

Evaluation of potential human health risk and investigation of drinking water quality in Isparta city center (Turkey)

Simge Varol and Aysen Davraz

ABSTRACT

Isparta city center is selected as a work area in this study because the public believes that the tap water is dirty and harmful. In this study, the city's drinking water in the distribution system and other spring waters which are used as drinking water in this region were investigated from the point of water quality and health risk assessment. Water samples were collected from major drinking water springs, tap waters, treatment plants and dam pond in the Isparta province center. Ca-Mg-HCO₃, Mg-Ca-HCO₃, Ca-Na-HCO₃, Ca-HCO₃, Ca-HCO₃-SO₄ and Ca-Mg-HCO₃-SO₄ are dominant water types. When compared to drinking water guidelines established by World Health Organization and Turkey, much greater attention should be paid to As, Br, Fe, F, NH₄, PO₄ through varied chemicals above the critical values. The increases of As, Fe, F, NH₄ and PO₄ are related to water-rock interaction. In tap waters, the increases of As and Fe are due to corrosion of pipes in drinking water distribution systems. The major toxic and carcinogenic chemicals within drinking water are As and Br for both tap water and spring water. Also, F is the non-carcinogenic chemical for only spring waters in the study area.

Key words | drinking water, health risk assessment, Isparta, water quality

Simge Varol (corresponding author)
Suleyman Demirel University, Water Institute,
Isparta,
Turkey
E-mail: simgevarol@sdu.edu.tr

Aysen Davraz
Department of Geology Engineering,
Suleyman Demirel University,
Isparta,
Turkey

INTRODUCTION

Safe and good quality drinking water is a basic need for human development, health and well-being, and hence, an internationally accepted human right (WHO 2001). Water provides essential elements, but when polluted it may become the source of undesirable situations dangerous to human health (Karavoltzos *et al.* 2008). The contamination of water resources has important repercussions for the environment and human health (Emmanuel *et al.* 2009; Muhammad *et al.* 2011; Baba & Tayfur 2011; Khan *et al.* 2013). Therefore, the quality of drinking water has increasingly been questioned from a health point of view for the last many decades (Garg *et al.* 2009).

Drinking water sources which closely concern environmental and human health can be contaminated from geogenic and anthropogenic factors. Nowadays, the most important reason for water resources contamination is

anthropogenic contamination due to increasing population, industrialization and technology. In addition, mixed trace elements and heavy metals in drinking water, depending on the geological characteristics, cause drinking water contamination. The common problems of drinking water include exposure to toxic inorganic substances, heavy metals, bacterial and other pathogens, increased nitrogen concentrations and other trace chemicals and micronutrients in drinking water resources (Rapant & Krcmova 2007; Garg *et al.* 2009).

Generally, drinking water containing different anions and heavy metals has significant adverse effects on human health either through deficiency or toxicity due to excessive intake. For example, like many elements, fluoride which generally occurs in nature is beneficial to human health in trace amounts, but can be toxic in excess. The links between low intakes of fluoride and dental protection are well

doi: 10.2166/wh.2015.187

known; however, fluoride is a powerful calcium-seeking element and can interfere with the calcified structure of bones and teeth in the human body at higher concentrations causing dental or skeletal fluorosis (Fordyce *et al.* 2007).

Arsenic is a toxic chemical that is naturally found in the environment and is a proven carcinogen for humans when exposed through oral, dermal and inhalation pathways (NRC 1997; ATSDR 2000; WHO 2001; Gunduz *et al.* 2010).

Furthermore, nitrate (NO₃) and nitrites (NO₂) are found naturally in water (Jordao *et al.* 2002; Khan *et al.* 2013) and the toxicology of nitrate to humans is mainly attributable to its reduction to nitrite. The major biological effect of nitrite is its involvement in the oxidation of normal hemoglobin to methemoglobin, which is unable to transport oxygen to the tissues (Gupta *et al.* 2000; Khan *et al.* 2013).

Because of its importance for human life, the European Union Council Drinking Water Directive 98/83/EC (EUCD 1998) of 3 November 1998 on the quality of water intended for human consumption was adopted because of the difficulties in achieving safe drinking water. Its objective is to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean. Because the people in Isparta believe that the tap waters are polluted and harmful, the drinking water in the city center has been investigated. Provisions concerning the quality of drinking water established by the Directive allow Member States to adapt the monitoring of water quality to local conditions, in order not only to evaluate its safety for consumption, but also to detect any relative toxicological problems and introduce the appropriate measures for the restoration and achievement of good drinking water quality.

Isparta city center was selected as a work area in this study because the public believes that the tap water was dirty and harmful. Therefore, they use different water sources as a drinking water source in the city. Isparta drinking water is provided from Eğirdir Lake, Darıdere dam and various springs. They are Andık, Yarıkdişi, Akyokuş and Aktaş sources and these waters are collected in storage facilities (Demir & Memiş 2011). Eğirdir Lake water, Darıdere dam water and spring water are treated in drinking water treatment plants and fed into the city's public water system. In this study, the city's drinking water in the distribution system and other spring waters which are used as drinking water in Isparta city center were

investigated in terms of chemical properties, heavy metals, pollution, coliform bacteria and human health risks associated with the intake of contaminated water.

Study area

The study area is situated within the Lake District in the southwest of Turkey and it has an 8,933 km² area (Figure 1). Total population of the Isparta district center was reported to be around 228,730 according to the 2014 census results (TUIK 2014). Generally, the climate of the Isparta district center and its vicinity is affected by the Mediterranean climate zone in the middle Anatolian climate zone. Based on the data from the Isparta district Meteorological Station collected between 1954 and 2013, mean annual temperature of the region is 10.28 °C. The hottest months are July and August with monthly averages of 23.5 °C and 23.2 °C, respectively, and the coldest months are January and February with monthly averages of 2.1 °C and 2.7 °C, respectively. According to 42 years of meteorological data (1971–2013), the region receives an average precipitation of 500.7 mm (Turkish State Meteorological Service website, www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=ISPARTA#sfB). Monthly averages of the highest and lowest precipitation occur in December and August with totals of 84 mm and 11 mm, respectively (Turkish State Meteorological Service website, www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=ISPARTA#sfB).

MATERIALS AND METHODS

Sampling and analysis

Water samples were collected in April 2014. A total of 20 water samples were collected from major drinking water springs, tap waters, treatment plants and dam pond of the Isparta province center (Figure 1). Samples were stored in two polyethylene bottles. One of the bottles was acidified with suprapure HNO₃ for determination of cations and another was kept unacidified for the anion analyses. The discharge temperature, pH and electrical conductivity (EC) were measured in the field. The major chemical constituents were analyzed by inductively coupled plasma-mass

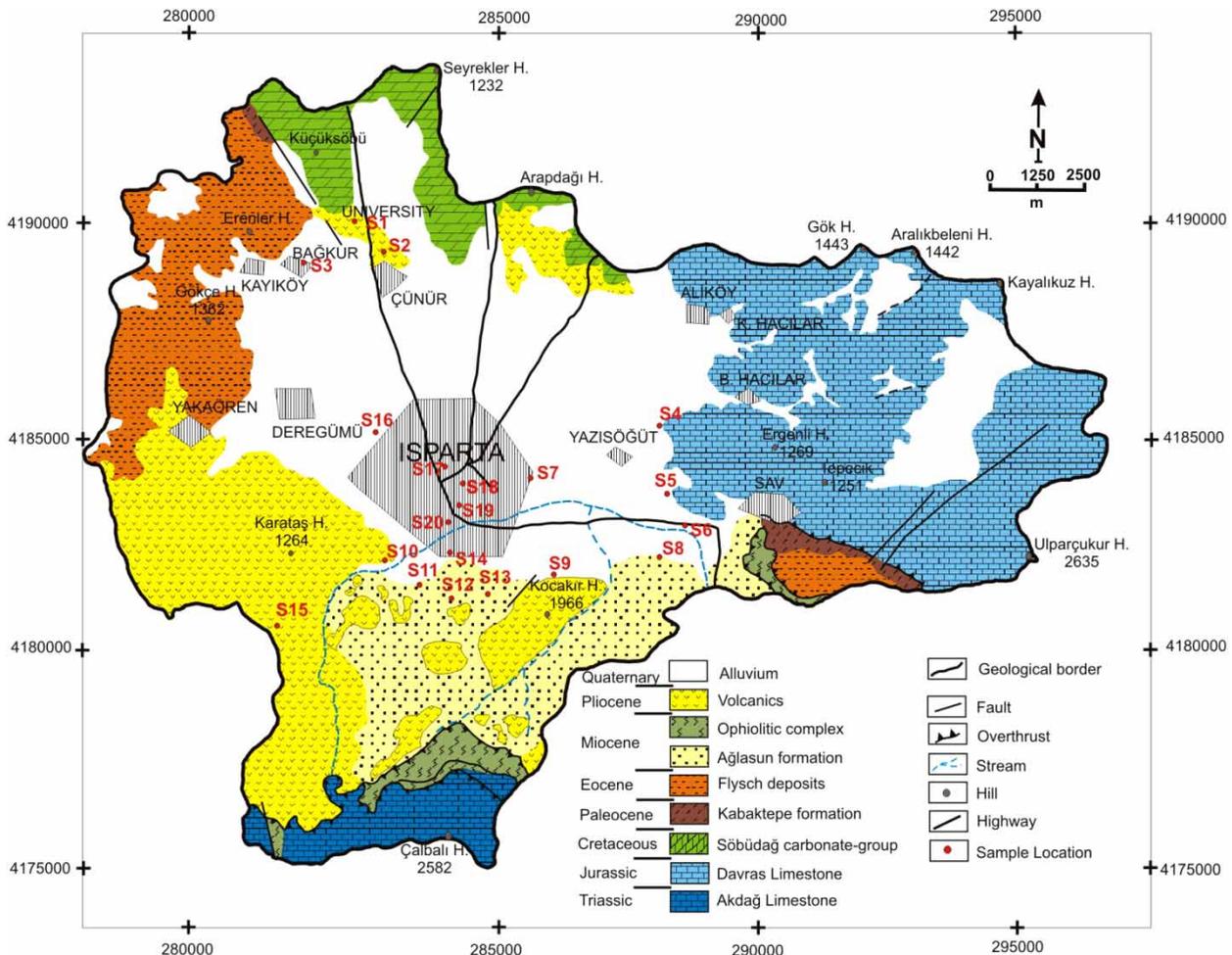


Figure 1 | Location and geological maps of the study area (Karagüzel & İrlayıcı 1998).

spectrometer at the ACME Laboratory (Vancouver, Canada). HNO_3^- and CO_3^{2-} concentrations were determined by titrimetric method; Cl^- and SO_4^{2-} were determined using ion chromatography in the laboratory of the Suleyman Demirel University, Research and Application Center for Geothermal Energy, Groundwater and Mineral Resources (Isparta, Turkey) (Table 1). The charge-balance error of the water samples was less than 5%, which is within the limits of acceptability. Data were analyzed with the SPSS software version 10.0 for Windows. Continuous variables from the study groups were reported as mean \pm standard deviation. Statistical significance was defined as $p < 0.05$. In addition, water samples were examined for total coliforms at Isparta Food Control Laboratory Directorate (Table 1). To assess total coliforms, water samples were

analyzed using the membrane filtration method for enumeration of the coliform bacteria (TS 2004). Total coliforms were isolated and enumerated using the membrane filtration technique. TTC Chapman Agar (Lactose Agar TTC with Tergitol 7) is a selective and differential medium prepared according to ISO 9308-1 (TS 2004), is used for the presumptive control of coliforms in waters for human consumption by the membrane filtration technique. Two samples of water were taken on two membranes and incubated in TTC Chapman Agar at $36 \pm 2^\circ\text{C}$ and $44 \pm 4^\circ\text{C}$, respectively, and incubated for a further 21 ± 3 h. All yellow colonies extending on the membrane were counted with the aid of a magnifying lens and recorded as presumptive total coliform. The results were always referred to as counts per 100 ml of sample.

Table 1 | Analytical methods used in the study

Parameters	Method	Laboratory
Discharge temperature (T °C), pH, and EC	<i>In situ</i>	<i>In situ</i>
Ag, Al, As, Au, B, Be, Bi, Br, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, Os, P, Pb, Pd, Pr, Pt, Rb, Re, Rh, Ru, S, Sb, Sc, Se, Si, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr	ICP mass spec. (inductively coupled plasma-mass spectrophotometer)	ACME Laboratory (Vancouver, Canada, an ISO 9002 accredited company)
F, SO ₄	Ion chromatography method	Suleyman Demirel University, Research and Application Center for Geothermal Energy, Groundwater and Mineral Resources (Isparta, Turkey)
NO ₃ , NO ₂ , NH ₄ , PO ₄	Ion chromatography method	Suleyman Demirel University, Research and Application Center for Geothermal Energy, Groundwater and Mineral Resources (Isparta, Turkey)
HCO ₃ , CO ₃ , Cl	Titrimetric method	Suleyman Demirel University, Research and Application Center for Geothermal Energy, Groundwater and Mineral Resources (Isparta, Turkey)
Bacteriological analyses (<i>E. coli</i> , total coliforms, fecal coliforms)	Membrane filtration method for enumeration of the coliform bacteria	Isparta Food Control Laboratory Directorate (Isparta, Turkey)

Geological and hydrogeological setting

Isparta city is located in the Lake District of Turkey, and its bedrock consists of two geological units, autochthonous and allochthonous (Yalçınkaya 1989; Karaman 1999), in the Isparta Plain. The autochthonous units are named alluvium, Davraz Limestone, Söbüdağ carbonate group, Kabaktepe formation, Ağlasun formation, flysch deposits, and Gölcük volcanics. The allochthonous units include the Akdağ Limestone and Isparta ophiolitic complex (Karagüzel & Irlayıcı 1998) (Table 2; Figure 1). The units of the determination are shown on the geological map (Figure 1).

Ophiolitic complex is composed of mafic-ultramafic rocks such as serpentinite, harzburgite, gabbro, peridotite and pelagic-terrigenous sediments such as radiolarite, chert, limestone, shale and sandstone (Robertson 1993; Davraz *et al.* 2008). 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 (Ağlasun formation) have been formed from the intercalation of sandstone,

claystone, marl, shale and overlain by conglomerate which has polygenic pebbles (Gormus & Ozkul 1995). Eocene clastic sediments were deposited as flysch facies and impermeable rock unit. Gölcük volcanics consist of andesite which has been fractured and undergoes partial alteration (Davraz *et al.* 2008). In addition Gölcük pyroclastics consist of thin-medium layered sediments in the form of sandstone, claystone, marl, tuff and tuffite. Alluvium deposits occur dominantly with unconsolidated clay, silt, sand and gravel constituents derived from surrounding volcanic units (Table 2; Figure 1).

Geological units and their hydrogeological properties are described in the research area. The rock units in the Isparta Plain are classified as permeable, semipermeable and impermeable (Karagüzel & Irlayıcı 1998). On the map, the Kabaktepe formation, Ağlasun formation, and flysch deposits are impermeable rock units. The ophiolite complex has an impermeable nonkarstic rock property (Robertson 1993; Davraz *et al.* 2008). The volcanic units, which have various lithological and sedimentological properties, include some pumice layers, and are classified as semipermeable. The andesite is classified as semipermeable rock units. The limestone in the investigation area is permeable karstic

Table 2 | Lithostratigraphic relations of the geologic units and hydrogeological properties (Karagüzel & Irlayıcı 1998; Davraz *et al.* 2008)

Age	Formation	Lithology	Hydrogeological properties
Quaternary	Alluvium (Qal)	The unit consists of unconsolidated clay, silt, sand, and gravel constituents which derive from surrounding volcanic and carbonate units	Permeable (Granular Aquifer)
Pliocene (Neogene)	Gölcük volcanics (PQg)	The unit consists of fractured andesite that undergoes partial alteration. Golcuk pyroclastics are interbedded with thin-medium layered sediments in the form of sandstone, claystone, marl, tuff and tuffite	Semipermeable
Miocene	Ophiolitic complex (To)	The unit is composed of mafic-ultramafic rocks such as serpentinite, harzburgite, gabbro, peridotite and pelagic-terrigenous sediments such as radiolarite, chert, limestone, shale, sandstone	Impermeable (Aquifuge)
Miocene	Ağlasun formation (Tma)	The unit has been formed from the intercalation of sandstone, claystone, marl, shale and overlain by conglomerate which has polygenic pebbles	Impermeable (Aquifuge)
Eocene	Flysch deposits (Tek)	The unit consists of sandstone, shale, clayey limestone and cherty limestone	Impermeable (Aquifuge)
Paleocene	Kabaktepe formation (Tek)	The unit is composed of fine-grained sandstone interlayers with red mudstones	Impermeable (Aquifuge)
Cretaceous	Söbüdağ carbonate group (Ks)	This unit is mostly massive and is composed of thick-bedded limestone	Permeable (Karstic Aquifer)
Jurassic	Davraz limestone (Med)	The unit is composed of massive limestone	Permeable (Karstic Aquifer)
Triassic	Akdağ limestone (TRa)	The unit is composed of thick-bedded massive limestone	Permeable (Karstic Aquifer)

rock. The alluvium deposits are classified as permeable. Among these hydrogeological units, the alluvium, volcanics (tuff) and limestones are the aquifers in the area (Karagüzel & Irlayıcı 1998).

RESULTS AND DISCUSSION

Hydrochemistry

Understanding the water quality is important, as it is the main factor determining its suitability for drinking, domestic, agricultural and industrial purposes. The physical and chemical parameters including statistical measures, such as minimum concentration, maximum concentration, mean concentration, and standard deviation are given in Table 3.

The chemical composition of the water samples ($n = 20$) in the study region shows a wide range. The pH of spring waters varied between 7.70 and 8.40. The pH of the spring water of 7.70–8.25 indicates that the dissolved carbonates are

predominantly in the HCO_3^- form (Adams *et al.* 2001) and indicates the alkaline nature of the samples. The differences in the pH of the water are associated with the lithological features of the discharge rocks. In addition, the pH of the tap water was measured in the range 7.75–8.40. The T ($^{\circ}\text{C}$) of spring water and tap water varied in the range 10.4–17.4 and 13.8–20.4, respectively. The EC values of spring waters were measured as 190–1,750 $\mu\text{S}/\text{cm}$. The EC values of tap waters also varied between 370 and 1,470 $\mu\text{S}/\text{cm}$. The total dissolved solids (TDS) in drinking water reveal the saline behavior of water, which indicates the organic pollution level of the water. TDS values of spring and tap waters ranged from 90 mg/l to 580 mg/l and 180 mg/l to 590 mg/l, respectively. According to WHO (1996), TDS should be between 500 and 1,500 mg/l in drinking waters. The limit value determined by WHO (1996) of TDS values is not exceeded in the study area.

Hydrochemical classification

Hydrogeochemical types reflect the effects of chemical reactions occurring between the minerals within the

Table 3 | Descriptive statistics of chemical and physical ions in water samples (all values are in mg/l except pH, EC ($\mu\text{S}/\text{cm}$), T ($^{\circ}\text{C}$)) and drinking water standards

	N	Minimum	Maximum	Mean	Std Deviation	Standards for drinking water samples	
						WHO standard (2008)	TS-266 (2005)
Na	20	0.89	29.06	6.24	6.21	200	100
Ca	20	10.41	86.01	43.94	17.17	300	200
Mg	20	2.39	48.34	11.85	11.34	300	150
K	20	0.29	13.20	2.85	2.91	12	12
CO ₃	20	0.00	0.00	0.00	0.00	–	–
HCO ₃	20	36.61	353.92	183.06	77.00	–	–
Cl	20	1.23	6.64	3.11	1.34	250	250
SO ₄	20	1.47	134.98	24.39	28.81	250	250
T	20	10.40	20.40	14.91	2.67		–
TDS	20	0.09	0.59	0.24	0.13	500–1,500	1,500
EC	20	190.00	1,750.00	559.50	401.76	–	–
pH	20	7.38	8.40	8.00	0.27	6.5–8.5	6.5–9.5
F	20	0.04	2.48	0.59	0.74	1.5	
NO ₂	20	0.01	0.01	0.01	0.00	3.0	0.5
NO ₃	20	0.20	8.83	2.39	2.38	50	50
PO ₄	20	0.05	1.22	0.16	0.35	0.1	–
NH ₄	20	0.06	0.08	0.06	0.00	0	0
As	20	0.00	0.02	0.00	0.00	0.01	0.01
Br	20	0.00	0.01	0.00	0.00	0.01	0.01
Fe	20	0.01	0.10	0.03	0.03	–	0.05
Valid N (listwise)	20						

WHO (2008) *Guidelines for Drinking-Water Quality*; TS-266 (2005) Turkish Drinking Water Standard.

lithology framework and groundwater. Hydrogeochemical diagrams are aimed at facilitating interpretation of evolutionary trends, particularly in groundwater systems, when they are interpreted in conjunction with distribution maps and hydrogeochemical types. An overall characterization of hydrogeochemical data can be possible by finding the hydrogeochemical types of water, generally known as water type, using various plots. Accordingly, Ca-Mg-HCO₃, Mg-Ca-HCO₃, Ca-Na-HCO₃, Ca-HCO₃, Ca-HCO₃-SO₄ and Ca-Mg-HCO₃-SO₄ were the dominant water types observed in the Piper diagram due to water-rock interaction in the study area (Figure 2; Table 4). Ca²⁺ can be derived from dissolution of carbonate minerals (e.g. calcite, dolomite, aragonite) as well as carbonate cement within formations. The primary source of Mg²⁺ in natural water is ferromagnesian minerals (olivine, diopside, biotite,

hornblende) within igneous and metamorphic rocks and magnesium carbonate (dolomite) in sedimentary rock (Singh *et al.* 2012). The increase of Mg²⁺ is responsible for sedimentary rock of the Ağlasun formation due to water-rock interaction. The increase of Na⁺ is due to sodium minerals such as Albite (Na- AlSi_3O_8) and clays minerals in the study area. An important source of sulfate in groundwater is the oxidation of pyrite (ferrous sulfide) which is widely distributed in sedimentary rocks. The increase of SO₄²⁻ in the groundwater samples is related to water-rock interaction with Ağlasun formation. The largest portion of Isparta drinking water is provided from Eğirdir Lake. Therefore, the water facies of Eğirdir Lake are dominant in tap waters. The Eğirdir Lake water is composed of Ca-Mg-HCO₃ facies (Davraz & Karagüzel 2008; Şener 2010).

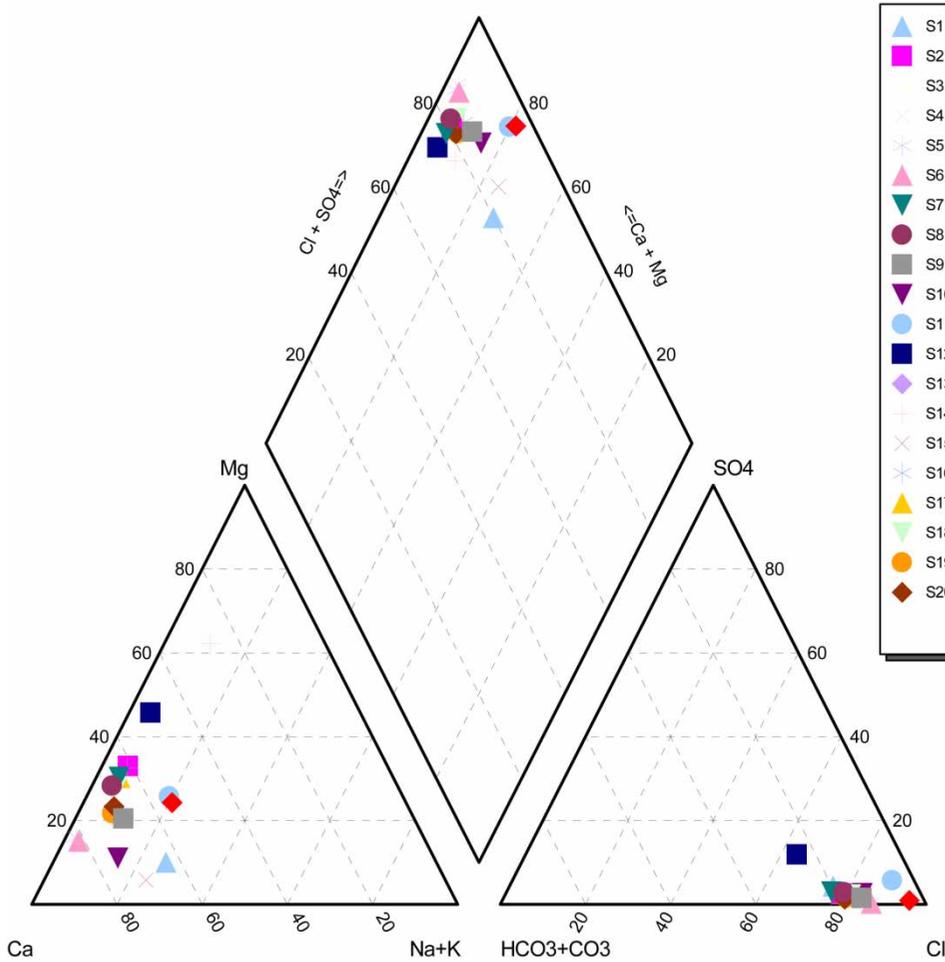


Figure 2 | Piper diagram (Piper 1944).

Table 4 | Water types according to the sample number and resource types in the study area

Sample no.	Location	Resource type	Water facies	Sample no.	Location	Resource type	Water facies
S1	University	Well water	Ca-Na-HCO ₃	S11	Bezirgan spring	Spring water	Ca-HCO ₃ -SO ₄
S2	Cünür spring	Spring water	Ca-Mg-HCO ₃	S12	Gokcay spring	Spring water	Ca-Mg-HCO ₃ -SO ₄
S3	M. Tonge District	Tap water	Ca-Mg-HCO ₃	S13	Muharrem Dede spring	Spring water	Ca-HCO ₃
S4	Davraz spring	Spring water	Ca-HCO ₃	S14	Treatment plant	Treatment plant	Mg-Ca-HCO ₃
S5	Davraz District	Spring water	Ca-HCO ₃	S15	Golcuk-Milas spring	Spring water	Ca-Na-HCO ₃
S6	Sav spring	Spring water	Ca-HCO ₃	S16	Fatih-Zafer District	Tap water	Ca-HCO ₃
S7	Davraz Home	Tap water	Ca-Mg-HCO ₃	S17	Anadolu District	Tap water	Ca-Mg-HCO ₃
S8	Dardere Dam Pond	Dam pond	Ca-Mg-HCO ₃	S18	Istiklal District	Tap water	Ca-Mg-HCO ₃
S9	Ayazmana Spring	Spring water	Ca-HCO ₃	S19	City center	Spring water	Ca-HCO ₃
S10	Dere spring	Spring water	Ca-HCO ₃	S20	Turan District	Tap water	Ca-HCO ₃

Statistical analysis

Correlation analysis. The bivariate correlation analysis method is applied to describe the degree of relation of hydrogeochemical parameters (Ugbaja *et al.* 2012). The results of the correlation analysis are given in Table 5. A high correlation coefficient (near 1 or -1) means a good relationship between two variables and its value around zero means no relationship between them at a significance level of $p < 0.05$. More precisely, it can be said that parameters showing $r > 0.7$ are considered to be strongly correlated whereas r between 0.5 and 0.7 shows moderate correlation (Kumar *et al.* 2006). The relationship between various elements has been studied using Spearman rank coefficient which is based on the ranking of the data in this study.

The correlation matrices for T, TDS, EC, pH, F, NO₃, NH₄, PO₄, As, Br, Fe and major ions were prepared and illustrated in Table 5. T shows high positive correlation with HCO₃, moderate positive correlation with TDS, EC, Ca, Mg and HCO₃, and negative correlation with NO₃, PO₄, NH₄ and Br. TDS shows high positive correlation with EC, Ca, Mg, HCO₃ and Cl, moderate positive correlation with SO₄ and negative correlation with NO₃, PO₄, NH₄ and Br. EC shows high positive correlation with TDS, Ca and Mg, moderate positive correlation with HCO₃ and Cl, and negative correlation with PO₄, NH₄ and Br. pH shows negative correlation with K, Cl, SO₄, F, NO₃, NH₄, PO₄, As and Br. Na shows high positive correlation with K, F and As, moderate positive correlation with Cl and SO₄ and negative correlation with PO₄ and Fe. Ca shows high positive correlation with HCO₃ and SO₄, moderate positive correlation with Mg and negative correlation with NO₃, PO₄, NH₄ and Br. Mg shows high positive correlation with HCO₃ and negative correlation with NO₃, PO₄, NH₄ and Br. K shows high positive correlation with F and As, moderate positive correlation with SO₄, and negative correlation with Fe. HCO₃ show moderate positive correlation with Cl and As and negative correlation with NO₃, PO₄, NH₄ and Br. Cl shows negative correlation with PO₄, NH₄ and Fe. SO₄ shows moderate positive correlation with F and negative correlation with NO₃ and Br. F shows moderate positive correlation with As and negative correlation with PO₄ and Fe. NO₃ shows

negative correlation with PO₄, As and Fe. PO₄ shows high positive correlation with NH₄. NH₄ shows negative correlation with Fe. As ions show negative correlation with Fe. In addition Br shows negative correlation with Fe. Weathering processes and anthropogenic inputs are the two main contributors for changing the geochemical composition of the water in the study area.

Factor analysis. Factor analysis, a multivariate statistical method, yields the general relationship between measured chemical variables by showing multivariate patterns that may help to classify the original data. It enables the geographical distribution of the resulting factors to be determined. The geological interpretation of factors yields insight into the main processes, which may govern the distribution of hydrochemical variables (Liu *et al.* 2003).

Factor analysis allows for the determination of basic independent dimensions of variables (Chidambaram *et al.* 2003). Therefore, factor analysis is used in this study as a numerical method of discovering variables that are more important than others for representing parameter variation and identifying hydrochemical processes (Davis 1986; Kumar *et al.* 2006). The variables for factor analysis were T, TDS, EC, pH, Na, Ca, Mg, K, HCO₃, Cl, SO₄, F, NO₃, PO₄, NH₄, As, Br and Fe in this study (Table 6).

Six factors are extracted to statistically represent the contributions influencing chemical composition of groundwater. R-mode factor analysis (Varimax rotation with Kaiser normalization) was carried out with the help of SPSS-15 software to extract the factors. In general, the factor will be related to the largest eigenvalue and will explain the greatest amount of variance in the data set. Factor analysis on the combined datasets provided three factors with eigenvalue > 1 that can explain approximately 91.07% of the data variability (Table 6). Factor loadings are classified by Liu *et al.* (2003) as 'strong', 'moderate' and 'weak' corresponding to absolute loading values of > 0.75 , 0.75–0.50, and 0.50–0.30, respectively. In this study, this classification was used to evaluate data (Table 6; Varol & Davraz 2015).

Factor 1 of the PCA matrix of groundwater around the study area is characterized by the strong loading of Na, K, F and As. This factor explains 19.88% of the total variance (Table 6). The strong loads in Factor 1 represent the natural

Table 5 | Spearman rank correlation matrix (r)

		T	TDS	EC	pH	Na	Ca	Mg	K	HCO ₃	Cl	SO ₄	F	NO ₃	PO ₄	NH ₄	As	Br	Fe	
T	r	1.00																		
TDS	r	0.60	1.00																	
EC	r	0.53	0.87	1.00																
pH	r	0.48	0.28	0.27	1.00															
Na	r	0.11	0.42	0.26	-0.46	1.00														
Ca	r	0.66	0.75	0.72	0.28	0.19	1.00													
Mg	r	0.64	0.74	0.70	0.46	0.15	0.54	1.00												
K	r	-0.06	0.23	0.12	-0.59	0.85	0.10	0.01	1.00											
HCO ₃	r	0.72	0.77	0.68	0.17	0.41	0.71	0.76	0.29	1.00										
Cl	r	0.42	0.72	0.57	-0.01	0.68	0.33	0.49	0.46	0.52	1.00									
SO ₄	r	0.33	0.53	0.45	-0.05	0.51	0.71	0.32	0.52	0.47	0.37	1.00								
F	r	0.13	0.27	0.12	-0.37	0.83	0.35	0.03	0.81	0.36	0.45	0.68	1.00							
NO ₃	r	-0.24	-0.00	0.03	-0.41	0.32	-0.13	-0.36	0.19	-0.11	0.11	-0.20	0.21	1.00						
PO ₄	r	-0.42	-0.52	-0.52	-0.36	-0.07	-0.51	-0.33	0.26	-0.51	-0.28	0.04	-0.01	-0.22	1.00					
NH ₄	r	-0.18	-0.20	-0.23	-0.45	0.15	-0.23	-0.32	0.44	-0.24	-0.06	0.23	0.15	0.03	0.79	1.00				
As	r	0.22	0.26	0.09	-0.40	0.72	0.22	0.11	0.81	0.53	0.41	0.40	0.69	-0.00	0.02	0.23	1.00			
Br	r	-0.43	-0.01	-0.01	-0.69	0.43	-0.40	-0.30	0.43	-0.27	0.30	-0.03	0.08	0.41	0.35	0.49	0.11	1.00		
Fe	r	0.38	0.13	0.06	0.54	-0.42	0.25	0.33	-0.23	0.14	-0.06	0.05	-0.21	-0.65	0.11	-0.01	-0.00	-0.58	1.00	

Table 6 | Results of the R-mode factor analysis on the chemical parameters from the study area

	Component					
	1	2	3	4	5	6
T	0.13	0.44	-0.41	0.07	0.64	0.06
TDS	0.16	0.84	-0.07	0.42	0.04	0.15
EC	0.06	0.90	-0.05	0.24	0.09	0.11
pH	-0.40	0.07	-0.60	-0.30	0.44	-0.03
Na	0.75	0.48	0.14	0.05	-0.07	0.33
Ca	0.38	0.51	-0.37	0.60	0.06	-0.19
Mg	-0.18	0.06	-0.15	0.89	0.06	0.35
K	0.78	0.45	0.23	0.21	-0.08	0.17
HCO ₃	0.27	0.35	-0.48	0.64	0.20	0.17
Cl	0.30	0.16	-0.16	0.17	0.03	0.84
SO ₄	0.23	0.20	0.15	0.90	-0.11	-0.11
F	0.86	0.07	-0.03	-0.01	-0.28	0.04
NO ₃	0.18	0.72	0.00	-0.29	-0.55	0.03
PO ₄	-0.08	-0.26	0.92	-0.09	0.08	-0.02
NH ₄	0.23	0.20	0.90	-0.12	0.06	0.06
As	0.92	-0.04	0.03	0.09	0.05	0.14
Br	0.16	0.10	0.42	-0.03	-0.39	0.74
Fe	-0.21	-0.09	0.19	-0.02	0.80	-0.15
Initial eigenvalues	6.31	3.92	1.90	1.55	1.45	1.24
% of variance	19.88	18.35	16.50	16.25	10.60	9.47
Cumulative %	19.88	38.23	54.73	70.99	81.59	91.07

Note: extraction method: principal component analysis; rotation method: Varimax with Kaiser normalization.

hydrogeochemical evolution of water by groundwater–rock interaction which can be explained by the dissolution of rocks and minerals in sediments by chemical weathering. The reason for this may be that the volcanics and clays in the Eocene clastic sediments (flysch) are widespread in the study area. Arsenic may derive from reductive dissolution of iron and microbial oxidation of organic matter. The arsenic content was high in the silty sand and silty clay sediments, which are generally enriched in Fe and Mn oxyhydroxides, organic carbon, clay minerals and thus contain a higher concentration of As (Anawar *et al.* 2002). In addition, the source of this F contamination in the water of the study area is thought to be the presence sediments like tuff and tuffite within the Gölcük volcanics.

Factor 2 explains a significant proportion of 18.35% of the total variance and has strong positive loading on TDS,

EC and NO₃ (Table 6). Factor 2 represents water–rock interaction and the contribution of point and nonpoint source pollution from domestic and industrial wastes.

Factor 3 explains 16.50% of the total variance and has strong positive loading on PO₄ and NH₄ (Table 6). The increases of NH₄ and PO₄ in water samples are due to water–rock interaction with Ağlasun formation and volcanics. Anthropogenic effects are not present in the locations surrounding springs in the study area.

Factor 4 explains 16.25% of the total variance and has strong positive loading on Mg and SO₄ (Table 6). The SO₄ sources in groundwater and surface waters include: (1) atmospheric deposition (Wayland *et al.* 2003); (2) sulfate-bearing fertilizers; and (3) bacterial oxidation of sulfur compounds (Sidle *et al.* 2000). Accordingly, the sulfate might come from the breakdown of organic substances of

weathered soils, leachable sulfate from fertilizers and other human influences like sulfuric salts in domestic wastewater (Craig & Anderson 1979; Bahar & Yamamuro 2008). Loading of Mg ion indicates that they may be derived from rock–water interaction processes in the study area (Varol & Davraz 2015). This factor group has moderate positive loading on Ca and HCO₃. The moderate loading of HCO₃ ions with alkali and alkaline earth metals supports the view of natural weathering sources. The HCO₃ can come from the dissolution of carbonate minerals, from soil CO₂ or from the bacterial degradation of organic contamination (Varol & Davraz 2015). This situation can be explained by the Söbüdağ, Davraz and Akdağ limestone in the study area.

Factor 5, which accounts for 10.60% of the total variance, has strong positive loading on Fe, has moderate positive loading on T (°C) and weak positive loading on pH (Table 6). The poor correlation of the above variables with pH reflects that alteration in the pH of these waters has no significant effect over these ions. The strong positive loading on Fe shows anthropogenic pollution in the water. This situation is seen in samples of tap water.

Factor 6 explains 9.47% of the total variance and has strong positive loading on Br and Cl (Table 6). These constituents are common in fertilizers and may derive from soil dissolution and also the dissolution of existing salts in soils. In the study area again in this case, it is seen in samples of tap water.

Evaluation of water quality

Evaluation of chemical quality of the water samples

In the study area, the assessment of water quality was carried out in order to identify its suitability for drinking purposes. The analytical results of physical and chemical parameters of waters were compared with the standard guideline values as recommended by the World Health Organization (WHO 2008) for drinking and public health purposes (Table 3). The table shows the most desirable limits and maximum allowable limits of various parameters.

According to Table 3, the fluoride (F) concentration of water samples S1, S10 and S15 exceed the WHO (2008) and TS (2005) limits. S1 sample is a distributed water sample from the opened drilling well on the Gölcük

volcanics (Figure 1). The high F in the spring waters occurs depending on the water–rock interaction. The fluoride contents of drinking water in Isparta region is strikingly related to circulation of water within volcanic and pyroclastic rocks (Davraz *et al.* 2008).

The concentration of PO₄ in water samples S11 and S13 exceeds the WHO (2008) and TS (2005) limits. Natural sources of phosphorus in both surface and groundwater include atmospheric deposition, natural decomposition of rocks and minerals, weathering of soluble inorganic materials, decaying biomass, runoff, and sedimentation (Fadiran *et al.* 2008). The increase of PO₄ in water samples is due to water–rock interaction with Ağlasun formation and volcanics.

The NH₄ concentration in the water collected from the sampling sites S1, S11 and S13 exceeds the WHO (2008) and TS (2005) limits. Nitrogen is found within volcano fumaroles and magmatic rock minerals. In addition, nitrogen is the form of ammonium in magmatic rock minerals (Sahinci 1991). The increase of NH₄ is originated from water–rock interaction. Anthropogenic effects are not present in locations surrounding springs in the study area.

Arsenic (As) concentration of water samples S1, S15 and S20 exceeds the WHO (2008) and TS (2005) limits. Inorganic arsenic occurs naturally in certain types of rocks, sediments and many minerals. The most common minerals are arsenopyrite (FeAsS), orpiment (As₂S₃) and realgar (As₄S₄). Sediments derived from volcanic rocks generally have higher arsenic concentrations (Saldivar & Soto 2009). The As concentration of spring water samples is associated with arsenic-containing bedrock formations such as volcanics and Ağlasun formation. Corrosion of household plumbing systems is also an important source of trace metals found in tap waters (Calderon 2000; Tamasi & Cini 2004). Significant levels of trace metals may be detected after stagnation of the water in distribution systems, especially during night-time (van Dijk-Looijaard & van Genderen 2000; Seifert *et al.* 2000). The increase of As concentration in tap water in the study area is originated from corrosion of pipes in drinking water distribution systems.

The concentration of Br in water samples S1, S9 and S14 exceeds the WHO (2008) and TS (2005) limits. The presence of Br in drinking water shows that it is

anthropogenically contaminated water. Bromide (Br^-) is the anion of the element bromine, which is a member of the common halogen element series that includes fluorine, chlorine, bromine and iodine. Natural levels of bromide are low in the environment, except in sources associated with fossil fuels (most notably in coal). Bromide is a trace element in the earth's crust. It commonly exists as salts with sodium, potassium and other cations, which are usually very soluble in water. The bromides of calcium, sodium, and zinc account for a sizable part of the bromine market. These salts form dense solutions in water that are used as drilling fluids in wells (Flury & Andreas 1993; Lyday 2007; WHO 2009). In addition, the main source in drinking water is its formation during ozonation when the bromide ion is present in water (WHO 2011).

Iron (Fe) concentration of water samples S2, S3, S8, S16 and S17 exceeds the WHO (2008) and TS (2005) limits. The origin of high iron content in water samples is both geogenic and anthropogenic. The main naturally occurring iron minerals are magnetite, hematite, goethite and siderite. Weathering processes release the element into waters. The increase of Fe in the spring and dam pond waters is a result of water-rock interaction in the sandstone levels of the Ağlasun formation. In tap water, iron may be released from iron-based materials in drinking water distribution systems during the corrosion process.

Evaluation of bacteriological quality of the water samples

The public health significance of water quality cannot be over-emphasized. Many infectious diseases are transmitted by water through the fecal-oral route. Diseases contracted through drinking water kill about 5 million children annually and make one-sixth of the world's population sick (WHO 2004a). Water is vital to our existence and its importance in our daily life makes it imperative that thorough microbiological and physio-chemical examinations be conducted on water. Potable water is the water that is free from disease producing microorganisms and chemical substances that are dangerous to health (Lamikanra 1999; Shittu *et al.* 2008).

The contaminants leading to water pollution include a wide variety of chemicals, pathogens, and physical or sensory changes such as elevated temperature and discoloration.

Pathogens can produce water-borne diseases in either human or animal hosts (Davraz & Varol 2012). There are numerous point and non-point contamination sources of microorganisms to groundwater including agricultural and urban runoff, non-watertight septic tanks, wastewater discharges, unintentional releases of sewage and land-surface irrigation with primary treated water (Mahler *et al.* 2000; Davraz & Varol 2012). Currently total coliforms, fecal coliforms, *Escherichia coli* and enterococci are bacterial indicators which are used in water quality and health risk assessments. Each group of bacteria is normally prevalent in the intestines and feces of warm-blooded mammals, including wildlife, livestock, and humans (Davraz & Varol 2012). The indicator bacteria themselves are usually not pathogenic. The coliform and fecal bacteria in water are the cause of gastrointestinal infections such as typhoid, dysentery and hepatitis. The hepatitis A infection is observed in about 1.5 million patients every year. It originates from water and sanitation system insufficiency. Malaria, trachoma and intestinal helminthes infections are likely to decrease with better access to potable water (WHO 2004b; Davraz & Varol 2012). Therefore, bacteriological content of drinking water is the most important factor and bacteriological analyses were performed to determine the potability of water in the study area. According to the analyses results, bacteriological contamination was not encountered in drinking water in the study area.

Human health risk assessment

Risk assessment is the determination of the quantitative or qualitative value of risk related to a concrete situation and a recognized threat (also called hazard). A health risk assessment is a questionnaire used to identify factors in individuals that increase their risk of impairments or disabilities and then recommend behavioral modifications to minimize their impact (USEPA 2013).

In many parts of the world drinking water is still a major contributor to the community burden of enteric disease because available water sources are faecally contaminated and untreated, inadequately treated or have become contaminated during collection, handling, storage and use. The impact of inadequate drinking water quality on human health can take numerous shapes of varying severity and clinical significance, ranging from asymptomatic

infections to gastroenteritis and diarrhea to severe illness and ultimately death (Havelaar & Melse 2003).

Risk assessment is an attempt to identify and quantify potential risks to human health resulting from exposure to various contaminants. It involves evaluation of toxicity data for chemicals to which humans are exposed, and estimation of potential exposure levels. Among three main routes of exposure (ingestion, inhalation, and dermal absorption), only the ingestion route was taken into consideration in this study. Ingestion was reported to be the most important route for exposure to trace metals (O'Rourke *et al.* 1999; Kavcar *et al.* 2009).

In order to estimate the daily exposure of an individual, USEPA (2005) suggests the lifetime average daily dose as the exposure metric (Kavcar *et al.* 2009). The following equation is a similar representation of daily exposure for ingestion route modified from USEPA (1992) and Chrostowski (1994):

$$ADD = C \times IR \times ED \times EF / BW \times AT \quad (1)$$

where *ADD* is the chronic daily intake (mg/kg/d), *C* is the drinking water contaminant concentration (mg/l), *IR* is ingestion rate per unit time (l/day), *ED* is exposure duration (years), *EF* is exposure frequency (days/years), *BW* is body weight (kg) and *AT* is average time (30/70 × 365 days). Deterministic exposure assessment involved using Equation (1) to estimate individual exposures to each trace metal (Kavcar *et al.* 2009; Nguyen *et al.* 2009).

Risk characterization is the final stage of risk assessment. The objective of this stage is to calculate the risk. The results of toxicity and exposure assessment are integrated to arrive at quantitative estimates of cancer risk and hazard indices (Lim *et al.* 2008). Carcinogenic risk is the probability of an individual developing any type of cancer from lifetime exposure to carcinogenic hazards. The acceptable or tolerable risk for regulatory purposes is in the range of 10^{-6} to 10^{-4} (Lim *et al.* 2008). These values mean from one additional case in a population of 1 million to one in 10,000 people is acceptable (Lim *et al.* 2008). Cancer risk associated with ingestion exposure is calculated using the following equation (Patrick 1994):

$$R_{\text{cancer}} = ADD \times SF \quad (2)$$

where *R* is the excess probability of developing cancer over a life time as a result of exposure to a contaminant (or carcinogenic risk), *ADD* is the chronic daily intake (mg/kg/d), and *SF* is the slope factor of the contaminant (mg/kg/d)⁻¹ (Kavcar *et al.* 2009; Equation (2)).

The potential for non-carcinogenic agents to occur is assessed by comparing exposure or average intake of hazardous substances with the corresponding reference dose (*RfD*) (Lim *et al.* 2008). To estimate non-carcinogenic risk, the hazard quotient (*HQ*) is calculated using the following equation (USEPA 1999):

$$HQ = ADD / RfD \quad (3)$$

where *RfD* is the reference dose (mg/kg/d). *SF* and *RfD* values employed in this study were obtained from the United States Environmental Protection Agency (USEPA) (IRIS 2005; Kavcar *et al.* 2009). The *HQ* value more than 1 (*HQ* > 1) shows a significant risk level. The higher the value, the greater the likelihood of an adverse non-carcinogenic health effect (USEPA 1989; Khan *et al.* 2008; Muhammad *et al.* 2011; Qaiyum *et al.* 2011; Jamaludin *et al.* 2013; Equation (3)).

The results of chemical analysis of the drinking water evaluated according to WHO (2008) and TS-266 (2005) was determined to exceed the limit values for As, Br, and F (Table 3).

Arsenic is known as a human carcinogen and assigned to a Group A classification by the USEPA. Studies on long-term exposure for arsenic showed that arsenic in drinking water could be associated with liver, lung, kidney and bladder cancers, as well as skin cancer. Most organic arsenic species are less toxic than inorganic arsenic (ATSDR 2000; Bissen & Frimmel 2003; Nguyen *et al.* 2009). The toxicity of arsenic in terms of cell survival (genotoxicity) strongly depends on its oxidation states. According to studies by Fischer *et al.* (1985) and Bertolero *et al.* (1987) As (V) was at least 10-fold less toxic than As (III). As (III) was about 40-fold more toxic to KB oral epidermoid carcinoma cells (Huang & Lee 1996; Nguyen *et al.* 2009). As the results of arsenic biotransformation show, As (V) is rapidly reduced to As (III) in the human body (Bertolero *et al.* 1987; Vahter 2002; Nguyen *et al.* 2009). For this

reason, total arsenic is usually counted in human health risk assessments of arsenic through oral pathways.

Bromate is not normally found in water, but can occur as a result of pollution from industrial sources, sometimes as a consequence of its presence in contaminated soil. However, the main source in drinking water is its formation during ozonation when the bromide ion is present in water (WHO 2011). Bromate is believed to be a cancer causing agent and has been classified by the International Agency for Research on Cancer as probably carcinogenic to humans. An estimate of lifetime cancer risk based on an average adult's drinking water intake is 1 in 10^4 for a bromate concentration of 5 ppb (Creed *et al.* 1996).

Fluoride is one of the chemical elements necessary for human life. Deficiency or excess of fluoride level in the environment is closely associated with human health (Rui-Kong 1993). 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 (Davraz *et al.* 2008). Fluoride can also have more serious effects on skeletal tissues. Long-term accumulation of fluoride likely also affects thyroid function (Balabolkin *et al.* 1995), may have neurological effects (Mullenix *et al.* 1995), may induce reproductive problems (Dominguez *et al.* 1995) and may affect the pineal gland (Luke 1994). Fluoride's well-known genotoxic properties may be showing up in the population as an increased risk for various cancers (Zeiger *et al.* 1993;

Tohyama 1996; Davraz *et al.* 2008). The distribution of endemic fluorosis in Isparta city is closely related to abnormal concentrations of fluoride in drinking water.

As the waters in the study area are used for drinking water, a health risk assessment was performed. The health risk assessment was made in terms of public health according to the results of the water samples analysis (Table 7). According to Table 7, excessive consumption of S1 water in the study area carries a high risk of cancer for As and Br and an additional non-carcinogenic risk for F. The excessive consumption of S9 and S14 water in the study area carries a high risk of cancer for Br. The consumption of S10 water carries a non-carcinogenic risk for F. The consumption of S15 and S20 water carries a high risk of cancer for As. Also, the consumption of S15 water carries a non-carcinogenic risk for F.

The results show that As and Br are the major toxic and carcinogenic chemicals in drinking water in the study area. Carcinogenic risk is between 1.4×10^{-3} and 5.1×10^{-3} for As, indicating an additional 1–5 cancer patients among 1,000 people. In addition, for Br, carcinogenic risk is between 7.38×10^{-3} and 8.72×10^{-3} , indicating the possibility of an additional 7–9 cancer patients among 1,000 people.

CONCLUSION

A correlation analysis for EC, pH, T, TDS, NO_3 , NO_2 , NH_4 , F, PO_4 , As, Br, Fe and major ions was performed with the

Table 7 | Calculated carcinogenic and non-carcinogenic risk of drinking water

Substance	Water sample no.	C (mg/l)	IR (l/day)	ED (years)	EF days/years	BW (kg)	AT (days)	ADD (mg/kg)	*Rfd (mg/kg/d)	*SF (mg/kg/d) ⁻¹	R _{cancer}	HQ _{non-cancer}
As	S1	0.014	2	15	350	70	30/70 × 365	0.015	3×10^{-4}	1.5	5.1×10^{-3}	33.33
	S15	0.019	2	15	350	70	30/70 × 365	0.018	3×10^{-4}	1.5	2.7×10^{-3}	60
	S20	0.010	2	15	350	70	30/70 × 365	9.58×10^{-3}	3×10^{-4}	1.5	1.4×10^{-3}	31.93
F	S1	1.810	2	15	350	70	30/70 × 365	1.735	6×10^{-2}	–	–	28.91
	S10	2.450	2	15	350	70	30/70 × 365	2.349	6×10^{-2}	–	–	39.15
	S15	2.480	2	15	350	70	30/70 × 365	2.378	6×10^{-2}	–	–	39.65
Br	S1	0.011	2	15	350	70	30/70 × 365	0.010	4×10^{-3}	7×10^{-1}	7.38×10^{-3}	2.5
	S9	0.011	2	15	350	70	30/70 × 365	0.010	4×10^{-3}	7×10^{-1}	7.38×10^{-3}	2.5
	S14	0.013	2	15	350	70	30/70 × 365	0.012	4×10^{-3}	7×10^{-1}	8.72×10^{-3}	3

*Data from USEPA (2005).

bivariate method to describe the relation between hydrochemical parameters. In the study area, some groups of species show moderate to strong correlation ($r < 0.7$). Weathering processes and anthropogenic inputs are the two main contributors for changing the geochemical composition of the water in the study area. Factor analysis was carried out on a subset of 18 selected variables (T, TDS, EC, pH, Na, Ca, Mg, K, HCO₃, Cl, SO₄, F, NO₃, PO₄, NH₄, As, Br, Fe), which represent the overall geochemical framework. Six factors are extracted to statistically represent the contributions influencing chemical composition of groundwater. Factor 1 (strong loads Na, K, F, As) represents the natural hydrogeochemical evolution of water by groundwater-rock interaction which can be explained by the dissolution of rocks and minerals in sediments by chemical weathering.

A Piper diagram was used to determine hydrogeochemical types of drinking water. Accordingly, Ca-Mg-HCO₃, Mg-Ca-HCO₃, Ca-Na-HCO₃, Ca-HCO₃, Ca-HCO₃-SO₄ and Ca-Mg-HCO₃-SO₄ were the dominant water types observed in these diagrams due to water-rock interaction in the study area. The increases of Mg²⁺ and SO₄²⁻ are the result of water-rock interaction in the sedimentary rock of the Ağlasun formation. The increase of Na⁺ originates from sodium minerals such as Albite and clays minerals in the study area.

When compared with the drinking water guidelines established by WHO and TS, much greater attention should be paid to the various As, Br, Fe, F, NH₄, and PO₄ compounds that occur above the critical values. Extreme values of As, Br and Fe were determined in both tap water and spring water. The increases of As and Fe in the spring water are related to water-rock interaction. In tap waters, these increases are due to corrosion of pipes in drinking water distribution systems. The presence of Br in drinking water shows that it is anthropogenically contaminated water. The extreme values of F, NH₄ and PO₄ were determined in spring water. High fluoride is a prominent aspect of the Isparta region. 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 increases of NH₄ and PO₄ in water samples are due to water-rock interaction with Ağlasun formation and volcanics. Bacteriological content of drinking water is the most important factor and

bacteriological analyses were performed to determine the potability of water in the study area. According to analysis results, bacteriological contamination was not encountered in drinking water in the study area.

Risk assessment is an attempt to identify and quantify potential risks to human health resulting from exposure to various contaminants. In this study, only the ingestion route was taken into consideration. The major toxic and carcinogenic chemicals within drinking water are As and Br for both tap water and spring water. Also, F was identified as a non-carcinogenic chemical in only spring waters in the study area.

Considering the results of this research, it is observed that the spring waters pose a risk to health contrary to the popular belief in the study area. In addition, the belief that spring waters are clean and there is no adverse effect on health may have negative consequences. Therefore, public water systems must be monitored and enforceable health standards set regarding contaminants in drinking water.

REFERENCES

- Adams, S., Titus, R., Pietersen, K., Tredoux, G. & Harris, C. 2001 Hydrochemical characteristics of aquifers near Sutherland in the Western Karoo, South Africa. *J. Hydrol.* **241**, 91–103.
- Anawar, H. M., Komaki, K., Akai, J., Takada, J., Ishizuka, T., Takahashi, T., Yoshioka, T. & Kato, K. 2002 Diagenetic control on arsenic partitioning in sediments of the Meghna River delta, Bangladesh. *Environ. Geol.* **41**, 816–825.
- ATSDR 2000 *Toxicological profile for arsenic (update)*. US Department of Health and Human Services Agency for Toxic Substances and Disease Registry PB/2000/108021, Atlanta, Georgia.
- Baba, A. & Tayfur, G. 2011 Groundwater contamination and its effect on health in Turkey. *Environ. Monit. Assess.* **183** (1–4), 77–94.
- Bahar, M. M. & Yamamuro, M. 2008 Assessing the influence of watershed land use patterns on major ion chemistry of river waters in the Shimousa Upland Japan. *Chem. Ecol.* **24** (5), 341–355.
- Balabolkin, M. I., Mikhailets, N. D., Labouskaia, R. N. & Chernousova, N. V. 1995 The inter-relationship of the thyroid and immune statuses of workers with long-term fluoride exposure. *Ter. Arkh.* **67** (1), 2–41.
- Bertolero, F., Pozzi, G., Sabbioni, E. & Saffiotti, U. 1987 Cellular uptake and metabolic reduction of pentavalent to trivalent arsenic as determinants of cytotoxicity and morphological transformation. *Carcinogenesis* **8**, 803–808.

- Bissen, M. & Frimmel, F. H. 2003 **Arsenic: a review. Part I: occurrence, toxicity, speciation, mobility.** *Acta Hydrochim. Hydrobiol.* **31**, 9–18.
- Calderon, R. L. 2000 **The epidemiology of chemical contaminants of drinking water.** *Food Chem. Toxicol.* **38**, S13–S20.
- Chidambaram, S., Ramanathan, A. L., Srinivasamoorthy, K. & Anandhan, P. 2003 **WATCLAST – A Computer Program for Hydrogeochemical Studies.** Recent Trends in Hydrogeochemistry (case studies from surface and subsurface waters of selected countries). Capital Publishing Company, New Delhi, pp. 203–207.
- Chrostowski, P. C. 1994 **Exposure assessment principles.** In: *Toxic Air Pollution Handbook* (D. R. Patrick, ed.). Van Nostrand Reinhold, New York, p. 154.
- Craig, E. & Anderson, M. P. 1979 **The effects of urbanization of ground water quality. A case study of ground water ecosystems.** *Environ. Conserv.* **30** (2), 104–130.
- Creed, J. T., Magnuson, M. L., Pfaff, J. D. & Brockhoff, C. 1996 **Determination of bromate in drinking waters by ion chromatography with inductively coupled plasma mass spectrometric detection.** *J. Chromatogr. A.* **753**, 261–267.
- Davis, J. C. 1986 *Statistics and Data Analysis in Geology.* Wiley, New York.
- Davraz, A. & Karagüzel, R. 2008 **The importance of hydrogeology assessments for agricultural water demand: a case study from Southwest Turkey.** *Beykent Üniversitesi Fen ve Mühendislik Dergisi* **2** (2), 218–234.
- Davraz, A. & Varol, S. 2012 **Microbiological risk assessment and sanitary inspection survey of Tefenni (Burdur/Turkey) region.** *Environ. Earth Sci.* **66**, 1213–1223.
- Davraz, A., Sener, E. & Sener, S. 2008 **Temporal variations of fluoride concentration in Isparta public water system and health impact assessment (SW-Turkey).** *Environ. Geology J.* **56**, 159–170.
- Demir, S. A. & Memiş, Ü. 2011 **Investigation of different fluoride contents of drinking waters in Isparta City center.** *Ekoloji* **20** (79), 77–82.
- Dominguez, L., Diaz, A., Fornes, M. W. & Mayorga, L. S. 1995 **Reagents that activate GTP-binding proteins trigger the acrosome reaction in human spermatozoa.** *Int. J. Androl.* **18** (4), 203–207.
- Emmanuel, E., Pierre, M. G. & Perrodin, Y. 2009 **Groundwater contamination by microbiological and chemical substances released from hospital wastewater and health risk assessment for drinking water consumers.** *Environ. Int.* **35**, 718–726.
- EU 1998 **EU, Council Directive 98/83/EC.**
- Fadiran, A. O., Dlamini, S. C. & Mavuso, A. 2008 **A comparative study of the phosphate levels in some surface and groundwater bodies of Swaziland.** *Bull. Chem. Soc. Ethiop.* **22** (2), 197–206.
- Fischer, A. B., Buchet, J. P. & Lauwerys, R. R. 1985 **Arsenic uptake, cytotoxicity and detoxification studied in mammalian cells in culture.** *Arch. Toxicol.* **57**, 168–172.
- Flury, M. & Andreas, P. 1993 **Bromide in the natural environment: occurrence and toxicity.** *J. Environ. Qual.* **22** (4), 747–758.
- Fordyce, F. M., Vrana, K., Zhovinsky, E., Povoroznuk, V., Toth, G., Hope, B. C., Iljinsky, U. & Baker, J. 2007 **A health risk assessment for fluoride in Central Europe.** *Environ. Geochem. Health* **29**, 83–102.
- Garg, V. K., Suthar, S., Singh, S., Garima, A. S. & Jain, M. S. 2009 **Drinking water quality in villages of southwestern Haryana, India: assessing human health risks associated with hydrochemistry.** *Environ. Geol.* **58**, 1329–1340.
- Gormus, M. & Ozkul, M. 1995 **Stratigraphy of the area between Gonen-Atabey (Isparta) and Aglasun (Burdur).** *J. Sci. Inst. Suleyman Demirel University* **1**, 43–64 (in Turkish).
- Gunduz, O., Simsek, C. & Hasozbek, A. 2010 **Arsenic pollution in the groundwater of Simav Plain, Turkey: its impact on water quality and human health.** *Water Air Soil Pollut. J.* **205**, 43–62.
- Gupta, S. K., Gupta, R. C., Seth, A. K., Gupta, A. B., Bassin, J. K. & Gupta, A. 2000 **Recurrent acute respiratory tract infections in areas with high nitrate concentrations in drinking water.** *Environ. Health Perspect.* **108**, 363e366.
- Havelaar, A. H. & Melse, J. M. 2003 **A burden of disease approach: Quantifying public health risk in the WHO Guidelines for Drinking-Water Quality.** RIVM report 734301022/2003.
- Huang, R. N. & Lee, T. C. 1996 **Cellular uptake of trivalent arsenite and pentavalent arsenate in KB cells cultured in phosphate-free medium.** *Toxicol. Appl. Pharmacol.* **136**, 243–249.
- IRIS (Integrated Risk Information System) 2005 **US Environmental Protection Agency, Cincinnati, OH.** <http://www.epa.gov/iris>, September 2005.
- Jamaludin, N., Sham, S. M. & Ismail, S. N. S. 2013 **Health risk assessment of nitrate exposure in well water of residents in intensive agriculture area.** *Am J. Appl. Sci.* **10** (5), 442–448.
- Jordao, C. P., Pereira, M. G., Bellato, C. R., Pereira, J. L. & Matos, A. T. 2002 **Assessment of water systems for contaminants from domestic and industrial sewages.** *Environ. Monitor. Assess.* **79**, 75–100.
- Karagüzel, R. & Irlayıcı, A. 1998 **Groundwater pollution in the Isparta Plain, Turkey.** *Environ. Geol.* **34** (4), 303–308.
- Karaman, M. E. 1999 **The basic geological properties of southern Isparta.** *Bull. Geol. Soc. Turkey* **33**, 57–67 (in Turkish).
- Karavoltos, S., Sakellari, A., Mihopoulos, N., Dassenakis, M. & Scoullou, M. J. 2008 **Evaluation of the quality of drinking water in regions of Greece.** *Desalination* **224**, 317–329.
- Kavcar, P., Sofuoglu, A. & Sofuoglu, S. 2009 **A health risk assessment for exposure to trace metals via drinking water ingestion pathway.** *Int. J. Hyg. Environ. Health* **212**, 216–227.
- Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z. & Zhu, Y. G. 2008 **Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing China.** *Environ. Pollut.* **152**, 686–692.
- Khan, S., Shahnaz, M., Jehan, N., Rehman, S., Shah, M. T. & Din, I. 2013 **Drinking water quality and human health risk in Charsadda district, Pakistan.** *J. Cleaner Prod.* **60**, 93–101.
- Kumar, M., Ramanathan, A. L. R. & Kumar, M. S. B. 2006 **Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India.** *Environ. Geol.* **50** (7), 1025–1039.

- Lamikanra, A. 1999 *Essential Microbiology for Students and Practitioners of Pharmacy, Medicine and Microbiology*, 2nd edn. Amkra Books, Lagos, pp. 406–410.
- Lim, H. S., Lee, J. S., Chon, H. T. & Sager, M. 2008 Heavy metal contamination and health risk assessment in the vicinity of the abandoned Songcheon Au–Ag mine in Korea. *J. Geochem. Exploration*. **96**, 223–230.
- Liu, C. W., Lin, K. H. & Kuo, Y. M. 2003 Application of factor analysis in the assessment of groundwaters quality in a blackfoot disease area in Taiwan. *Sci. Total Environ.* **313**, 77–89.
- Luke, J. A. 1994 Effect of fluoride on the physiology of the pineal gland. *Caries Res.* **28**, 204.
- Lyday, P. A. 2007 *2006 Minerals Yearbook: Bromine*. United States Geological Survey. <http://minerals.usgs.gov/minerals/pubs/commodity/bromine/myb1-2006-bromi.pdf> (accessed 3 September 2008).
- Mahler, B. J., Personne, J. C., Lods, G. F. & Drogue, C. 2000 Transport of free and particulate-associated bacteria in karst. *J. Hydro.* **238**, 179–193.
- Muhammad, S., Shah, M. T. & Khan, S. 2011 Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. *Microchem. J.* **98**, 334–343.
- Mullenix, P. J., Denbesten, P. K., Schunior, A. & Kernan, W. J. 1995 Neurotoxicity of sodium fluoride in rats. *Neurotoxicol Teratol.* **17** (2), 77–169.
- Nguyen, V. A., Bang, S., Viet, P. H. & Kim, K. W. 2009 Contamination of groundwater and risk assessment for arsenic exposure in Ha Nam province, Vietnam. *Environ. Int.* **35**, 466–472.
- NRC 1997 *Arsenic: Medical and biological effects of environmental pollutants*. Committee on Medical and Biological Effects of Environmental Pollutants, National Research Council.
- O'Rourke, M. K., van de Water, P. K., Jin, S., Rogan, S. P., Weiss, A. D., Gordon, S. M., Moschandreas, D. J. & Lebowitz, M. D. 1999 Evaluations of primary metals from NHEXAS Arizona: distributions and preliminary exposures. *J. Expo. Anal. Environ. Epidemiol.* **9**, 435–445.
- Patrick, D. R. 1994 Risk assessment and risk management. In: *Toxic Air Pollution Handbook* (D. R. Patrick, ed.). Van Nostrand Reinhold, New York, NY, p. 347.
- Piper, A. M. 1944 A graphic procedure in the chemical interpretation of water analysis. *Am Geophys Union Trans.* **25**, 914–923.
- Qaiyum, M. S., Shaharudin, M. S., Syazwan, A. I. & Muhaimin, A. 2011 Health risk assessment after exposure to aluminium in drinking water between two different villages. *J. Water Resource Prot.* **3**, 268–274.
- Rapant, S. & Krcmova, K. 2007 Health risk assessment maps for arsenic groundwaters content, application of national geochemical databases. *Environ. Geochem. Health* **29**, 131–141.
- Robertson, A. H. F. 1993 Mesozoic-Tertiary sedimentary and tectonic evolution of Neotethyan carbonate platforms, margins and small ocean basins in the Antalya Complex, southwest Turkey. *Spec. Publ. Int. Ass. Sediment.* **20**, 415–465.
- Ruikong, F. 1993 *Chinese Medical Geography*. Southeastern Chinese Normal University Press, Shanghai, pp. 102–108 (in Chinese).
- Sahinci, A. 1991 *Geochemistry of natural waters*. The Reform Printing Office, Izmir.
- Saldivar, A. & Soto, V. 2009 Arsenic: an abundant natural poison. ProQuest Discovery Guides. <http://www.csa.com/discoveryguides/arsenic> (accessed 6 January 2014).
- Seifert, B., Becker, K., Helm, D., Krause, C., Schulz, C. & Seifert, M. 2000 The German environmental survey 1990/1992 (GerES II): reference concentrations of selected environmental pollutants in blood, urine, hair, house dust, drinking water and indoor air. *J. Expo. Anal. Environ. Epidemiol.* **10**, 552–565.
- Şener, Ş. 2010 *Hydrogeochemical investigation of Egirdir Lake water and bottom sediments*, PhD thesis. Suleyman Demirel University, Isparta, Turkey (in Turkish).
- Shittu, O. B., Olaitan, J. O. & Amusa, T. S. 2008 Physico-chemical and bacteriological analyses of water used for drinking and swimming purposes in Abeokuta, Nigeria. *African J. Biomed. Res.* **11**, 285–290.
- Sidele, W. C., Roose, D. L. & Shanklin, D. R. 2000 Isotopic evidence for naturally occurring sulfate pollution of ponds in the Kankakee River Basin, Illinois-Indiana. *J. Environ. Qual.* **29** (5), 1594–1603.
- Singh, A. K., Mahato, M. K., Neogi, B., Tewary, B. K. & Sinha, A. 2012 Environmental geochemistry and quality assessment of mine water of Jharia coalfield, India. *Environ. Geol.* **65**, 49–65.
- Tamasi, G. & Cini, R. 2004 Heavy metals in drinking waters from Mount Amiata (Tuscany, Italy): possible risks from arsenic for public health in the province of Siena. *Sci. Total Environ.* **327**, 41–51.
- Tohyama, E. 1996 Relationship between fluoride concentration in drinking water and mortality rate from uterine cancer in Okinawa prefecture, Japan. *J. Epidemiol.* **6** (4), 184–191.
- TS 2004 Water quality: detection and enumeration of *Escherichia coli* and coliform bacteria Part-1 Membrane filtration method, ISO 9308–1, Turkish Standard 2004.
- TS 2005 Standards for drinking waters-266, Turkish Standards Institution, Ankara-Turkey.
- TUIK 2014 *Census results for Isparta Province*. Turkish Statistical Institute, Ankara (in Turkish).
- Ugbaja, A., Edet, A. & Offiong, O. 2012 Application of statistical methods in evaluating groundwater in parts of Mamfe Embayment, Southeastern Nigeria. *J. Geog. Geol.* **4** (3), 1.
- USEPA 1989 *Risk Assessment Guidance for Superfund. Vol. I. Human Health Evaluation Manual. Part A. Interim Final*. Office of Emergency and Remedial Response, US Environmental Protection Agency, Washington, DC.
- USEPA 1992 *Guidelines for Exposure Assessment*. EPA/600/ Z-92/001. US Environmental Protection Agency, Risk Assessment Forum, Washington, DC.
- USEPA 1999 *Guidance for Performing Aggregate Exposure and Risk Assessments*. US Environmental Protection Agency, Office of Pesticide Programs, Washington, DC.
- USEPA 2005 *Guidelines for Carcinogen Risk Assessment*. EPA/630/P-03/001F. US Environmental Protection Agency, Risk Assessment Forum, Washington, DC.
- USEPA 2013 Risk Assessment IRIS (Integrated Risk Information System). http://www.epa.gov/risk_assessment.

- Vahter, M. 2002 Mechanisms of arsenic biotransformation. *Toxicology* **181–182**, 211–217.
- Van Dijk-Looijaard, A. M. & Van Genderen, J. 2000 Levels of exposure from drinking water. *Food Chem. Toxicol.* **38**, S37–S42.
- Varol, S. & Davraz, A. 2015 Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey). *Environ. Earth Sci.* **73**, 1725–1744.
- Wayland, K., Long, D., Hyndman, D., Pijanowski, B., Woodhams, S. & Haack, K. 2003 Identifying relationships between baseflow geochemistry and land use with synoptic sampling and R-mode factor analysis. *J. Environ. Qual.* **32**, 180–190.
- WHO (World Health Organization) 1996 *Guidelines for Drinking Water Quality*, 2nd edn. World Health Organization, Geneva.
- WHO 2001 Water health and human rights, World Water Day. <http://www.worldwaterday.org/thematic/hmnrights.html#n4> (accessed 6 November 2015).
- WHO 2004a *Water Sanitation and Health Programme. Managing water in the home: accelerated health gains from improved water sources*. World Health Organization, Geneva. www.who.int.
- WHO 2004b *Water, sanitation and hygiene links to health*. World Health Organization, Geneva. http://www.who.int/water_sanitation_health/publications/facts2004/en/index.html (accessed 6 November 2015).
- WHO 2008 *Guidelines for drinking-water quality*. World Health Organization, Geneva, Switzerland.
- WHO 2009 Bromide in drinking-water. Background document for development of WHO *Guidelines for Drinking-water Quality*. World Health Organization, Geneva.
- WHO 2011 *Guidelines for Drinking-Water Quality*, 4th edn. World Health Organization, Geneva, Switzerland.
- Yalçınkaya, S. 1989 *Geology of Isparta – Aglasun (Burdur)*. PhD thesis, İstanbul University (in Turkish).
- Zeiger, E., Shelby, M. D. & Witt, K. L. 1993 Genetic toxicity of fluoride. *Environ. Mol. Mutagen.* **21** (4), 309–318.

First received 25 August 2015; accepted in revised form 1 November 2015. Available online 4 December 2015