Journal of Advances in Environmental Health Research

Spatial distribution of fluoride in groundwater resources in selected parts of Kurdistan Province, Iran, using the geographical information system

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Original Article

Abstract

Fluoride in drinking water has a profound effect on teeth. Since drinking water is an important source of fluoride, the evaluation of the fluoride content of water resources is necessary. Temporal variations and spatial distribution of fluoride in drinking water of some selected parts of Kurdistan Province, Iran, have been studied using geographic information system (GIS) techniques. Thus, 40 villages were selected and 80 samples taken in two wet and dry seasons in 2013. Fluoride concentration was measured via ion chromatography (IC) method. Geospatial analysis of the data was performed using the ArcGIS software developed by Environmental Systems Research Institute (Esri). The results showed that the average fluoride concentration in drinking water ranged from 0.096 to 1.102 mg/l with the concentration being less than 0.50 mg F/l in 57 samples (71.25%), between 0.51 and 1.0 mg F/l in 21 samples (26.25 %), and greater than 1.0 mg F/l in 2 samples (2.5%). No difference was observed between the concentrations of fluoride in the two-stage sampling with the nonparametric Wilcoxon test (P > 0.01).
KEYWORDS: Fluoride, Spatial Distribution, Kurdistan, Iran

Date of submission: 27 Oct 2014, ***Date of acceptance:*** 28 Jan 2015

Citation: Bahmani P, Maleki A, Mahvi AH, Daraei H, Ghahremani E, Naghipour-Khalkhaliani D. **Spatial distribution of fluoride in groundwater resources in selected parts of Kurdistan Province, Iran, using the geographical information system.** J Adv Environ Health Res 2015; 3(2): 71-7.

Introduction

The chemical composition of groundwater is a function of various factors and the interaction of these factors results in different types of water that can affect water consumption purposes.[1-4] Among the various characteristics of water quality, fluoride has unique properties. Based on guidelines for drinking water quality, fluoride, arsenic, and nitrate are key chemicals which have large scale health effects through drinking water exposure.[5,6] Fluoride is one of the essential micronutrients for humans and animals. However, shortage or excess of fluoride can cause serious dental and health problems in humans.[7] Since drinking water is an important way of receiving fluoride,[8-11] the evaluation of the fluoride content of water resources is necessary.

The concentration of fluoride in groundwater is variable and depends on several factors such as the pH, temperature, and solubility of fluorine-bearing minerals and other cations in water.[1,9,12] Therefore, the amount of fluoride in water in different regions varies according to the

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chemical composition of water and aquifer conditions.[13] Previous studies have shown different amounts of fluoride in drinking water resources of Kermanshah[14] (0.32 mg/l), Kerman[15] (0.17 mg/l), Ahvaz[16] (0.31-0.51 mg/l), Zanjan[17] (0.56 mg/l), Kashan[18] (0.25 mg/l), and Hamedan[19] (0.19 mg/l). These conditions expose consumers to different concentrations of fluoride, and thus, the health aspect of fluoride exposure in each region is different. Hence, it is necessary to determine the relationship between water quality parameters in order to analyze the dominant chemical compounds in water and their trends and aquifer conditions. Therefore, the present study was undertaken to investigate the concentration of F and its correlation with physicochemical parameters of rural drinking water resources in Kurdistan Province, Iran.

Materials and Methods

This cross-sectional study was performed to determine the quality of drinking water of 40 villages in Kurdistan Province. A total of 80 samples were collected in wet and dry seasons (June and September) and were analyzed according to standard methods.[20] The concentration of fluoride and other anions was measured using ion chromatography (IC) method (Metrohm Compact IC plus 882). Descriptive statistics were used to interpret the results. In order to compare the results of the two phases of the study and because the date distribution was not normal, a non-parametric test (Wilcoxon test) was applied using SPSS software for (version 20, SPSS Inc., Chicago, IL, USA). To determine the correlation between physical and chemical characteristics of water, the Pearson correlation coefficient was used. The temporal variations and spatial distribution of fluoride concentrations in rural drinking water resources were studied using geographical information system (ArcGIS) software.

Results and Discussion

Figure 1 illustrates the variation in fluoride concentration in the studied water supplies during wet and dry seasons. Based on figure 1 average fluoride concentration in groundwater samples varied from 0.1 mg/l in Shahrak to 0.97 mg/l in Bodla. According to drinking water quality standards set by the Institute of Standards and Industrial Research of Iran (ISIRI)[21] and World Health Organization (WHO),[5] in 70% of samples fluoride concentration was less than the permissible limit (0.5 mg/l). In addition, only in 30% of the samples, fluoride content was at a permissible level. These results are in agreement with that of the studies by Maleki et al.[7] and Carton,[22] which show the low fluoride content of drinking water in Sanandaj, Iran. Based on the results of water fluoride measurement, it is likely that the incidence of dental caries in the study area is high. Therefore, fluoride can be provided by other sources such as foodstuff, tea, and toothpastes. Water fluoridation is not recommended because it is not a preferred method in Iran. Moreover, Carton also opposed water fluoridation.[22] The Iranian Fluoride Scientific Association has stated that fluoride concentrations greater than 0.7 mg/l have more disadvantages in comparison to its scarcity.[11] Therefore, the continuous monitoring of the fluoride content of water and screening of dental caries, especially in children, are necessary.

The study of the relation between fluoride concentration and other water quality parameters is important in order to explain the changes of fluoride levels in the aquifer. Hence, correlational studies were performed and the results are shown in table 1. pH is an important parameter affecting the solubility of fluoride. Results showed that pH value varies from 7.1 to 8.7. This condition represents an alkaline condition and it is suitable for the solubility of fluorine-bearing minerals. Saxena and Ahmed stated that at alkaline pH, fluoride is released into the water; however, at acidic pH, it remains in the soil.[23] In addition, fluoride can be replaced with other anions; hence, Ca^{2+}, Na^{+}, and hydroxyl ion may alter the concentration of fluoride in water resources.[24,25] Therefore, when the calcium concentration exceeds the solubility of fluorite, the dissolution of fluorite will be limited.[13] Raju et al. observed a strong inverse correlation between F and Ca^{2+} in groundwater with a Ca content higher than the solubility of fluoride minerals.[25] For this reason, the main water cations and anions were determined and the results are presented in tables 2 and 3. According to these tables, the concentration of calcium and sodium in the studied samples vary from 34 to 194 mg/l and 10 to 160 mg/l, respectively. According to table 3, the average concentration of Ca^{2+} (74.95 mg/l) was higher than Na^{+} (71 mg/l), which may be the reason for the low concentration of fluoride in groundwater. Evidently, low fluorine-bearing minerals in the soil should not be ignored.

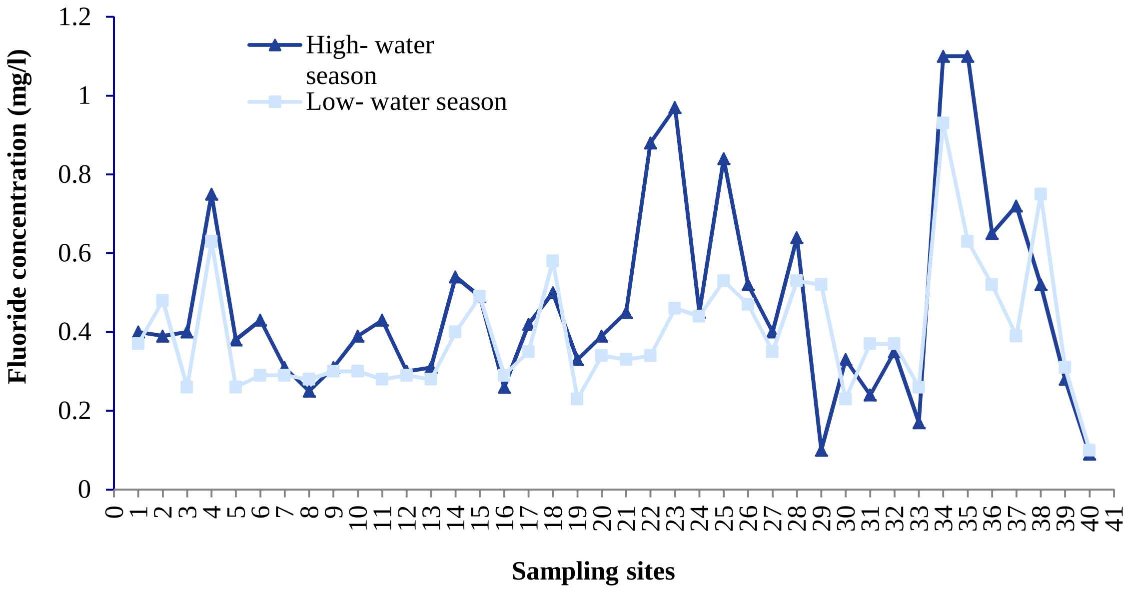

Figure 1. Fluoride concentration of different sampling sites in wet and dry seasons

Table 1. Correlation matrix of studied water quality parameters

	Ca	Mg	Na	K	F	HCO_3	CI	SO_4	NO_3	TH	TDS	EC	pH
Ca	1												
Mg	$0.71^{\S}$	1											
Na	$0.47^{\S}$	$0.58^{\S}$	1										
K	$0.27^{\#}$	0.36^{*}	$0.19^{\#}$	1									
F	$0.29^{\#}$	0.4^{*}	$0.15^{\#}$	0.33^{*}	1								
HCO_3	$0.7^{\S}$	$0.51^{\S}$	$0.62^{\S}$	$0.27^{\#}$	0.21	1							
Cl	$0.62^{\S}$	$0.43^{\S}$	$0.64^{\S}$	$0.19^{\#}$	$0.12^{\#}$	$0.45^{\S}$	1						
SO_4	$0.57^{\S}$	$0.53^{\S}$	$0.80^{\S}$	$0.13^{\#}$	0.002	$0.33^{\S}$	$0.50^{\S}$	1					
NO_3	$0.06^{\#}$	$-0.12^{\#}$	$-0.12^{\#}$	$0.24^{\#}$	$016^{\#}$	$0.17^{\#}$	$-0.20^{\#}$	$0.04^{\#}$	1				
TH	$0.96^{\S}$	$0.87^{\S}$	$0.56^{\S}$	0.37^{*}	0.35^{*}	$0.88^{\S}$	$0.60^{\S}$	$0.61^{\S}$	$0.01^{\#}$	1			
TDS	$0.82^{\S}$	$0.84^{\S}$	$0.86^{\S}$	0.34^{*}	$0.3^{\#}$	$0.9^{\S}$	$0.66^{\S}$	$0.77^{\S}$	$-0.02^{\#}$	$0.9^{\S}$	1		
EC	$0.82^{\S}$	$0.85^{\S}$	$0.86^{\S}$	0.34^{*}	$0.31^{\#}$	$0.9^{\S}$	$0.65^{\S}$	$0.78^{\S}$	$0.02^{\#}$	$0.9^{\S}$	$0.99^{\S}$	1	
pH	$-0.27^{\#}$	$-0.25^{\#}$	$-0.24^{3\#}$	$-0.11^{\#}$	$-0.43^{\S}$	$-0.30^{\#}$	-0.25^{3}	$-0.13^{\#}$	$0.14^{\#}$	$-0.27^{\#}$	$-0.27^{\#}$	$-0.28^{\#}$	1

* Correlation is significant at the 0.05 level; § Correlation is significant at the 0.01 level; $^{\#}$ Non-significant

TH: Total hardness; TDS: Total dissolved solid; EC: Electrical conductivity

Total dissolved solids (TDS) and electrical conductivity (EC) showed better correlation with fluoride than the other studied parameters. TDS amount in water samples ranged between 320 and 1270 mg/l. Calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate, and nitrates are the main ions that cause TDS.[26] Gillardet et al.[27] and Han et al.[28] announced that land use and environmental pollution caused by animal waste, agricultural fertilizers, and industrial and municipal wastewater may cause alteration in TDS. As seen in table 2, the mean concentration of total hardness of groundwater is higher than 270 mg/l $CaCO_3$.

Table 2. Average concentration of physicochemical parameters of groundwater in rural areas

Village	Location Code	Ca	Mg	Na	K	SO_4	NO_3	CI	F	pH	TDS	EC	Alkalinity	TH
Amir Abad	1	80	11	37	9	17	20	10	0.39	7.5	490	715	260	240
Chomoghloo	2	46	9	64	5	16	16	7	0.44	7.7	430	650	232	148
Najafabad	3	65	19	56	1	34	8	6	0.33	7.6	520	795	282	240
Tazehabad	4	93	52	160	8	135	2	82	0.69	7.2	1270	1820	610	440
Bayeh	5	67	15	56	1	54	8	18	0.32	7.4	505	755	239	224
Zarinabad	6	57	24	51	2	26	17	14	0.36	7.3	510	770	266	240
Alahyari	7	64	2	49	2	25	17	13	0.30	7.3	400	595	195	160
Dirakloo	8	52	19	48	2	24	17	14	0.27	7.5	459	690	235	208
Muzafarabad	9	70	12	49	3	25	17	13	0.31	7.5	452	720	250	220
Zivieh	10	42	5	57	1	34	13	11	0.35	7.7	390	570	171	124
Saeedabad	11	67	9	31	1	7	23	8	0.36	7.3	395	590	210	200
Vinsar	12	98	15	123	2	166	37	31	0.30	7.5	815	1235	280	300
Ghandab Sufla	13	85	14	122	2	176	38	31	0.30	7.4	810	1240	230	260
Ghandab Olya	14	57	10	65	5	52	36	11	0.47	7.7	480	715	200	180
Dosar	15	82	20	102	6	77	32	45	0.49	7.2	725	1130	299	284
Babashaydolla	16	87	19	119	2	174	38	21	0.28	7.9	770	1200	245	288
Baharloo	17	82	13	118	2	158	36	29	0.39	7.9	809	1230	234	252
Jodaghyeh	18	103	28	84	7	70	23	30	0.54	7.6	815	1235	382	368
Miham Olya	19	49	14	19	1	11	12	4	0.28	7.5	320	470	178	172
Miham Sufla	20	65	16	35	1	14	19	12	0.37	7.4	450	660	234	224
Gharbelaghkhan	21	34	19	78	19	85	32	24	0.39	7.8	490	750	188	160
Qzblagh	22	116	33	55	9	59	8	30	0.61	8.0	800	1225	393	420
Kotan Sufla	23	148	33	55	18	59	206	81	0.71	8.3	925	1380	250	500
Maydanmofazar	24	101	25	29	9	16	20	11	0.44	7.9	665	938	365	352
Jafarabad	25	90	22	65	3	52	28	23	0.68	8.7	660	1010	310	311
Golblagh	26	67	19	43	1	19	38	8	0.50	8.6	490	715	246	240
Aqcheghonbad	27	194	6	124	4	163	6	167	0.38	8.0	1130	1660	375	500
Engiarkh	28	99	24	138	4	138	3	157	0.59	7.4	992	1460	360	342
Kharabechoaarkh	29	89	44	139	5	141	3	225	0.32	7.3	903	1500	166	398
Aghblagh Tghamin	30	77	15	17	1	9	17	9	0.28	7.9	425	630	227	248
Ochgol	31	58	2	29	1	6	32	4	0.31	8.0	330	477	160	150
Khosroabad	32	65	11	75	8	49	21	16	0.32	7.1	550	825	252	203
Aminabad	33	65	11	73	8	51	21	16	0.21	7.2	541	820	249	203
Bodla	34	49	11	72	1	15	38	5	0.97	8.0	465	700	237	164
Darvishkhaki	35	85	37	134	10	48	4	111	0.87	7.4	910	1460	400	360
Maghot	36	58	9	57	1	37	10	10	0.59	7.9	440	670	216	178
Babareshani	37	82	17	86	4	38	16	73	0.56	7.2	720	1020	264	270
Khandanqoli	38	69	25	88	2	53	37	27	0.64	7.5	650	1015	299	272
Dehragheh	39	65	12	37	1	10	46	5	0.30	7.7	420	630	210	208
Shahrak	40	59	11	10	1	12	1	10	0.10	7.4	330	473	190	190
Permissible maximum (mg/l) (ISIRI-1053)		250	50	200	-	400	50	400	1.50	-	1500	-	-	500
WHO guideline		-	-	200	-	500**	50	250*	1.5	6.5-8.5*	1500*	-	-	-

* Recommendation based on aesthetic consideration such as taste and color; ** No health-based guideline value is set; however, values less than 500 mg/l are recommended due to gastrointestinal damage

TDS: Total dissolved solid; EC: Electrical conductivity; TH: Total hardness

Table 3. Descriptive statistics of elemental concentration for the studied parameters

Parameter	n (in each season)	Dry season				Wet season			
		Mean	SD	Min	Max	Mean	SD	Min	Max
EC	40	945.0	347.00	470.0	1820.0	816.0	312.00	110.0	1655.0
TDS	40	627.0	228.00	320.0	1270.0	564.0	188.00	290.0	1108.0
pH	40	7.6	0.35	7.0	8.7	7.5	0.22	6.8	8.0
Ca	40	78.5	27.30	34.0	194.0	71.4	21.30	32.0	166.0
Mg	40	17.9	10.90	2.0	52.0	13.6	6.80	3.0	41.0
Na	40	72.8	38.20	17.0	160.0	69.2	35.50	10.0	161.0
K	40	4.5	4.50	1.0	19.0	4.5	4.40	0.5	20.0
HCO_3	40	328	104.00	202.0	744.0	288.0	80.00	183.0	645.0
Cl	40	37.4	42.50	4.0	225.0	34.4	36.10	2.3	202.0
SO_4	40	59.1	53.20	6.0	176.0	61.0	48.50	6.0	168.0
F	40	0.4	0.14	0.1	0.9	0.5	0.09	1.1	0.7

EC: Electrical conductivity; TDS: Total dissolved solid; SD: Standard deviation

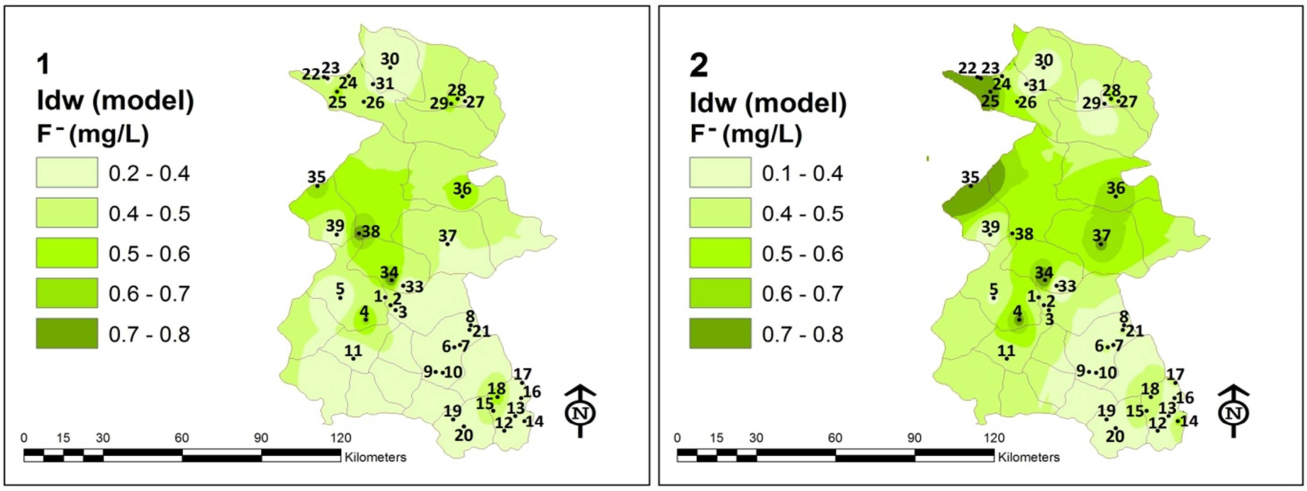

Figure 2. Spatial distribution of fluoride in groundwater in low and high water seasons

According to the finding of Govardhan Das, water with fluoride concentration of higher than 1.5 mg/l has a hardness of lower than 200 mg/l.[29] Thus, the relationship between water hardness and fluoride seems reasonable. A positive correlation was observed between fluoride and other anions and cations except pH. These results are similar to findings by other researchers.[4,9]

Except pH, EC (µS/cm), alkalinity (mg/l $CaCO_3$), and TH (mg/l $CaCO_3$), all other parameters are expressed in mg/l.

Figure 2 shows the spatial distribution of fluoride and reveals that high concentrations of fluoride can be seen in the northern part of the region. Statistical analysis (Wilcoxon test) demonstrated that there was no significant difference between the fluoride concentrations of samples collected in wet and dry seasons ($P > 0.01$).

Results also showed that the majority of anions and cations are within the standard ranges (except nitrate in one sample). The results showed that water hardness in all the villages is temporary hardness, which was categorized as completely hard, hard, and slightly hard. According to geochemical facies, calcium and bicarbonate are the dominant cation and anion, respectively, introducing calcic-bicarbonate as the water type. The high concentration of bicarbonate ions in the water is due to erosion and weathering of carbonate and silicate minerals. Correlation coefficients showed the highest correlation between bicarbonate and Ca^{2+} (Table 1).

Conclusion

The present study attempted to investigate the fluoride concentration of groundwater in rural areas of Northeastern Kurdistan Province, and its correlation with other physicochemical parameters of water quality. It was found that the groundwater is slightly alkaline and hard in nature. In 70% of samples, fluoride concentration was lower than the permissible limit set by ISIRI. Therefore, the continuous monitoring of the fluoride content of water and screening for dental caries especially in children are necessary.

Conflict of Interests

Authors have no conflict of interests.

Acknowledgements

The authors are grateful for the financial support provided by the Kurdistan Rural Water and Wastewater Company

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