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ORIGINAL PAPER

Hydrogeochemistry of the drinking water sources of Derebogazi Village (Kahramanmaras) and their effects on human health

Yusuf Uras · Yagmur Uysal · Tugba Atilan Arikan · Alican Kop · Mustafa Caliskan

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Abstract The aim of this study was to investigate the sources of drinking water for Derebogazi Village, Kahramanmaras Province, Turkey, in terms of hydrogeochemistry, isotope geochemistry, and medical geology. Water samples were obtained from seven different water sources in the area, all of which are located within quartzite units of Paleozoic age, and isotopic analyses of ^{18}O and ^{2}H (deuterium) were conducted on the samples. Samples were collected from the region for 1 year. Water quality of the samples was assessed in terms of various water quality parameters, such as temperature, pH, conductivity, alkalinity, trace element concentrations, anion–cation measurements, and metal concentrations, using ion chromatography, inductively coupled plasma (ICP) mass spectrometry, ICP-optical emission spectrometry techniques. Regional health surveys had revealed that the heights of local people are significantly below the average for the country. In terms of medical geology, the sampled drinking water from the seven sources was deficient in calcium and magnesium ions, which promote bone development. Bone mineral density screening tests were conducted on ten females using dual energy X-ray absorptiometry to investigate possible developmental disorder(s) and potential for mineral loss in the region. Of these ten women, three had T-scores close to the osteoporosis range (T-score < -2.5).

Keywords Hydrogeology · Hydrogeochemistry · Isotope geochemistry · Drinking water · Medical geology

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Introduction

Water is one of the primary necessities for sustainability of human life, and groundwater sources are often the source of water for public consumption due to the good quality of water in these sources. For this reason, groundwater have always been utilized as drinking water sources throughout history in almost all parts of the world. Groundwater is generally described as the subsurface water that is found beneath the water table in soils or saturated geological formations (Freeze and Cherry 2003). At the present time, more than half of the world's population depends on groundwater to sustain their lives, and groundwater is also the primary source for household, industrial, and agricultural activities (Delgado et al. 2010). During the hydrologic cycle, groundwater does not remain as pure H_2O, rather it incorporates the materials that flow through it. The types and quantities of materials taken up by H_2O are controlled by many different factors, and the properties of groundwater may change depending on climate conditions and water supply. In addition, determination of the environmental isotopic concentrations of groundwater can be used to solve numerous hydrogeological problems (Clark and Fritz 1997), such as the origin and age of the groundwater and the area of recharge, as well as to determine the rock–groundwater relationship. In this study, we have analyzed the drinking water sources of Derebogazi Village in terms of water quality parameters and investigated the potential health effects of these water quality parameters on the general health of the local population from a medical geology perspective. To this end, we conducted general geological, hydrogeological, isotope geological, water chemistry, and medical geological studies of the area where the drinking water resources of Derebogazi Village, about 31 km southwest of Kahramanmaras City center, are located. Using the study results, we evaluated the application of environmental isotope and geochemical methodologies to find answers to the following hydrogeological questions: (1) What is the origin and mechanisms of groundwater recharge? (2) What is the relationship between shallow and deep aquifer systems? (3) What is the apparent groundwater age?

Materials and methods

Study areas and sampling locations

Water samples were collected in different months over a period of 1 year with the aim to evaluate the geological and water quality aspects of the drinking water sources of Derebogazi Village. Various water parameters, such as pH, dissolved oxygen (DO), electrical conductivity (EC), and temperature, were determined in situ during sampling. Thereafter, the samples were brought to the laboratory and stored in a refrigerator at +4 °C for further analyses. A total of 38 water samples, including rain and snow samples, were collected from seven different drinking water sources over a 1-year period. Heavy metal and anion–cation analyses of these samples were conducted at the ACME Analytical Laboratories (Vancouver, BC, Canada) using ion chromatography (IC), inductively coupled plasma mass spectrometry (ICP-MS) , ICP-optical emission spectrometry (ICP-OES) techniques. Oxygen-18 (^{18}O), deuterium (^{2}H), and tritium (^{3}H) isotopic analyses were carried out in the isotope laboratories of the Technical Research and Quality Control Department (TAKK) of the General Directorate of State Hydraulic Works in Ankara, Turkey. The bone mineral density (BMD) of ten local women was measured at the Medical Faculty of Kahramanmaras Sutcu Imam University using dual energy X-ray absorptiometry (DEXA) to investigate the effects of water quality on local people from a medical geology perspective. Following the analyses on the drinking water sources of Derebogazi Village, the water samples were classified initially, and the analytical results were compared against each other to establish a correlation between the samples and with other factors. The main aim of this chemical classification was to determine the origin of the waters, compare the dominant and total dissolved ion concentrations, and assess whether the water from the difference sources is suitable for human health. We therefore attempted to assess the anion–cation and heavy metal composition of the groundwater samples and rationalize the anomalies in the measured parameters. One of the major factors that affect the quality of water resources for Derebogazi Village is the lithological properties of the rock units through which these waters flow. Therefore, it is important to establish the hydrogeochemical characteristics of the water sources and to identify the lithological units that are in contact with these water sources.

In terms of plate tectonics of study area, the Ordovician Tut (Ot, Otki, Otko) and Devonian Berke (Sb) formations and the Yavuzeli Basalt (Tmy) lie within the Southeast Anatolian Autochthon, whereas the Triassic–Early Cretaceous Andırın Limestone is a part of the Orogenic Belt. Among these, the former units contained by the Southeast Anatolian Autochthon overlie the Andırın Limestone of the Orogenic Belt (Ates et al. 2008; Fig. 1).

The oldest unit in the study area is the Tut Formation, comprising the lowermost part of the Southeast Anatolian Autochthon. The Tut Formation, which was first named by Ketin (1966), consists of lithological units such as dolomite–dolomitic limestone, clayey limestone, shale–sandstone, quartzite,

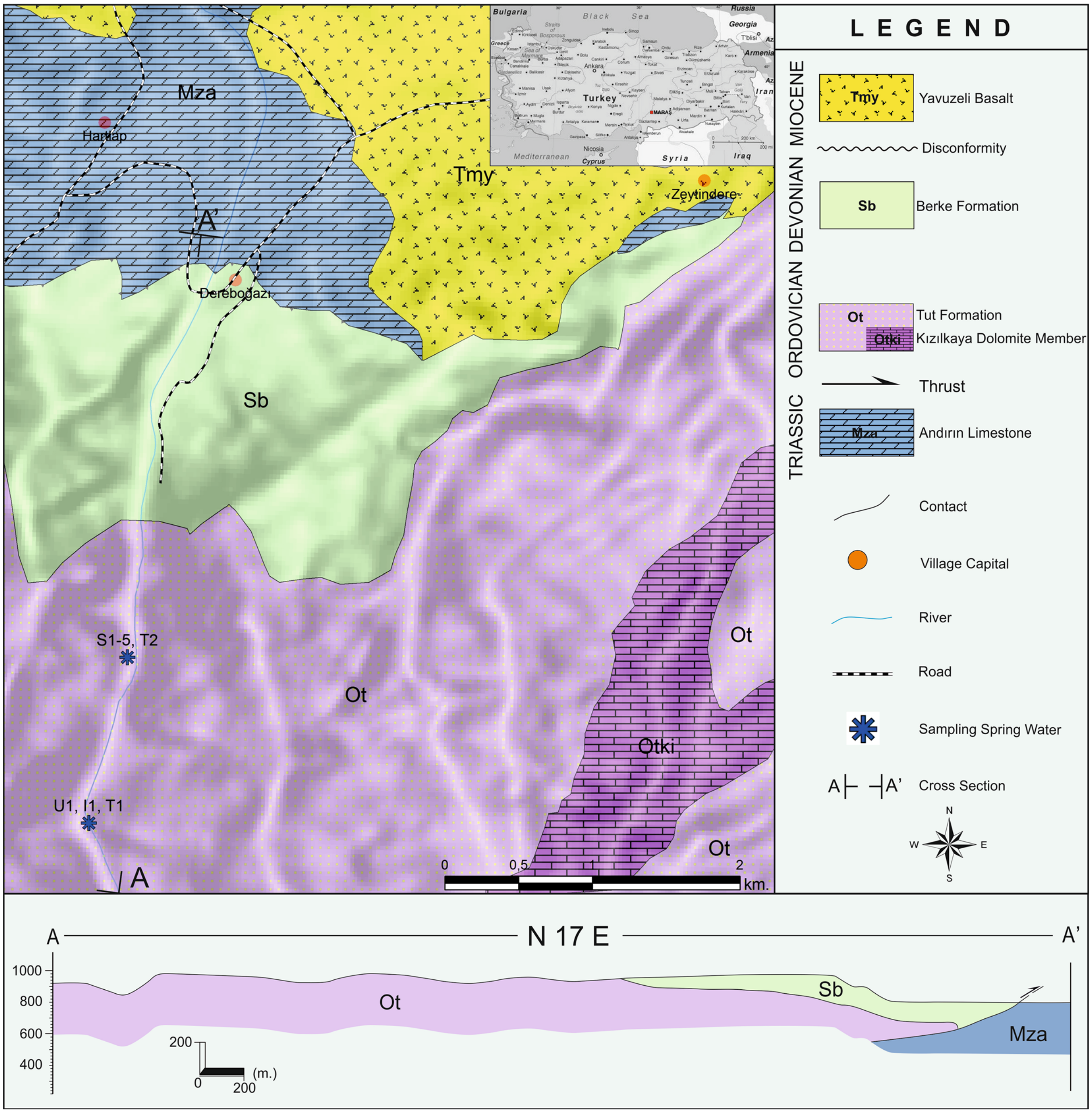


Fig. 1 Geological map, location map (*inset*) and cross-section of Derebogazı Village area and the surrounding area (Ates et al. 2008). *Ot* Ordovician Tut formation, *Sb* Devonian Berke formation, *Tmy* Yavuzeli Basalt

and quartzitic pebblestone. The Kızılkaya Dolomite Member (Otki) of the Late Ordovician Tut Formation mainly consists of dolomite–dolomitic limestone and interbedded claystone levels (Lahner 1972; Dean and Monod 1985; Kop et al. 2002). The upper part of the Tut formation, called Kocabogan Member (Otko), is also described as consisting of alternating claystone, siltstone, quartzitic sandstone, and pebblestone layers (Ketin 1966). The lower part of the Kızılkaya Dolomite Member starts with gray/black-colored cherty dolomites and dolomitic limestones which are mostly thick and locally massively bedded, competent, intact, highly fractured, calcite and quartz infilled locally. These units are overlain by pink-purple, medium-bedded clayey limestones, which themselves are overlain by yellow, medium-bedded, locally claystone interbedded dolomites, dolomitic limestones, and clayey limestones. The Kocabogan Member represents the uppermost levels of the Tut Formation, and it starts with green/dark-gray/gray-colored, thinly to moderately bedded intercalations of clayey limestone, claystone, shale, sandstone, and quartzitic sandstones. Lithology including quartzitic sandstones and conglomeratic quartzites appears towards the top levels of the Kocabogan Member (Fig. 2). The drinking water sources of Derebogazi Village studied in this paper are located within the sandstone–quartzitic sandstone

Fig. 2 The general view of the quartzites associated with the Tut Formation

units of the Kocabogan Member (Fig. 3). The Berke Formation conformably overlies the Tut Formation in the study area. This unit, best exposures of which can be observed between Hartlap and Berke Villages (Kahramanmaras), comprises yellowish- to light-green-colored intercalations of thinly-bedded shale and phyllite. Baydar and Yergök (1996) assigned a Silurian age to the Berke Formation through stratigraphic correlation, as it conformably sits atop the Ordovician Tut Formation. The youngest unit identified within the Southeast Anatolian Autochthon is the Late Miocene Yavuzeli Basalt (Yoldemir 1987a), which is reddish/dark-brown/blackish–dark gray in color, brecciated, locally tuffaceous, and often vesicular with vesicles infilled by calcite. The lavas, usually comprising olivine basalt and amygdaloidal olivine basalt, are exposed along fracture zones associated with fault systems.

Radiometric dating by Baydar and Yergök (1996) indicated an age of 12.1 ± 0.4 Ma (Middle Miocene). In the study area, the Orogenic Belt is represented by Triassic–Lower Cretaceous Andırın Limestone (Ayaslıoğlu 1970; Kozlu 1987; Perincek and Kozlu 1984), which appears to have a steep morphology. The Andırın Limestone is gray/dark-gray and white-colored, thinly to medium-bedded, and highly competent, and it contains abundant dissolution pits and cracks. Its upper sections contain intercalations of cherty or reefal

Fig. 3 Photographs showing the water sources of Derebogazı Village. **a** Sites I1, U1, and T1, **b** Sites S1, S2, S3, S4, S5, and T2

limestones and are partly recrystallized. This unit locally contains abundant fossil shells and is highly fractured and jointed with fractures often infilled by calcite. The lithological units of the Southeast Anatolian Autochthon tectonically overlie the outcrops of the Andırın Limestone in the study area.

Hydrogeology

The Kahramanmaras Province lies in an area where three different geographic regions of Turkey (Mediterranean, Eastern Anatolia, and Southeastern Anatolia regions) come closest together; this results in three different climatic conditions in this area. Due to increased elevation, the northern parts of Kahramanmaras Province are considered to have a continental climate, whereas the southern parts of the province experience climatic conditions that are more similar to the "Degenerate Mediterranean Climate". As a result, in the study area the summer periods are hot and dry, whereas winter periods are wet and mild. Long-term (1970–2012) monthly total precipitation records [DMI (Turkish State Meteorological Service) 2014] indicate that the average precipitation levels in the study area during January–May and October–December of the study period exceeded 40 mm, whereas during the months of June–September the average amount of precipitation did not exceed 10 mm (Fig. 4). Therefore, it would appear that the region regularly receives precipitation throughout the winter, spring, and fall seasons, whereas the summer season remains dry.

According to the long-term (1970–2012) monthly maximum precipitation data (DMI 2014), the study area received high amounts (>100 mm) of precipitation during the months of December, January, and February of the study period, whereas during the June–September period of the study the precipitation levels fell to <10 mm. On the other hand, based on the long-term (1970–2012) monthly maximum snow cover depth data (DMI 2014), the study area seems to have remained under snow cover during December–March periods, with the thickest snow cover reached during February months (Fig. 5). Due to the mild and wet climate conditions mentioned above, the study area is rich in surface waters.

The Tut Formation is widely exposed in the study area and has undergone extensive tectonic deformation, resulting in its highly fractured and jointed nature. This has led to a high permeability of the rock units, allowing surface waters to infiltrate into the underground aquifers within which these waters can be stored. Derebogazi Village, around which the current study was conducted, draws its name from Derebogazi Stream, which runs through the village itself. The water sources of Derebogazi Village are named Softalar (S1, S2, S3, S4, and S5), Imirballi (I1), and Uzunoluk (U1). Water from the Imirballi (I1) and Uzunoluk (U1) sources are first collected in reservoir T1 (elevation 1,015 m a.s.l.) and

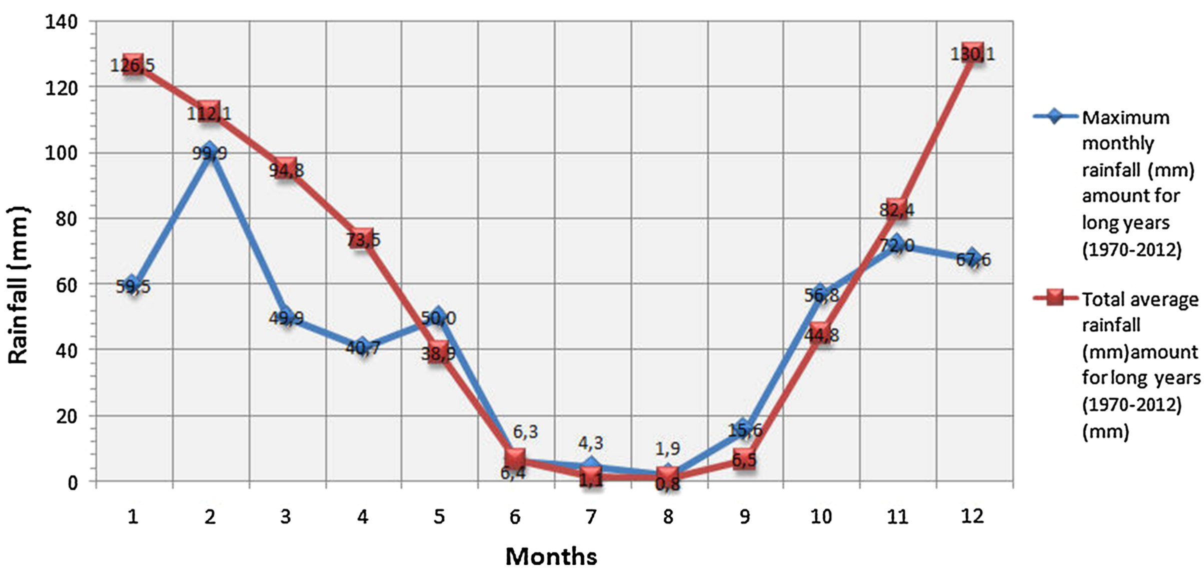


Fig. 4 Graph showing the variations in the average long-term monthly maximum precipitation and total monthly total precipitation values for the Kahramanmaraş area, including Derebogazı Village (DMİ 2014)

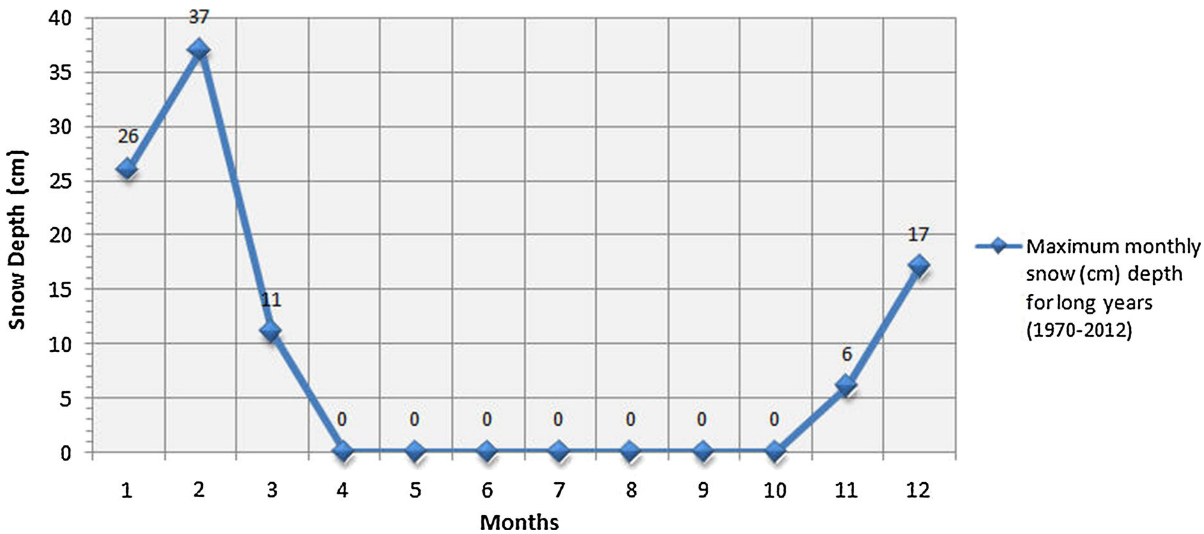


Fig. 5 Graph showing the variation in the average long-term monthly maximum snow cover depth for the Kahramanmaras area, including Derebogazı Village (DMİ 2014)

then drained through a pipe into reservoir T2 (elevation 913 m a.s.l.) into which the remaining water sources (Softalar water sources) are also collected (T1 + S1 + S2 + S3 + S4 + S5) (Fig. 3). The drinking water supply of Derebogazi Village is obtained from this composite source (T2). The rain (Y1) and snow (S1) water samples collected over our 1-year study period were also analyzed to determine the effects of precipitation on the quality of the regional groundwater. The water sources of Derebogazi Village are formed within the quartzite units of the Ordovician Tut Formation. Morphologically, the quartzite unit forms sharp peaks and steep rocky areas, especially to the south of Derebogazi Village; due to the high permeability of this unit, the latter is thought to have a significant impact on the aquifer quality.

Results

Hydrogeochemistry

Measurements on temperature, pH, EC, alkalinity, trace element concentrations, anion–cation composition, and metal concentration were carried out to determine the quality of the drinking water sources of Derebogazi Village (Table 1). The drinking water sources in the Derebogazi area have been classified as cold waters as their temperatures vary between 10 and 14 °C annually. DO values of all water sources were similar, but the Na^+ concentrations ranged between 1.71 and 4.41 ppm which is much lower than the permissible limit (200 mg/L; WHO 1985). These low Na^+ concentrations were interpreted to reflect the low salinities of the water sources themselves. The significantly low EC (29–79 µs/cm) of the water samples further support the interpretation that the water sources have very low ion concentrations and salinities. The water sources of Derebogazi Village are classified as "very well" based on the Wilcox diagram (Fig. 6), whereas on the U.S. Salinity Laboratory diagram they plot within the C1–S1 field (Fig. 7).

The hydrogeochemical facies of the waters in the region were determined on the basis of the results of the chemical analyses. Samples collected from sources S1, S2, S3, S4, S5, I1, U1, T1, and T2, as well as the rain and snow water samples were been classified as mixed waters with total dissolved ion concentrations of >0.5 g equiv/liter, based on the Piper diagram (Piper 1944) (Fig. 8).

The results of the anion–cation analyses compiled for the drinking water sources of Derebogazi Village are shown in Table 2 using a Schoeller diagram (Schoeller 1962) (Fig. 9). The order of cation concentrations for the sources I1, S3, S5, and T2 was $Na^+ + K^+ > Mg^{2+} > Ca^{2+}$, while that of the other sources is $Na^+ + K^+ > Ca^{2+} > Mg^{2+}$. In

Table 1 Geochemistry of the drinking water sources of Derebogazı Village (July 2012)

Geochemical parameters	Water sources[a]										
	S1	S2	S3	S4	S5	T1	T2	U1	I1	Y1	K1
Temperature (°C)	13	10	12	11	10	12	14	12	13	–	–
pH	7.02	7.03	7.01	7.08	7.21	7.32	7.21	7.14	7.10	5.89	6.32
EC (μS/cm)	56	75	67	79	75	35	68	29	46	15	30
DO (%)	41.6	46.3	47	43.2	41.3	44.2	43.4	42.6	45.4	–	–
Na^+ (ppm)	3.04	2.79	4.41	2.70	2.82	2.27	3.61	2.63	1.71	2.51	0.48
K^+ (ppm)	0.62	0.75	1.03	0.70	0.75	0.79	0.72	0.78	0.68	083	0.29
Ca^{+2} (ppm)	1.82	1.95	1.76	1.69	1.25	0.59	0.84	0.78	1.23	0.28	0.60
Mg^{+2} (ppm)	2.31	2.26	2.80	2.06	2.86	2.34	2.53	1.90	2.28	0.91	0.18
Cl^- (ppm)	3.00	4.00	1.00	2.00	2.00	1.00	7.00	2.00	2.00	1.00	1.00
HCO_3^- (ppm)	6.21	4.51	3.25	2.46	3.22	3.21	3.46	4.35	2.34	5.69	4.32
CO_3^{-2} (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO_4^{-2} (ppm)	5.00	4.00	3.50	4.50	5.60	4.60	4.80	5.40	5.20	3.70	2.10
Fe^{+2} (ppm)	0.065	0.039	0.171	0.033	0.134	0.089	0.143	0.081	0.027	0.249	0.044
Cu^{+2} (ppm)	0.0044	0.0013	0.0051	0.0007	0.0061	0.0052	0.0101	0.0012	0.0007	0.0295	0.0020
Al^{+3} (ppm)	0.060	0.020	0.145	0.030	0.115	0.047	0.097	0.032	0.018	0.166	0.037
Mn^{+2} (ppm)	0.039	0.002	0.078	0.004	0.090	0.023	0.023	0.004	0.002	0.040	0.003
NO_3^-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B	5.00	7.00	8.00	4.00	5.00	3.00	9.00	2.00	3.00	1.00	6.00

EC Electrical conductivity, DO dissolved oxygen

[a] I1, Imirballi source, U1, Uzunoluk source; T1, water from I1 and U1 are initially collected and held in reservoir T1); S1, S2, S3, S4, S5 Softalar water sources; T2, water from the T1 reservoir are drained into the T2 reservoir holding water from the S1, S2, S3, S4, and S5 sources; Y1, water from rain samples; S1 water from snow samples

comparison, the order of anion concentrations for all samples was $HCO_3^- > SO_4^{-2} > Cl^-$. According to the Schoeller diagram, the drinking water sources of Derebogazi Village can be classified as "normal chloride waters" based on their chlorine concentration; as "normal sulfate waters" based on their sulfate concentration; as "hypocarbonate waters" based on their carbonate–bicarbonate concentration (Fig. 9).

Interpretations regarding ionic concentrations (in mg/L) of the Derebogazi water sources were made using pie diagrams (Fig. 10). In the pie diagrams cations were placed in the northern hemisphere, the anions were placed in the southern hemisphere; the radii of the diagrams show the amount of total ionization in the water. The sum of cation and anion concentrations is equal to 100 % meq/L or 180°. The center of the diagram indicates total mineralization in milligrams per liter. The analyses did not show significant variations between water samples collected during different months, leading to the assumption that the water sources were recharged from the same aquifer.

Environmental isotopes in springs

Environmental isotope studies were carried out to determine the aquifer source, recharge area, and the duration of water–rock interaction of the drinking water sources of Derebogazi Village. In these studies, tritium (^3H) radioisotopes and stable isotopes of ^{18}O and deuterium (^2H) were used. Recharge elevation estimates were calculated using $\delta^{18}O$ and δ^2H values (Table 3), and variations between these values were compared to the Global Meteoric Water Line (GMWL; Craig 1961) and the Mediterranean Water Line (MWL). The values of $\delta^{18}O$ and δ^2H in the drinking water sources of Derebogazi Village ranged between −8.44 and −9.01 ‰ and between −45.75 and −53.24 ‰, respectively (Table 3).

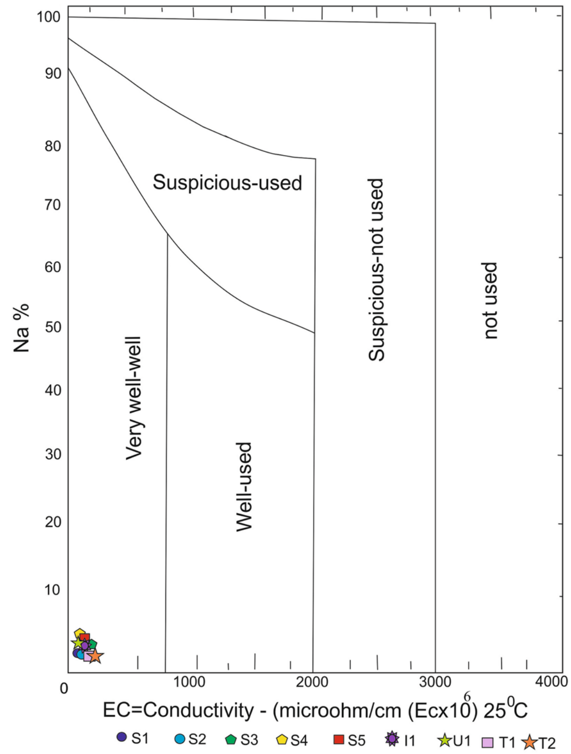


Fig. 6 The Wilcox diagram of Derebogazı Village drinking water sources. See Fig. 1 and footnote to Table 1 for explanations of the sampling sites/waters

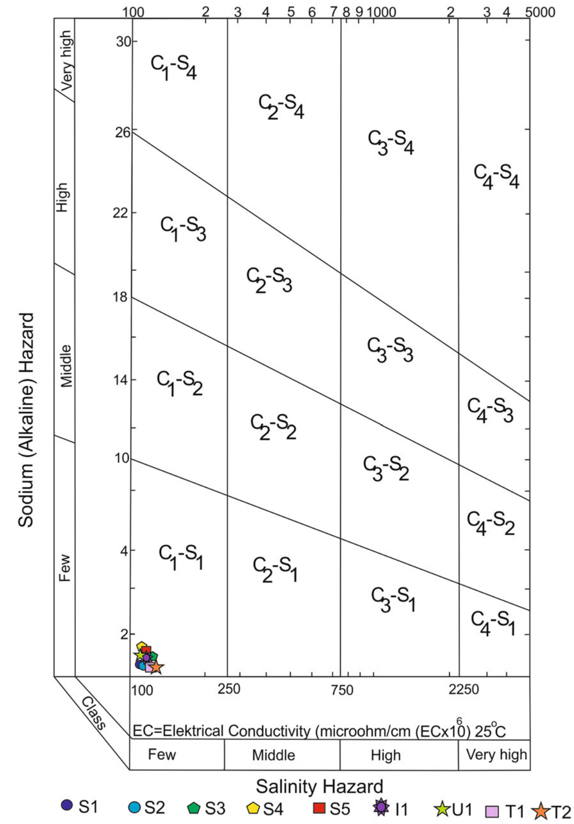


Fig. 7 The U.S. Salinity Laboratory diagram of the drinking water sources of Derebogazı Village. See Fig. 1 and footnote to Table 1 for explanations of the sampling sites/waters

The results show that the data corresponding to the recharge elevation estimates of Derebogazi Village drinking water sources plot on both the GMWL and the MWL, indicating that the aquifers recharging the water sources are fed by meteoric water, i.e., from surface precipitation (rain and snow) without evaporation taking place (Fig. 11a). This leads to the conclusion that the groundwater recharging the drinking water sources of Derebogazi Village forms through the infiltration of surface runoff from precipitation along fracture zones and fault surfaces and is stored at depth until ascending to the surface again along these fault surfaces and fracture zones. The excess values of deuterium were calculated from the $\delta^{18}O$ and $\delta^{2}H$ values of the water sources using the formula $d = \delta^{2}H - 8 \times \delta^{18}O$ (Dansgaard 1964). The high deuterium excess values thus obtained are indicative of a dominantly marine precipitation, whereas continental precipitation predominates on the points with low deuterium excess (Kehinde 1993). Table 2 shows that the d_f values for the water sources of Derebogazi Village waters range between 18.65 and 23.85, with S1 having the minimum d_f value of 18.65 and S5 having the maximum d_f value of 23.85. Based on the deuterium excess values, therefore, the water sources of Derebogazi Village can be regarded as continental falls. Since oxygen and hydrogen are the two elements that form water molecules, isotopes of ^{18}O, $\delta^{2}H$, and ^{3}H can be utilized to trace water transport during different stages of the hydrologic cycle (Pasvanoglu and Gültekin 2007), with ^{3}H concentrations used to constrain the relative ages and transit times of water sources. According to the ^{18}O–^{3}H diagram, the Derebogazi spring waters were recharged by low elevation waters of a similar age and with a short transit time (Fig. 11b). The ^{3}H values in the water sources of Derebogazi Village were evaluated in terms of residence time of the groundwater within the aquifer. These water sources were found to have ^{3}H values of between 3.65 and 4.65. Both the

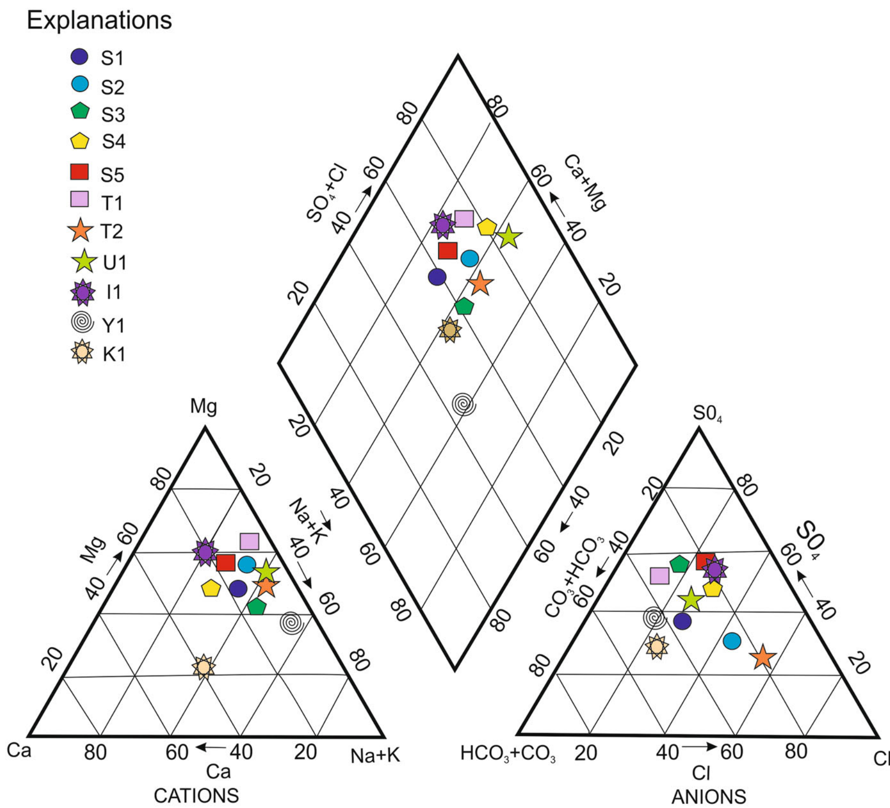


Fig. 8 Piper diagram of the drinking water sources of Derebogazı Village. See Fig. 1 and footnote to Table 1 for explanations of the sampling sites/waters

high ^{3}H values contents of the drinking water sources together with their low EC values indicate shorter residence times in the aquifer, since longer flow times result in higher radioactive decay of tritium.

Tritium is a radioactive isotope of hydrogen with a significantly short half-life of 12.43 years (Clark and Fritz 1997). It can be produced by cosmic radiation, either naturally or artificially, and enters the hydrologic system through precipitation; as a radioactive isotope of hydrogen, it can be used to trace the transit time of groundwater (Karakuş et al. 2005). Tritium-bearing waters are defined as young waters with transit times of 5–10 years (Clark and Fritz 1997). According to the Cl^{-}–^{3}H graph, the water sources of Derebogazi Village have high ^{3}H and low Cl^{-} contents, and their aquifers are recharged by young groundwater with short transit times (Fig. 11c). However, the relationship between deuterium and tritium implies that the circulation time for water source S4 is slightly longer than that of the other water resources (Fig. 11d). High ^{3}H concentrations and low EC values imply short periods of water–rock interactions for the regional groundwater and insignificant levels of water–rock interactions, and they are indicative of residence times of <50 years (Carreira et al. 2013) (Fig. 11e).

Effects of water sources on human health

Osteoporosis is a systematic disease characterized by low bone mass and microstructural deterioration of bone tissue leading to increased bone fragility and susceptibility to fracture. This disease is observed in one of every two women aged ≥50 years (Irani et al. 2013; Lee et al. 2013). Calcium (Ca) and magnesium (Mg) are vital elements for bone development and the Ca to Mg ratio of the foods should not exceed 2:1 in order for them to be beneficial to human body (Rude 1996). The classification shown in Table 4 is based on the BMD or the bone mineral content, as well as on the presence of bone fractures (Miller 2006).

Table 2 The anion–cation values for the drinking waters of Derebogazi Village

Sample site/number[a]	Cation concentration	Anion concentration
I1	$Na^{+} + K^{+} > Mg^{2+} > Ca^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
U1	$Na^{+} + K^{+} > Ca^{2+} > Mg^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
T1	$Na^{+} + K^{+} > Ca^{2+} > Mg^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
S1	$Na^{+} + K^{+} > Ca^{2+} > Mg^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
S2	$Na^{+} + K^{+} > Ca^{2+} > Mg^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
S3	$Na^{+} + K^{+} > Mg^{2+} > Ca^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
S4	$Na^{+} + K^{+} > Ca^{2+} > Mg^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
S5	$Na^{+} + K^{+} > Mg^{2+} > Ca^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$
T2	$Na^{+} + K^{+} > Mg^{2+} > Ca^{2+}$	$HCO_3^{-} > SO_4^{-2} > Cl^{-}$

[a] See footnote to Table 1 for explanations of the sampling sites/waters

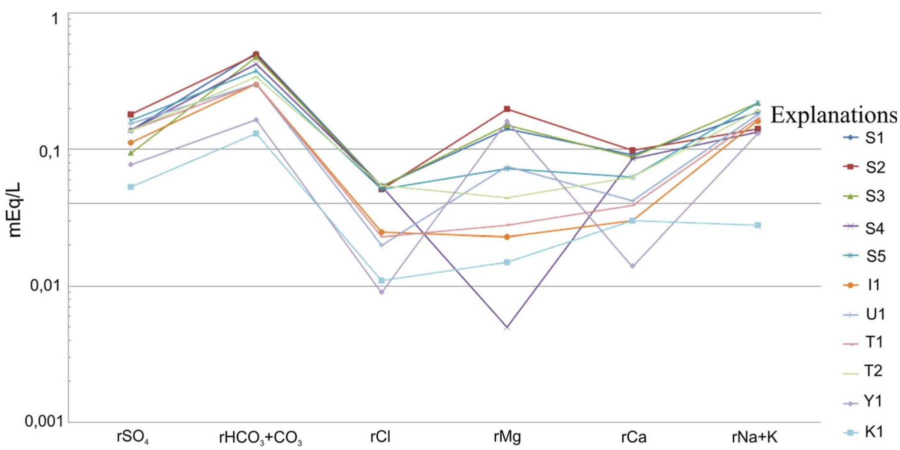


Fig. 9 Schoeller diagram for drinking water samples from the Derebogazı Village. See Fig. 1 and footnote to Table 1 for explanations of the sampling sites/waters

The Ca and Mg deficiency of the Derebogazi Village drinking waters with respect to the standard values poses a potential risk of osteoporosis (Table 5). We performed BMD measurements on ten young pre-menopausal women (age range 28–43 years) using dual energy X-ray absorptiometry (DEXA). T-scores are close to the osteoporosis range were observed in three women.

The absence of bone mineral loss in the other seven tested using DEXA is interpreted to be a result of their consumption of green leafy vegetables and dairy products, which are rich in Ca- and Mg-bearing minerals. According to the Turkish Statistical Institute (TUIK) figures (Kanis 2002), the average height for Turkish males and females is 172.6 and 161.4 cm, respectively. Based on the 2012 population census, Derebogazi Village has a population of 1,809, of which 878 are men and 931 are women. In this study, height measurements were conducted on a total of 40 local persons of both sexes. The results obtained were significantly below the country averages (Fig. 12).

From the medical geology point of view, these results may be related to the low Ca and Mg contents of the regional drinking waters. We suggest that the drinking water needs of the inhabitants of Derebogazi Village are met by water sources which are deficient in both of these elements, possibly having adverse effects on the bone development of local people, as indicated by average heights below the country average.

Discussion

Results of the chemical analyses of the drinking water samples collected for a period of 1 year and during all four seasons indicated that the drinking water used by the inhabitants of Derebogazi Village was derived from similar sources and from identical aquifer

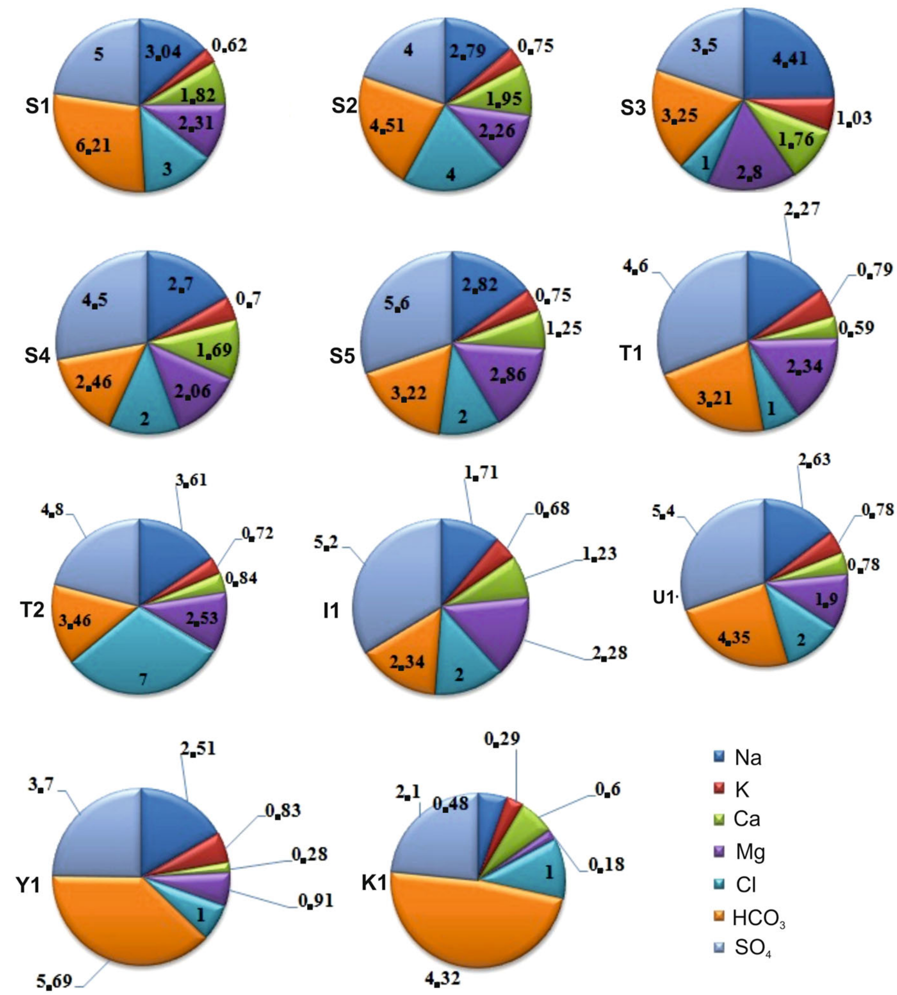


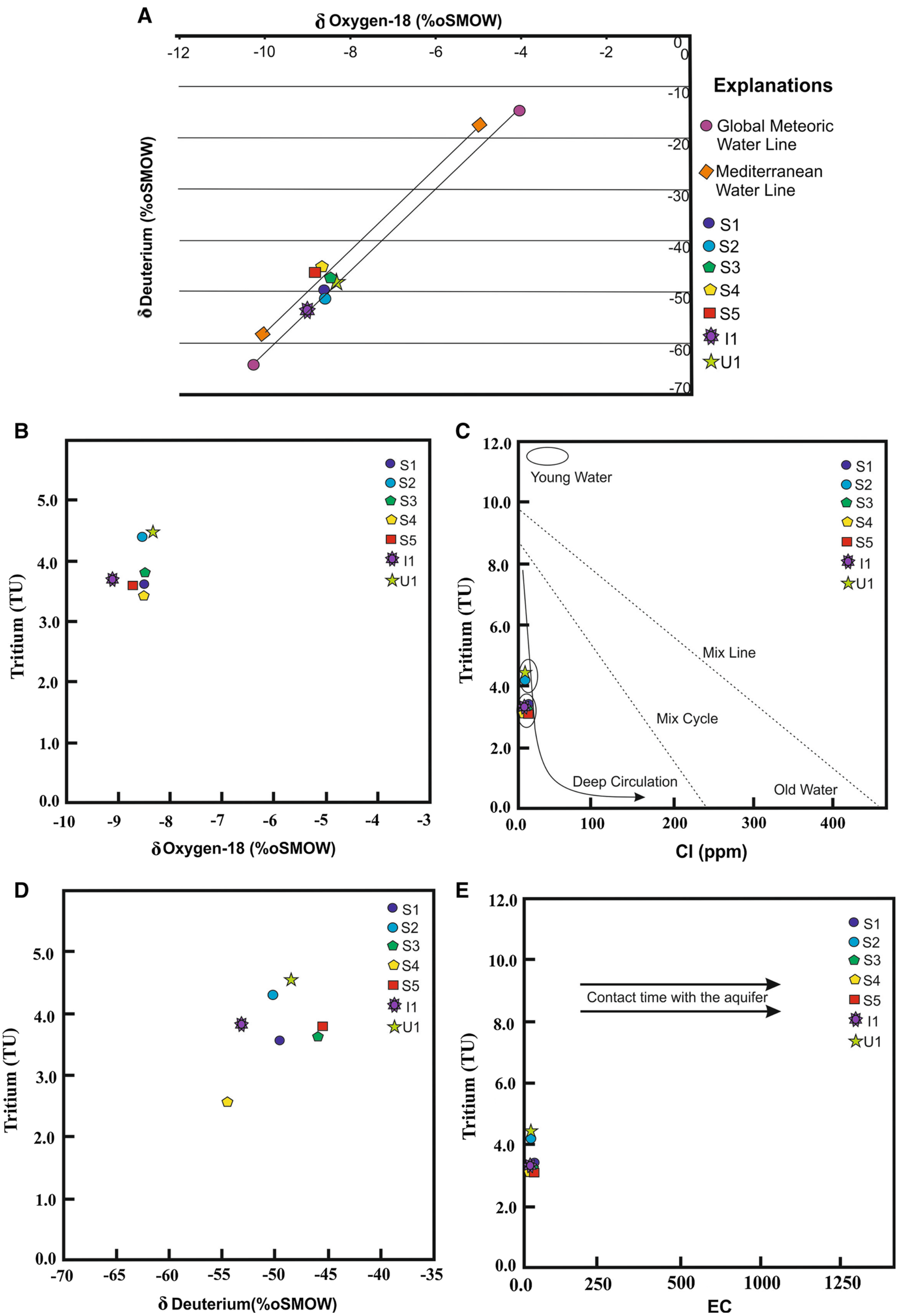
Fig. 10 Pie diagrams of the water sources of Derebogazı Village. See Fig. 1 and footnote to Table 1 for explanations of the sampling sites/waters

Table 3 Results of the oxygen-18, deuterium, and tritium analyses

Drinking water sources of Derebogazı Village[a]	Date	Oxygen-18 ($\delta^{18}O$) (‰)	Deuterium ($\delta^{2}H$) (‰)	Excess value (*d*) (‰)	Tritium (^{3}H)
S1	18.06.2013	−8.54	−49.65	18.65	3.76
S2	18.06.2013	−8.80	−50.58	19.82	4.32
S3	18.06.2013	−8.52	−47.02	21.14	3.80
S4	18.06.2013	−8.62	−46.08	22.88	3.65
S5	18.06.2013	−8.70	−45.75	23.85	3.78
U1	18.06.2013	−8.44	−48.06	19.46	4.61
I1	18.06.2013	−9.01	−53.24	19.84	3.87

[a] See footnote to Table 1 for explanations of the sampling sites/waters

lithologies, based on interpretations from using a Schoeller diagram. In the same diagram these waters fall into the class of "normal chlorine waters" based on their chlorine concentrations, "normal sulfate waters" based on their sulfate concentrations, and "hypocarbonate waters" based on their carbonate + bicarbonate concentrations. On a Piper diagram, these waters plot on the ninth region and they


A
δ Oxygen-18 (%oSMOW)
δ Deuterium (%oSMOW)
Explanations
Global Meteoric Water Line
Mediterranean Water Line
S1
S2
S3
S4
S5
I1
U1
B
Tritium (TU)
δ Oxygen-18 (%oSMOW)
C
Young Water
Mix Line
Mix Cycle
Deep Circulation
Old Water
Tritium (TU)
Cl (ppm)
D
Tritium (TU)
δ Deuterium(%oSMOW)
E
Contact time with the aquifer
Tritium (TU)
EC

◀ **Fig. 11** **a** The relationship between the drinking water sources of Derebogazı Village and the Global Meteoric Water Line, the Mediterranean Water Line, and oxygen-18 ($\delta^{18}O$), (% SMOW = Standard Mean Ocean Water) **b** ^{18}O-tritium (^{3}H; *TU*) relationship of Derebogazı Village water sources, **c** Cl-TU relationship of Derebogazı Village water sources, **d** deuterium ($\delta^{2}H$)–TU relationship of Derebogazı Village water sources, **e** The electric conductivity (*EC*; µS/cm)–TU relationship of the Derebogazı Village water sources

Table 4 Bone mineral density (T-score)[a]

Description	Bone mineral density (T-score)
Normal	Above −1 SD in a young adult
Osteopenia	Between −1 and −2.5 SD
Osteoporosis	−2.5 SD or lower
Established osteoporosis	Less than −2.5 SD, with one or more osteoporotic fractures

SD, Standard deviation

[a] According to Miller (2006)

Table 5 Risk factors[a]

Risk factor categories	Risk factors
Structural and genetic factors	Aging, low bone mass, female sex, race (Caucasian), hereditary (mother) osteoporosis, premature menopause, small stature
Life style and/or nutrition	Inactive and sedentary life, low dietary calcium and vitamin D intake, alcohol usage, smoking
Medical situations	Medication (e.g., cortisone, methotrexate), immobilization, amenorrhea
Falls risk, and personal and environmental risk factors	Loss of balance and gait disturbance, sedative usage, decreased muscle strength, cognitive disorders

[a] According to Kanis (2002)

are classified as mixed waters with total dissolved ion concentrations not exceeding 50 %. Also, they are classified as "very good" according to the Wilcox diagram and as C1–S1 waters based on the U.S. Salinity Laboratory diagram.

Properties of drinking waters vary between countries depending on the climate conditions and water potential. According to Table 1 of the Water Pollution Control Regulations (Skky 2004) included in the Continental Water Sources Quality Classification Criteria of the Republic of Turkey Ministry of Environment and Forest, the drinking water sources of Derebogazi Village are classified as Class I waters. In contrast, according to the World Health Organization (WHO) standards these waters are regarded as drinkable waters. In a previous study on water samples collected from one water source (T2) from Derebogazi Village, Abacı (2000) indicated that these waters are of good quality based on their Na^{+}, Cl^{-}, SO_4^{2+}, and EC values when plotted on a drinkable water diagram of Schoeller. Similar results were also reported by Abacı (2000) for water samples collected from the same water source (T2). In the present study, analyses conducted on samples collected from seven different water sources revealed slightly lower concentrations for the parameters investigated. However, our results, when interpreted together with the data reported by Cakar (1996), indicate that the drinking water sources of Derebogazi Village can be classified as Class 1 drinking water in terms of the water quality parameters based on the drinkable water diagram of Schoeller.

The Ca^{2+} (1.82–0.28 ppm) and Mg^{2+} (0.18–2.86 ppm) values recorded for the water sources of Derebogazi Village during the summer period are much lower than the permissible limits of WHO which are in the range of 75–200 ppm for Ca^{+2} and 50–150 ppm for Mg^{+2} (WHO 2011). In general, the waters in the Kahramanmaras area have a high content of lime and are therefore "hard" (190–200 mg $CaCO_3$/L), but the drinking water sources of Derebogazi Village have been classified as "very soft" as their hardness values average around 20 mg $CaCO_3$/L annually. The soft nature (2 FS°) of the drinking water sources of Derebogazi Village compared to the generally hard character of the groundwater in Kahramanmaras area is of great significance.

The drinking water resources of Derebogazi Village are located within the sandstone–quartzitic sandstone lithologies of the Kocabogan Member of the Tut Formation. These lithologies are highly fractured and broken in nature and therefore provide a permeable zone through which rain waters infiltrate, forming the aquifers of the water sources. The lower EC and water hardness values of the water sources can be explained by a natural filtration process following interaction with sandstone–quartzitic sandstone lithologies.

According to the ^{18}O–^{2}H diagram, the aquifers of Derebogazi Village supplying the drinking water are

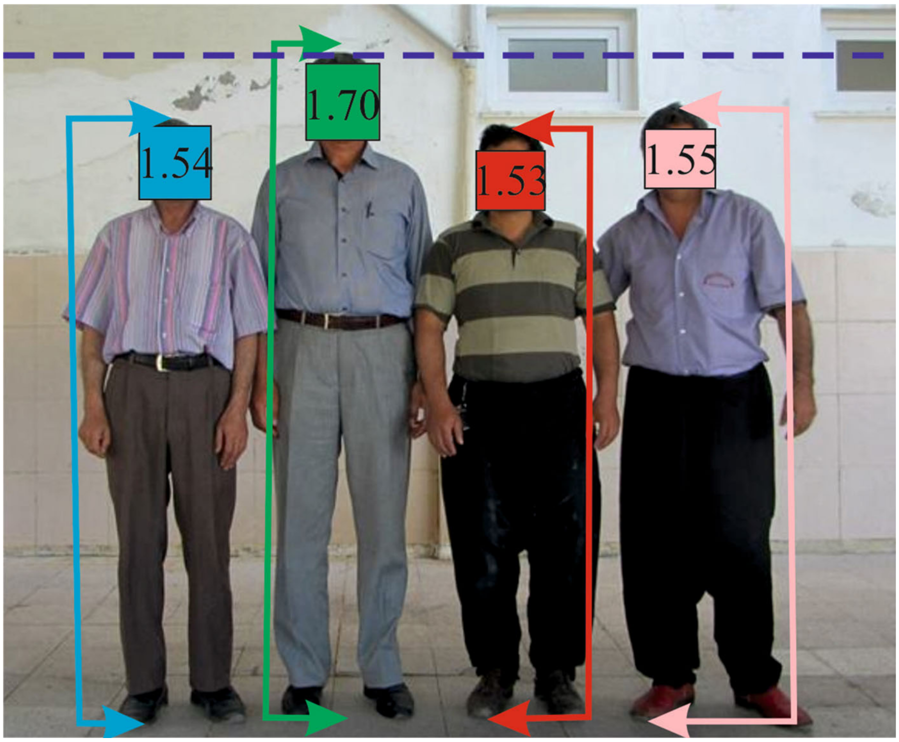
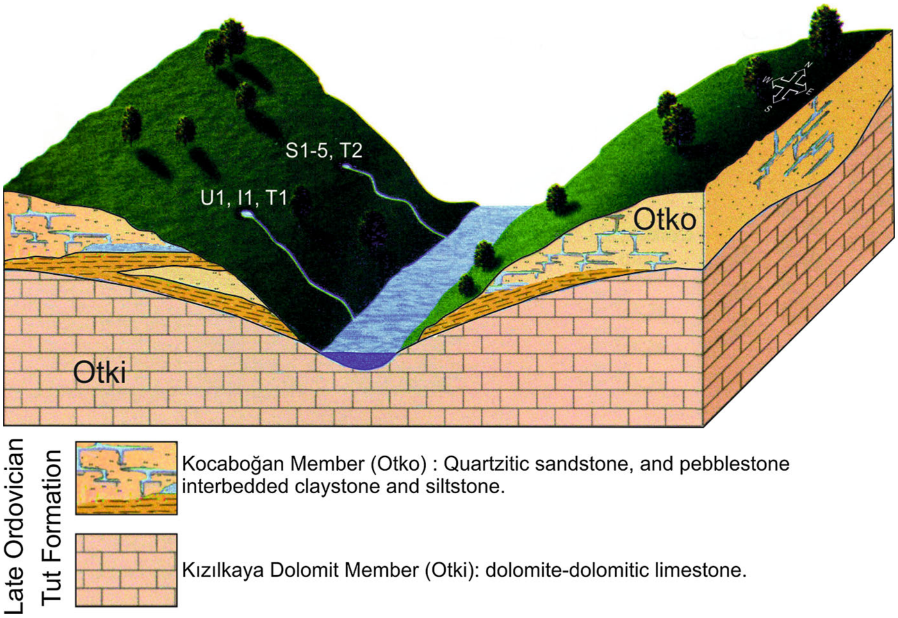


Fig. 12 Height measurements of local people from Derebogazı Village. *Green arrow* Man with a height of 1.70 m who was the control (not from Derebogazı Village)

Fig. 13 Geological model of the spring waters in the study area



recharged by meteoric waters. High ^3H concentrations and low EC values indicate that the groundwaters in the region are transient in character and that they are no older than 50 years. On a Cl^-–^3H diagram, high ^3H concentrations and low Cl^- contents imply that these groundwater sources are young; as evidenced by the pH–EC values, which indicate that these waters are shallowly circulating modern waters and that their contact time with the aquifer is short. The isotopic analyses suggest a good correlation between the water sources of Derebogazi Village and the general lithological properties of the rock units of the Tut Formation. In this respect, according to the established water cycle closed to the Derebogazi water sources, the surface waters can only infiltrate through the upper levels of the quartzites within the Tut Formation, and after a short residence time in the aquifer they reach to the surface via different water sources.

Conclusions

The isotopic interpretations are in good agreement with the general lithological properties of the Tut Formation hosting the water sources. The Tut Formation starts with dolomite–dolomitic limestone and clayey limestone lithology at its lower parts, passing into a sequence of shale–sandstone, quartzite, and quartzitic pebblestone. In addition, the upper sections of the formation have undergone low–medium grade regional metamorphism. The lithology within the Tut Formation is highly broken and fractured due to a deformation history. However, the dolomite–dolomitic limestone, clayey limestone, and quartzite sections of the Formation have a particularly hardened structure as a consequence of metamorphism, which causes these units to be more resistant to water-induced weathering. In the vicinity of the Derebogazi Village, surface runoff from precipitation infiltrates through the quartzite units to form the upper levels of the Tut Formation, and the infiltrated bodies of water are kept within an aquifer system within this unit without further infiltration. These waters later ascend to surface along fractured and broken surfaces. This process forms a water cycle throughout which the waters can only reach to the shallow aquifers confined within the quartzites of the upper levels of the Tut Formation. After staying in these aquifer systems for a short time, these waters ascend towards the surface in the form of different water sources (Fig. 13).

Additionally, even if the waters could infiltrate towards deeper levels, they would not be able to dissolve the already marbleized and hardened dolomite–dolomitic limestone and clayey limestone lithology due to their short residence time in the subsurface environment.

To study the health effects of the Derebogazi Village water sources on the local people, we made BMD on ten young women (age range 28–43 years) using the DEXA technique. The results revealed a relatively high rate of osteoporosis (30 %) which can be regarded as high for women in this age interval. Additional height measurements revealed that local people had significantly lower height values than the average height values for the Turkish general population. From the medical geology point of view, the lower height measurements may be the result of the low Ca and Mg content of the regional drinking water sources, suggesting that the residents of Derebogazi Village should consume Ca- and Mg-rich food products, especially developing children, to prevent Ca and Mg deficiency and to support bone development.

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