i=1}^{n}\mathrm{HQ} \tag{2}$$

DISCUSSION

Radon and health outcomes

Table 1 shows a summary of radon contamination of potable water and its health outcomes in Iran. We found 13 studies reporting radon in potable water and its health outcomes. The lowest mean concentration of radon in drinking water was 0.1988±0.0619 Bq/L in Jask and the highest radon level was 4.667 ± 2.077 and 31.550 ± 4.912 Bq/L in Zarand (Table1). The concentration of radon in potable water in Zarand was slightly higher than EPA guideline limits. The minimum and maximum annual effective dose of radon for adults was observed in Minab(0.003-0.006 mSv/y) and Rafsanjan (181.5 mSv/y) cities, respectively and the lowest and highest annual effective dose for children was observed in Minab(0.007-0.011 mSv/y) and Rafsanjan (284.9 mSv/y) cities, respectively(Table1). Radon levels varied in different locations because of the sampling time, geographic parameters, and geological data. There is no health risk posed by radon outside potable water use in the studied articles (Table1). Keramati et al.(2018) reported that the effective ingestion dose of radon for users in Gillan, Mashhad, Mazandaran, and Kerman was more than the WHO standard of 0.1 mSv/y(Keramati *et al.* 2018). Mousavi et al.(2009) found Khorasan Razavi (Mashhad) to have the maximum cancer incidence rate between 2003 and 2006 (Mousavi *et al.* 2009). The findings of another study by Messier and Serre showed that the chance of stomach cancer increased as a result of an increase in the level of radon in the groundwater (Messier and Serre 2017). Naji et al.(2021) found that the average effective dose of radon in potable water in Baghdad(Iraq) city was considerably less than the EPA and WHO prescribed limit of 500 Bq/m^3 and 1 mSv/y, respectively (Naji *et al.* 2021). A study reported that the maximum proportion of radon enters the human body by breathing, through bath, and from potable water, and found that radon concentration is over 100 Bq/L in drinking water in Portugal (Inácio *et al.* 2017). A study by Abu-Khader et al. indicated that the mean concentration of radon in the groundwater in Jordan is 5.77 Bq/L which is within the admissible universal range (Abu-Khader *et al.* 2018). The results of another study by Mamun and Alazmi found the annual effective dose of radon contact for infants, children, and adults to range between 0.05 and 16.24 μSv/y, with an average level of 5.89 μSv/y in groundwater

Table 1. Radon contamination of drinking water and its health outcomes in Iran

Location	Level	Source	Ref
Minab	Geometric mean level of Radon:5℃: 0.78±0.06 and 15℃: 0.46±0.04 Bq/L and effective doses: adults(0.006 and 0.003 mSv/y), children(0.011 and 0.007 mSv/y)	Groundwater	(Fakhri *et al.* 2016b)
Bandar Abbas	Range : 0.87-0.384,mean: 0.232±0.7 Bq/L	Drinking tap water	(Fakhri *et al.* 2016a)
Rafsanjan	Range :0.323 -13.90 Bq/L maximum annual effective dose: adults181.5 and children248.95 mSv/y	Groundwater	(Malakootian *et al.* 2014a)
Bam	Mean of range:1.2 - 9.88 Bq/L, annual effective dose: max = 30.82 and min= 3.74 mSv/y for adults	Groundwater	(Malakootian and Nejhad 2017)
Aliabad Katou	Mean radon: 2.90 ± 0.57 Bq/L	Drinking water	(Adinehvand *et al.* 2016)
Jask	Range : 105-304,mean: 0.1988±0.0619 Bq/L	Tap water	(Fakhri and Mirzaei 2015)
Kermanshah	Mean: 2.96 ± 0.966 Bq/L, annual effective dose: 0.0072 ±0.00 24 mSv/y for adults	Drinking water	(Pirsaheb *et al.* 2015)
Taft	Range:0.88-43.01 Bq/L, Annual effective dose:0.00-0.11 mSv/y	Groundwater	(Malakootian *et al.* 2016)
Zarand	Range:4.667 ± 2.077 and 31.550 ± 4.912 Bq/L	Groundwater	(Rahimi *et al.* 2022)
Mehriz	Range ; 0.187 - 14.8 Bq/L, annual effective dose: 0.0005-0.04 msv/y	Groundwater	(Malakootian and SALMANI 2015)
Borujerd	Mean: 3.451 Bq/L, annual effective dose: 5.4×10^{-3} to 72.1×10^{-3},mean: 34.9×10-3 msv/y for all age groups	Drinking water	(Adinehvand *et al.* 2019)
Zarand	Range: 5.16- 14.4 Bq/L, annual effective dose<0.1msv/y	Drinking water	(Darabi Fard *et al.* 2020)
Lalehzar fault	Range:0.74 – 26.88 Bq/L, annual effective dose:2.29-52.7µsv/y	Drinking water	(Malakootian *et al.* 2015)

in Saudi Arabia(Mamun and Alazmi 2022). The findings of a study by Khaled et al. indicated that radon level range from 22.0±0.7 to 118±3 mBq/L in all kinds of potable water in Qena city (Egypt), and found the annual effective dose due to aspiration and digestion of radon to be below the limit prescribed value of 100 µSv/y (Khaled *et al.* 2020). The lowest and highest concentration of mean radon levels was respectively 0.10 ± 0.02 Bq/L and 9.2 ± 0.02 Bq/L in potable water in Saudi Arabia and the annual effective dose for children and adults ranged from about 0.51 µSv/y to 46.69 µSv/y(Abuelhia 2019). A study by Wook Cho et al. indicated that radon concentration ranges from 0.1 to 2393.5 Bq/L in potable water in South Korea (Cho *et al.* 2019). The findings of a study by Khaled et al. showed that radon level ranged from 3.16 to 16.68 Bq/L with an average concentration of10.39 Bq/L in potable water in Turkey and the annual effective dose due to aspiration and digestion of radon was 52.72 µSv/y (Kuluöztürk *et al.* 2017).

Nitrate and health outcomes

Table 2 shows a summary of nitrate and nitrite concentration in potable water and their health outcomes in Iran. Figure1 shows a summary of nitrate concentration in different water

Table 2. Nitrate and nitrite in drinking water and their health outcomes in Iran

Location	Level	Health outcomes	Source	Ref
Tehran	Mean ±SD:36.15±14.74,Range:4.52 - 80.83 mg/L	Hazard quotient (HQ): Children (1.71), Infants (1.24) ,Teenagers (1.2) ,Adults (0.96)	Ground water (40%) and surface water (60%)	(Kalteh *et al.* 2022)
Kakhk	Mean ±SD= 20.00 ± 14.81mg/L	HQ ≥ 1 for 40.4 % of the areas	Groundwater	(Qasemi *et al.* 2023)
Gonabad and Bajestan	Range: Gonabad=1.8 - 82.2,mean :29.3 and Bajestan=5.5-84.3,mean:37.95mg/L	non-carcinogenic riskof Gonabad and Bajestan; infants > children > adults	Groundwater	(Qasemi *et al.* 2018a)
Hormozgan province	Range:0.3 to 30 with Mean ±SD: 7.37 ± 5.61 mg/L	HQ<1 all age groups	Groundwater	(Mohammadpour *et al.* 2022)
Isfahan	Rural: range: 0.4-137,mean:33.72 mg/L and urban: 2.9-209,mean:38.87 mg/L	HQ mean > 1 for infant	Groundwater	(Aghapour *et al.* 2021)
Divandarreh	Mean: nitrate (31.37 ± 18.87), nitrite(1.45 ± 0.90) mg/L	Total target hazard quotient: adults(1.78) and children(1.54)	Groundwater	(Ali *et al.* 2018)
Kashan	range 4.2 to 51.3 mg/L and mean (±SD): 20.5 ±10.2 mg/L	HQ: infants(1.9), children(1.44), teenagers(1.11), and adults(0.87)	Groundwater	(Rezvani Ghalhari *et al.* 2021)
Sanandaj	Rural: Nitrate; range=1.28-80,mean:17.7 mg/L Nitrite;range0.03-1.65 and Urban: nitrate; range=0.28-27.27,mean:7.69 mg/L nitrite, range=0.15-0.66 mg/L	(HQ > 1) for all age groups	Groundwater	(Rezaei *et al.* 2019a)
Bardaskan	Mean:17.56±17.69,minimum(0.00) and maximum(72.2) mg/L	HQ> 1 for children, teenagers, and adults	Groundwater	(Radfarda *et al.* 2019)
Khash	Range: 6 to 35 and mean 16.083 mg/L	HQ< 1 for children, teenagers, infants, and adults	drinking water	(Radfard *et al.* 2018a)
Azadshahr	Well:mean16.8 mg/L, range 1- 36 mg/L. springs: mean 22.7,range 5- 51 mg/L	HQ>1 for 41% of children and infants	Groundwater	(Qasemi *et al.* 2018a)
South Provinces	Ilam: Mean ± SD(14.58 ± 2.62) Bushehr(9.97 ± 3.14), Khuzestan(52.77 ± 19.15), Fars(64.63 ± 19.92), Lorestan(22.85 ± 6.91)mg/L	Relationship between gastrointestinal cancer prevalence and nitrate, carcinogenic risk of nitrate Khuzestan(8.8 × 10−5), Fars(1.3 × 10−5)	Groundwater and surface water	(Jaafarzadeh *et al.* 2021)

Continued Table 2. Nitrate and nitrite in drinking water and their health outcomes in Iran

Location	Level	Health outcomes	Source	Ref
Saravan	Annual average level(5 years) 14.24 mg/L	Maximum HQ >1 for all age groups	Groundwater	(Azhdarpoor *et al.* 2019)
Tabriz	Rural: mean= 13.1±12.8 Urban: mean=14.6±12.8 mg/L	HQ< 1 for all age groups	Drinking water	(Mohammadi *et al.* 2021)
Shiraz	Mean(5years):25.54 mg/L	HQ< 1 for all age groups	Groundwater	(Badeenezhad *et al.* 2021)
Kazerun	Mean: nitrate(13.5),nitrite(0.008) mg/L, Max: nitrate(25.5), nitrite(0.0056) mg/L	HQ< 1 for all age groups	Drinking water	(Golaki *et al.* 2022)
Kamyaran	Mean: 22.42 ± 11.44 mg/L	HQ< 1 for all age groups	Groundwater	(Jamshidi *et al.* 2021)
Mashhad	Range : 8-166.1,mean:42 mg/L	Health Risk Index (HRI) < 1 for children	Groundwater	(Zendehbad *et al.* 2022)
Kurdistan	Range :0.5-225, mean:31 mg/L	HQ=0.55 for men,0.83 for women,1.65 for children	Drinking water	(Maleki and Jari 2021)
Qorveh	Range :3.20-428 ,mean:152.95±115.49 mg/L	HQ >1 for all age groups	Groundwater	(Solgi and Jalili 2021)

Fig. 1. Nitrate concentration in different water resources in Iran

resources in Iran.

We found 20 studies reporting nitrate/ nitrite and their health outcomes. The minimum (7.37 ± 5.61 mg/L) and maximum nitrate level (152 ± 115.49 mg/L) was found in Hormozgan province and Qorveh city, respectively (Fig 1 and Table2). An elevated nitrate value in groundwater resources is an intense water resources administration concern in several places in Iran, like Qorveh city, Fars, and Khuzestan province. The HQ was lower than one for all age groups in Hormozgan province, while in Qorveh, the HQ was higher than one for all age groups. There is an association between gastrointestinal cancer prevalence and nitrate. The carcinogenic risk of nitrate in Fars province was 1.3×10^{-5}. The non-carcinogenic risk assessment estimated for the studied groups in Bajestan and Gonabad was as follows: infants>children>adults (Table2). More than 36% of the studies in Iran had HQ>1 for infants, children, teenagers, and adults. About 47% of the studies in Iran had HQ>1 for at least one age group. The findings of a study by Yu et al. indicated that the nitrate level in the ground waters in rural districts of Yantai, China, ranges from 0.075 to 166.4 mg/L. About 63.3% of the monitoring points exceeded the WHO recommended level of 11 mg/L, and the risk of exposure in each group was graded as: children > adult female > adult male(Yu *et al.* 2020). Another study found nitrate in groundwater of India to range from 17 to 120 mg/L, with an average concentration of 58.74 mg/L. Nearly, 57% of instances exceeded the highest allowable limit of Indian potable water standard, and the values of non-carcinogenic risks in children were 1.38 and 1.15 fold higher than those in females and males(Adimalla 2020). In a study, Picetti et al. reported a positive relationship between nitrate contact with stomach cancer (OR(Odds Ratio)=1.91, 95% Confidence Interval=1.09-3.33) per 10 mg/L increase in NO_3^- in potable water across the world(Picetti *et al.* 2022). Another study indicated that patients consuming nitrate-polluted groundwater with concentrations above 50 mg/L were at approximately a three-fold elevated risk of colorectal cancer (OR= 2.82, 95% Confidence Interval= 1.075–7.395, $p < 0.05$)(Fathmawati *et al.* 2017). A study by Królak and Raczuk showed that nitrate levels in dug wells range from 0.153 to161.1 mg/L. The maximum health risk associated with methemoglobinemia occurs for neonates(Królak and Raczuk 2018). In a study, Hameed et al. reported the NO_2 level to range between 0.00 and 0.005 with a mean concentration of 0.002, and NO_3 level of 0.00–14.086 with a mean concentration of 1.34 mg/L in potable water of Vehari, Punjab, and Pakistan. They also found the HQ<1 for all age groups(Hameed *et al.* 2021). In their study, Ahada and Suthar found the NO_3^- concentration of 38.45–198.05 mg/L, and reported HQ of 1.09–5.65 for adults and 2.56–13.20 mg/L for children in Punjab, India(Ahada and Suthar 2018). Khan et al. reported the maximum nitrate levels of 100 mg/L in groundwater in India. They found that children and woman groups are more vulnerable to health risks as compared with men(Khan *et al.* 2021). Li et al. reported the level of nitrate to range between 2.50 and 22.21 mg/L with a mean concentration of 10.62 mg/L in groundwater, and to range between 2.50 and 15.11 mg/L with a mean of 8.32 mg/L(Li *et al.* 2019). In a study, Rao et al. reported nitrate levels in groundwater in India to range from 2 to 700 mg/L, and found the HI to be more than the allowable limit of 1 for infants, children, and adults(Rao *et al.* 2021).Overall, increase nitrate level in the groundwater in Iran and other countries as a result of inorganic fertilizer for agricultural actions, industrial operations, leachate from landfill and human and livestock waste contaminations(Lee *et al.* 2020, Rezvani Ghalhari *et al.* 2021).

Fluoride and health outcomes

Table 3 represents a summary of fluoride concentration in potable water and its health outcomes in Iran. Figure 2 shows the low and high fluoride levels for each country. The minimum mean value of fluoride was 0.22 mg/L in Kurdistan(Sanandaj) and the highest mean fluoride level was 8.10±1.44 mg/L in west Azerbaijan (Poldasht) (Table 3). The relationship between fluoride and fertility, infertility without recognized etiological parameters, and abortion without known etiological parameters was found in west Azerbaijan (Poldasht)(Yousefi *et al.* 2017). The HQ was higher than one for all age groups in Kurdistan (Sanandaj) province. About 41% of the studies in Iran had HQ>1 for at least one age group. In their study, Kom et al. found the fluoride concentration of 0.2-2.4 mg/L in groundwater in India. They reported the levels of total hazard index (THI) for infants (mean = 4.76), children (mean = 2.95), and adults (mean =1.57) (Kom *et al.* 2022). Another study by Tokath et al. demonstrated that fluoride levels in Turkey potable water range between 0.02 and 0.192 mg/L, and reported the HQ levels

Table 3. Fluoride of drinking water and health outcomes in Iran

Location	**Level**	**Health outcomes**	**Source**	**Ref**
Maku	Cold season: Mean ±SD(1.65±.44),range(0.29-6.68), Warm season: Mean ±SD(2.75±3.33), range (0.1-11.4)mg/L	HQ>1 for children, teenagers, and adults a elevated risk of fluorosis	Ground waters	(Fallahzadeh *et al.* 2018)
Bahabad	Range(0.22- 2.35mg/L	A considerable relationship between the high values of fluoride in the water and the prevalence of fluorosis	Groundwater	(Dehbandi *et al.* 2018)
Kakhk	Range(0.2-2.8),mean ±SD(.32 ± 0.17) mg/L	HQ < 1 for children and adults	Groundwater	(Qasemi *et al.* 2023)
Ardakan	Range(0.9–6),mean(2.92) mg/L	HQ>1 for all age groups	Groundwater	**(Mirzabeygi *et al.* 2018)**
Poldasht	Range(0.22-10.30) mg/L	A considerable relationship between the fluoride levels in the water and the prevalence of skeletal fluorosis	Groundwater	(Mohammadi *et al.* 2017)
Poldasht	Range(.46-10.30) mg/L and low use mean(1.9±0.37) and high use mean (8.10±1.44) mg /L	There were no statistically considerable differences in the reproductive factors(Abortion, infertility, fertility) between the low and high F regions	Groundwater	(Yousefi *et al.* 2017)
west Azerbaijan	Range(0.68-10.30) mg/L	Hypertension, Body Mass Index, and Waist Circumference, fluoride concentration in potable water (P = 0.041) had a considerable relationship with incremented blood pressure	Groundwater	(Yousefi *et al.* 2018b)
Sarayan and Poldasht	Range(1.5 -3) mg/L	Association between the level of fluoride in potable water and abortion	Groundwater	(Moghaddam *et al.* 2018)
Poldasht and Piranshahr	Range(0.25-3.94) mg/L	Relationship between the high level of fluoride in potable water and intelligence quotient of children	Groundwater	(Karimzade *et al.* 2014)

Continued Table 3. Fluoride of drinking water and health outcomes in Iran

Location	Level	Health outcomes	Source	Ref
Gonabad and Bajestan	Gonabad: range(0.17-1.21), mean(0.48) and Bajestan: range(0.43-2.2), mean(0.98) mg/L	HI>1 for 44% children and 90% infants in rural districts of Gonabad and Bajestan. non-carcinogenic health risk: infants > children > adults	Groundwater	(Qasemi *et al.* 2018b)
Mashhad	Range(0.01-0.63), mean(0.35) mg/L	HQ<1 for children, and adults	Groundwater	(Ghaderpoori *et al.* 2019)
Sanandaj	Rural: range (0.01–1.1), mean(0.27) mg/L and Urban: range(0.02–0.94), mean(0.22) mg/L	HQ > 1 for all age groups	Groundwater	(Rezaei *et al.* 2019a)
Poldasht	Range(0.27-10.3) mean(1.70) mg/L	HQ > 1 for all age groups Agh ot logh and Sari soo areas	Groundwater	(Yousefi *et al.* 2018a)
Iran(whole country)	Range(0.23-1.86), mean(0.53±0.3) mg/L	Relationship between the average concentrations of F and the hypertension prevalence	Groundwater	(Amini *et al.* 2011)
Bardaskan	Mean:0.56±0.18,minimum(0.2) and maximum(1.036) mg/L	HQ< 1 for children, teenagers, and adults	Groundwater	(Radfarda *et al.* 2019)
Larestan	Range(0.35–3.46),mean(1.64) mg/L	70.6, 48.2 and 34.4% of HQ levels for children, teenagers and infants> 1	Groundwater	(Dehghani *et al.* 2019)
Saravan	Range (0.1-1.76),annual average level(0.42-0.67) mg/L	Maximum HQ >1 for all age groups	Groundwater	(Azhdarpoor *et al.* 2019)
Bazman	Range(0.5 - 3.75) ,mean(1.66) mg/L	HQ>1 for children, teenagers, and adults	Groundwater	(Naderi *et al.* 2020)
Showt	Range(0.00-5.50) ,mean(1.47±1.43) mg/L	(HQ > 1 for children, teenagers, and adults	Drinking water	(Yousefi *et al.* 2019b)
Jazmourian	Range(0.4 - 4.8) mg/L	HQ< 1 for children	Groundwater	(Abbasnejad *et al.* 2022)
Kazerun	Mean(0.52),Max(0.72) mg/L	HQ< 1 for all age groups	Drinking water	(Golaki *et al.* 2022)
Kurdistan	Range(0.1-1.1) ,mean(0.34) mg/L	HQ< 1 for all age groups	Drinking water	(Maleki and Jari 2021)
Isfahan	Range (0.02- 2.8),mean(0.29) mg/L	Mean HQ< 1 for all age groups	Groundwater	(Aghapour *et al.* 2018)

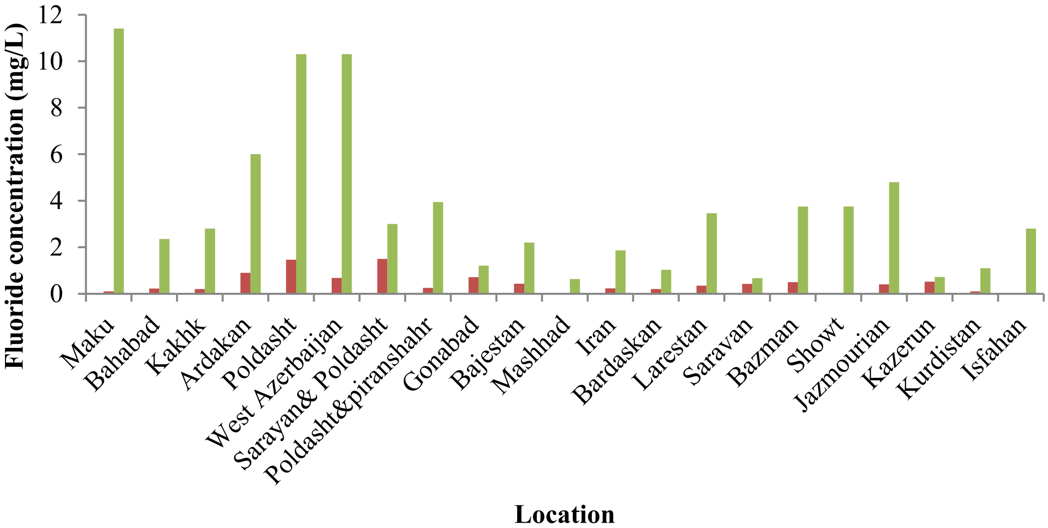

Fig. 2. Low and high F levels for each county

for all age groups to be lower than one(Tokatlı *et al.* 2022). Giwa et al. found that fluoride levels in Nigeria potable water range from 0.35 to 3.46 mg/L, leading to fluorosis, dental fluorosis (38%), skeletal fluorosis(27%), dental and skeletal(22%), and free fluorosis (13%) in this population (Giwa *et al.* 2021). Khan et al. reported the highest fluoride level of 1.78 mg/L in India's groundwater. They found child and woman groups to be more sensitive to health risks compared to men(Khan *et al.* 2021).In their study, Li et al. reported the fluoride level to range from 0.54 to 1.95 mg/L with a mean concentration of 0.96 mg/L in groundwater, and varies from 0.5 to 1.66 mg/L with a mean of 1.05 mg/L. Children were at upper health risk than adults in this study (Li *et al.* 2019). Mukate et al. reported the fluoride level to exceed the acceptable limit of 1.5 mg/L in groundwater in Bhokardan, and found the highest THQ level of fluoride to be 2.42 for children(Mukate *et al.* 2022). A study by Adeyeye et al. indicated that the mean level of fluoride in groundwater in China was 2.09 mg/L, and showed fluoride health risks to be as follows: infant > children > adult(Adeyeye *et al.* 2021). Rao et al. reported fluoride levels in India's ground waters to range from 0.3 to 4.7 mg/L. They found the HI to be higher than the allowable limit of 1 for infants, children, and adults(Rao *et al.* 2021). A study by Rahman et al. indicated that fluoride levels in Bangladesh potable water range from <0.50 to 1.5 mg/L, and the HQ is higher than the allowable limit of 1 for infants and children(Rahman *et al.* 2020). Gugulothu et al. demonstrated that fluoride levels in India's groundwater range from 0.22 to 5.41 mg/L. They found the mean Health Risk Index (HRI) to be 2.82 and 4.34 for adults and children, respectively (Gugulothu *et al.* 2022). In a study, Su et al. studied F^- and NO_3^- pollution and the potential health risks in Jiaokou region, China. They reported that infants and children are more prone to non-carcinogenic health hazards of F^- and NO_3^- than teenagers and adults(Su *et al.* 2021).

Heavy metals and health outcomes

Table 4 represents a summary of heavy elements concentration (i.e. Cd, As, Cr, Pb, Ni, Zn, Al, Cu, Mn, and Fe) in potable water and health outcomes in Iran. The range and mean levels of heavy elements (i.e. As, Cd, Pb, Cr, Zn, Ni, Cu, Al, Mn, and Fe) present in potable water in different areas of Iran are represented in Table 4. The lowest mean level of As in potable water was 0.18±0.05 µg/L in Mashhad and the highest As level was 41.6±28.18 µg/L in Rafsanjan. About 26% of the studies had As level above the WHO and 1,053 Iranian standards limits(Iran

Table 4. Heavy metals in drinking water and their health outcomes in Iran

Heavy metal type	Location	Level	Health outcomes	Source	Ref
Cd	Gonabad and Bajestan	Range :Gonabad (0.087 to 14.32),mean:2.864 and Bajestan (0.417 to 18.36),mean:5.984 μg/L	Mean HQ<1 for all age groups	Groundwater	(Qasemi *et al.* 2019)
As	Sistan and Baluchestan	Range :0.42- 5.8 μg/L	The highest HQ=1.09 for children. Excess lifetime cancer risk: adults (8.90×10^{-5}) and for children (1.4×10^{-7})	Groundwater	(Radfard *et al.* 2019)
Fe, As	Neyshabur	Mean: Fe (9.78 ± 5.61), As (1.30 ± 2.99) μg/L	HQ<1, total risk: 40.164×10^{-7} to 174.8×10^{-7}	Groundwater	(Saleh *et al.* 2019)
Zn, Ba, Ni, Cu, Cr, Pb, Mo, Cd,	Khorramaba	Mean: Zn (47.01), Ba (81.13), Pb (3.2), Ni (3.47), Cr (5.08), Cu(6.79), Cd (0.43)Mo(0.51) (μg/L)	HQ<1, carcinogenic risk> 1×10^{-6} for Ni, Cd, Pb and Cr	Groundwater	(Mohammadi *et al.* 2019)
Pb, Cd, Cu	Kerman	Pb mean:0.0165±0.0045,Cd:0.00021±0.0006,Cu:0.00059±0.008 mg/L	HI Child=2.78, HI Adult = 0.126	Tap water	(Abedi Sarvestani and Aghasi 2019)
As, Cd ,Cr	Joghatai	Range:As:0.0152-0.0220,Cr:0.0194-0.1806,Cd:0.003-0.0018 mg/L	HI>1 and carcinogenic risk: As>Cr>Cd	Groundwater	(Shams *et al.* 2022)
Pb, Cd, As	Dehgolan's Villages	Pb: Mean: 0.0026 mg/L, Cd: 0.0009 mg/L, As: 0.0068 mg/L	Carcinogenic risk for adults : 1×10^{-4} to 1×10^{-6}	Groundwater	(Rezaei *et al.* 2019b)
As, Pb, Ni, Cr, Hg	Mashhad	Mean ±SD:As(0.18±0.05), Pb(0.58±0.206), Ni(1.69±2.15), Cr(4.94±5.53),Hg(0.01±0.048) μg/L	HQ < 1, total carcinogenic risk 1.33×10^{-4}(children) and 7.38×10^{-5}(adults)	Drinking water	(Alidadi *et al.* 2019)
Pb, As,Cr, Ni ,Cu, Zn, Al, Mn, Fe	Shabestar	Range :As(2-49), Pb(<3-29), Cr(<3-24),Ni(<1-17),Cu(<3-33),Zn(<1-235),Al(<10-237),Mn(2-50),Fe(19-1420) μg/L	HQ>1 for children and adults HI mean: children (4.37),adults (1.87)	Groundwater	(Barzegar *et al.* 2019b)
As, Pb, Cr, Ni, Zn, Al, Mn, Fe, Cd	Khoy	Range :As(1-52), Pb(2-21.5), Cr(4-35),Ni(8-17.6),Cd(1-4.6),Zn(0.5-150),Al(20-132),Mn(1-1500),Fe(13.2-1200), Co(3-19.3) μg/L	HI mean =4.37 for children and 1.87 for adults	Groundwater	(Barzegar *et al.* 2019a)

Continued Table 4. Heavy metals in drinking water and their health outcomes in Iran

Heavy metal type	Location	Level	Health outcomes	Source	Ref
Pb, Cd, As, Cu, Fe, Mg, Cr, Mn	Rafsanjan	Mean ±SD :As(41.61 ± 28.18), Pb(9.44 ± 6.08),Cd (0.914 ± 0.23),Cr(4.89 ± 3.91), Cu(9.86 ± 7.84),Fe(0.084 ± 0.05), Mg(12.59 ± 8.86),Mn (0.010 ± 0.01) µg/L	Mean HQ children(9.246), adults(2.972)	Groundwater	(Eslami *et al.* 2022)
Pb, As, Mn, Hg	West Azerbaijan	Mean: Pb(0.3±0.8), As(4±30), Mn (2±0.7), and Hg(2±111) µg/L	HI>1 for As, and HI<1 for Pb, Mn, and Hg, mean total risk<1	Groundwater	(Jahani *et al.* 2022)
Cr, Pb, Cd	Torbat heydariyeh,	Range :Cr (2.2 - 173.7), Pb(0.5 – 10) , and Cd(0.2- 0.9) µg/L	HQ:1.04 and HI:1.149 for infant,HI: Pb>Cd >Cr, HI and HQ: Infant> children> teenager> adult	Groundwater	(Soleimani *et al.* 2022)
Cr, Pb,Ni, and Cd	Divandarreh	Mean: Cr(18.37), Pb(2.7),Ni(9.13), and Cd(6.5) µg/L	HQ>1, mean HI for children=1.68 and adults =0.68	Drinking Water	(Ghahramani *et al.* 2020)
Pb, Cr, Zn, Cu, Mn, Fe, Cd	Varamin	Mean for dry and wet seasons: Pb(5.9, 12.48), Cr(3.45,5.95),Zn(7.42,10.78), Cu(2.92,4.75),Mn(6.71,7.59), Fe(57,88.92),Cd(5.74,8.02) µg/L	HI=0.583 for adults, HI=1.4 for children	Ground water	(Movafaghi Ardestani and Pardakhti 2020)
As, Cr, Zn Pb	Ghayen	Mean:As(11.375), Cr(6.188),Zn(36.281) and Pb(2.28) µg/L	HI=5.16 for Children, HI=1.35 for adults,	Ground water	(Sajjadi *et al.* 2022)
As, Cr,Cd Pb	Kurdistan	As(range:1-54,mean:3.5), Cr(0.1-53,6.76),Cd (0.1-0.2,0.11) and Pb(0.00-0.37,1.37 µg/L	HQ=4.74 for men,5.5 for women,11 for children	Drinking water	(Maleki and Jari 2021)
AS	Qorveh	Range :0.39-220.82 ,mean:30.16 µg /L	HQ <1 for all age groups	Groundwater	(Solgi and Jalili 2021)
Cd, As, Cr, Pb	Zahedan	Mean:Cd(0.0035),,As(0.0025), Cr(0.0015), Pb(0.003) mg/L	HI<1 for children and adults, carcinogenic trace elements: 10^{-6} to10^{-4}, low risk and low- medium risk	Drinking water	(Dashtizadeh *et al.* 2019)
Cd, As, Cr, Pb, Hg, Ni	Iran(whole country)	Mean:Cd(0.4),As(2.3),Cr(12.1),Pb(2.5),Hg(0.7),Ni(19.7) µg /L	Mean HQ: entire country(0.48),rural(0.65),urban(0.45)	Drinking water	(Naddafi *et al.* 2022)
As, Zn, Sb, Se	Gonbad - e - Kav u s	Mean: Zn (151.23 ± 227.98) , As (9.02 ± 6.7), Se (7.16 ± 4.94), and Sb (1.97 ± 1.07) µg /L	Mean HQ<1 for all age groups	Groundwater	(Sadeghi and Noroozi 2021)
As, Cd	Zabol	Mean: As(0.0407),Cd(0.0034) mg/L	Mean HI=9.62 for children,4.14 for adults, total carcinogenic risk = 1.79×10-3	Drinking water	(Shahriyari *et al.* 2020)

Continued Table 4. Heavy metals in drinking water and their health outcomes in Iran

Heavy metal type	Location	Level	Health outcomes	Source	Ref
Mn, Ba, Cd, Pb	Hamadan province	Dry season: Mn(0.08–25.63),Ba(0.15–70.13) and Wet season: Mn(0.08–20.03),Ba(0.84–65) μg/L , Cd and Pb<LOD	HI=0.29×10^{-3} for children and 2.17×10^{-3} for adults	Drinking water	(Shokoohi *et al.* 2021)
Cr	South Khorasan province	Range: 1.79 to 1017.05 μg/ L	HQ < 1 for 90.37% of samples	Drinking water	(Kazemi *et al.* 2022)
Cd, Pb, Zn	Bandar Abbas	Range: Cd(1-13),Zn(5-377),Pb (2-164) μg /L	HI: Pb> Zn>Cd	Groundwater	(Farimani Raad *et al.* 2021)

2010). The lowest mean level of Cd in drinking water was 0.43 μg/L in Lorestan (Khorramaba) and the highest Cd level was 8.02 μg/L in Varamin. About 26% of the studies reported Cd level to be above the WHO and 1,053 Iranian standards limits. The lowest level of Cr in drinking water was 4.94±5.53 μg/L in Mashhad and the highest Cr level was between 1.79 and 1017.05 μg/L in South Khorasan. Nearly, 4.3% of the studies reported Cr level above the WHO and 1,053 Iranian standards limits(Iran 2010), (Table 4). The lowest level of Zn in potable water was 7.42 μg/L in Varamin and the highest Zn level was 151.23 ± 227.98μg/L in Gonbad e-Kavus, and 13.04% of the studies reported Zn level above the WHO and 1,053 Iranian standards limits(Iran 2010). The lowest level of Pb in potable water was 0.00-0.37 μg/L in Kurdistan and the highest Pb level was 2-164μg/L in Bandar Abbas. About 39% of the studies found Pb level to be above the WHO limits. The lowest level of Ni in potable water was 1.69±2.15 μg/L in Mashhad. The highest level range of Ni in groundwater was <1-235 μg/L in Shabestar. The highest level range of Fe in groundwater was19 to 1420 μg/L in Shabestar, and 8.69% of the studies reported Fe level to be above the WHO and 1,053 Iranian standards limits. Others heavy elements like Hg, Ba, Cu, and Se were lower than WHO and Iran standards. Generally, natural parameters such as geology and human agents like the effects of effluent, solid waste, metals and worn water supply networks cause potable water contamination. More than 65% of the studies reported the HI/HQ values of heavy metals to be higher than one in potable water in Iran for infant, children, teenagers, and adults. The cancer risk (CR) level higher than one in million (10^{-6}) was commonly considered remarkable by the EPA(Radfard *et al.* 2018b). A study by Liu and Ma indicated that both the carcinogenic risks and HQs of Ni and Cr are more than the prescribed standard level in groundwater in China(Liu and Ma 2020). A study by Hussain et al. reported that the Mn, Ni, and Cr levels were 695, 1306, and 2593 ng/g, respectively in the potable water of Pakistan. They found the health risk index (HRI) levels to exceed the safe limits>1(Hussain *et al.* 2019). In a study by Khan et al., Pb and Cd contaminants in the potable water of Peshawar, Pakistan were found to be considerably higher than their highest acceptable limits set by WHO, and the HQ values were found to be >1(Khan *et al.* 2016). In a study by Duggal et al. the levels of B, Fe, Be, Al, Cr, Zn, Mo, As, Cu, Ba and Sb in Rajasthan were found to be lower than their corresponding allowable limits, the total excess lifetime cancer risk of elements contact was in accord to the suitable lifetime risks for carcinogens in potable water (10^{-6} to 10^{-4})(Duggal *et al.* 2017). Another study indicated that the HQ values of Cd, As, Cr, Pb, and Hg were greater than 1, and the HI level for children was higher than that for adults(Ahamad *et al.* 2020). In a study by Magesh et al., the mean levels of Pb, Ni, Cr, Cu, Mn, Zn and Fe in groundwater of India were reported to be 0.003, 0.007, 0.007, 0.007, 0.02, 0.066, and 0.269 mg/L, respectively, and the HQ levels were found to be less than one(Magesh *et al.* 2017). Im et al. demonstrated the range of levels of Fe (217.13 ± 301.03), Mn (102.36 ± 153.04), Cu (3.80 ± 3.56), Cd (0.01 ±

Table 5. Trihalomethanes in drinking water and their health outcomes in Iran

Location	Level	Health outcomes	Source	Ref
Ilam	THMS: mean(20 and 30.3) μg/L	Cancer Risk :Min(5.95 × 10^{-6}),Max(6.59 × 10^{-6})	Surface water	(Arman *et al.* 2016)
Hamadan and Tuyserkan	THMs: Summer(42.75±30.76) and winter (17.75±30.76) μg/L	Hamadan cancer risk:Male:1.4×10^{-5} and female: 4.8×10^{-5}	Groundwater	(Nadali *et al.* 2019)
Yazd	THMs :Winter (39),Fall(31) μg/L	Mean lifetime cancer risks (LTCR) were acceptable and low-risk levels, HI<1	Drinking water	(Mohammadi *et al.* 2020)
Ardabil	Bromodichloromethane(101.97 ± 58.51), Chloroform(85.18 ± 47.79), dibromochloromethane(51.67 ± 29.57)and Bromoform(11.89 ± 6.64) μg/L	Mean of lifetime cancer risks: ingestion(2.85×10^{-4}) inhalation(6.46×10^{-7}), and dermal(1.26×10^{-7})	Drinking water	(Sadeghi *et al.* 2019)
Ahvaz	THMs: range (17.35- 174.75),mean(45.8) μg/l	HI<1	Drinking water	(Babaei *et al.* 2015)
Abadan	THMs: Non-drinking water(98.1- 101.9) μg/L, drinking water(8.88-14.96) μg/L	Total cancer risk> 10^{-6}	Drinking and non-drinking water	(Kujlu *et al.* 2020)
Tabriz	Winter(10.2±9.3), Spring(252±185.9),total(133.2),mean(133.2 ± 179.5) μg/L	Lifetime cancer risk :spring (2 × 10^{-4}) and Winter (3.3 × 10^{-6})	Drinking water	(Mosaferi *et al.* 2021)

0.01), Pb (0.46 ± 0.52), Zn (23.33 ± 79.63) and Ni(5.14 ± 11.57) μg/L in surface water of South Korea, and found the HI values to be one for both adults and children. They also reported that the health hazards did not exceed the allowable limit (1 × 10^{-4}) for adults and children(Im *et al.* 2022). A study by Giri and Singh indicated that the carcinogenic risk of As for adults and children was within the allowable cancer risk value of 1 × 10^{-4} and the HI ranged from 0.15 to 9.71 and 0.18 to 11.34 for children and adults, respectively (Giri and Singh 2015). A study by Varola and Tokath indicated that both HQ and HI indices for adults and children in both seasons were less than the allowable risk value of 1 in groundwater, and the mean levels of Cd, Cu, Mn, Ni, Pb, As, Cr and Zn, in both seasons(dry and wet) were less than the potable water limits(Varol and Tokatlı 2022). In a study by Ullah et al. it was demonstrated that the mean values of As (39.49 μg/L), Zn (1.07), Mn (0.19), Cu (0.41), Ni (0.03), Pb (0.05), and Fe (0.26) mg/L in groundwater in Punjab, Pakistan, were above the allowed limit prescribed by WHO for drinking water. Moreover, the noncarcinogenic risk (HQ) levels of heavy metals were found to be within the allowed limit <1, while carcinogenic risk (CR) levels of all elected heavy metals were less than the highest limit CR level (1 × 10^{-4})(Ullah *et al.* 2022). A study by Chakraborty et al. indicated that the mean levels of Mn and Fe were 0.05-0.93 and 0.14-3.7 mg/L, respectively in groundwater in Bangladesh. They also investigated the non-carcinogenic health risks during digestion of Fe (HQ equal to 1.446 for adults and 0.590 for children) and Mn (HQ equal to 2.459 for adults and 1.004 for children)(Ahamad *et al.* 2020).Over all, the most common source of heavy metals in potable water in Iran and other countries including agricultural runoffs, mining actions, geological nature, industrial wastewaters(Saleh *et al.* 2019, Im *et al.* 2022, Ullah *et al.* 2022).

THMs and health outcomes

Table 5 shows the summary of THMs concentrations in drinking water and their health outcomes in Iran. We found 7 studies reporting THMs in potable water and their health outcomes in Iran. One study reported the presence of THMs in potable water from different districts of Iran, such as Tehran, Ahwaz, Hamadan, Tuyserkan, Yazd, Ilam, Abdanan, Ardabil, and Tabriz (Table5). The lowest level range of THMs in potable water was reported to be 8.88-14.96 μg/L in Abadan, and the highest THMs level was found to be 10.2±9.3 to 252±185.9 in Tabriz. More than 60% of the studies on THMs in drinking water had total cancer risk> 10^{-6}. A study by Gupta and Mishra illustrated that the THMs level in the potable water in India varied from 274–511 μg/L and cancer risks of THMs from drinking water were 100 fold more than recommended USEPA limits(Kumari *et al.* 2015). A study by Siddique et al. indicated that the health cancer risk for TTHMs via ingestion and dermal pathway was calculated to be within the allowable-low risk limit in drinking water in Karachi, Pakistan(Siddique *et al.* 2015). In a study by Pan et al. the median total cancer risk of THMs and haloacetic acids (HAAs) in potable water of China was calculated to be 7.34×10^{-7} in disability-adjusted life years (DALYs) per person-year (ppy), which is less than the reference level of risk determined by WHO(10^{-6} DALYs ppy)(Pan *et al.* 2014). A study by Niu et al. reported the mean THMs concentration in the surface water in China to be 2.93 ± 1.98 μg/L and found the ecological risks of THMs from surface water to be remarkably low (Niu *et al.* 2017). Another study reported that the colon cancer rate in Addis Ababa, Ethiopia, increased with the prevalence of disinfection byproducts-related cancers (DBRCs) whose levels elevated in societies supplied with disinfected surface water(Tafesse *et al.* 2022). A study by Wang et al. indicated that the THMs level in the potable water in China ranges from 8.81 to 38.96 μg/L and reported that bromodichloromethane is highly related to both non-cancer risk and cancer risk(Wang *et al.* 2019). Evans et al. reported that in the U.S.A., the potable water cumulative risk and lifetime cancer risk of haloacetic acids and THMs were 2.9×10^{-4} and 3.0×10^{-3}, respectively(Evans *et al.* 2020). Another study indicated that long time use of disinfected potable water is related to bladder cancer, mainly in males (Villanueva *et al.* 2003).

CONCLUSIONS

This review was carried out to study of contaminants in Iranian drinking water and their health outcomes.

The water sources in this study are surface water, groundwater, and drinking water. In this review, the health outcomes of nitrate, fluoride, THMs, radon, and heavy metals were studied. The results of this review indicated that radon level in potable water in few areas of Iran was slightly higher than EPA standard limits.

More than 50% of the studies in this review reported fluoride in potable water to be above 1.5 mg/L based on the WHO guidelines and Iran standards. The total level of nitrate in potable water in Iran was below the WHO and Iran standard limits. The minimum level range of THMs in potable water was 8.88- 14.96 μg/L in Abadan. In more than 26% of the areas studied, As level was above the WHO standard, and more than 17.39% of the studies had Pb level above the WHO limits. The highest range value of 19 to 1420 μg/L in the groundwater of the studied areas was found for Iron and the minimum value of 0.00 to 0.37μg/L was related to lead. In this study, the HQ/HI is more than 1 for children and adults in 47.22 % and 30.5 % of the studies respectively. Children are vulnerable residents in most of the studied articles, and they are at an elevated risk for non-carcinogenic dangers from exposure to potable water with elevated F, NO_3, THMs, radon, and heavy metals values.

These contaminations could be attributed to the geology properties and water supply network, but parameters like misadministration of solid waste, wastewater, and the distribution system of industries were also influential. In the recent study on drinking water contaminants and their health outcomes, the authors would like to focus on the following aspects:

-Need for collaborations between environmental health specialists, chemists, toxicologists, and epidemiologists to discuss issues related to emerging pollutants' health outcomes.

-Using epidemiological information in public health policy development.

-Due to the higher level of some heavy metals than permissible values, suitable treatment, and governmental intermediaries for management of potable water are recommended.

-A monitoring and supervision plan and health instruction should be implemented in areas where potable water has a high potential concentration of NO_3 pollution like in agricultural districts.

-To control THMs in drinking water, physical treatment processes such as organic precursors by activated carbon, nanofiltration, coagulation-flocculation, other disinfectants such as ozone and ultraviolet, and an optimal dose of chlorine should be used.

-Using several techniques for remove the adverse impact of these contaminants such as oxidation, sedimentation, advance oxidation processes, adsorption, reverse osmosis, electrodialysis, precipitation, micro and ultrafilteration, and photocatalytic process.

GRANT SUPPORT DETAILS

The author declares that no funding sources or grants were assigned to this work.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

ACKNOWLEDGMENT

The author would like to thank Shahrekord University of Medical Sciences.

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