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Health risk assessment to fluoride and nitrate in drinking water of rural residents living in the Bardaskan city, arid region, southeastern Iran

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ABSTRACT

In recent decades, harmful contaminants such as nitrate and fluoride have become more common. This cross-sectional study was conducted in 2016 on the ground water resources of Baradaskan city. In order to investigate the concentration fluoride and nitrate, sampling was done in 30 drinking water resources, then chemical parameters were analyzed according to standard method. The purposes of this investigation was (1) to provide an overview of present drinking water quality and compare it with the national standard (2) to determine spatial distribution of groundwater quality fluoride and nitrate concentrations, (3) to map groundwater quality in the study area, using GIS (V10.3), and (4) human health risk assessment was performed by calculating the chronic daily intake (CDI) and hazard quotient (HQ) of fluoride and nitrate through oral intake for infants, children, teenagers and adults. The minimum and maximum values of nitrate and fluoride concentrations were between 0.0–77.2, 0.2–1.036 mg/l, respectively. Spatial distributions of nitrate and fluoride concentrations showed that highest nitrate and lowest fluoride concentrations occurred in the north-east region of the study area. HQ values of nitrate for children, teenagers and adults 3, 1, 2 villages were more than one. In contrast, mean HQ values of fluoride were lower than 1, which was mostly acceptable.

Keywords: Drinking water; Nitrate; Fluoride; Health risk; Bardaskan

1. Introduction

Today's concern about environmental related diseases are on the rise in human societies [1,2]. According to World Health Organization (WHO) report, approximately a quarter of mortalities have resulted from environmental risk factor. Hence, it is imperative to invest in strategies for reducing environmental risk factors [3,4]. Exposure to drinking water with high concentration of nitrate and fluoride can be attributed to environmental factors affecting human health [4]. Source of pollutant in the ground water resources are associated with human activities. Groundwater contamination can be related to waste disposal, land disposal of solid waste, municipal wastewater, wastewa-

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ter impoundments, and land spreading of sludge, brine disposal from the petroleum industry, mine wastes, and animal feedlot wastes [5]. Nitrate is the final composition of the organic biodegradation processes in the nature [6]. Nitrate is converted to nitrite and nitrous oxidation by reduction, and can form nitrozoamines with first and second-order organic amines [7]. Excessive exposure to nitrogenous compounds can cause cancer in humans and other harmful effects such as hyper proven adrenal cortex [7–9]. Several researches reported a direct association between methaemoglobinaemia in children under six months with high concentration of nitrate in drinking water. Also, more recent studies have shown that elevated levels of nitrate in drinking water supplied to women during the first trimester of pregnancy was associated with birth defects [7,8]. Accordingly, the maximum contamination level (MCL) for drinking water is suggested to be not more than 50, mg/L for nitrate by the WHO [9,10]. Fluoride is an element that is widely distributed in all water, air and soil sources; hence, human can receive this element through many ways [11–13]. One of the best ways to obtain fluoride is through drinking water [14,15] because fluoride content in drinking water resources is constant, and humans' daily intake is 2–3 L of water [11,15]. Fluoride concentration between 0.5–1.5 mg/L in drinking water can have a positive effect on the health of teeth and bones of young people, but exposure to fluoride content above 1.5–4 mg/L for long term can cause harmful effects on human health such as birth defects, weight and height disorders in infants, effect on fertility, kidney and liver, neurological effects, and effect on thyroid hormones [16–21]. Dental and skeletal fluorosis is a major problem for endemic areas containing high fluoride drinking water sources such as India, Africa, China and Iran [20,22,23]. On the other hand, low fluoride concentration in drinking water leads to the increase of dental caries. Therefore, WHO and national standard of Iran recommend 0.5–1.5 mg/L of F in drinking water [24,25]. Hence, it is essential to evaluate nitrate and fluoride concentrations in drinking water resources and assesses its potential health risks. Today risk assessment is an important instrument to estimate the potential effects of stress or factors on the receivers [12,15]. Risk assessment activities often concentrate on the identification and investigation of contaminants, their effect on plant and animal species as well as biological patterns and processes [12,26]. Several researches have been performed on the risk assessment for fluoride and nitrate exposure, mostly from drinking water [12,15,27,28]. The purpose of this investigation was (1) to provide an overview of present drinking water quality and compare it with national standard (2) to determine spatial distribution of groundwater quality fluoride and NO_3^- concentrations, (3) to map groundwater quality in the study area, using GIS (V10.3), and (4) to estimate the health risk assessment in non-cancer diseases for four group's infants, children, teenagers and adults.

2. Materials and methods

2.1. Area of study

The weather in the north part of Khorasan Razavi province is cold and in the south and central parts changes from semi dry to hot and dry. City of Bardaskan is located in the Khorasan Razavi province, encompassing an area of about 8535 km^2. Bardaskan is situated in an altitude of 985 m above the sea level. Annual rainfall average is 150 mm. Bardaskan slowest and highest temperature are –7°C and 50°C, respectively.

There is no permanent river in the Bardaskan and it has 3 towns and 293 villages. At the 2017 census, its population was 28,233 with 8570 families [1].

2.2. Water chemical analysis

This cross-sectional descriptive study was performed in the villages of Bardeskan County in 2016. A total of 120 water samples were collected from groundwater resources (each season 30 sample). The samples of drinking water were collected in sterile polythene bottles (100 ml) after running (ring well and deep well) for at least half an hour from different villages and the samples were then transported to a laboratory. The samples were stored at 4–8°C and analyzed in 48 h of sampling. The chemical characteristics of the groundwater samples were analyzing by standard methods [29]. Chloride concentration measures by the $AgNO_3$ titration method, and sulfate concentration by the $BaCl_2$ turbidity method was done using a spectrophotometer (DR/2500, Hach, USA). Calcium and magnesium concentrations were determined by titration with EDTA [30,31]. Sodium and potassium concentrations were measured using a flame photometer (PFP7, Jenway) [29,32]. Fluoride concentration was determined using sodium 2-(parasulfophenylazo)-1, 8-dihydroxy-3, 6-naphthalene disulfonate (SPADNS) method and a DR/2500 spectrophotometer (Hach, USA) [29,33,34]. Spectrophotometer of HACH Company, DR5000 model with 520 and 570 nm wavelengths was used to measure nitrate and nitrite concentration in water [29]. The results were compared with the Iranian national standards and according to WHO guideline.

2.3. Human risk assessment of nitrate and fluoride

Human health risk assessment for water contaminants calculate the nature and probability of adverse health effects for the resident who receive chemicals from drinking water. It provides a systematic approach for developing a management strategy to supply safe drinking water. The data obtained from the analysis of samples for nitrate and fluoride in 30 drinking water resource in rural area in Bardeskan County in Khorasan Razavi province underwent a health risk assessment for non-cancer effects. Exposure evaluation were estimated for infants, teenagers and adults based on body weight and water consumption [15]. Consequently, the quantitative health risk assessment (HQ) of fluoride concentration through the consumption of drinking water was evaluated amongst residents living in the villages of Bardeskan County, Khorasan Razavi Province. For this purpose, we divided population into four age groups based on physiological and behavioral differences similar to Ghoochani et al. study [35] as follow: infants (less than 2 years), children (2 to <6 years), teenagers (6 to <16 years) and adults (≥ 16 years). The following

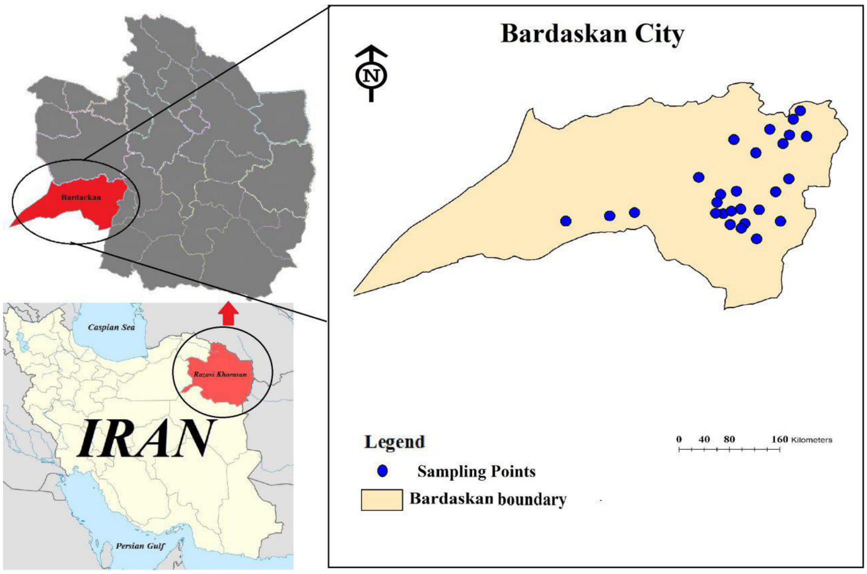

Fig. 1. Location map of the study area and sampling locations of Bardaskan and Khorasan-e- Razavi province, Iran.

equation (Eq. (1)) was used to calculate the non-carcinogenic health risk assessment:

$$HQ = \frac{EDI}{RfD} \quad (1)$$

where HQ is non-carcinogenic risk quotient. EDI and RfD are chronic daily intake (mg kg^{-1} d^{-1}) and reference dose (mg kg^{-1} d^{-1}), respectively. The intake reference dose for F is 0.06, 1.6 mg kg^{-1} d^{-1}. The following Eq. (2) is used to calculate the EDI:

$$EDI = \frac{C_f \times C_d}{B_w} \quad (2)$$

Estimated daily intake (EDI) of F is estimate based on the daily average consumption of drinking water (C_d), concentration of nitrate and fluoride in drinking water (C_f) and body weight (B_w). EDI is expressed in unit of milligrams per kilogram of bodyweight per day [15]. The water consumption data and body weight were estimated based on a questionnaire that were asked of the target groups (infants, children, teenager and adults). The average water consumption rates in infants (0–2 years old), children (2–6 years old), teenagers (6–16 years old) and adults (≥16 years old) were 0.08, 0.85, 2 and 2.5 L day^{-1}, respectively. Body weight of the target groups were considered 10, 15, 50 and 78 kg, respectively.

3. Results and discussion

3.1. Ground water quality: general parameters

The result of descriptive analyzes are presented in Table 1, which is comparable with both National and global standard Table 2.

The pH values of all the samples were within the optimum range (6.5–8.5) in accordance to the WHO and national Iranian standards. The results showed that there were large variations in TDS values among different sampling sites. TDS ranges between 307 and 2864 mg/L with a mean level of 835 mg/L, and 10% of the samples exceeded the acceptable limit (500–1500 mg/L) based on the and Iranian standards for TDS and 14.3% of the samples higher than WHO guideline (1200 mg/l).The results indicated that the concentrations of Ca and Mg were reported as 9.6–105.6 and 4.8–220.8 mg/L in the study area, respectively. Fourteen samples had low levels of Ca and Mg, which was within the desirable range of national Iranian standards. Therefore, lake of calcium and magnesium in the groundwater could cause water to be classified as soft water. High chloride level in water usually creates a salty taste, and might cause corrosion of metal pipes. The maximum permissible limit of sulfate and chloride is 500 and 250 mg/L for drinking purposes that is recommended by WHO. The results showed that only 78.5–88% of water samples were within the permissible range of the Iran national standard and 12–12.5% were higher than the standard range. The sudden increase in the chloride content can be regarded as a possible indicator of anthropogenic pollution. EC refers to the electrical conductivity of the water solution. The minimum and maximum value of water EC 495, 4620 µm hos/cm, respectively. And 13% of the samples exceed the permissible limit (2000 µm hos/cm) based on the Iranian standards for EC.

3.2. Distribution and occurrence of nitrate

The minimum and maximum values of nitrate concentrations between 0–77.2 mg/L were measured in the village number No. 2, No. 30, respectively. Nitrate concentrations for these two drinking water samples exceed the Iranian national standard. Spatial distributions of nitrate concentrations are shown in Fig. 3. It is shown that the high nitrate concentrations (77.2 mg/L) occurred in the north-east part of the villages of Bardeskan County. A study by Chen et al. showed that the nitrate concentration in the groundwater samples varied from 2.66 to 103 mg/L. Also this report

Table 1
Parameters used in the present study for health risk assessment (HQ)

Parameter	Risk exposure factors	Values for groups			
		Infants	Children	Teenagers	Adults
Fluoride	C_f, mg/L				
	C_d, L/d	0.08	0.85	2	2.5
	B_w, kg	10	15	50	78
	RfD, mg/kg·d	0.06	0.06	0.06	0.06
Nitrate	C_f, mg/L				
	C_d, L/d	0.08	0.85	2	2.5
	B_w, kg	10	15	50	78
	RfD, mg/kg·d	1.6	1.6	1.6	1.6

Table 2
Statistical evaluation of drinking water quality parameter resources in the study area

Village number	pH	T °C	F^- (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	TDS (mg/L)	EC (μm mho/cm)	SO_4^{2-} (mg/L)	Cl^- (mg/L)
1	8.38	22.3	0.8	11.59	0.014	96	11.2	698	1125	173	106
2	8.27	21.2	0.71	0	0	11.52	12.8	556	897	127	77
3	8.24	22.6	0.58	6.72	0.02	13.44	14.4	642	1036	157	115
4	8.23	22.7	0.54	5.89	0.006	10.56	14.4	575	928	147	86
5	8.32	22.5	0.55	6.07	0.003	10.56	16	613	989	185	93
6	8.39	22.4	0.67	5.52	0	4.8	11.2	478	771	113	60
7	8.29	20.8	0.67	9	0.048	12	16.8	815	1314	211	148
8	7.96	20.2	0.29	6.72	0.003	70.08	59.2	811	1308	189	95.06
9	8.33	20.8	0.57	9.02	0.008	10.56	19.2	843	1359	174	179
10	8.02	20	0.33	22.45	0.006	108	68	1414	2280	296	451
11	8.13	20.2	0.88	11.04	0.004	29.28	44	2864	4620	704	926
12	8.26	20.9	0.64	0.92	0.003	20.16	25.6	1063	1714	428	175
13	8.33	21.4	0.86	14.35	0.006	7.68	12.8	753	1214	169	121
14	8.13	21.3	1.03	18.58	0.003	9.6	25.6	1045	1686	206	221
15	8.04	26.2	0.31	18.95	0.003	6.72	35.2	307	495	43.58	22.54
16	7.65	25.9	0.49	17.2	0.007	27.84	73.6	725	1170	124	128
17	7.8	25.8	0.41	12.05	0.01	30.72	60.8	586	945	145	46.06
18	7.89	25.8	0.2	15.92	0.003	7.68	49.6	358	577	48.3	27.44
19	7.93	25.8	0.39	46.55	0.006	15.36	54.4	455	734	65.1	44.1
20	8.03	25.8	0.5	22.36	0.004	20.16	48	650	1049	152	75.46
21	7.88	25.5	0.49	13.43	0.001	24	68	678	1094	75.6	51.94
22	8.15	25.6	0.41	26.13	0	15.36	44.8	487	785	96	46.06
23	7.81	22.7	0.68	68.24	0.002	43.2	104	1662	2680	567	416
24	8.2	23.1	0.59	24.38	0.006	12.48	24	1037	1672	263	171
25	8.31	23.1	0.46	5.89	0	11.52	14.4	596	962	209	88.2
26	8.32	23	0.49	8.98	0	13.44	16	627	1012	256	92.12
27	8.14	22.7	0.63	8.19	0	5.76	12.8	443	715	135	62.72
28	8.28	22.6	0.61	9.57	0.004	17.28	9.6	520	839	147	64.68
29	8.47	21.5	0.57	24.25	0.017	220.8	12.8	963	1554	207	198
30	7.82	12.8	0.73	77.37	0.008	43.2	105.6	1810	2920	586	437
Mean	8.1333	22.573	0.5693	17.569	0.0065	30.992	36.16	835.8	1348.13	213.286	160.8
Max	8.47	26.2	1.03	77.37	0.048	220.8	105.6	2864	4620	704	926
Min	7.65	12.8	0.2	0	0	4.8	9.6	307	495	43.58	22.54
SD	0.2116	2.7103	0.1852	17.6996	0.0093	43.853	27.657	521.401	840.993	158.807	183.9

Table 3
Chemical quality of drinking water parameters compared with national Standards (1053IR Standard)

Parameter	1053IR Standard			Percentage of villages		
	Desirable	Permissible	W.H.O Guide Line	Desirable	Permissible	More than standard
pH	6.5–8.5	6.5–9	6.5–9.5	100	–	–
TDS (mg/L)	1000	1500	1200	70	20	10
Cl^- (mg/L)	250	400	250	–	88	12
SO_4^{2-} (mg/L)	250	400	500	10	77.5	12.5
NO_3^- (mg/L)	–	50	50	–	94	6
NO_2^- (mg/L)	–	3	–	100	–	–
Ca^{2+} (mg/L)	300	–		100	–	–
Mg^{2+} (mg/L)	30	–		16.5	83.5	–
F^- (mg/L)	0.5	1.5	1.5	65	35	–
EC (μmhos/cm)	1500	2000		13	74	13

proved that thirty samples had high nitrate level exceeding the acceptable limits of WHO (50 mg/L) [22]. Another study by Mohammadi et al. showed that the nitrate level in the drinking water samples of Bandar-e Gaz County was lower than the permissible limit of the WHO and national Iranian standard [36].

3.3. Distribution and occurrence of fluoride

The minimum and maximum values of fluoride were measured as 0.2 and 1.036, respectively. There was no drinking water sample in which the fluoride exceeded the MCL of 1.5 given by the Iranian Standards. Spatial distributions of fluoride concentrations are shown in Fig. 2. It shows that the lowest fluoride concentrations (0.2) occurred in the north-east villages of Bardeskan County.

A previous study revealed that fluoride contamination in villages of Sixaola was 0.056 to 0.45 mg/L. This research reported the fluoride level in 100% of the samples was less than the standard [37]. Mirzabeygi et al. found that the mean concentration of fluoride was 2.92 mg/L (range: 0.2–6 mg/L), also in half of the villages, the concentration range of this element was over the standard level (1.5 mg/L) given by WHO [11]. Chen et al. study showed that the fluoride content ranged from 0.11 to 6.33 mg/L with a mean of 0.85 mg/L. It is founded that four and 11 samples had high concentrations exceeding the permissible limits for F^- based on the WHO guideline (1.5 mg/L) [22].

3.4. Human health risk assessment (HHRA)

The minimum, maximum and mean Estimated Daily intake (EDI) and hazard quotient (HQ) of fluoride and nitrate In rural areas were studied for all group (infants, children, teenager and adults) are given in Tables 4, 5.

The maximum and minimum of hazard quotient index calculated for nitrate infants, children, teenager and adults in fluoride concentration study area were 0.387–0.000, 2.740–0.000, 1.934–0.000, and 1.555–0.000, respectively. The

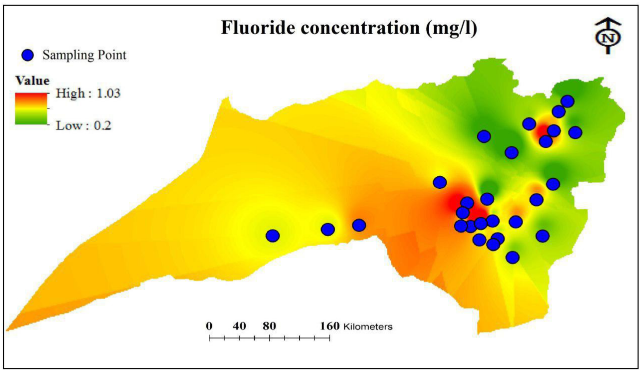

Fig. 2. Spatial distribution maps of fluoride concentration in the studied area.

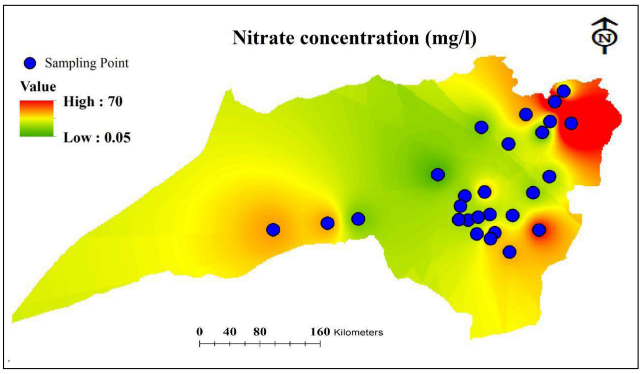

Fig. 3. Spatial distribution maps of nitrate concentration in the studied area.

HQ values calculated for infant of nitrate content in the studied areas for all sample were less than one. Furthermore, the HQ calculated values for children in the studied areas 3 villages were more than one (HQ > 1). Also for the teenagers and adult values of HQ in the studied areas vil-

Table 4
Fluoride hazard quotient (HQ) and EDI value in the studied area for different age groups (infants, children, teenager and adults)

Statistical	EDI				HQ			
	Infants	Children	Teenagers	Adults	Infants	Children	Teenagers	Adults
Mean	0.005	0.032	0.023	0.018	0.076	0.538	0.380	0.304
Max	0.008	0.058	0.041	0.033	0.137	0.973	0.687	0.550
Min	0.002	0.011	0.008	0.006	0.027	0.189	0.133	0.107

Table 5
Nitrate hazard quotient (HQ) and EDI value in the studied area for different age groups (infants, children, teenager and adults)

Statistical	EDI				HQ			
	Infants	Children	Teenagers	Adults	Infants	Children	Teenagers	Adults
Mean	0.141	0.996	0.703	0.563	0.088	0.622	0.439	0.352
Max	0.619	4.384	3.095	2.480	0.387	2.740	1.934	1.550
Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

lage number 1, 2 were more than one. In a similar study on risk assessment of nitrate in ground water resources, conducted by Wang et al. results showed a great danger of nitrate in ground drinking water. In this study, 56% of the samples (infants) were at risk [28]. In another study by Taneja et al. it was reported that the average nitrate concentration in the rural and urban areas were between 45.69 ± 2.08 and 22.53 ± 1.97 mg/L, respectively. Furthermore, their result showed that 59 drinking water samples were more than the Indian standards, and the comparison of nitrate figure revealed significant groundwater contamination of nitrate in the rural areas [27]. The maximum and minimum of hazard quotient index calculated for infants, children, teenager and adults in fluoride concentration study area were 0.033–0.006, 0.137–0.027, 0.973–0.189, 0.55–0.107, respectively. In our study the hazard quotient index for all the studied groups was less than one. Hence, in these rural areas, there is no potential risks of dental fluorosis. Similar study conducted by Ghaderpoori et al. revalued the hazard quotient of fluoride values to be lower than 1 [12]. In contrast, a study on fluoride health risk assessment conducted by Narsimha et al. found hazard quotient fluoride were 0.44–2.44 and 0.89–4.67 for children, 0.36–2.00 and 0.73–3.82 for females, and 0.41–2.26 and 0.82–4.31 for males in pre- and post-monsoon seasons, respectively [38]. The fluoride level in the study area varied from 0.14–4.88 mg/L. Out of 73, the fluoride levels in 45 villages did not meet the permissible WHO guideline. The hazard quotient analysis revealed that children were found to be at maximum risk followed by infants and adults. As reported by Ali et al., on fluoride health risk assessment study revealed that non carcinogenic risk was maximum in BaroliAhir block (HQ = 7.38) followed by Saiyan (HQ = 4.84) while it was minimum in Etmadola block (HQ = 2.12). Therefore, when the HQ level is more than 1, concern rises for non- carcinogenic risk. Amongst different age groups, children were found to be at maximum risk (2.31–8.052) followed by infants (2.13–7.42) and adults (2.12–7.39) [39]. Therefore, if drinking water is considered as the main pathway of fluoride intake of the rural area population of Bardeskan County, implementations should be considered to avoid dental cavities.

4. Conclusions

Nitrate and fluoride pollution in drinking water is widespread, affecting human health. Excessive exposure to nitrogenous compounds can cause cancer in humans with other harmful effects such as hyper proven adrenal cortex and polar gastric neoplasia. The excessive intake of fluoride through drinking water might lead to the prevalence of dental, bone and skeletal fluorosis in different parts of the world. Non-carcinogenic health risk assessment is a helpful method to show the status of drinking water in an area. The minimum and maximum values of nitrate and fluoride concentrations between 0–77.2, 0.2 and 1.036, respectively mg/L were measured. Spatial distributions of nitrate and fluoride concentrations showed that high nitrate and low fluoride concentrations occurred in the north-east region of the studied area. HQ values of nitrate for children, teenagers and adults 3, 1, 2 villages were more than one. In contrast, mean HQ values of fluoride were lower than 1, which was mostly acceptable. In this study, levels of fluoride were lower than that of WHO guidelines, which necessitate the implementation of precautionary options including water fluoridation to avoid dental cavities and other health problems. Also, the results showed that the measured concentration for nitrate in some samples were over the limit set by the WHO for drinking water; hence, the aquifer for domestic water usage for people, especially the reported amounts of nitrate is dangerous for teenagers and adults. Drinking water requires to be frequently monitored in order to protect the inhabitants by meeting the drinking water guidelines.

Conflict of Interest

The authors of this article declare that they have no conflict of interests.

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