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ORIGINAL ARTICLE

Temporal variations of fluoride concentration in Isparta public water system and health impact assessment (SW-Turkey)

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Abstract Water–rock interaction is one of the prime factors affecting the fluoride contents of surface and groundwater. If fluoride concentration of drinking water has been neglected, excess fluoride can cause serious dental and medical problems on human health, which is well known at Golcuk-Isparta region. In the research area, Egirdir lake, Golcuk lake and surrounding springs have been utilized as drinking water sources. Golcuk lake water and surrounding groundwaters have high fluoride content (1.4–4.6 mg/l), which is above the WHO standards. Fluoride is predominantly supplied by dissolution of fluoride within the fluormicas of volcanics during the circulation of water. Fluoride concentrations of waters have shown variations for dry and rainy seasons depending on the degree of interaction between groundwater and volcanic rocks. It tends to decrease in rainy seasons and increase in dry seasons for all years. In this study, temporal variations and spatial distribution of fluoride concentration in public water system of Isparta were investigated to get benefit using GIS techniques from1990 to 2003 years. Extremely fluoride concentrations were measured in the public water system in 1990 at almost every district of the city. In 2003, fluoride content of the public water system decreased in some district of city due to drinking water has started obtaining from Egirdir lake in 1995. The fluoride contents of Isparta drinking water ought to be modified with suitable mixture of lake waters and groundwater point of view to health impact.

Keywords Public water system · Fluoride · Health risk · Isparta · Turkey

Introduction

Fluoride is the most known electronegative element. It is highly reactive and not found in the elemental state in nature, only in solid salts or fluoride ions in aqueous solution (Sreedevi et al. 2006). Naturally occurring fluoride in groundwater has been the subject of numerous studies in a variety of geologic settings.

Especially, the effects of fluoride on human health are well-studied. The maximum tolerance limit of fluoride in drinking water specified by the World Health Organization (WHO 1984) is 1.5 mg/l. Many epidemiological studies of possible adverse effects of the long-term ingestion of fluoride via drinking water have been carried out. These studies clearly establish that fluoride primarily produces effects on skeletal tissues (bones and teeth). Low concentrations provide protection against dental caries, especially in children. Fluoride may give rise to mild dental fluorosis at drinking water concentrations between 0.9 and 1.2 mg/l (Dean 1942). As a rough approximation, for areas with a temperature climate, manifest dental fluorosis occurs at lower concentrations in the drinking water because of the greater amounts of water consumed (Cao and Li 1992).

Fluoride can also have more serious effects on skeletal tissues. Skeletal fluorosis (with adverse changes in bore structure) is observed when drinking water contains 3–6 mg of fluoride per liter. Crippling skeletal fluorosis develops where drinking water contains over 10 mg of fluoride per liter (WHO 1984). Long-term accumulation of fluoride likely also affects thyroid function (Balabolkin et al. 1995), may have neurological effects (Mullenix et al.

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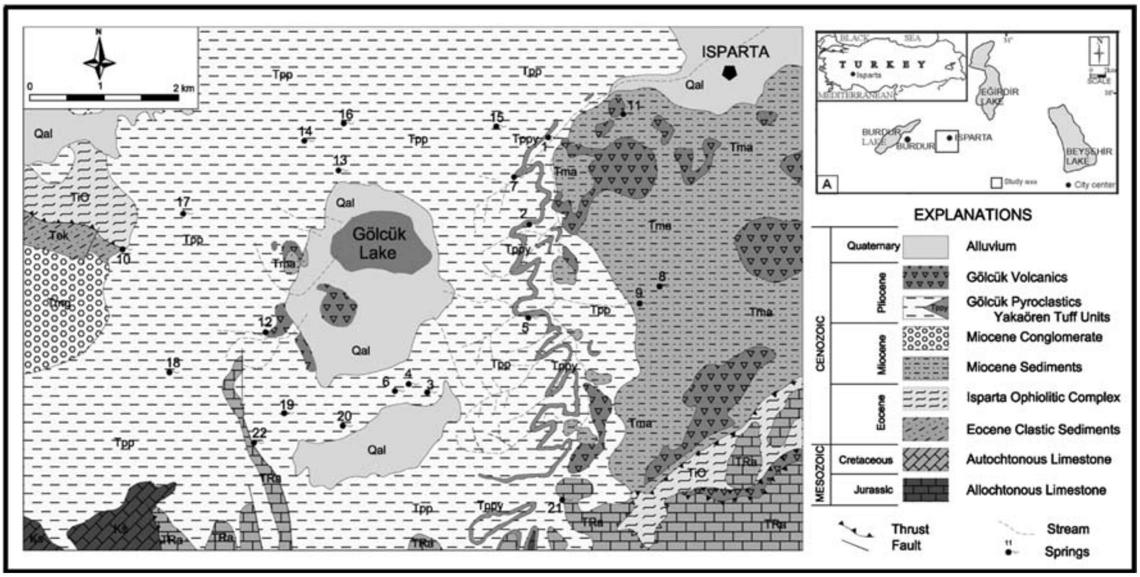

Fig. 1 Geological map (were taken Yalcınkaya 1989)

1995), may induce reproductive problems (Dominguez et al. 1995) and may affect the pineal gland (Luke 1994). Fluoride's well-know genotoxic properties may be showing up in the population as an increased risk for various cancers (Tohyama 1996; Zeiger et al. 1993).

Many investigations have been made related to origin and hydrogeochemistry of high fluoride in groundwater for the different regions of the world (Kundu et al. 2001; Carrillo-Rivera et al. 2002; Rukah and Alsokhny 2004; Gupta et al. 2005; Jacks et al. 2005; Karro et al. 2006; Ozsvath 2006; Gou et al. 2006; Sreedevi et al. 2006; Valenzuela-Vasquez et al. 2006). In these researches, groundwaters have studied on water samples obtaining from springs and dug wells, and determining theirs high fluoride contents have originated from water–rock interaction and regional thermal water mixing. In this research, fluorine contents and temporal variations were investigated using GIS techniques in the public water system of Isparta city as a different research work of previous works. Regional hydrogeology, origin and hydrogeochemistry of high fluoride contents were also carried out in this study as a case investigation.

The research area is situated within the Lake District in the southwest of Turkey (Fig. 1). For along time, fluorine problem related to drinking water of Isparta region have been well known. Published studies were predominantly concentrated on the existence of fluoride in water and rocks, fluorosed human teeth at the Isparta area (Ayhan 1983; Pekdeger et al. 1992; Irlayıcı 1993; Coban et al. 2001). Dental fluorosis causes high amounts of fluoride (1.15–3.6 mg/l) in drinking water has been observed since 1954 in the Isparta (Samsar 1983). Samsar (1983) reported existence of fluorosis at a ratio 100% among the children in the Isparta. Ermis et al. (2003) were determined increasing the water fluoride levels were associated with higher prevalence and severity of dental fluorosis and had no influence on caries experience among children in their study doing on fluorosed teeth were collected from Isparta.

Negative effects of fluoride in drinking water have been well known matter in Isparta since previous years. However, any research work on fluoride control within drinking water has not yet been performed. In this study, in order to control fluoride, temporal variations of fluoride contents for public water system and effected regions of residential areas have been examined for 1990–2003 years. The understanding of the origin and distribution of fluoride within water may be useful in devising water exploitation, sustainable management strategies and health risk analysis. Risk analysis plays an important role for environmental health. Currently, it is a primary tool for providing the quantitative data aimed at identifying and mitigating environmental health hazards (Kay 1999). Therefore, hydrogeology of research area and hydrogeochemistry of fluoride waters have also been investigated.

Methodology

The data was obtained in this study by following the methods. Water samples were collected in different periods. Samples were safely stored in two polyethylene bottles. One of the bottles was acidified with suprapure HNO_3 for determination of cations analyses and another was kept unacidified for the anion analyses. Temperature, pH and electrical conductivity (EC) were also measured in the field. The major chemical constituents were analyzed at the ACME Laboratory (Canada-ISO 9002 Accerredited Co.). HCO_3 was determined volumetrically and SO_4 by the gravimetric method in the laboratory of Environmental Engineering Department in Suleyman Demirel University (Isparta/Turkey). Fluoride analyses of drinking waters were measured Scott Sanchis colourmetric method using Zr-Alizarine Red solution (TSE 1997) and Orion ion electrometer. Previous fluoride data of drinking water were obtained from the State Hydraulic Works (SHW) and Public Health Laboratory (PHL), Isparta, Turkey.

The detection of disease clusters, where high incidence rates are observed around a specific location, has benefited from the development of methods and tools in GIS. Therefore, fluoride contents of Isparta public for water system were evaluated using GIS techniques. ArcGIS software, Spatial Analyst extension and inverse distance weight (IDW) interpolation methods were applied throughout research evaluations. For the research, Quickbird satellite four band multispectral 2.44 m resolution image acquired on the date 15 July 2006 was used. Quickbird satellite is an orthorectified, radiometrically calibrated, corrected for sensor and platform-induced distortions, and mapped to a UTM Zone 36 N, ED50 datum.

Geology and hydrogeology

Isparta city is located in the Lake District of Turkey, and its bedrocks consists Neogene volcanic products of Golcuk volcanism and Eocene and Miocene sediments, Isparta ophiolitic complex, allochthonous and autochthonous limestone. Geological units in the research area and their hydrogeological properties are described in Fig. 1.

Ophiolitic complex is composed of mafic-ultramafic rocks such as serpentinite, harzburgite, gabbro, peridotite and pelagic-terrigeneous sediments as radiolarite, chert, limestone, shale, sandstone (Robertson 1993). The ophiolitic complex has an impermeable rock property. Allochthonous and autochthonous limestones contain some folds–cracks and they are also permeable karstic aquifer. Eocene sediments consist of sandstone, shale, clayey limestone and cherty limestone. Miocene clastics have been formed from the intercalation of sandstone, claystone, marl, shale and overlain by conglomerate which has polygenic pebbles (Gormus and Ozkul 1995). Eocene clastic sediments were deposited as flysch facies and impermeable rock unit. Golcuk volcanites consist of andesite fractured and undergoes partially alteration. Golcuk pyroclastics consist of interbedded with thin-medium layered sediments in the form of sandstone, claystone, marl, tuff and tuffite. Alluvium deposits have occurred dominantly unconsolidated clay, silt, sand and gravel constituents derived from surrounding volcanic units.

Recharge of groundwater mainly occurs via vertical seepage of meteoric water in the research area. Aquifer units discharging the springs are mainly Miocene clastics, Golcuk pyroclastics and volcanic rocks. This pyroclastics were slightly permeable due to tuff levels. They keep in stock some groundwater and its different permeabilities cause a number of aquifers and aquitards lying one above the other. Furthermore, andesite also keeps in stock some groundwater within its fractures. In addition, springs discharged from conglomerate and shale levels within the Miocene sediments.

Hydrogeochemistry

To follow the research analysis, approximately total 80 samples were collected from waters based on different years for the research area from Golcuk-Egirdir lake water and public water system of Isparta city. Until 1995 from 1962, all of the drinking waters of Isparta city have been obtained from Golcuk lake and Andik spring. Later, due to increasing demand of water, additional drinking water has also been obtained from Egirdir Lake which is located northeast of Isparta, since 1995. Recently, Golcuk lake water and Andik spring water have been only given as drinking water for particular districts of Isparta city.

Spring locations to take water samples for the chemical analyses are presented in a geological map form in Fig. 1. The results of the chemical analyses and water types of the spring-lake waters are listed in Table 1. pH values of spring waters are ranged from 6.2 to 8.3, indicating alkaline nature. Electrical conductivity (EC) values of spring waters were also determined. Their values are between about 544 and 143 μS/cm and temperature were measured between 8.1 and 14.4°C. pH values of Golcuk lake water 7.8–8.2 and electrical conductivity values were measured as 235 and 290 μS/cm. Electrical conductivity values of Egirdir lake are ranged from 402 to 440 μS/cm. The major ions of waters are shown as a Piper triangular diagram in Fig. 2. Based on the Piper classification, spring and lake waters are bicarbonates. Classification of waters was based on the principles of International Association of Hydrogeologists (IAH 1979). The contents of major ions for waters changes are related to their interaction rocks. As a result of water–rock interaction, Na and K ions have increased in the springs discharged from tuff level, due to cation exchange reaction with increasing Na^+ concentrations and Ca^{2+} concentration decreases (Table 1).

The correlation matrixes between the major ions calculated with Aquacem 3.7 computer code are presented in Table 2. Fluoride content showed a positive correlation with a sodium concentration and a strong negative correlation including calcium and bicarbonate concentrations.

Table 1 Major anions, cations and fluorine concentrations of springs in the research area and lake water

	pH	*T* (°C)	EC (μs/cm)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Cl (mg/l)	F (mg/l)	Water class	Discharge lithology	SI_c	SI_f
S1	7.4	10.5	339	23.04	3.04	28.06	14.85	115.9	55.23	6.02	3.71	Na–Ca–HCO_3	Tuff	−0.795	−0.280
S2	8.0	13.4	360	28.05	1.94	20.93	8.99	132.4	16.8	15.24	3.81	Ca–Na–HCO_3	Tuff	0.00	0.370
S3	7.9	10.7	184	20.04	1.94	10.12	3.12	85.43	12.0	10.28	2.78	Ca–HCO_3	Golcuk pyc	−0.421	0.020
S4	7.9	14.4	245	31.06	3.04	11.96	7.04	146.4	9.12	9.57	3.18	Ca–HCO_3	Golcuk pyc	0.008	0.245
S5 (Kanlıdere)	6.2	11.1	228	14.03	0.97	13.76	7.82	65.9	14.41	9.45	5.62	Ca–Na–HCO_3	Tuff	−2.405	−0.923
S6 (Menekseli	8.3	10.1	196	23.05	3.04	11.96	3.91	97.63	13.45	10.64	3.13	Ca–HCO_3	Golcuk pyc	0.033	0.159
S7 (Andik)	7.7	10.8	235	15.6	2.8	13.9	8.01	79.4	18.7	11.5	4.1	Ca–Na–HCO_3	Tuff	−0.226	−1.173
S8	7.8	12.1	414	65.93	8.99	3.91	5.08	276.4	10.56	8.86	0.97	Ca–HCO_3	Miocene cl.	0.466	−0.,486
S9	6.2	12.3	311	68.94	3.04	8.05	5.08	220.8	7.20	6.74	1.02	Ca–HCO_3	Miocene cl.	−1.177	−0.290
S10	7.9	11.6	328	67.93	17.99	2.99	1.17	262.4	5.28	13.83	0.39	Ca–HCO_3	Miocene cl.	0.512	−1.273
S11 (Bezirgan)	7.5	10.3	327	46.5	6.64	12.3	5.04	181.5	31.4	7.0	0.8	Ca–HCO_3	Miocene cl.	−0.798	0.662
S12	8.3	8.9	175	21.04	0.97	8.05	1.17	91.53	13.93	8.51	2.65	Ca–HCO_3	Golcuk pyc.	−0.006	0.027
S13 (Mellisu)	7.9	9.8	260	47.09	3.07	13.11	7.04	176.9	22.09	9.22	2.72	Ca–HCO_3	Golcuk pyc.	−0.080	0.249
S14 (Milas)	7.6	10.4	240	54.9	3.04	12.42	5.86	164.7	29.3	11.7	1.81	Ca–HCO_3	Golcuk pyc.	−0.094	0.029
S15	7.9	13.4	544	45.09	4.98	20.93	10.16	122.0	74.44	10.99	3.95	Ca–HCO_3	Golcuk pyc.	0.082	0.551
S16	7.5	9.8	240	52.90	3.04	14.95	6.65	164.7	29.77	23.05	2.17	Ca–HCO_3	Golcuk pyc.	−0.171	0.177
S17	7.6	12.4	495	74.95	5.95	10.12	5.08	311.2	1.92	16.66	1.64	Ca–HCO_3	Golcuk pyc.	0.296	0.019
S18	7.9	14.9	276	40.08	1.94	8.97	5.08	183.1	7.20	6.74	2.77	Ca–HCO_3	Golcuk pyc.	0.291	0.219
S19	8.3	13.3	267	27.98	0.97	10.12	9.03	91.53	10.08	9.22	3.76	Ca–HCO_3	Golcuk pyc.	−0.018	0.174
S20	8.5	9.7	362	11.02	0.97	8.22	1.17	61.02	6.72	13.12	2.91	Ca–HCO_3	Golcuk pyc.	−0.262	−0.161
S21	7.9	8.1	143	52.90	4.01	0.92	1.17	183.1	5.28	5.32	0.18	Ca-HCO_3	Limestone	0.301	−1.939
S22	8.1	13.6	232	39.07	8.02	3.91	5.08	164.7	2.88	8.51	0.05	Ca–HCO_3	Limestone	0.333	−3.267
Golcuk 1999*	7.8	6.1	290	36.1	5.5	16.1	6.2	116	20.1	8.9	2.25	Ca–HCO_3	Lake water		
Golcuk 2003*	8.0	13	268	36.5	6.2	13.1	6.7	119	25.9	5.7	1.72	Ca–HCO_3	Lake water		
Golcuk 2004*	8.0	9.8	247	29.7	4.5	11.5	4.7	97.5	14.1	6.1	2.3	Ca–HCO_3	Lake water		
Golcuk 2005*	8.0	5.8	250	38.9	2.1	15.4	6.2	107	27.3	5.7	1.78	Ca–HCO_3	Lake water		
Golcuk 2006*	8.2	17	235	26	4.3	13.8	4.7	95.5	11.7	7.1	2.05	Ca–HCO_3	Lake water		
Egirdir 2003*	8.2	22	410	38.5	24.3	8.0	3.1	207	19.2	13.1	0.18	Ca–Mg–HCO_3	Lake water		
Egirdir 2004*	8.6	22	420	39.8	24.0	11.5	3.5	190	13.4	12.8	0.2	Ca–Mg–HCO_3	Lake water		
Egirdir 2005*	8.4	18	440	42.0	23.2	17.7	3.2	198.5	18.6	12.4	0.17	Ca–Mg–HCO_3	Lake water		
Egirdir 2006*	8.7	21	402	41.6	22.8	11.5	2.98	195.0	17.3	10.6	0.2	Ca–Mg–HCO_3	Lake water		

* SHW (1999–2006)

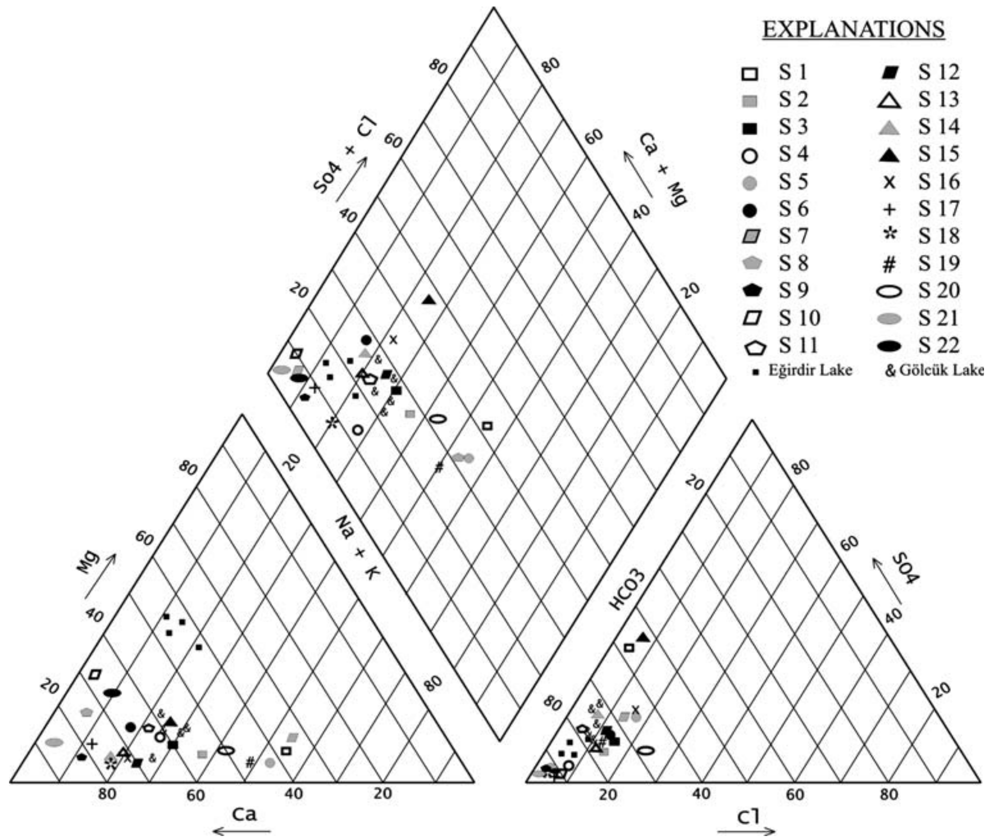

Fig. 2 Piper diagram

This situation was also presented in Fig. 3 showing the relationships among F with Ca, Mg, HCO_3, Na, K, pH values. Concentration of fluoride in the rock, long residence time of rock water interaction and Ca and HCO_3 contents of groundwater are the important factors to determine the degree of fluoride dissolution (Kundu et al. 2001). The solubility of fluoride in waters increases in relation with high concentrations of Na^+.

Fluoride concentrations of springs are shown in a geological map with circular diagrams which prepared in different scales according to fluoride content (Fig. 4). Apparently, these contents could change the related to geological structure. The fluoride contents of springs discharged from tuff levels are between 3.71 and 5.62 mg/l. The springs discharged from Golcuk pyroclastic rocks bearing volcanic level also contain a range of 1.81–3.95 mg/l. The fluoride contents of springs discharged from Miocene clastics are between 0.39 and 1.02 mg/l (Table 1; Fig. 5). Generally, fluoride content in groundwater usually depends on rock type, interaction period with host rock, as well as the dissolution kinetics for fluorite, apatite or silicate minerals (Sreedevi et al. 2006).

The fluoride contents of drinking water in Isparta region is strikely related to circulation of water within volcanic

Table 2 Correlation matrix of chemical parameters

	pH	Ca	Mg	Na	K	Cl	SO_4	HCO_3	F	EC
pH	1	−0.262	0.042	−0.156	−0.114	0.082	−0.083	−0.172	−0.145	−0.05
Ca		1	0.611	−0.363	−0.278	0.156	−0.072	0.941	−0.545	0.385
Mg			1	−0.401	−0.292	0.1	−0.098	0.661	−0.513	0.3
Na				1	0.637	0.167	0.757	−0.407	0.649	0.318
K					1	−0.053	0.471	−0.255	0.466	0.231
Cl						1	0.0093	0.112	−0.035	0.235
SO_4							1	−0.239	0.423	0.398
HCO_3								1	−0.54	0.411
F									1	0.132
EC										1

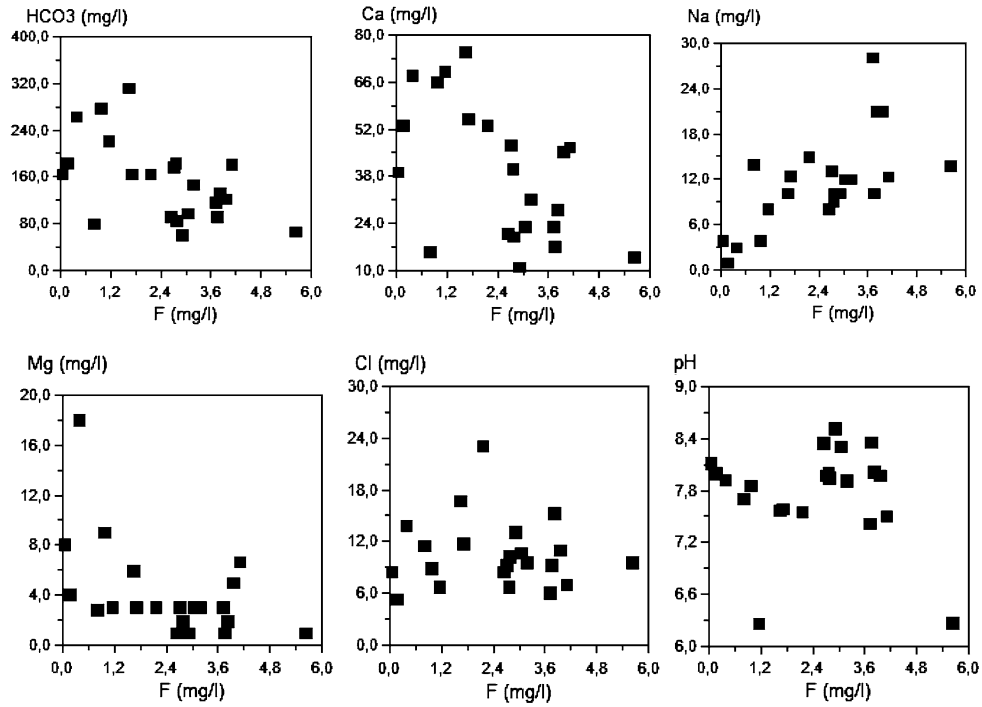

Fig. 3 Plots of Ca, HCO_3, Na, Mg, Cl and pH against F

and pyroclastic rocks. However, fluoride contents of pyroclastics are much lower than that of volcanics. Mica (phlogopite/biotite), apatite and amphibole are the main fluoride carrying minerals in the research area. The fluormicas (predominantly fluorphlogopite) is predominant the main fluoride source mineral. Hence, high fluoride is attributed to abundance of micas (Coban et al. 2001). However, micas are very efficient at removing fluoride from a melt. Overhead explained data show that, fluoride contents of water are increased with the interaction of water–volcanic rocks (Fig. 5).

Generally, flour generally migrates in form of F^- ion in the alkaline nature. Under the circumstances, migrate of flour is supervised by calcium within the water. The solubility limits of fluorite and calcite provide a natural control for water composition. Mineral saturation index for calcite and fluorite were calculated as discharge temperature and pH by the Solmineq 88 (Kharaka et al. 1988) computer code

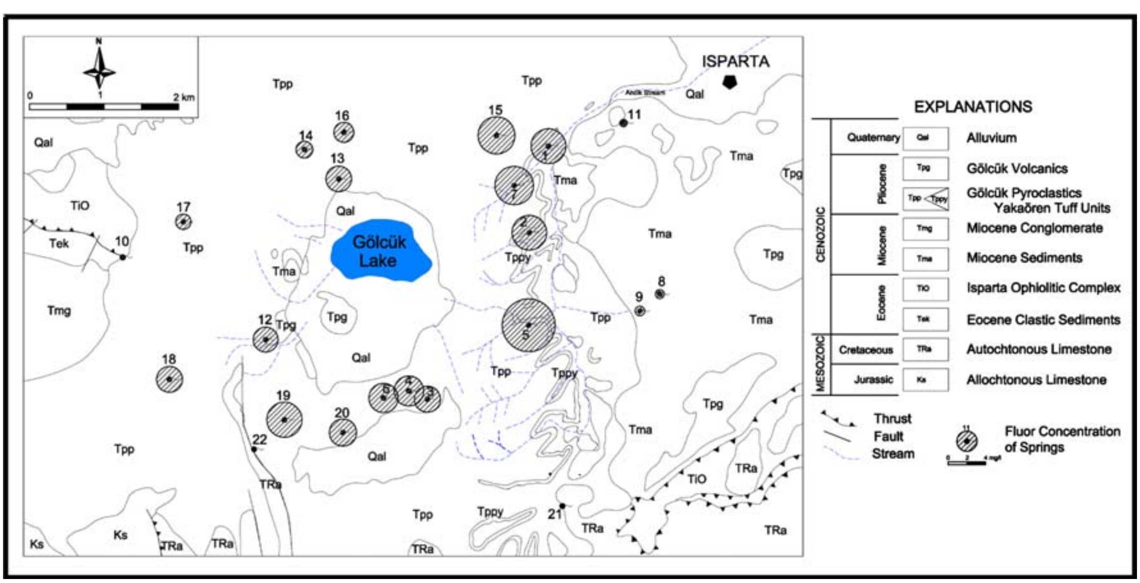

Fig. 4 Fluoride concentration of springs

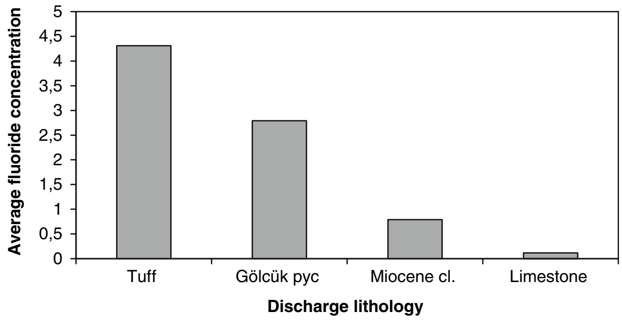

Fig. 5 Relation to fluoride and water discharge lithology

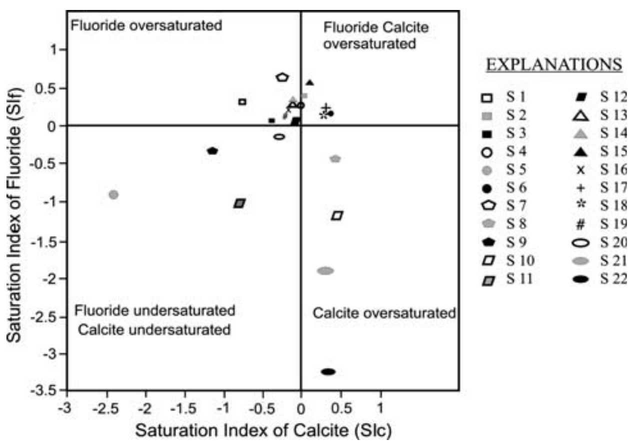

Fig. 6 Plot of calcite saturation index (SI_c) versus fluoride saturation index (SI_f)

(Table 1). The plot of calcite saturation index (SI_c) and fluorite saturation index (SI_f) are shown in Fig. 6. Most of the samples were almost over-saturated respect to fluorite. Some of the samples discharged from Miocene clastic and limestone units were only over-saturated respect to calcite.

In different periods, the water samples taken from the Golcuk Lake and Andik stream, supplied drinking water of Isparta city, were examined and the results of fluoride analyses are given in Table 3. The fluoride contents of Golcuk lake water are between 1.4 and 2.65 mg/l, and of the Andik stream water are between 2.61 and 5.3 mg/l (Table 3). The higher fluoride content of the Andik mobile water is possibly originated from more interaction time with volcanic rocks, relative to Golcuk stagnant water.

In addition, Table 3 indicates the fluoride content of the Golcuk and Andik waters decreases in rainy periods while increasing the dry periods for all the years (Fig. 7a, b). The presence of dissolved fluorine is possibly only under favorable physico-chemical conditions and when residence time is long enough. Therefore, the water quantity and residence time were important factors playing a major role in increasing F^- concentration of water in a dry period. The residence time of waters with the aquifer materials also significantly regulates the F^- concentrations in groundwater (Rommohana Rao et al. 1993; Wodeyar and Sreenivasan 1996; Saxena and Ahmed 2001; Subba Rao 2003). Because, the dissolution rates of fluoride minerals are generally slow (Gaus et al. 2002) and fluoride solubility increase as a relationship with residence time. In the rainy periods, spring waters generally have a sudden discharging tendency as connected with increase of rainfall. Speed of water is usually faster than the dry period. Therefore, the residence time between water with aquifers is short and F^- content of groundwater is less in the rainy period. The discrimination is more strike for Andik stream water, considering the precipitation fall into region (Fig. 7a, b).

Spatial distribution of fluoride for drinking water

As in many areas of GIS researches, this type of work could supply a benefit from recent developments in relatively basic and inexpensive equipment (Wright et al. 2004). Considerable recent attention has focused on health in urban areas. GIS has also been used to help predict future public health risks such as those arising from extremely GIS. It has a useful role to play in policy-related studies of health care utilization and accessibility (Arcury et al. 2005; Wang and Luo 2005).

The fluoride contents of public water system in Isparta for health impact assessment were also evaluated using GIS techniques. The fluoride contents of public water system were measured at random locations of Isparta city in 1990 and in 2003 by PHL (PHL 1990–2005). Using this data, the spatial distribution maps for fluoride on the development plan of city have been established for the years of 1990 and 2003. These maps have been prepared using inverse distance weighted (IDW) interpolation methods with ArcGIS Spatial Analyst extension and overlaying with Quickbird satellite image (Figs. 8, 9).

Extreme fluoride values were then measured in public water system. According to 1990 data, the fluoride contents of all drinking waters are ranged between 1.42 and 2.47 mg/l. Overall drinking water of Isparta city were currently taken from Golcuk lake and Andık stream. All of the measured fluoride contents are rather exceeding than the upper limit of fluoride concentration (1.5 mg/l) advised by WHO. In 2003, drinking water was supplied from Egirdir Lake, Golcuk Lake and Andik stream for different districts of Isparta as unmixed and partially mixed. In this year, fluoride contents of drinking water have generally decreased and suitable to WHO. But, the fluoride contents of domestic-drinking water, only obtained from Andik water in some district of city, increased up to 3.6 mg/l (Fig. 9). In addition, fluoride contents of Isparta domestic-drinking water are given in Table 4. The fluoride contents decreased up to 93% ratio depending on the mixing with

Table 3 Results of fluorine analyses for Golcuk lake and Andik waters

Period	Date	Location	Precipitation (mm)	F^- (mg/l)	Period	Date	Location	Precipitation (mm)	F^- (mg/l)
Rainy	03-1991[c]	Golcuk	24.5	2.25	Dry	08-1990[a]	Andik	1.2	3.88
Dry	06-1991[c]	Golcuk	11.4	2.65	Rainy	02-1996[a]	Andik	99.3	2.75
Rainy	12-1991[c]	Golcuk	101.4	2.0	Rainy	03-1996[a]	Andik	41.9	2.65
Rainy	03-1992[c]	Golcuk	94.5	1.72	Rainy	04-1996[a]	Andik	50.8	2.80
Rainy	04-1992[c]	Golcuk	46.9	1.74	Rainy	05-1996[a]	Andik	62.2	2.95
Dry	07-1992[c]	Golcuk	13.4	1.75	Dry	06-1996[a]	Andik	32.4	3.12
Dry	10-1992[c]	Golcuk	5.2	1.78	Dry	07-1996[a]	Andik	18.7	3.22
Rainy	01-1993[c]	Golcuk	37.6	1.6	Dry	08-1996[a]	Andik	11.3	3.33
Rainy	04-1993[c]	Golcuk	22.0	1.61	Dry	09-1996[a]	Andik	17.2	3.35
Dry	07-1993[c]	Golcuk	0.0	1.65	Dry	10-1996[a]	Andik	3.2	3.54
Dry	10-1993[c]	Golcuk	10.2	1.7	Rainy	11-1996[a]	Andik	29.2	2.87
Rainy	01-1994[c]	Golcuk	84.7	1.78	Rainy	12-1996[a]	Andik	132.1	2.61
Rainy	04-1994[c]	Golcuk	26.8	1.5	Rainy	01-1997[a]	Andik	27.9	2.62
Dry	07-1994[c]	Golcuk	18.4	1.86	Rainy	02-1999[b]	Andik	78.6	2.75
Rainy	01-1995[c]	Golcuk	47.5	1.6	Rainy	04-1999[b]	Andik	24.3	2.80
Rainy	04-1995[c]	Golcuk	34.2	1.9	Dry	06-1999[b]	Andik	15.8	3.12
Dry	10-1995[c]	Golcuk	24.0	2.0	Dry	09-1999[b]	Andik	4.7	3.35
Rainy	01-1996[c]	Golcuk	43.3	1.4	Rainy	12-1999[b]	Andik	21.5	2.61
Rainy	04-1996[c]	Golcuk	50.8	1.75	Dry	07-2001[b]	Andik	5.5	4.1
Dry	10-1996[c]	Golcuk	29.2	2.0	Dry	10-2001[b]	Andik	0.0	5.3
Rainy	01-1997[c]	Golcuk	27.9	1.5	Dry	08-2003[b]	Andik	2.6	4.6
Rainy	04-1997[c]	Golcuk	76.8	1.5		03-1992[c]	Egirdir		0.1
Dry	07-1997[c]	Golcuk	0.0	1.7		04-1993[c]	Egirdir		0.0
Dry	10-1997[c]	Golcuk	40.8	1.65		07-1994[c]	Egirdir		0.1
Rainy	04-1998[c]	Golcuk	46.1	1.75		01-1995[c]	Egirdir		0.26
Dry	10-1999[c]	Golcuk	66.2	2.1		07-1995[c]	Egirdir		0.20
Dry	07-2001[c]	Golcuk	30.6	2.4		10-1996[c]	Egirdir		0.2

[a] From Cengiz et al. (1998)

[b] From PHL

[c] From SHW

the different sources of water—the two lakes and the stream. On the other hand, increasing fluoride contents was observed for two drinking water locations because of getting from only Andik stream in 2003 (Table 4).

Health impact assessment

According to upstairs knowledge's, the high fluoride concentration has notified in determining the public water system of Isparta city. Nowadays, some regions for Isparta city are also threated of health risk although Egirdir lake water has been used as widespread in the city. Therefore, it is suggested that, urgently fluoride poisoning can be prevented or minimized by using alternative water sources, by removing excessive fluoride from drinking waters.

For the study area, alternative water sources could be a surface water and groundwater containing low fluoride. Alluvium is the most important aquifer in Isparta plain

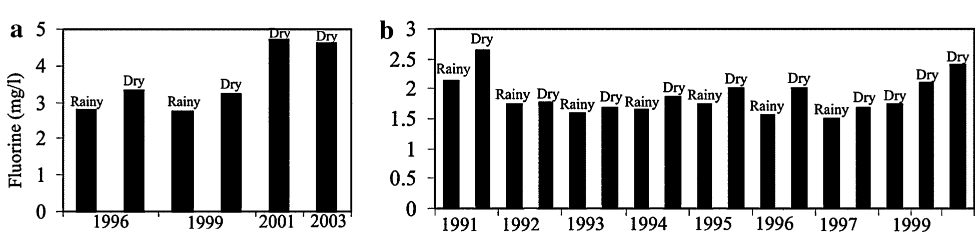

Fig. 7 Fluoride content. **a** Andık water, **b** Golcuk lake water

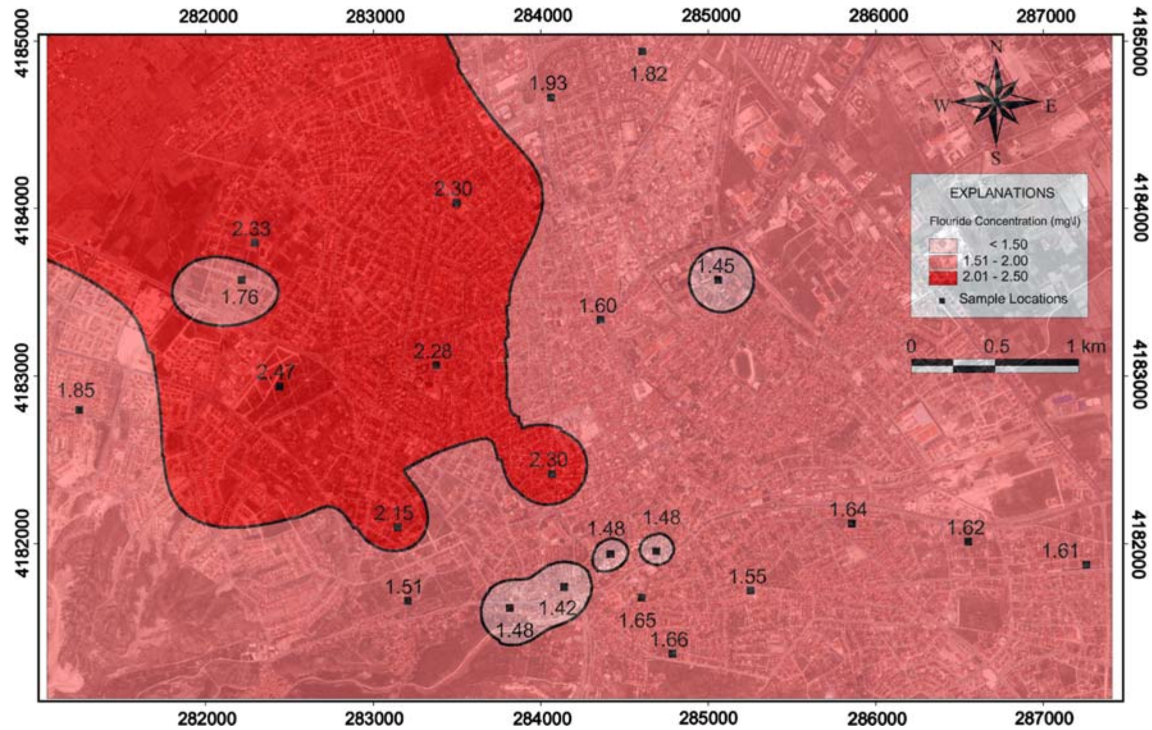

Fig. 8 Spatial distribution of fluoride in public water system of Isparta in 1990

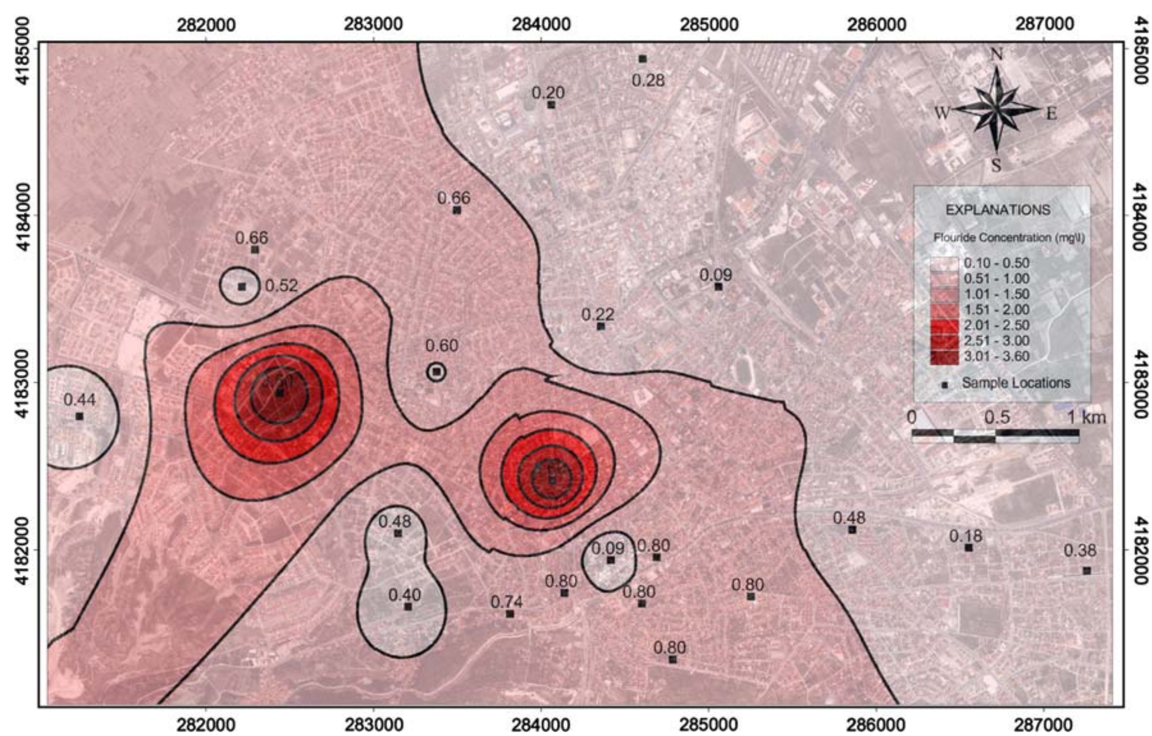

Fig. 9 Spatial distribution of fluoride in public water system of Isparta in 2003

located in the city residential area. Wells having irrigation purpose are extant. The measured flow-rates of wells in the alluvium aquifer range between 10 and 40 l/s (Irlayıcı 1993). But, favorable areas which may obtain groundwater for drinking water of Isparta residential area are limited to take into consideration of contamination due to

Table 4 The fluoride contents of public water system of Isparta

Location	Fluoride concentration (mg/l)				Change ratio (%)
	1990	Water resources taking domestic water	2003	Water resources taking domestic water	
1	1.82	Golcuk-Andik	0.28	Egirdir lake	−85
2	1.93	Golcuk-Andik	0.2	Egirdir lake	−90
3	2.33	Andik spring	0.66	Egirdir-Golcuk	−71.6
4	2.30	Andik spring	0.66	Egirdir-Golcuk	−71.3
5	2.30	Andik spring	3.6	Andik spring	+56
6	2.28	Andik spring	0.6	Egirdir lake	−73.7
7	2.47	Andik spring	3.6	Andik spring	+45.7
8	1.76	Golcuk-Andik	0.52	Egirdir lake	−70.5
9	1.42	Golcuk lake	0.8	Egirdir-Andik	−43.6
10	1.48	Golcuk lake	0.8	Egirdir-Andik	−45.9
11	1.48	Golcuk lake	0.74	Egirdir-Andik	−50
12	1.66	Golcuk lake	0.8	Egirdir-Andik	−51.8
13	1.65	Golcuk lake	0.8	Egirdir-Andik	−51.5
14	1.55	Golcuk lake	0.8	Egirdir-Andik	−48.4
15	1.64	Golcuk lake	0.48	Egirdir lake	−70.7
16	1.85	Golcuk lake	0.44	Egirdir lake	−76.2
17	1.61	Golcuk lake	0.38	Egirdir lake	−76.4
18	1.62	Golcuk lake	0.18	Egirdir lake	−88.8
19	1.48	Golcuk lake	0.09	Egirdir lake	−93.9
20	1.60	Golcuk lake	0.22	Egirdir lake	−86.3
21	1.45	Golcuk lake	0.09	Egirdir lake	−93.8
22	2.15	Andik spring	0.48	Egirdir lake	−77.7
23	1.51	Golcuk lake	0.4	Egirdir lake	−73.5

urbanization. The enough quantity drinking water for Isparta obtaining from this area is impossible. Furthermore, the fluoride content of groundwater recharging from volcanic rocks in the Isparta plain was determined as 1.1 and 2 mg/l (Irlayıcı 1993). Therefore, utilizing from surface waters is more reasonable. The drinking water of Isparta city is still partially supplied from Egirdir lake. The fluorine contents of Egirdir lake water are appropriate to WHO drinking water standards. It is suggested that, fluoride contents of Isparta drinking water should be modified by suitable mixed waters of both Egirdir lake having less fluoride and Golcuk lake, or Egirdir lake and Andik water.

Another alternative is also a defluoridation of water. Basically there are two approaches for treating water supplies to remove fluoride; flocculation and adsorption. Hydrate aluminum salts, a coagulant commonly used for water treatment, is used to flocculate fluoride ions in the water. Adsorption, the other approach is to filter the water down through a column packed with a strong adsorbent, such as activated alumina (Al_2O_3), activated charcoal, or ion exchange resins. But, both the community and household defluoridation systems have pros and cons (Meenakshi 2006). Furthermore, method of defluoridation water was expensive and it has application difficulty.

Conclusion and discussion

High fluoride is a prominent aspect of Golcuk-Isparta region, SW Turkey and causes dental problems. Fluoride in natural waters in the study area originated from the solution of apatite and more commonly from the solution of fluoride-bearing micas and amphiboles. The fluormicas (predominantly fluorphlogopite) is a predominant the main fluoride source mineral. Mainly aquifer units which discharged springs are Miocene clastics, Golcuk pyroclastics and volcanic rocks.

The fluoride contents of springs discharged from volcanic rocks, Golcuk pyroclastic and Miocene clastic are changed between 3.71–5.62, 1.81–3.95 and 0.39–1.02 mg/l, respectively. The fluoride contents of pyroclastic are much lower than that of volcanic. In addition, fluoride concentration changes for dry-rainy seasons as related to the degree of interaction between water and volcanic rocks. Fluoride contents tend to decrease in rainy seasons and to increase in dry seasons for all years. In the research area, fluoride concentrations of groundwater increase in related to residence time in the volcanic-proclastic rocks aquifer thereby having longer contact time for dissolution of fluoride bearing minerals.

In the research area, groundwater is classified as a bicarbonate type from Piper diagrams. Fluoride content showed positive correlation with sodium and negative correlation with calcium concentration. The groundwater analyses showed an over-saturated position respect to fluorite. Some of the samples discharged from Miocene clastic and limestone units were only over-saturated with respect to calcite.

All of the drinking water for Isparta city has been obtained from Golcuk lake and Andik spring from 1962 to 1995, later, it has also been obtained from Egirdir Lake since 1995. Extreme fluoride values were measured in public water system. The fluoride contents of Isparta public water system on behalf of health impact assessment were evaluated by GIS techniques. The some districts of Isparta city affecting high-fluoride water were determined. The drinking water of Isparta city is still partially supplied from Egirdir lake. The fluorine contents of Egirdir lake water are appropriate to WHO drinking water standards. It is suggested that, fluoride contents of Isparta drinking water should be modified by suitable mixed waters of both Egirdir lake having less fluoride and Golcuk lake, or Egirdir lake and Andik water.

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