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Quantification and health risk assessment of nitrate in southern districts of Tehran, Iran

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ABSTRACT

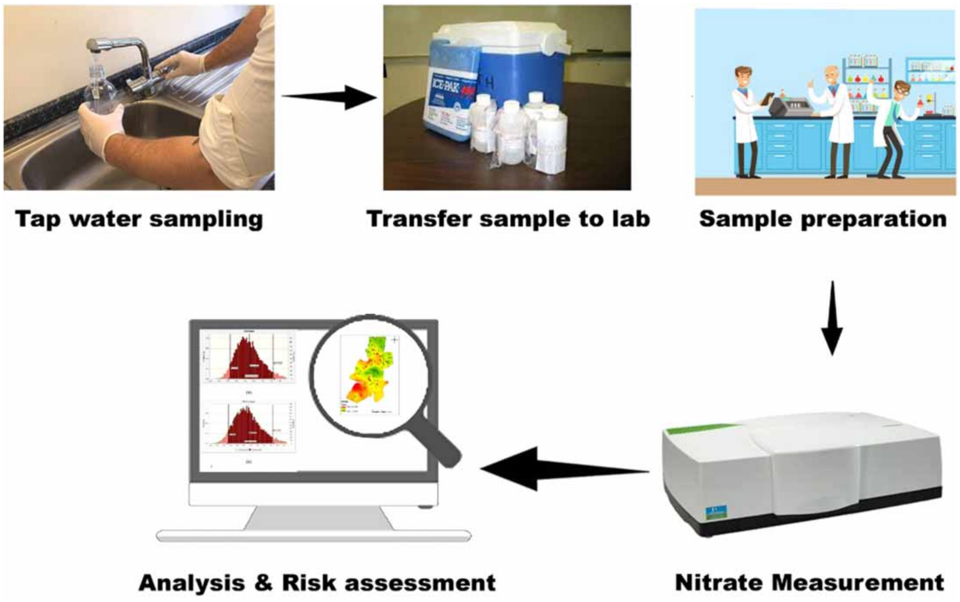
Nitrate is a common contaminant of drinking water. Due to its adverse health effects, this study aimed to determine nitrate levels in six southern districts of Tehran. A total of 148 samples were taken from tap waters. In 84.46% ($n = 125$) of the samples, the nitrate concentration was below national and WHO limits (50 mg/L); however, 15.54% ($n = 23$) were in violation of the criteria. The total mean concentration of nitrate was 36.15 mg/L ($\pm$14.74) ranging from 4.52 to 80.83 mg/L. The overall hazard quotient (HQ) for age groups were ordered as Children (1.71) > Infants (1.24) > Teenagers (1.2) > Adults (0.96). In all districts, the HQ values for infants and children groups were greater than 1, indicating potential adverse health risks. In teenagers age group, only the HQ estimations of districts 10 (HQ = 0.93) and 11 (HQ = 0.74) were lower than 1 and in adults age group, the estimated HQ values for districts were lower than 1 with the exception for district 19 (HQ = 1.19). The sensitivity analysis (SA) showed that nitrate content plays a major role in the value of the assessed risk.

Key words: age groups, health risk assessment, nitrate, tap water, water safety

HIGHLIGHTS

- Levels and noncarcinogenic risk of nitrate were assessed in tap water.
- The mean concentration of nitrate was 36.15 mg/L.
- Analysis showed that nitrate concentration in 84.46% of the samples was below the standard level limit.
- The highest noncarcinogenic risk was in the children group.
- The 95th percentile of the simulated nitrate HQ in children was 2.14.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is an irreplaceable, essential need for the survival of the human civilization (Biglari *et al.* 2016). It is estimated that over one-third of the world's available freshwater is used for different purposes, such as agriculture, industry and domestic applications (Mahvi *et al.* 2005; Nouri *et al.* 2008; Atafar *et al.* 2010). With the rapid population growth and the impact of stressors such as increased drought periods and climate change, providing safe and accessible water has become a significant challenge in the twenty-first century (Radfard *et al.* 2018). Moreover, with regard to the estimation of the United Nations, one in four people may experience water shortage by 2050. The importance of clean water has also been reflected in the United Nations sixth goal of the 2030 Sustainable Development plan (Schwarzenbach *et al.* 2010; Patel *et al.* 2020; United Nations 2021). The quality of the consumed water is highly dependent on the characteristics of the source (Lowe *et al.* 2021). To provide high-quality drinking water and ensure its safety, regulations have been established setting maximum permissible levels for various water contaminants (Patel *et al.* 2020). Nitrate is one of the most prevalent contaminants found in the water (Khaniki *et al.* 2008). This is due to its high solubility, mobility and nonreactivity under oxidizing conditions (Ghalhari *et al.* 2021). Pollution of groundwater or surface waters to nitrate can majorly be traced back to human activities such as the application of organic and inorganic fertilizers and generation of organic wastes by humans, livestock and the food industry (Rezvani Ghalhari *et al.* 2021a). It might also have a natural origin (i.e. organic nitrogen mineralization in the soil) (Zendehbad *et al.* 2019). The removal of nitrate from a contaminated source such as an aquifer is carried out using technologies such as adsorption (Yousefi *et al.* 2016), ion exchange (Shahbazi *et al.* 2010), physical approaches (Hosseini & Mahvi 2018) and dilution by other water resources (Wollheim *et al.* 2017), which were difficult and costly. However, in a number of studies, it is suggested that the discharge of wastewater containing nitrate can degrade water quality and thus make it unsuitable to use as potable water via methods such as desalination and industrial applications (Panagopoulos 2020, 2021, 2022). Therefore, the emphasis should be more on preventive measures (Qasemi *et al.* 2018a). The chief concern with nitrate and nitrite is the inordinate amounts that enter the body via diet or drinking water. The amount of intake from drinking water is usually low compared to foodstuff; however, it may significantly increase via drinking in case of contamination (Sadler *et al.* 2016; Qasemi *et al.* 2018a).

Epidemiological studies associate nitrate with health concerns such as congenital disabilities, complications such as small for gestational age (SGA), thyroid disorder, increased risk of abortion and various types of cancer (Gholami *et al.* 2019; Temkin *et al.* 2019). A severe adverse outcome of nitrate consumption via drinking water is infant methemoglobinemia or blue baby syndrome, which decreases the oxygen carrying capacity of red blood cells by disrupting their binding reaction with oxygen molecules (Mortada & Shokeir 2018; Hosseini *et al.* 2021). According to the international organizations such as the International Agency for Cancer Research (IARC), nitrate and nitrite are probable carcinogens when their consumption prompts the formation of N-nitroso compounds, which induce cancer and thus subject to regulations (Mortada & Shokeir 2018; Qasemi *et al.* 2018b; Messier *et al.* 2019; Temkin *et al.* 2019). The World Health Organization (WHO) and Iranian national standard maximum limits for nitrate are 50 mg/L (Khaniki *et al.* 2008). Tehran is a megacity hosting over 8.5 million people and since the 1990s, it faced challenges such as rapid urbanization, increased population, increased agricultural and industrial activity and postponed wastewater collection network, which have served to compromise the quality of its water resources especially groundwater where one-third of the drinking water demand of the city is supplied (Khorasani *et al.* 2020; Sarmadi *et al.* 2021).

Studies report that despite constant regulation and monitoring in most countries, the nitrate levels in drinking water frequently exceed the permissible limits (Picetti *et al.* 2022). In fact, in a study by Sherris Allison *et al.* (2021), it was stated as a leading cause of water quality regulation violations in California, United States (Sherris Allison *et al.* 2021). On the other hand, establishing a historical record on nitrate concentration and human health risk assessment is essential for both the public and the authorities, as well as providing data and findings for developing research (Omonona & Okogbue 2021; Sherris Allison *et al.* 2021; Picetti *et al.* 2022). The health implication of nitrate becomes more pronounced as more research projects focus on the outcomes of dietary nitrate exposure (Taneja *et al.* 2019; Hosseini *et al.* 2021; Picetti *et al.* 2022). What's more, it was stated that between 2011 and 2016, 50% of the groundwater in Tehran aquifer was refilled via untreated wastewater discharge while at the same time, 47% of its water withdrawal was used for drinking (Khorasani *et al.* 2020). It was been indicated that nitrate concentration greater than 1 mg/L indicates contamination (Hamed *et al.* 2012). Therefore, with regard to the mentioned issues and the lack of research on nitrate levels in the drinking water network of Tehran in recent years, the aim of this study is to determine nitrate concentrations at the consumption point (i.e. tap water) in the southern region of Tehran megacity and assess the probable health risk using the USEPA risk assessment method.

2. METHODS

2.1. Study area

Coordinated in 35.7117 °N 51.4070 °E, Tehran province is located in the southern slope of the Alborz Mountain chain. It has a semi-arid climate and has an altitude varying from 1,050 and 1,200 m to 1,800 m in southern, central and northern regions, respectively. The annual temperature varies from 42 °C to −12 °C. Tehran province has an area of 730 km^2 and 8,737,510 residents, of which 1,530,122 people live in the southern region where the sampling was conducted. This region includes districts 10, 11, 16, 17, 19 and Aftab district. The drinking water of Tehran is supplied from both ground water (40%) and surface water (60%) via Tehran-Karaj Aquifer and Karaj, Latian and Lar dams, respectively (Khorasani *et al.* 2020; Sarmadi *et al.* 2021).

2.2. Data collection

The municipal tap water was sampled in 148 spots in districts 10, 11, 16, 17, 19 and Aftab District (Figure 1). Next, the samples were transported to the laboratory for analysis, and nitrate concentration was analyzed using a UV-Vis spectrophotometer (DR-5000). All procedures were conducted according to Standard Methods for Water and Wastewater Analysis and were done in triplicates.

2.3. Health risk assessment

To evaluate the health risk of nitrate for the consumers, the US-EPA method for assessing the health risks of contaminants was used. In this method, the Daily Intake of four different age groups, including infants (<2 years old), children (2–6 yo), teenagers (6–16 yo) and adults (16>), was first calculated using the following equation:

$$\mathrm{EDI} = (C_\mathrm{N} \times C_\mathrm{d})/(\mathrm{BW}) \quad (1)$$

where EDI is the estimated daily intake (mg/kg), C_N is the nitrate concentration in drinking water, C_d is the average daily consumption of potable water (L/day) and BW is the average body weight (kg) in the studied groups.

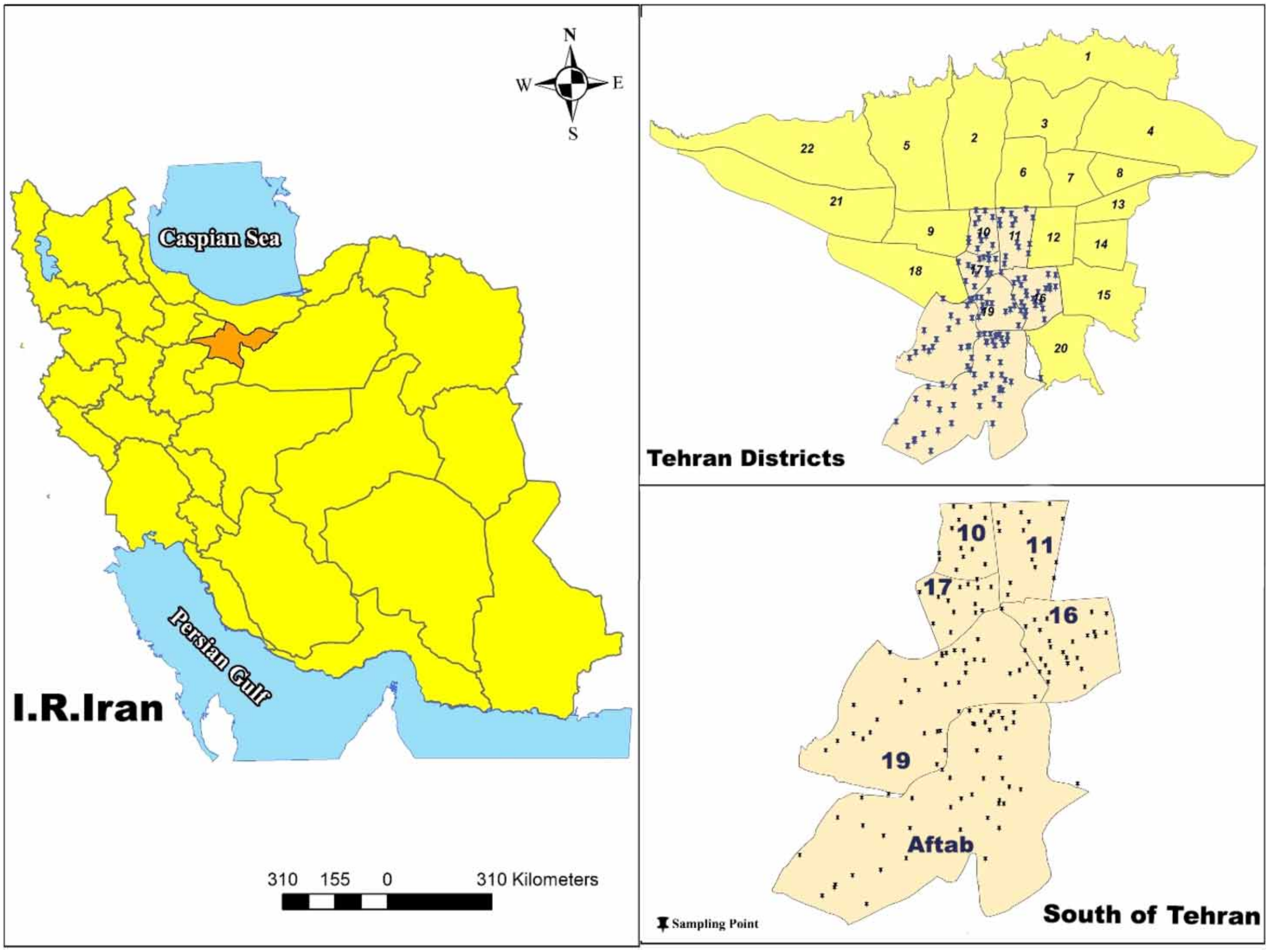


Figure 1 | Geographic location of the study area and water sampling sites.

Next, the noncarcinogenic risk of nitrate was estimated using the following equation:

$$HQ = EDI/R_F D \quad (2)$$

where $R_F D$ is the Reference Dose for Chronic Oral Exposure to nitrate (1.6 mg/kg/day). Table 1 shows the utilized parameters and their corresponding values for different age groups.

Table 1 | Parameters used in nitrate health risk assessment and their corresponding reference values

Parameters	Symbols	Units	Infants	Children	Teenagers	Adults	Reference
Age	–	Year	<2	2–6	6–16	>16	Gholami *et al.* (2019), Qasemi *et al.* (2018b), Rezvani Ghalhari *et al.* (2021b), Wang *et al.* (2021), Radfarda *et al.* (2019)
Nitrate concentration	C_N	mg/L	–	–		–	
Exposure duration	ED	Year	0.5	6	13	40	
Exposure frequency	EF	day/year	365	365	365	365	
Daily consumption	C_d	L/day	0.3	0.85	2	2.5	
Body weight	BW	kg	10	15	50	78	
Average time	AT	day	182.5	2,190	4,745	14,600	
Oral reference dose	$R_F D$		1.6	1.6	1.6	1.6	1.6

An HQ value less than 1 indicates that no adverse health effects may occur due to exposure to the reported pollutant, whereas an HQ value greater than 1 suggests potential adverse noncarcinogenic health effects may incur upon exposure (Raza *et al.* 2017; Kalteh *et al.* 2020).

2.4. Uncertainty analysis

According to USEPA guidelines, the obtained point estimate is not a suitable representative of the situation due to uncertainty issues (Bazeli *et al.* 2020). Therefore, a Monte–Carlo Simulation was carried out using Oracle Crystal Ball to address the uncertainty that might be caused by various factors and to provide an upper confidence limit (UCL). This was then followed by a sensitivity analysis (SA) to determine the contribution of each parameter involved in the analysis.

3. RESULTS

3.1. Nitrate concentration

In this study, the concentration of nitrate was determined in six districts located in the south of Tehran megacity. The samples were taken from tap waters connected to the municipal drinking water distribution networks at different spots ($n = 148$). Overall, the results of the spectrophotometer analysis showed that out of 148 samples, in 23 samples (% = 15.54) nitrate levels were in violation of national and WHO standards (50 mg/L) while in the rest of the samples, counting 125 samples (% = 84.46), the nitrate levels were below the limit. Moreover, the number of samples violating the national and WHO standard per district was in the following order: Aftab District ($n = 11$) > District 19 ($n = 7$) > District 16 ($n = 4$) > District 17 ($n = 1$). In districts 10 and 11, no exceeding nitrate levels were observed. Table 2 shows the overall and district-wise descriptive details of the study. According to Table 2, the concentration of nitrate across all the studied areas ranged from 4.52 (observed in district 19) to 80.83 mg/L (observed in Aftab district) with a total mean concentration of 36.15 (±14.74) mg/L. From highest to the lowest mean concentration of nitrate, the districts were ordered as District 19 (44.86 ± 13.67) > Aftab District (37.32 ± 16.33) > District 16 (37.26 ± 15.09) > District 17 (34.51 ± 10.61) > District 11 (27.95 ± 4.56) > District 10 (22.32 ± 2.44). Figure 2 shows the spatial distribution of nitrate across the studied area. The concentration gradient is colored from high (red) to low (green) concentrations.

3.2. Health risk assessment

With regard to the health implications of nitrate in drinking water, a human health risk assessment was conducted for infants, children, teenagers and adult age groups according to the USEPA methodology detailed in the previous section. Using this method, the dietary health risk of nitrate was assessed and was presented in Figure 3. The overall point estimate HQ values for infants, children, teenagers and adults were 1.18, 1.28, 0.9 and 0.72, respectively. The HQ values for infant and children age groups were above 1 indicating high potential adverse dietary health risks due to nitrate. Additionally, obtaining the point estimates of HQ for each district shows that infants and children might be at potential health risk in districts 16, 17, 19 and Aftab as the point estimate HQ value in those districts were greater than 1. Moreover, the health risk is more pronounced in district 19 as the point estimated HQ value for teenagers was greater than 1 as well. Lastly, the HQ point estimates in districts 10 and 11 were lower than 1 indicating no risks (Figure 3).

Table 2 | Nitrate concentration in the studied districts

Districts	Number of samples	Exceeding the limit[a] (%)	Min (mg/L)	Max (mg/L)	Mean (mg/L)	(±SD)
10	13	0 (0)	22.06	33.87	27.95	4.56
11	10	0 (0)	18.96	25.96	22.32	2.44
16	26	4 (15)	15.90	64.51	37.26	15.09
17	18	1 (6)	20.37	64.00	34.51	10.61
19	20	7 (35)	4.52	65.25	44.86	13.67
Aftaab	61	11 (18)	4.87	80.83	37.32	16.33
Total	**148**	**23 (15.54)**	**4.52**	**80.83**	**36.15**	**14.74**

[a]WHO permissible limit :50 mg/L.

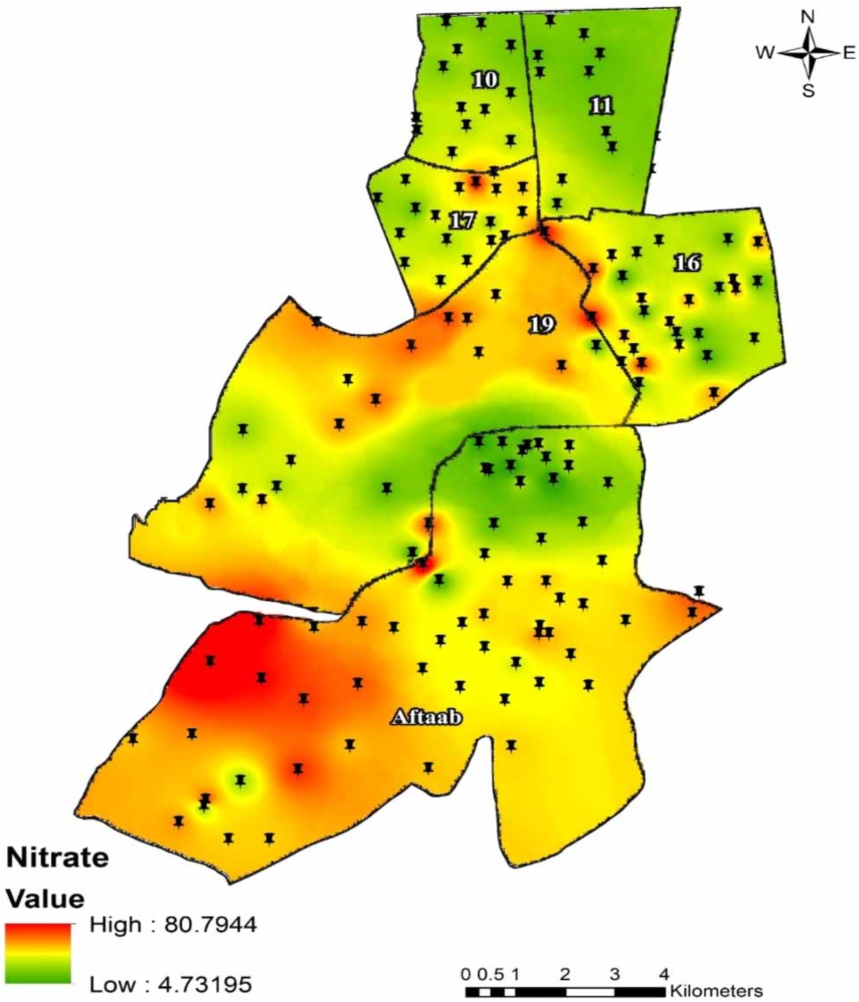


Figure 2 | Spatial distribution of nitrate in southern districts of Tehran. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/wrd.2022.007.

After obtaining the point estimate, MCSs were run using Oracle Crystal Ball to obtain the UCLs for the estimate HQs. The results of MSCs are presented in Figure 3. According to the figure, it was found that the total obtained UCL for the infants, children, teenagers and adults were 1.24, 1.71, 1.20 and 0.96, respectively. This means that all groups except adults were at the potential noncarcinogenic health risk. Running the analysis for districts individually showed that infants and children were at the risk ($HQ > 1$) in all districts. Followed by that, the teenagers' age group living in districts 16, 17, 19 and Aftab were also found to be at risk as well as the adults living in district 19. The overall MCS charts for the studied age groups are presented in Figure 4. In the health risk assessment, each parameter can have an independent and synergic effect on the evaluated health risk and determination of the role of each parameter can be conducive to risk mitigation efforts. Therefore, an SA was run to define the contribution of various parameters at play. As shown in Figure 5, it was found that nitrate concentration plays the main role on the imposed risk for all age groups, and more than 85% of the estimated risk was related to nitrate concentration. The tornado plots (Figure 5) shows that BW has a negative effect on the increasing assessed risk, and between the same age group with different weight, the probable risk in the persons with a higher weight are less than the persons with low weight. Additionally, it was found that IR can increase risk as it can increase the amount of nitrate entering the body.

4. DISCUSSION

Providing safe and high-quality drinking water for consumers is an imperative constant necessity as it might undermine population health. Therefore, monitoring contaminant levels such as nitrate in the water is subject to national and international regulations and health-related research (Królak & Raczuk 2018). In this study, the concentration of nitrate in 148 sampling

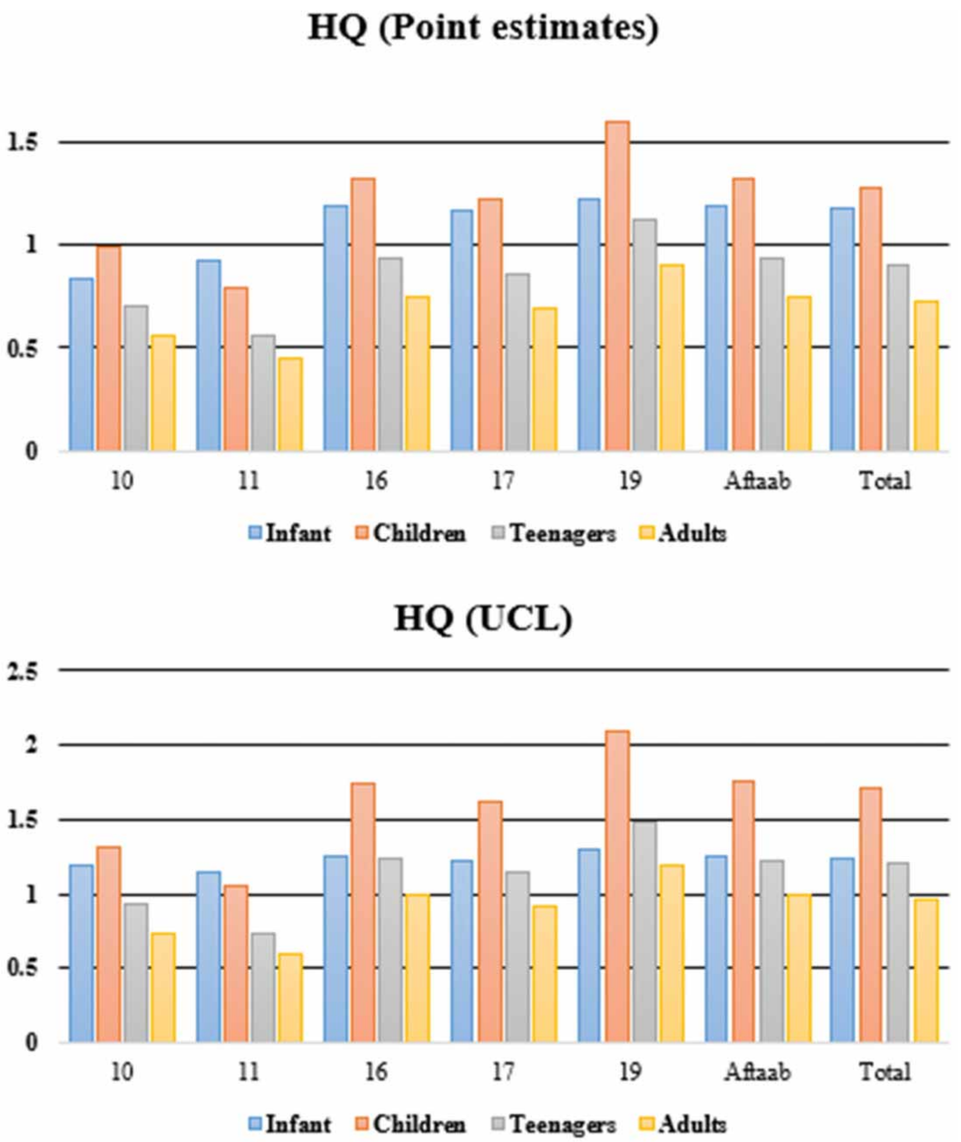


Figure 3 | Point estimate HQs and their corresponding upper confidence limit (P95) estimations for the studied districts.

spots within the municipal drinking water network of six districts located at the southern Tehran megacity was quantified according to Standard Methods for Water and Wastewater analysis in order to evaluate the water safety for consumers. Additionally, an HRA was conducted to assess the noncarcinogenic dietary health risks of nitrate. Comparison of nitrate levels of the samples with national and WHO permissible limits for nitrate showed that in the majority of the samples ($n = 125$, 84.46%), the nitrate concentration was below national and WHO limits; however, the levels in the rest of the samples ($n = 23$, 15.54%) were in violation of WHO and national criteria indicating the lack of safety for the consumers. Also, the total mean concentration of nitrate was 36.15 ($\pm$14.74) and sample concentrations ranged from 4.52 to 80.83 mg/L. Moreover, the highest mean concentrations of nitrate and the highest above-standard samples were found in Aftab and District 19. This might be due to the low depth of wells in District 19 and Aftab district compared to other districts which might increase the seepage of raw wastewater discharge into the groundwater resources (Khorasani *et al.* 2020). A study by Khorasani *et al.* (2020) found that between 2011 and 2016, 50% of the untreated wastewater has seeped into Tehran's groundwater resources while 47% of the withdrawn water was used for drinking. In that study, it was also stated that due to the hybrid use of surface and groundwater in the drinking water distribution network, the nitrate was diluted to levels lower than the standard (50 mg/L) (Khorasani *et al.* 2020). The nitrate levels of this work were also higher than

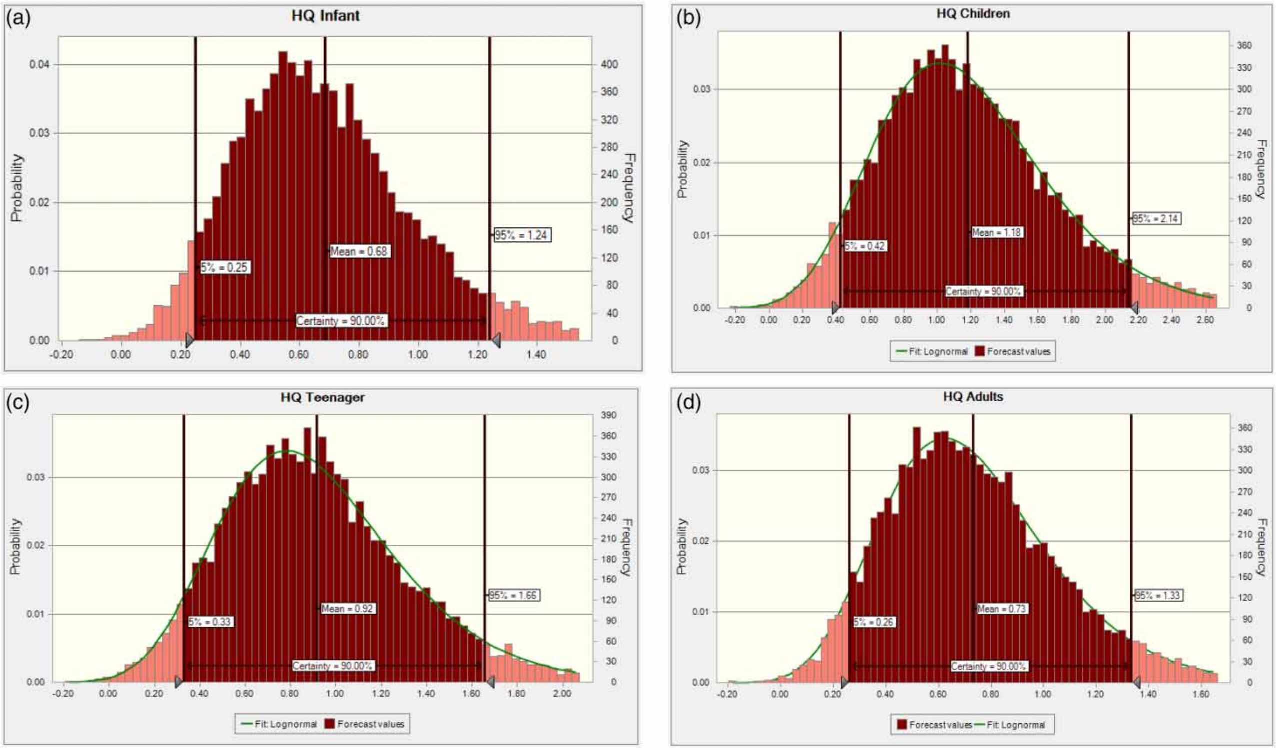


Figure 4 | Uncertainty analysis histograms of HQ in infants (a), children (b), teenagers (c) and adults (d) which exposed to nitrate.

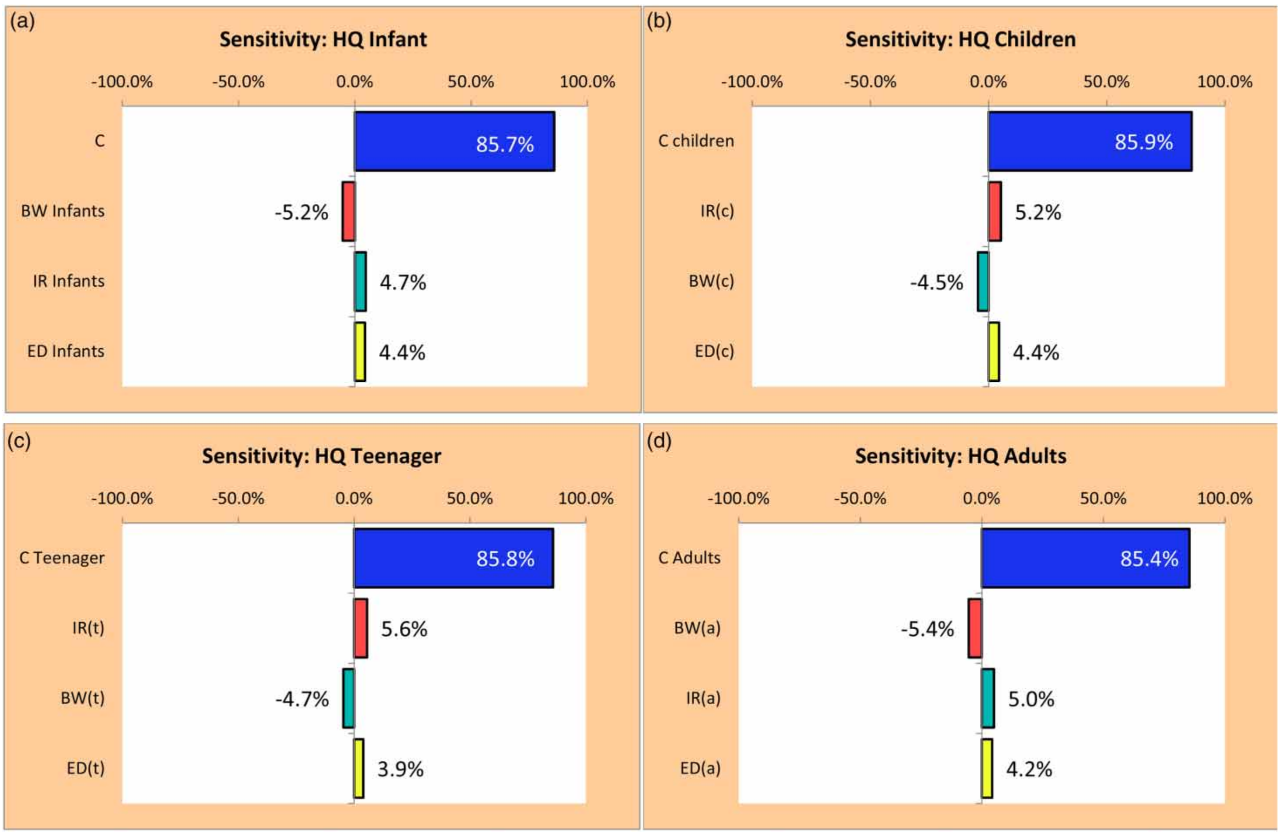


Figure 5 | Sensitivity analysis results for infants (a), children (b), teenagers (c) and adults (d) age groups.

the measurements by Shirazi *et al.* (2021). They investigated nitrate and nitrite levels in five random areas of Tehran city and found that the highest nitrate levels were observed in the western sampling sites of Tehran (4.6 ± 0.02 mg/L) which was lower than levels found in this study (Haji Seyed Mohammad Shirazi *et al.* 2021).

Comparing the observed mean concentration in this work with other recent similar studies conducted in Iran shows that despite being lower than WHO and national standards, the mean concentration of nitrate was higher than a number of studies carried out in other cities and provinces of Iran (Table 3). These include studies that were carried out in Ilam, Behbahan, Mashhad, Sanandaj and Semnan cities (Gholami *et al.* 2019; Heidariyeh *et al.* 2019; Oftadeh *et al.* 2019; Rezaei *et al.* 2019; Badeenezhad *et al.* 2021); a study in rural and urban areas of Isfahan province during spring and summer seasons (Aghapour *et al.* 2021); a study on drinking water nitrate in five southwest provinces of Iran (i.e. Ilam, Bushehr, Khuzestan, Fars and Lorestan provinces) (Jaafarzadeh *et al.* 2022). Additionally, the mean nitrate concentration in this work was higher than samples taken from wells in Hormozgan province, Kazerun city, Divandareh county, Gonabad and Bajestan (Bay *et al.* 2018; Qasemi *et al.* 2018a; Golaki *et al.* 2022; Mohammadpour *et al.* 2022); studies on the occurrence of nitrate in bottled water by Alimohammadi *et al.* (2018) and Rezvani Ghalhari *et al.* (2021b). However, the mean nitrate concentration of this study was lower than the mean levels quantified during the autumn and winter sampling periods in the study of Aghapour *et al.* (2021) in Isfahan province and the mean level in Shiraz city by Jaafarzadeh *et al.* (2022) (Aghapour *et al.* 2021; Jaafarzadeh *et al.* 2022). This suggests that the water quality of southern Tehran has lower quality compared to other cities and regions in Iran in terms of nitrate concentration.

Comparing the results of present study to other similar studies showed that the mean concentration of nitrate in the current study was higher than the studies conducted on tap water samples by Van de Brand *et al.* (2020), Taneja *et al.* (2019) and Alam *et al.* (2021) in Dakahlia governorate in Egypt, Dutch regions of Netherlands, Nagpur and Bhandara districts of India and Ahmadpur East in Pakistan, respectively (Mortada & Shokeir 2018; Taneja *et al.* 2019; van den Brand *et al.* 2020; Alam *et al.* 2021). It was also higher than levels reported by the studies of Hameed *et al.* (2021) and Rehman *et al.* (2020) on drinking water and on spring water, respectively, in Pakistan and Sadler *et al.* (2016) on drinking water wells in Semarang, Indonesia (Sadler *et al.* 2016; Rehman *et al.* 2020; Hameed *et al.* 2021). On the other hand, the mean concentration of nitrate in this work was lower than the levels reported by Wedyan *et al.* (2021), Adimalla & Qian (2021); Adimalla *et al.* (2019), Taneja *et al.* (2019), Rahman *et al.* (2020), Martínez *et al.* (2014) and Królak & Razcuk (2018) in Al Duliel Area in Jordan, South India, Nirmal province in India, Nagpur and Bhandara districts of India, Central Bangladesh, Mar del Plata in Argentina, southern districts of Punjab, and Poland, respectively (Martínez *et al.* 2014; Ahada & Suthar 2018; Królak & Raczuk 2018; Adimalla *et al.* 2019; Taneja *et al.* 2019; Rahman *et al.* 2020; Adimalla & Qian 2021; Wedyan *et al.* 2021). In general, the comparisons suggest that the quality of municipal drinking water in southern parts of Tehran megacity is lower than other cities and regions across the country as well as some cities and regions of the world in terms of nitrate levels. In all studies, the exceeding levels reported for sampling sites were majorly associated with excessive use of fertilizers in agriculture and human waste that can pollute the groundwater and surface water reservoirs (Martínez *et al.* 2014; Rahman *et al.* 2020; Adimalla & Qian 2021; Wedyan *et al.* 2021). For the southern districts of Tehran city, these issues are even more pronounced as factors such as late design and development of wastewater collection network, the prevalent use of cesspits and septic tanks and wastewater seepage into aquifers pose additional challenges for providing safe drinking water (Asadollahfardi 2009; Khorasani *et al.* 2020; Sarmadi *et al.* 2021).

Studies show that human waste and agricultural fertilizers are the main causes of nitrate pollution in cities and rural areas, respectively. Isotopic characterization of drinking water resources in Mashhad city, the second largest city in Iran, showed that human waste is the main contributing factor in the contamination of groundwater resources to nitrate, particularly when the sewer systems stand in poor condition, which might lead to direct sewer seepage (Zendehbad *et al.* 2019). A national-level study on the spatial distribution of nitrate in 2017 revealed that the nitrate levels have increased in populated regions over the past decade. In that study, the application of fertilizers was recognized as the primary source of this increasing trend (Alighardashi & Mehrani 2017).

Below-standard nitrate levels do not indicate low risks. For example, in Azhdarpoor *et al.* (2019)'s study in Saravan city in Iran, though more than 97% of the samples had concentrations lower than the standard limit, the estimated risk was greater than 1 for children, teenagers and adults (Azhdarpoor *et al.* 2019). According to Figure 3, the UCLs for the estimated HQ in the infants, children, teenagers and adults were 1.24, 1.71, 1.20 and 0.96, respectively. This means that all groups except adults were at potential noncarcinogenic health risk. The younger generations, especially infants and children, being at high risk was frequently reported in nitrate HRA studies that were discussed earlier and it was associated with factors

Table 3 | Comparison of the nitrate levels determined in this work with other similar studies

No.	Author	Year	Location	No. of samples	Sampling details	Mean ± SD (mg/L)	Reference
Studies in Iran	This study	2022	Tehran	148	Tap water	36.15 ± 14.74	–
	Shirazi *et al.*	2021	West of Tehran	–	Tap water	4.6 ± 0.02	Haji Seyed Mohammad Shirazi *et al.* (2021)
	Panahi *et al.*	2012	Robat-Karim city	40 (wells) 32 (tap water	Well, Tap water	2.1 2.05	Panahi & Alavi Moghaddam (2012)
	Gholami *et al.*	2019	Ilam city	77	Tap water	8.13 ± 5.4	Gholami *et al.* (2019)
	Badeenezhad *et al.*	2021	Behbahan city	90	Tap water	15.05 High rain season 13.35 Low rain season	Badeenezhad *et al.* (2021)
	Oftadeh *et al.*	2019	Mashhad city	72	Tap water	16.63 ± 10.88	Oftadeh *et al.* (2019)
	Rezvani *et al.*	2021	Kashan city	20	Bottled water	8.37 ± 7.32	Rezvani Ghalhari *et al.* (2021b)
	Mohammadpour *et al.*	2022	Hormozgan Province	54	Well	7.37 ± 5.61	Mohammadpour *et al.* (2022)
	Rezaei *et al.*	2018	Sanandaj city	106	Tap water	From 0.28 to 27.77 urban From 1.28 to 80 rural	Rezaei *et al.* (2019)
	Golaki *et al.*	2022	Kazerun, Fars province	25	Well	13.5	Golaki *et al.* (2022)
	Bay *et al.*	2018	Divandareh county, Kurdistan province	118	Well	31.37 ± 18.87	Bay *et al.* (2018)
	Aghapour *et al.*	2021	Isfahan province	Spring = 287 rural, 113 urban Summer = 285 rural, 139 urban Autumn = 89 rural, 71 urban Winter = 230 rural, 105 urban	1,178 Tap water samples 90 Spring samples 51 ghanat samples	Spring = 32.59 ± 24.96 rural, 30.15 ± 18.34 urban Summer = 33 ± 22.34 rural, 37.2 ± 30.14 urban Fall = 46.51 ± 25.68 rural, 47.98 ± 42.46 urban Winter = 33.45 ± 23.27 rural, 40.15 ± 34.29 urban	Aghapour *et al.* (2021)
	Bazeli *et al.*	2020	Khaf county,	28	Well	1.54	Bazeli *et al.* (2020)
	Alimohammadi *et al.*	2018	Iran	71	Bottled water	10.55	Alimohammadi *et al.* (2018)
	Jaafarzadeh *et al.*	2022	Ilam, Bushehr, Khuzestan, Fars and Lorestan provinces	–	Drinking water	Ilam = 14.58 ± 2.62 Bushehr = 9.97 ± 3.14 Khuzestan = 52.77 ± 19.15 Fars = 64.63 ± 19.92	Jaafarzadeh *et al.* (2022)

(*Continued.*)

Table 3 | Continued

No.	Author	Year	Location	No. of samples	Sampling details		Mean ± SD (mg/L)	Reference
							Lorestan = 22.85 ± 6.91	
	Heidariyeh *et al.*	2019	Semnan city	30 (tap water) 150 (bottled water)	Tap water		7.27 ± 5.1	Heidariyeh *et al.* (2019)
	Qasemi *et al.*	2018	Gonabad and Bajestan,	18 (Gonabad) 21 (Bajestan)	Well		29.33 ± 18.62 37.95 ± 20.37	Qasemi *et al.* (2018a)
Studies worldwide	Mortada and Shokeir	2018	Dakahlia governorate, Egypt	1291	Tap water		5.25 ± 1.61	Mortada & Shokeir (2018)
	Van den brand *et al.*	2019	Dutch regions, Netherland	185	Tap water		4.7	van den Brand *et al.* (2020)
	Wedyan *et al.*	2021	Northeast Jordan	–	Well		44.4	Wedyan *et al.* (2021)
	Adimalla	2019	Telangana province, India	35	Well		58.74	Adimalla *et al.* (2019)
	Adimalla	2021	Nirmal Province, India	30	Well		43.30 ± 16.88	Adimalla & Qian (2021)
	Taneja *et al.*	2017	Nagpur and Bhandara districts, India	77	Tap water		Rural = 45.69 ± 2.08 Urban = 22.53 ± 1.97	Taneja *et al.* (2019)
	Ahada *et al.*	2018	Punjab, India	76	Well		118.23 ± 33.45	Ahada & Suthar (2018)
	Wang *et al.*	2021	Zhangjiakou, China	489	Well		29.72	Wang *et al.* (2021)
	Hu *et al.*	2021	Wanbei, China	11	Well		24.01	Hu *et al.* (2021)
	Barakat *et al.*	2020	Tadla, Morocco	21	Well		24.73 ± 15.49	Barakat *et al.* (2020)
	Rahman *et al.*	2020	Bangladesh	99	Well		253.18 ± 168.8	Rahman *et al.* (2020)
	Sadler *et al.*	2016	Semarang, Indonesia	52	Well		20	Sadler *et al.* (2016)
	Martínez *et al.*	2014	Mar del Plata, Argentina	Zone A = 11 Zone B = 20 Zone C = 10	Well		Zone A = 72.9 Zone B = 38.2 Zone C = 67.3	Martínez *et al.* (2014)
	Hameed *et al.*	2020	Vehari District, Pakistan	48	Tap water		1.35 ± 4.02	Hameed *et al.* (2021)
	Alam *et al.*	2021	Ahmadpur, Pakistan	36	Tap water		0.4197	Alam *et al.* (2021)
	Rehman *et al.*	2020	Harnai, Pakistan	24	Spring water		0.389	Rehman *et al.* (2020)
	Królak and Raczuk	2018	Poland	196	Bottled water = 9, Supply water = 104 Deep wells = 25 Dug wells = 58	Bottled water, Supply water, Deep wells, Dug wells	Bottled water = 0.659 ± 0.422 Supply water = 2.714 ± 4.107 Deep wells = 9.509 ± 14.27 Dug wells = 43.52 ± 33.11	Królak & Raczuk (2018)

such as lower BW and behavioral peculiarity compared to adults (Rojas Fabro *et al.* 2015; Sadler *et al.* 2016; Qasemi *et al.* 2018a; Gholami *et al.* 2019; Rezaei *et al.* 2019; Adimalla & Qian 2021; Aghapour *et al.* 2021; Alam *et al.* 2021; Wedyan *et al.* 2021).

Continuous intake of nitrate might increase the risk of methemoglobinemia in infants and other health complications for other age groups in the long term (Adimalla *et al.* 2019). It should not be forgotten that the nitrate exposure from drinking water only comprises a fraction of total dietary exposure and contribution from foodstuff, especially vegetables as a highly consumed food category, other beverages and even breastfeeding should also be taken into account (Mortada & Shokeir 2018; Gholami *et al.* 2019; van den Brand *et al.* 2020).

The SA (Figure 5) showed that nitrate concentration plays a major role in increased risk for all age groups. This was consistent with other HRA studies on nitrate such as the work of Mohammadpour *et al.* (2022) in Hormozgan province, Bazeli *et al.* (2020) in Khaf county, Iran (Bazeli *et al.* 2020; Mohammadpour *et al.* 2022). All in all, preventive measures such as nitrate dilution, hybrid use of bottled and tap water, development of an efficient wastewater collection system and constant monitoring of drinking water are suggested to reduce nitrate levels to protect public health.

5. CONCLUSION

The investigation of nitrate concentration at the end point of municipal drinking water distribution network (i.e. tap water) in southern districts of Tehran showed that the mean concentration of nitrate in all districts was below the WHO and national standards. In total, 148 samples were taken from tap water of six districts in the southern part of Tehran megacity. The total mean concentration was 36.15 mg/L. Our analysis showed that 84.46% of the samples were below the standard level limit, while 15.54% of samples exceeded the criteria. Districts 19 and Aftab contained the highest nitrate levels. Compared to other studies, the determined levels of nitrate were relatively higher except for some studies. It was considered particularly high since the nitrate content was mostly lower than the studies carried out in rural areas or on water resources. The results of the health risk assessment showed that infants, children and teenagers were the most vulnerable groups (HQ > 1) mostly due to their higher water intake and absorption rate per body and the age groups were ranked as infants > children > teenagers > adults in the HQ overall estimate. The SA revealed than nitrate concentration had the most contribution to the estimated noncarcinogenic health risk. The findings of this work can help future works in the attempt, for example, to profiling nitrate content in other food and beverages, authorities by providing a status of nitrate in the drinking water distribution network to devise risk mitigation strategies and the public by providing knowledge about the possible health outcomes of nitrate in order to better self-regulate their dietary nitrate intake.

CONFLICT OF INTEREST

The authors declare that there are no conflicting interests and they are not affiliated with or involved with any organization or entity with any financial interest or nonfinancial interest in the subject matter or materials discussed in this paper.

AUTHORS CONTRIBUTIONS

Safa Kalteh has made a substantial contribution to the conception and design of methods, validated, drafted the original work, wrote, reviewed and edited the article, and also contributed to project administration. Farshad Hamidi has made a substantial contribution to the conception and wrote, reviewed and edited the manuscript. Mahdi Ahmadi Nasab contributed to sample preparation and verified the methods. Narges Mohseni Gharibdoosti verified the methods and fabricated the samples. Mohammad Rezvani Ghalhari conceived the study, drafted the manuscript, and helped in writing, reviewing and editing. Mina Parvizishad verified the methods and fabricated the samples. Amir Hossein Mahvi: has made a substantial contribution to the conception and design of methods, reviewed and editing the manuscript, drafted the original work and helped supervise the project.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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