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ORIGINAL ARTICLE

Health risk assessment of nitrate exposure in groundwater of rural areas of Gonabad and Bajestan, Iran

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Abstract

Prolonged exposure to excessive levels of nitrate through drinking water is a potential risk for human health. The current research reports the analytical results and associated health risk for water quality in term of nitrate in 39 groundwater samples during January 2018 in rural areas of Gonabad and Bajestan, Iran. Nitrate concentrations ranged from 1.8 to 82.2 and from 5.5 to 84.3 mg/L for Gonabad and Bajestan, respectively. In this work, the potential risk to human health was determined using the hazard quotient (HQ) for three age groups including adults, children and infants. Comparison of HQs among the 39 sampling sites showed that the rural areas in Bajestan had higher HQs than Gonabad. Among the studied groups, infants exposed to a higher risk than children and adults. The results also indicated that the health of individuals from nitrate exposure in most of the groundwater studied was not acceptable and most of the consumers were in danger from current nitrate concentrations. Therefore, there is an urgent need for enforcing effective plans to improve groundwater quality and to better manage and control probable nitrate contaminated sources.

Keywords Nitrate · Groundwater · Drinking water · Health risk assessment

Introduction

Safe water supplies, hygienic sanitation and good water management are necessary for human wellbeing (Dehghani et al. 2017; Khosravi et al. 2018; Qasemi et al. 2018). The access to clean drinking water resource is still a dream for approximately one-sixth of humankind on the earth (Karbassi et al. 2011). Groundwater is common source for drinking for much of the population in many arid and semiarid parts of developing countries; therefore, it is necessary to ensure its high quality at all time, so that the consumer health is not compromised (Dehghani et al. 2013; Fazlzadeh et al. 2017b; Mohammadi et al. 2017). It is an important renewable resource with many intrinsic advantages compared to surface water. The groundwater is used with the least purification and hence there is a significant risk of exposure to contaminants (Gorgij et al. 2017; Shankar and Shanker 2014).

Nitrate is ubiquitous in both surface and groundwater (Alif Adham and Shaharuddin 2014; Gelberg et al. 1999). It represents one of the most serious environmental problems in several countries and also in many parts of Iran due to rapid growing trend of industrialization and urbanization (Asadi et al. 2017; Ehteshami and Biglarijoo 2014; Esmaeili et al. 2014; Nezhad et al. 2017; Rezaverdinejad and Rahimi 2017; Ziarati et al. 2014). Nitrate in water originates from various natural and anthropogenic sources (Pirsaheb et al. 2017). Nitrate exists naturally in soils through microbial conversion of ammonia resulting from organic compounds such as plants, animals, and manure (Migeot et al. 2013; Thomson et al. 2007). Background levels of nitrate in groundwater in natural grasslands of temperate regions are usually lower than 2 mg/L (Aranibar et al. 2011). The extensive use of especially nitrogenous fertilizers in agriculture, untreated wastewater irrigation, discharge of industrial

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effluents, abandoned landfills, and contaminated lands are the major origins of nitrate contamination in ground and surface waters (Spalding and Exner 1993; Wakida and Lerner 2005). Nitrogenous fertilizers and the accumulation and application of animal manure are the largest correspondent to anthropogenic nitrogen on a global scale and have been exposed as an even more crucial source of drinking water nitrate in many rural areas (Derakhshani et al. 2017; Noroozi et al. 2011). In most of rural areas around the world, especially in developing countries, people keep some farm animals including cows, donkeys and horses, sheep and goats, birds, dogs, etc. for consumption or for commercialization (Wakida and Lerner 2005). Excreta, dung and urine of these animals comprise a possible origin of nitrate which can eventually be moved through the soil and get into the groundwater aquifers by precipitation (Sankararamakrishnan et al. 2008). Once groundwater is contaminated, treatment is difficult and expensive, thus the contamination prevention is the primary strategy used for water quality management (Corniello et al. 2007).

Drinking water is generally a low source of nitrate intake compared to food when the level is small, but it becomes considerable as the level increases to the World Health Organization (WHO) guideline. At levels above 50 mg/L, water is probably the main source of nitrate intake for the community, unless there are other sources of high nitrate intake such as use of some vegetables and fruits irrigated with sewages (Fan 2011). In areas where groundwater is the main source of drinking, domestic, and agricultural water, potentially considerable health risks are associated with the consumption of nitrate contaminated groundwater (Fazlzadeh et al. 2017a). The main health concern from high nitrate concentrations is methemoglobinemia or blue baby syndrome, which can affects infants under 6 months and can eventually result in the death of these infants (Shams et al. 2009; Wakida and Lerner 2005). Methemoglobinemia occurs when nitrite converts the Fe^{2+} in hemoglobin to the Fe^{3+} and consequently it cannot bind oxygen (WHO 2011).

Nitrate itself is not harmful, but in human gastrointestinal tract it can be endogenously reduced to toxic nitrite through nitrosation in the stomach with amines and amides to form various types of N-nitroso compounds (NOCs) (Ward 2005). Generally, 40–75% of NOCs are produced in the gastrointestinal tract. NOCs have increased the risk of cancer in a variety of animals in laboratory studies (Espejo-Herrera et al. 2015; Keszei et al. 2012; Zhu et al. 2014). According to previous reports, acute exposure to high levels of nitrate through drinking water can increase the risk of certain types of cancer, such as gastric, esophageal, and stomach cancer (Bao et al. 2017; Bittner 2000). Due to the serious effects of nitrate on human health, the World Health Organization (WHO) has recommended a guideline of 50 and 15 mg/L for adults and infants, respectively, in drinking water (Hashim et al. 2017). The US Environmental Protection Agency (USEPA) has set a maximum contaminant level of 45 mg/L for nitrate in public drinking water supplies (USEPA 2015).

Risk assessment for human health is a kind of evaluation method applied to estimate the degree of the health impacts that may be the result of exposure to non-carcinogenic and carcinogenic contaminants through a variety of exposure routes (Qasemi et al. 2018). Since the health risk of nitrate contamination has not been addressed to date in rural areas of Gonabad and Bajestan, we aimed in this research to investigate nitrate concentrations in groundwater applied for drinking and to evaluate the health risk from consuming the contaminated water in these areas. For health risk assessment of nitrate through the consumption of drinking water, the values of chronic daily intake (CDI) and the hazard quotient (HQ) were determined for the selected rural areas and then the obtained data were compared. The results of this work are expected to indicate specific regions where the health risk exceed the values of standards which would help health professionals, authorities and decision makers to develop more effective health management plans in terms of local and regional groundwater quality protection.

Materials and methods

Description of study area

The field research is focused on 39 rural areas of Gonabad and Bajestan as shown in Fig. 1a–c. Gonabad and Bajestan, located in south of Khorasan Razavi in east of Iran, were selected for the purpose of the present study because of high levels of nitrate reported by the health professionals in groundwater of some of these areas. These two counties have hot summers and cool winters with annual average temperature of 16.4–17.3 °C located in semi-arid regions with low average annual precipitation in range of 149–155 mm. Gonabad and Bajestan have many rural areas of mostly low-income earners with no or limited sewerage facilities. The geology of the studied rural areas varies from location to location but is mainly sedimentary rocks consisting of igneous and metamorphic rocks, metamorphosed to slate, schist, and quartzite and intrusions subvolcanic rocks. The rural areas have many small farms and the farmers actively spread manure and commonly use nitrogenous fertilizers as prerequisites to enhance the agricultural output. Almost all of inhabitants in the areas use unprotected wells for their wastewater disposal which increasing the risk of groundwater contamination with nitrate. In this study, it is assumed that most of the inhabitants in the rural areas derive 100 percent of their drinking water from the selected wells.

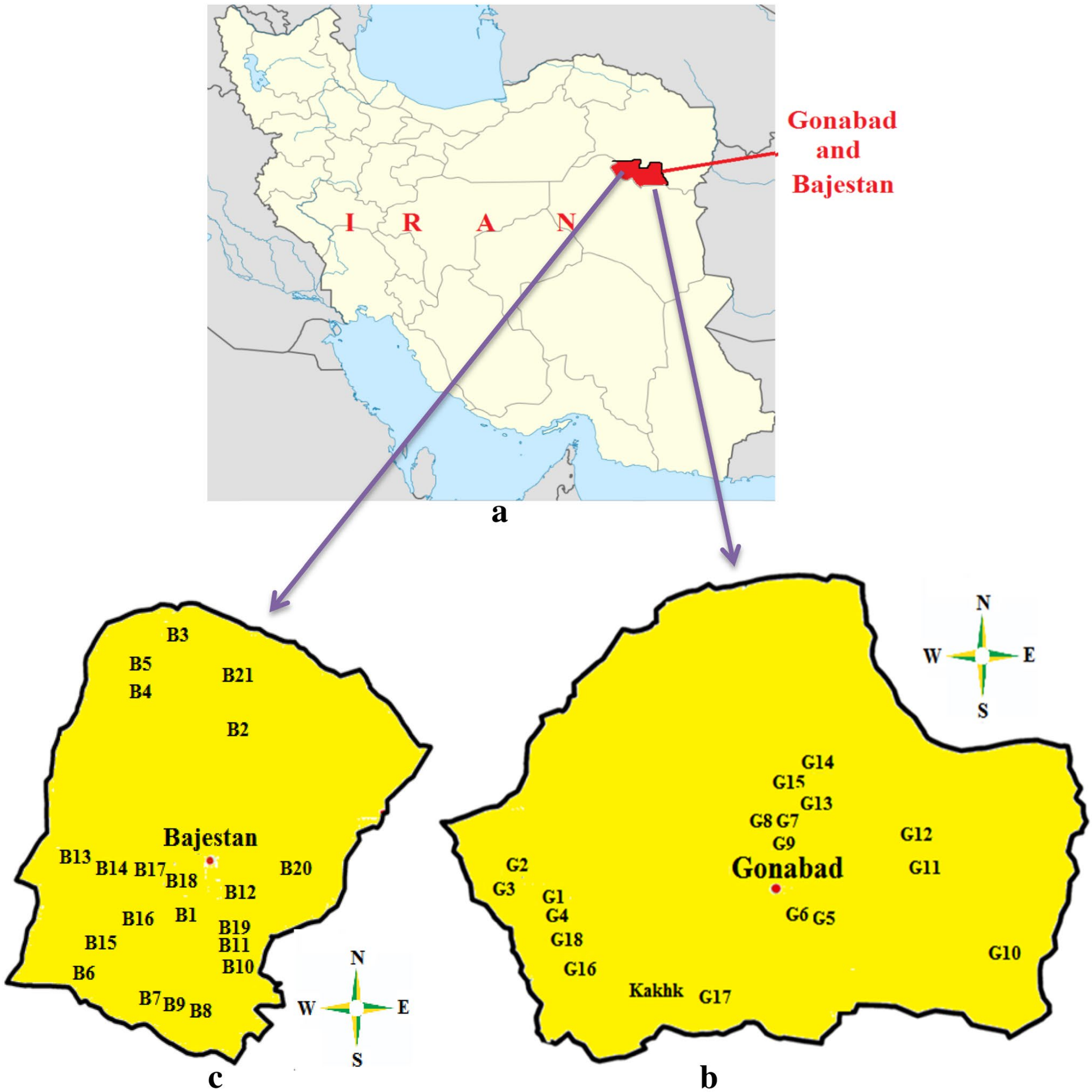


Fig. 1 Map of Gonabad and Bajestan in Iran (**a**), sampling locations in rural areas of Gonabad (**b**) and Bajestan (**c**)

Groundwater sampling and analysis

Duplicate groundwater samples were collected from each of 39 rural areas during January 2018, with a total of 78 samples being collected. The samples were taken from domestic wells and sampling stations were selected on the basis of lack of appropriate sanitary facilities considering WHO criteria. Groundwater samples were collected in plastic bottles, stored in ice-box, and sent to the chemistry laboratory of Gonabad University of medical sciences for analysis within 24–48 h. Finally, nitrate concentrations of the samples were analyzed using a UNICO-2100 spectrophotometer. The data of nitrate concentration used for the health risk assessments were average of duplicate groundwater samples from each sampling village. As the sampling frequency from each rural area was during one month (January), the observed level variations were negligible.

Health risk assessment

The non-carcinogenic risk assessment was performed using hazard quotient (HQ) by considering the chronic daily intake dose (CDI), calculated for the nitrate based on the results of chemical detections for the groundwater samples in the study areas. The hazard quotient method has been used in many studies for quantitative risk assessment (Edokpolo et al. 2015; Qiming et al. 2012).

For the estimation of chronic daily intake (CDI, mg/kg/day) to an individual contaminant through ingestion, the data measured for nitrate in drinking water were converted to daily intake using the parameters given in Table 1 as well as the following equation (Ghaderpoori et al. 2018; Qasemi et al. 2018):

$$\mathrm{CDI} = \frac{C \cdot \mathrm{DI} \cdot F \cdot \mathrm{ED}}{\mathrm{BW} \cdot \mathrm{AT}}$$

where C is nitrate content in water (mg/L), DI is daily water intake (L/day), F is exposure frequency (days/year), ED is exposure duration (years), BW is body weight (kg), and AT is averaging time for non-carcinogens (days).

The details of selected parameters and their values for determining the chronic daily intake through oral ingestion for adults, children and infants are given in Table 1.

The hazard quotient (HQ) was applied to evaluate nitrate risks using the following formula (Das et al. 2017; Yu et al. 2010):

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RfD}}$$

where RfD is the reference dosage of nitrate in mg/kg/day.

The reference dose (RfD) in this study was considered 1.6 mg/kg/day for nitrate based on the United States Environmental Protection Agency (USEPA) report (USEPA 2015). Groundwater samples with HQ values above 1 (HQ > 1) pose significant health risk due to nitrate contamination. The higher the value, the greater the probability of harmful non-carcinogenic health impacts (Khan et al. 2016; Ullah et al. 2017).

Table 1 Parameters applied for health exposure assessment in water

Risk exposure factors	Values for groups			Unit
	Adults (age > 19)	Children (6 > age > 12)	Infants (age < 1)	
C				mg/L
DI	2	1.5	0.8	L/day
F	365	365	365	Days/year
ED	40	10	1	Years
BW	70	20	10	kg
AT	14,600	3650	365	Days

C nitrate concentration, *DI* daily water intake, *F* exposure frequency, *ED* exposure duration, *BW* body weight, *AT* average timing

Results and discussion

As summarized in Table 2, for rural areas of Gonabad, the mean concentration of nitrate in the drinking water in this research was 29.3 mg/L, ranging from 1.8 to 82.2 mg/L. The mean concentration of nitrate in the drinking water of rural areas of Bajestan was 37.95 mg/L ranging from 5.5 to 84.3 mg/L. Totally, the results clearly indicated that nitrate levels in 11 percent of rural areas in Gonabad and 19 percent of rural areas of Bajestan were above 50 mg/L, which was the maximum limit of WHO guideline for nitrate in drinking water. This concluded that the mean nitrate levels in rural areas of Bajestan were higher than that in Gonabad.

Figure 2 indicates that sites G2, G3 and G4 have very low nitrate concentrations, and site G15 has very high nitrate concentrations. G15 (Bilond) is a rural area downward of Gonabad city. Its water is supplied from a Qanat system crosses along Gonabad city. Gonabad city has no wastewater collection system, and almost all the residents use absorbing wells for wastewater disposal. The high levels of nitrate in G15 (Bilond) was due to wastewater leakage from these wells. In Bajesten, B2 (Chah Paliz), B13 (Qasemabad) and B18 (Mazar) had high nitrate levels due to the absorbing wells and agricultural activities (Fig. 3).

Based on risk assessment formula mentioned above, the amounts of CDI calculations are necessary for the estimation of non-carcinogenic health risk assessment. The mean values of CDI for adults, children and infants were 0.79 (0.05–2.34), 2.08 (0.13–6.16) and 2.22 (0.14–6.57) mg/kg/day, respectively, in rural areas of Gonabad. For rural areas of Bajestan, the mean values of CDI for adults, children and infants were 1.03 (0.15–2.40), 2.73 (0.41–6.32) and 2.91 (0.44–6.74) mg/kg/day, respectively. Using the value of CDI and reference dose, hazard quotients (HQs) for nitrate in drinking water were determined. Chronic daily intake (CDI) estimations are given for each individual in Table 3. From the above data, it can be generally stated that the mean values of CDI in rural areas of Bajestan were higher than those of rural areas of Gonabad.

Figures 4 and 5 illustrate the health risk assessment distribution in rural areas of Gonabad and Bajestan, respectively, for adults, children, and infants. According to the figures, the health risk of infants was higher than those of children and adults.

Drinking groundwater showed high levels of nitrate in the study area, with nitrate being detected in all the samples and at excessive concentrations in 34.3% of the samples. The parameters applied in the study were primarily selected from the USEPA guideline for risk assessment;

Table 2 Comparison of nitrate concentrations found in rural areas of Gonabad and Bajestan

Rural areas of Gonabad				Rural areas of Bajestan			
S. no	Name	Nitrate (mg/L)	Population	S. no	Name	Nitrate (mg/L)	Population
G1	Now Dehe Meyrmaharab	29	314	B1	Darzab	18.8	256
G2	Sanu	4.1	958	B2	Chah Paliz	73.3	31
G3	Musiraz	5.4	200	B3	Sar Daq	32	1295
G4	Zibad	1.8	777	B4	Mansuri	36	794
G5	Rahn	29.3	1735	B5	Fakhrabad	31.1	1554
G6	Riab	29	758	B6	Abuol Khazen	23.8	279
G7	Dowlui	39.6	2043	B7	Jazin	32.4	2177
G8	Kheybari	25.8	1307	B8	Nuq	35.1	858
G9	Mend	36.8	1893	B9	Boqchir	30.6	92
G10	Geysvarnusazi	28.6	1565	B10	Ahang	36.7	365
G11	Bimorgh	37.1	1031	B11	Sarideh	24.3	376
G12	Rushnavand	54.7	3744	B12	Rezaiyeh	39.9	68
G13	Bagh-e Asiya	27	1910	B13	Qasemabad	84.3	666
G14	Quzhd	23.8	1568	B14	Motrabad	35.6	159
G15	Bilond	82.2	9034	B15	Nian	11.3	166
G16	Kalat	32.8	258	B16	Senjedak	5.5	44
G17	Ostad	25.3	282	B17	Solhabad	41.7	356
G18	Ruchi	15.7	268	B18	Mazar	81.9	910
				B19	Zeynabad	40.9	1015
				B20	Khar Firuzi	30.4	95
				B21	Marandiz	51.4	2812

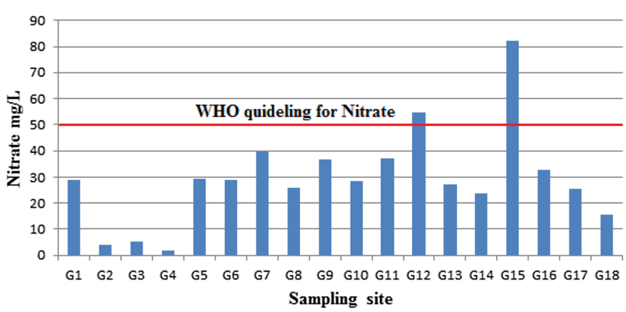


Fig. 2 Comparison of mean nitrate concentrations in rural areas of Gonabad with WHO guideline of nitrate in drinking water

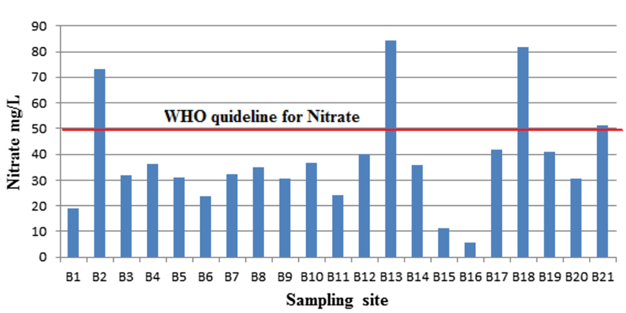


Fig. 3 Comparison of mean nitrate concentrations in rural areas of Bajestan with WHO guideline of nitrate in drinking water

therefore, additional studies are necessary to determine data specific to the study area.

For non-carcinogenic risk assessment, the values of HQ were calculated separately for adults, children and infants. The mean values of HQ for adults, children and infants were 0.49 (0.03–1.46), 1.30 (0.08–3.85) and 1.39 (0.09–4.11), respectively, in rural areas of Gonabad. For rural areas of Bajestan, the mean values of HQ for adults, children and infants were 0.65 (0.09–1.50), 1.70 (0.25–3.95) and 1.82 (0.27–4.21), respectively. For rural areas of Gonabad, 77% of sites showed a HQ above 1 for children and infants (Fig. 4). But only 0.05% of adults had HQ values above 1. For studied groups in Bajestan, 85% of calculated HQ values for infants and children were above 1 (Fig. 5). For adults, 14% of HQs were above 1. Totally, the results indicated that the risk of adverse health effects of nitrate contamination in groundwater in rural areas of Gonabad and Bajestan was high especially for infants and children. Comparison of HQs among the 39 sampling sites showed that the groundwater of rural areas in Bajestan had higher HQs than Gonabad.

Generally, levels of nitrate in surface and groundwater are normally in the range of 0–18 mg/L (Schmoll et al. 2006). However, many rural areas in the current study had much higher levels, highlighting the groundwater

Table 3 Chronic daily intake (CDI, mg/kg/day) estimation

Gonabad				Bajestan			
S. no	CDI adults	CDI children	CDI infants	S. no	CDI adults	CDI children	CDI infants
G1	0.82	2.17	2.32	B1	0.53	1.41	1.50
G2	0.11	0.30	0.32	B2	2.09	5.49	5.86
G3	0.15	0.40	0.43	B3	0.91	2.4	2.56
G4	0.05	0.13	0.14	B4	1.02	2.7	2.88
G5	0.83	2.19	2.34	B5	0.88	2.33	2.48
G6	0.82	2.17	2.32	B6	0.68	1.78	1.90
G7	1.13	2.97	3.16	B7	0.92	2.43	2.59
G8	0.73	1.93	2.06	B8	1.00	2.63	2.80
G9	1.05	2.76	2.94	B9	0.87	2.29	2.44
G10	0.81	2.14	2.28	B10	1.04	2.75	2.93
G11	1.06	2.78	2.96	B11	0.69	1.82	1.94
G12	1.56	4.10	4.37	B12	1.14	2.99	3.19
G13	0.77	2.02	2.16	B13	2.40	6.32	6.74
G14	0.68	1.78	1.90	B14	1.01	2.67	2.84
G15	2.34	6.16	6.57	B15	0.32	0.84	0.90
G16	0.93	2.46	2.62	B16	0.15	0.41	0.44
G17	0.72	1.89	2.02	B17	1.19	3.12	3.33
G18	0.4	1.17	1.25	B18	2.34	6.14	6.55
				B19	1.16	3.06	3.27
				B20	0.86	2.28	2.43
				B21	1.46	3.85	4.11

Fig. 4 Values of hazard quotient (HQ) for rural areas of Gonabad city for three age groups (adults, children, and infants)

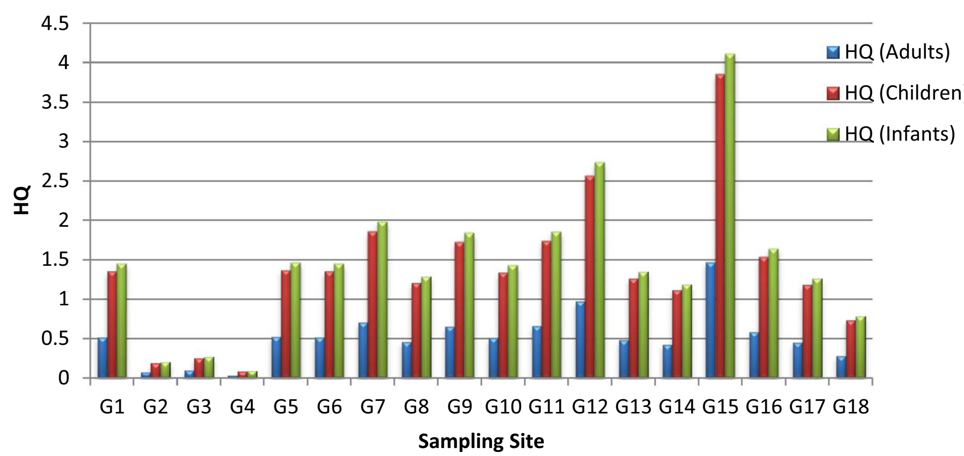
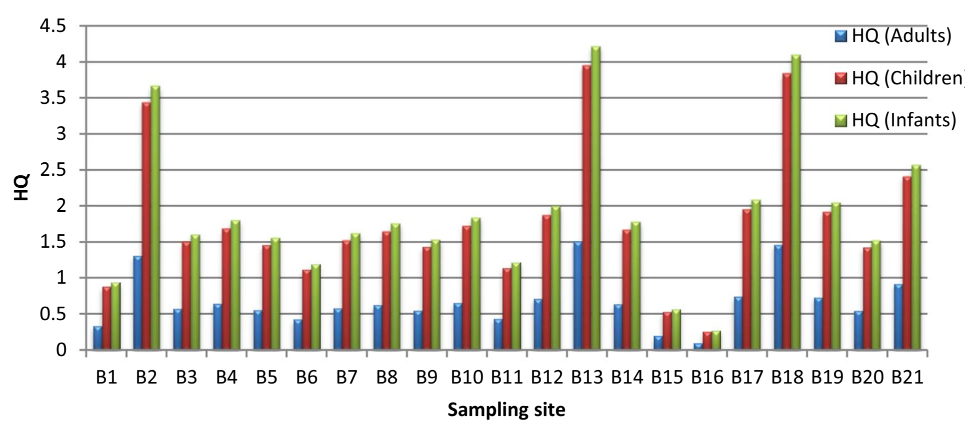


Fig. 5 Values of hazard quotient (HQ) for rural areas of Bajestan for three age groups (adults, children, and infants)



contamination in the areas. In the rural areas, high nitrate levels can be a cumulative outcome of the different activities in the areas. In this case, reducing the amounts of nitrogen transferred by effluents, septic tanks and unprotected sewage wells to groundwater, and also equalizing nitrogenous compounds used in farmlands is entirely mandatory. Therefore, in these areas, a stringent sewage disposal policy will be unavoidable. As a rule of thumb, after water contamination, water treatment processes for diminishing nitrate levels cannot be performed in such large areas, and implementation of preventive procedures are the best option. However, the results of the present study clearly indicated that the level of nitrate may pose considerable adverse health effects to the individuals of some rural areas in Gonabad and Bajestan via oral ingestion of water. In a study, groundwater nitrate levels in eight wells in Dehloran, Ilam, Iran, were determined in 2015. The nitrate levels in all of the analyzed samples were lower than 20 mg/L (Almasi et al. 2016). In another study, nitrate levels of groundwater in Lar area, south Iran were studied. The levels of nitrate ranged from 1.47 to 70.66 mg/L. They attributed the high deteted levels of nitrate to widespread use of nitrogenous inorganic fertilizers (Rezaei et al. 2017). In a similar study, the levels of nitrate in Andimeshk and Susa plains in north of Khozestan-Iran were analyzed. The mean nitrate level was 14.2 mg/L which was below the WHO guideline of 50 mg/L (Mahvi et al. 2005).

Moreover, nitrate concentrations were evaluated in 43 active wells of Shiraz, South-central Iran, by statistical models during 2010–2014. The concentrations of nitrate in the samples ranged from 5 to 72 mg/L, and 11% of the samples had nitrate concentrations above the standard level of 45 mg/L as nitrate (Nezhad et al. 2017) regulated by United States Environmental Protection Agency (USEPA). In another work, trends of nitrate occurrence in Zanjan groundwater resources were evaluated during 2006–2010 in 72 wells. The results of this study showed that only one well had nitrate concentration above the standard and other wells were acceptable regarding to nitrate concentrations. The data showed a rising trend in nitrate levels during the study period (Eslami and Ghadimi 2017).

In a study, spatial distribution and the reason behind the increasing nitrate content in central district of Khodabandeh, Iran were evaluated. The results indicated that nitrate contamination in the south and south-west regions was due to geological processes, agricultural activities, and the discharge of human sewage into absorbing wells (Khosravi et al. 2017).

In another study, the concentration of nitrate of drinking water wells in a Tonekabon village, Iran was analyzed. The nitrate concentration ranged from 8 to 33.7 mg/L (Roholamin Kasmaei et al. 2017). In a cross-sectional study, the levels of nitrate in 100 groundwater samples in Talesh in the North of Iran in three consequent months were analyzed. The results revealed that all samples had nitrate contents above 50 mg/L recommended by WHO (Gheshlagh et al. 2013). In another research, the effects of urbanization on groundwater quantity in the Zahedan Aquifer, southeast Iran were evaluated and high levels of nitrate (up to 295 mg/L as nitrate) were observed in groundwater samples (Khazaei et al. 2004). In another study, health-risk related to nitrate in the drinking water in the Sanandaj, Kurdistan County, Iran was assessed for men, women, and children. The level of nitrate in urban and rural drinking water ranged from 0.28 to 27.77 and from 1.28 to 80 mg/L, respectively. The level of nitrate reported in rural samples was more than that of urban samples. The results of this research showed that all 3 studied groups (men, women, and children) were exposed to health risk due to nitrate (hazard quotients above 1) (Rezaei et al. 2018).

As the results of the present study showed, the level of nitrate was higher in some of the studied rural areas which can be attributed to various human activities and natural processes including agricultural activities, cultivation and fertilizers, improper discharge of human sewage into absorbing wells and sewage disposal manners, landfills, farm/feedlot animal wastes, general rural development, degradation of natural vegetation and termites.

Conclusions

Nitrate contamination of drinking water supplies in many parts of Iran is pervasive and very serious. The identification of nitrate-vulnerable regions is the primary step towards the protection of groundwater against contamination. The research compares nitrate contamination of groundwater in rural areas of Gonabad and Bajestan with a special emphasis to determining non-carcinogenic health risk associated to nitrate contamination in these regions for three groups including adults, children and infants. For groundwater in rural areas of Gonabad, the nitrate concentrations ranged from 1.8 to 82.2 mg/L with only two rural areas in excess of the WHO guideline value of 50 mg/L. In rural areas of Bajestan, the nitrate concentrations ranged from 5.5 to 84.3 mg/L and 4 values exceeded the WHO guideline. However, the consumption of high nitrate containing water can appreciably impact the health of individuals. The non-carcinogenic risk assessment in the present work showed that the rural areas of Bajestan had higher CDI and HQ values than Gonabad. The non-carcinogenic risk assessment calculated for the studied groups in Gonabad and Bajestan were as follows: infants > children > adults. This clearly would notify consumers that the groundwater is not safe, especially for infants under 1 years of age. These findings also illustrate that nitrate concentrations in groundwater of the study area should be regularly monitored to ensure it is within the permissible levels. A comprehensive sanitation improvement plan in these areas will have a positive influence on reducing nitrate levels in groundwater resources. The last recommendation is to abandon water consumption of any well that is found to be contaminated with nitrates higher than the WHO guideline of 50 mg/L. Finally, as nitrate is costly to remove from drinking water supplies, control of the anthropogenic activities that contribute nitrate to groundwater including animal operations, crop fertilization, wastewater discharge, absorbing wells septic systems, etc. should be managed appropriately. The results of the present work would allow one to determine more definitively the levels of nitrate contamination in groundwater of rural areas of Gonabad and Bajestan, and thus to propose and select the most effective remediation and prevention alternatives. The results of this study also provide useful information for future work planning and important to assess the potential health consequences from nitrate exposure.

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References

Alif Adham Z, Shaharuddin M (2014) Nitrate levels in groundwater and health risk assessment in three villages in Pasir Puteh. Health Environ J 5(3):139–148

Almasi A, Shokri R, Momenzadeh R, Rezaei S, Jamshidi A, Yazdizadeh R (2016) Distribution of groundwater nitrate in Dehloran, Iran: a case study using GIS. J Adv Environ Health Res 4:155–160

Aranibar JN, Villagra P, Gomez M, Jobbágy E, Quiroga M, Wuilloud R, Monasterio R, Guevara A (2011) Nitrate dynamics in the soil and unconfined aquifer in arid groundwater coupled ecosystems of the Monte desert, Argentina. J Geophys Res Solid Earth 116:1–14

Asadi P, Ataie-Ashtiani B, Beheshti A (2017) Vulnerability assessment of urban groundwater resources to nitrate: the case study of Mashhad, Iran. Environ Earth Sci 76:41

Bao Z, Hu Q, Qi W, Tang Y, Wang W, Wan P, Chao J, Yang XJ (2017) Nitrate reduction in water by aluminum alloys particles. J Environ Manage 196:666–673

Bittner AAB (2000) Nepal drinking water quality assessment: nitrates and ammonia. Massachusetts Institute of Technology, University of Michigan (a thesis)

Corniello A, Ducci D, Ruggieri G (2007) Areal identification of groundwater nitrate contamination sources in periurban areas. J Soils Sediments 7:159–166

Das S, de Oliveira LM, da Silva E, Liu Y, Ma LQ (2017) Fluoride concentrations in traditional and herbal teas: Health risk assessment. Environ Pollut 231:779–784

Dehghani MH, Jahed G-R, Zarei A (2013) Investigation of low-pressure ultraviolet radiation on inactivation of Rhabitidae Nematode from water. Iran J Public Health 42:314

Dehghani MH, Zarei A, Mesdaghinia A, Nabizadeh R, Alimohammadi M, Afsharnia M (2017) Response surface modeling, isotherm, thermodynamic and optimization study of arsenic (V) removal from aqueous solutions using modified bentonite-chitosan (MBC). Korean J Chem Eng 34:757–767

Derakhshani E, Naghizadeh A, Yari AR, Mohammadi MJ, Kamranifar M, Farhang M (2017) Association of toxicochemical and microbiological quality of bottled mineral water in Birjand city Iran. Toxin Rev 37(2):1–6

Edokpolo B, Yu QJ, Connell D (2015) Health risk assessment for exposure to benzene in petroleum refinery environments. Int J Environ Res Public Health 12:595–610

Ehteshami M, Biglarijoo N (2014) Determination of nitrate concentration in groundwater in agricultural area in Babol County, Iran. Iran J Health Sci 2:1–9

Eslami A, Ghadimi M (2017) Study of five years nitrite and nitrate content trends of Zanjan groundwater resources using GIS from 2006 to 2010. J Health Field 1:30–36

Esmaeili A, Moore F, Keshavarzi B (2014) Nitrate contamination in irrigation groundwater, Isfahan, Iran. Environ Earth Sci 72:2511–2522

Espejo-Herrera N, Cantor KP, Malats N, Silverman DT, Tardón A, García-Closas R, Serra C, Kogevinas M, Villanueva CM (2015) Nitrate in drinking water and bladder cancer risk in Spain. Environ Res 137:299–307

Fan AM (2011) Nitrate and nitrite in drinking water: a toxicological review. California Environmental Protection Agency, Oakland, CA, USA

Fazlzadeh M, Adhami S, Vosoughi M, Khosravi R, Sadigh A (2017a) Nitrate ion adsorption from aqueous solution by a novel local green montmorillonite adsorbent. J Health 8:298–311

Fazlzadeh M, Khosravi R, Zarei A (2017b) Green synthesis of zinc oxide nanoparticles using *Peganum harmala* seed extract, and loaded on *Peganum harmala* seed powdered activated carbon as new adsorbent for removal of Cr (VI) from aqueous solution. Ecol Eng 103:180–190

Gelberg KH, Church L, Casey G, London M, Roerig DS, Boyd J, Hill M (1999) Nitrate levels in drinking water in rural New York State. Environ Res 80:34–40

Ghaderpoori M, Paydar M, Zarei A, Alidadi H, Najafpoor AA, Gohary AH, Shams M (2018) Health risk assessment of fluoride in water distribution network of Mashhad, Iran. Hum Ecol Risk Assess 1–12

Gheshlagh FS-N, Ziarati P, Bidgoli SA (2013) Seasonal fluctuation of heavy metal and nitrate pollution in ground water of farmlands in Talesh, Gilan, Iran. Int J Farming Allied Sci 2(20):836–841

Gorgij AD, Kisi O, Moghaddam AA, Taghipour A (2017) Groundwater quality ranking for drinking purposes, using the entropy method and the spatial autocorrelation index. Environ Earth Sci 76:269

Hashim KS, Shaw A, Al Khaddar R, Pedrola MO, Phipps D (2017) Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water—experimental, statistical, and economic approach. J Environ Manag 196:224–233

Karbassi A, Mir Mohammad Hosseini F, Baghvand A, Nazariha M (2011) Development of water quality index (WQI) for Gorganrood River. Int J Environ Res 5:1041–1046

Keszei AP, Goldbohm RA, Schouten LJ, Jakszyn P, van den Brandt PA (2012) Dietary *N*-nitroso compounds, endogenous nitrosation, and the risk of esophageal and gastric cancer subtypes in the Netherlands Cohort Study. Am J Clin Nutr 97:135–146

Khan ZI, Ahmad K, Ashraf M, Shoaib N, Parveen R, Bibi Z, Mustafa I, Noorka IR, Tahir HM, Akram NA (2016) Assessment of toxicological health risk of trace metals in vegetables mostly consumed in Punjab, Pakistan. Environ Earth Sci 75:433

Khazaei E, Mackay R, Warner JW (2004) The effects of urbanization on groundwater quantity and quality in the Zahedan aquifer, southeast Iran. Water Int 29:178–188

Khosravi Y, Zamani AA, Parizanganeh AH, Mokhtari MAA, Nadi A (2017) Studying spatial changes of groundwater's nitrate content

in Central District of Khodabandeh, Iran. J Hum Environ Health Promot 3(1):13–20
Khosravi R, Zarei A, Heidari M, Ahmadfazeli A, Vosughi M, Fazlzadeh M (2018) Application of ZnO and TiO_2 nanoparticles coated onto montmorillonite in the presence of H_2O_2 for efficient removal of cephalexin from aqueous solutions. Korean J Chem Eng 35:1000–1008
Mahvi A, Nouri J, Babaei A, Nabizadeh R (2005) Agricultural activities impact on groundwater nitrate pollution. Int J Environ Sci Technol 2:41–47
Migeot V, Albouy-Llaty M, Carles C, Limousi F, Strezlec S, Dupuis A, Rabouan S (2013) Drinking-water exposure to a mixture of nitrate and low-dose atrazine metabolites and small-for-gestational age (SGA) babies: a historic cohort study. Environ Res 122:58–64
Mohammadi AA, Yaghmaeian K, Hossein F, Nabizadeh R, Dehghani MH, Khaili JK, Mahvi AH (2017) Temporal and spatial variation of chemical parameter concentration in drinking water resources of Bandar-e Gaz City using geographic information system. Desalin Water Treat 68:170–176
Nezhad AB, Emamjomeh MM, Farzadkia M, Jafari AJ, Sayadi M, Talab AHD (2017) Nitrite and nitrate concentrations in the drinking groundwater of Shiraz City, South-central Iran by statistical models. Iran J Public Health 46:1275
Noroozi M, Heibati B, Mahvi A, Zarei A, Derakhshan S (2011) Evaluation of physical and chemical quality of drinking water in Mianeh, Iran. Am Eurasian J Agric Environ Sci 10:490–493
Pirsaheb M, Khosravi T, Fazlzadeh M, Sharafie K (2017) Effects of loading rate, resin height, and bed volume on nitrate removal from drinking water by non-selective strong anion exchange resin (A400E). Desalin Water Treat 89:127–135
Qasemi M, Afsharnia M, Zarei A, Farhang M, Allahdadi M (2018) Non-carcinogenic risk assessment to human health due to intake of fluoride in the groundwater in rural areas of Gonabad and Bajestan, Iran: a case study. Hum Ecol Risk Assess 24(6):1–12
Qiming JY, Cao Q, Connell DW (2012) An overall risk probability-based method for quantification of synergistic and antagonistic effects in health risk assessment for mixtures: theoretical concepts. Environ Sci Pollut Res 19:2627–2633
Rezaei M, Nikbakht M, Shakeri A (2017) Geochemistry and sources of fluoride and nitrate contamination of groundwater in Lar area, south Iran. Environ Sci Pollut Res 24:15471–15487
Rezaei H, Jafari A, Kamarehie B, Fakhri Y, Ghaderpoury A, Karami MA, Ghaderpoori M, Shams M, Bidarpoor F, Salimi M (2018) Health-risk assessment related to the fluoride, nitrate, and nitrite in the drinking water in the Sanandaj, Kurdistan County, Iran. Hum Ecol Risk Assess. https://doi.org/10.1080/10807039.2018.1463510
Rezaverdinejad V, Rahimi M (2017) Seasonal assessment of nitrate, nitrite, and heavy metals pollution in groundwater of Ardabil Aquifer, Iran. Pol J Environ Stud 26:2267–2276
Roholamin Kasmaei A, Nezhad Naderi M, Bahrami Z (2017) Water pollution management in wells of zawar village for investigation of effects of nitrogen fertilizers in nitrate entry into groundwater. J Appl Res Water Wastewater 4:354–357
Sankararamakrishnan N, Sharma AK, Iyengar L (2008) Contamination of nitrate and fluoride in ground water along the Ganges Alluvial Plain of Kanpur district, Uttar Pradesh, India. Environ Monit Assess 146:375–382
Schmoll O, Howard G, Chilton J, Chorus I (2006) Protecting groundwater for health: managing the quality of drinking-water sources. World Health Organization
Shams M, Nodehi RN, Alimohammadi M, Mahvi A (2009) A survey of nitrate and fluoride in water distribution networks of Tabas, Iran. World Appl Sci J 7:1516–1520
Shankar S, Shanker U (2014) Arsenic contamination of groundwater: a review of sources, prevalence, health risks, and strategies for mitigation. Sci World J 2014:304524
Spalding RF, Exner ME (1993) Occurrence of nitrate in groundwater—a review. J Environ Qual 22:392–402
Thomson B, Nokes C, Cressey P (2007) Intake and risk assessment of nitrate and nitrite from New Zealand foods and drinking water. Food Addit Contam 24:113–121
Ullah Z, Naz A, Saddique U, Khan A, Shah W, Muhammad S (2017) Potentially toxic elements concentrations and human health risk assessment of food crops in Bajaur Agency, Pakistan. Environ Earth Sci 76:482
USEPA (2012) Edition of the Drinking Water Standards and Health Advisories. United States Environment Protection Agency
USEPA (2015) EPA's Integrated Risk Information System (IRIS) Program Progress Report and Report to Congress U.S. Environmental Protection Agency: Office of Research and Development
Wakida FT, Lerner DN (2005) Non-agricultural sources of groundwater nitrate: a review and case study. Water Res 39:3–16
Ward MH (2005) Workgroup report: drinking-water nitrate and health—recent findings and research needs. Environ Health Perspect 113:1607
WHO (2011) Guidelines for drinking-water quality: recommendations. World Health Organization, Geneva
Yu FC, Fang GH, Ru XW (2010) Eutrophication, health risk assessment and spatial analysis of water quality in Gucheng Lake, China. Environ Earth Sci 59:1741–1748
Zhu Y, Wang PP, Zhao J, Green R, Sun Z, Roebothan B, Squires J, Buehler S, Dicks E, Zhao J (2014) Dietary *N*-nitroso compounds and risk of colorectal cancer: a case–control study in Newfoundland and Labrador and Ontario, Canada. Br J Nutr 111:1109–1117
Ziarati P, Zendehdel T, Bidgoli S (2014) Nitrate content in drinking water in Gilan and Mazandaran Provinces Iran. J Environ Anal Toxicol 4:2161-0525