Environ Earth Sci (2011) 64:1433–1443
DOI 10.1007/s12665-011-0967-2

ORIGINAL ARTICLE

Hydrogeology and hydrogeochemistry of Günyüzü semi-arid basin (Eskişehir, Central Anatolia)

Muhterem Demiroğlu · Yüksel Örgün · Cenk Yaltırak

Received: 25 May 2009 / Accepted: 8 February 2011 / Published online: 4 March 2011
© Springer-Verlag 2011

Abstract Groundwater is often the only water source in semi-arid regions of Turkey. Günyüzü Basin, located in the Sakarya River basin, SW of Eskişehir, exhibits semi-arid conditions. The study area is composed of Paleozoic metamorphic rocks, Eocene granitic rocks, Neogene sedimentary rocks, and Quaternary alluvium. In the basin, Paleozoic Marbles are the main reservoir rocks for hot and cold water, bordered by impermeable diabases dykes at the sides and by impermeable granites and schists. Neogene-aged limestones, conglomerates and alluvium represent the other significant aquifers. Water samples chosen to exemplify the aquifer characteristics, were collected from springs and wells in both the dry and the wet seasons. The cation and anion permutation of the samples show that carbonates are the dominant lithology in the formation of chemical composition. δ^{18}O (−11.2 to −8.9‰) and δ^{2}H (−79 to −60‰) isotopic values show that all waters (thermal and cold) are meteoric in origin. The hydrological, hydrochemical, and isotopic properties of the waters reveal that there exist two main groups of groundwater systems; one of these is deep circulating, while the other one is shallow. Tritium values, 0–4 TU (Tritium Unit) indicate the presence of old, static water in these aquifer systems.

M. Demiroğlu (✉) · Y. Örgün · C. Yaltırak
ITU Mining Faculty, Geological Engineering,
Istanbul Technical University, 34469 Ayazağa,
Istanbul, Turkey
e-mail: copuroglum@itu.edu.tr

Keywords Aquifer · Günyüzü basin · Groundwater · Hydrogeochemistry · Isotope

Introduction

The feature that differentiates groundwater from other natural sources is that they are renewable except for fossil water. Groundwaters are too valuable to be consumed rapidly and polluted, since they are formed under paleoclimatic conditions that lasted hundreds of thousands of years. There is some imbalance between recharge and discharge which is significant because groundwater is the principal water source in arid, semi-arid regions. Therefore, it is very important to know about the renewable time of the groundwater. Recently, important developments have been recorded in the recharge calculations of semi-arid basins (Gieske and De Vries 1990; Shurbaji and Campbell 1997; Dennis and Murray 2002; Aquilina et al. 2005). Especially in karstic areas, geological drainage area, and topographic drainage area are not coincident, which complicates the rainfall and recharge calculations (Dennis and Murray 2002; Kaçaroğlu 1999). In the definition of the hydrodynamic structures of the karstic aquifers, and in the calculations of the water budget, stable and radiogenic isotope analyses and geographic information technologies such as data collection and processing techniques have been used (Tezcan 1993; Zuber 1983; Özaydın et al. 2001; White 2002; Dennis and Murray 2002; Aydın 2005; Shaban et al. 2006).

In this study, hydrogeological and hydrogeochemical characteristics of the Günyüzü basin (Fig. 1) were defined using precipitation data, in-situ pumping test data, and seasonal water chemistry and isotopic analyses. A conceptual hydrogeological model of the basin was constructed using this information.

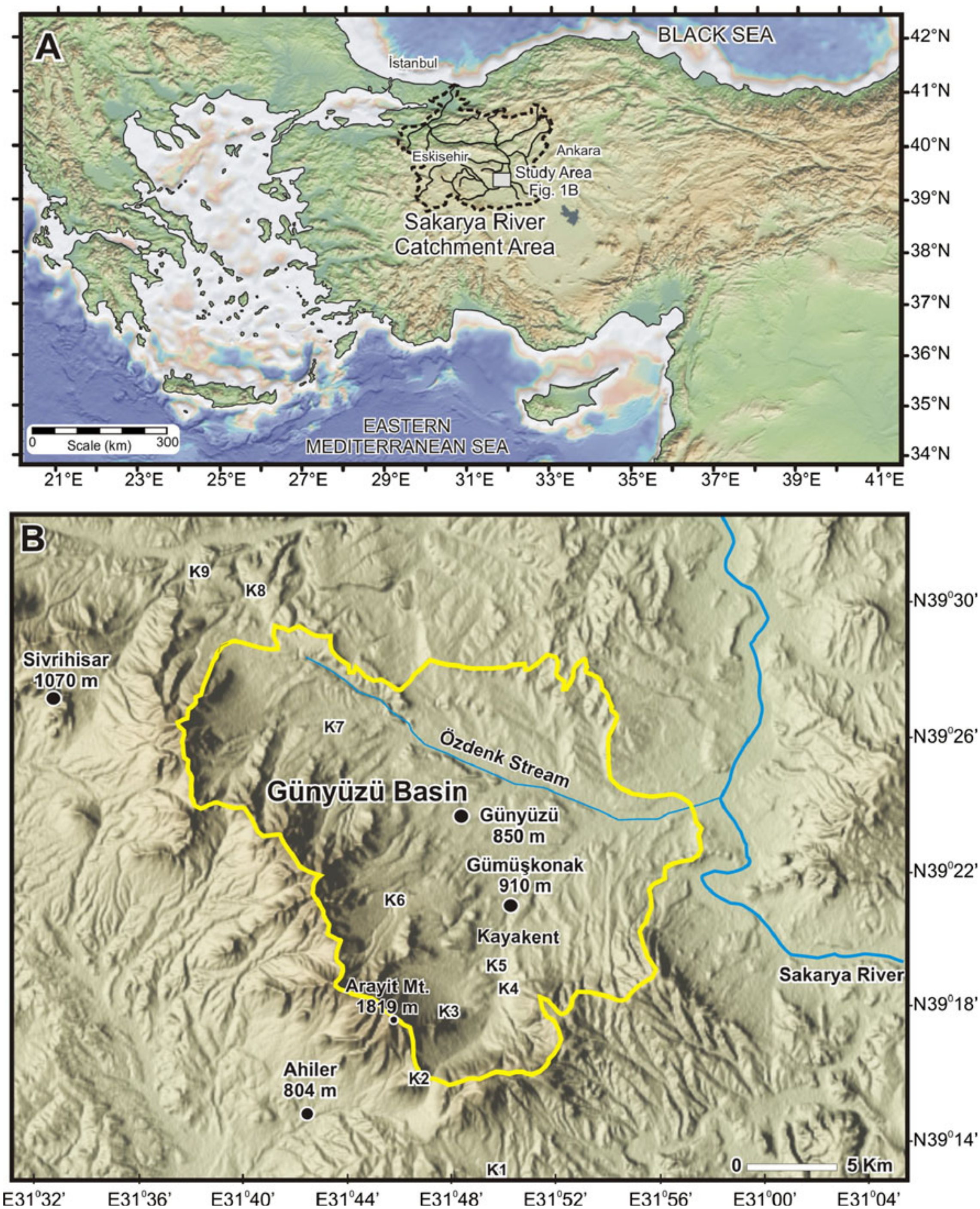

Fig. 1 **a** The location map of the study area, **b** Günyüzü Basin

Material and method

Eighteen groundwater samples were collected in nine sites during dry (August and September 2005) and wet (March and April 2006) periods in accordance with United State Environmental Protection Agency methodologies (US EPA 2000a). The groundwater, from which the samples were collected through springs and wells, is used for drinking and irrigation purposes by population in the region. Of these, one is a thermal spring (K7). Sampling sites representing different recharge and discharge zones were selected in terms of aquifer characteristics and the sites are shown in a hydrogeological map of the study area (Fig. 2). Information on the basic characteristics of the sampling sites, such as lithology, temperature (*T*), and yield (*Q*) are given in Table 1.

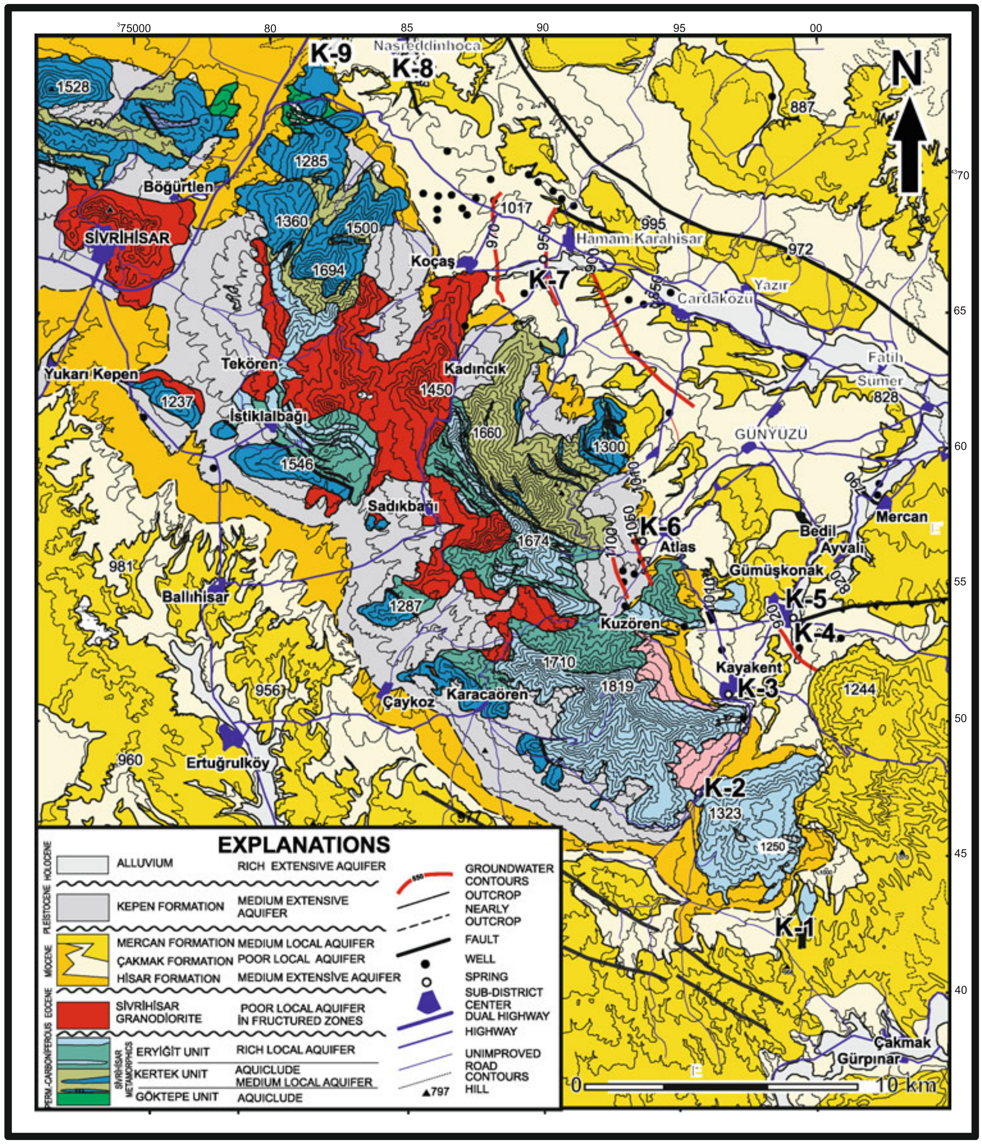

Fig. 2 Hydrogeological map of the study area

Table 1 Basic characteristic of the sampling locations

Sample	Type	Lithology	Discharge elevation (m)	Yield (l/s)	Aver. temp. (°C)
K1	Spring	Marble	887	47	23
K2	Rainfall	Sand and clay	1,068	0.2	13
K3	Spring	Marble	1,011	5	14
K4	Well	Limest.marl.conglom. + marble		65	30
K5	Spring	Limest.marl.conglom + marble	961	137	29
K6	Spring	Conglom. + marble	1,055	81	19
K7	Spring	Limest.marl.conglom. + marble	925	45	35
K8	Spring	Limest.marl + marble	943	170	23
K9	Spring	Sand and clay + marble	917	87	21

Physical properties of the water samples such as pH, redox potential (Eh; mV), temperature (T; °C), electrical conductivity (EC; μS/cm), dissolved oxygen (DO; mg/lt), total dissolved solids (TDS; mg/l) and salinity (ppt) were measured in situ with portable devices (YSI 556 MPS) that were calibrated with standard solutions. Acidity and alkalinity in the samples were measured in situ by titrating with Aquamerck 1.11109.0001 alkalinity and Aquamerck 1.111108 acidity tests, respectively. The anion and cation samples were filtered (0.45 μm) and stored in new polyethylene bottles, pre-rinsed three times with groundwater. Cation samples were acidified with 2 ml 65 % HNO_3 to below pH 2. The cations (Ca, Mg, Na, K, Al, Fe, F, Br, Cd, Cr, Cu, Co, Fe, Li, Mn, Ni, Pb, Si, and Zn) and anions (HCO_3, CO_3, Cl, SO_4, NH_3, NO_2, NO_3, PO_4) were determined in the Water Chemistry Laboratory of the International Research and Application Center for Karst Water Resources at Hacettepe University. The ionic balance error (IBE) computed on the basis of ions expressed in meq/l, was within the standard limit of ±5%.

Stable isotope compositions of water are expressed using δ notation, which is per mil relative to SMOW. Sixteen groundwater samples, collected from eight sampling location during dry and wet season, were chosen for ^{18}O, ^{2}H (deuterium) and ^{3}H (tritium) analysis. Oxygen-18 and ^{2}H were analyzed at the Nevada Stable Isotope Laboratories in the USA. Tritium analysis was performed at the Water Chemistry Laboratory at Hacettepe University in Ankara.

The geological and hydrogeological maps used in this study were constructed from maps created by earlier studies that were revised using field observations and satellite images. Information about deep wells was obtained from the State Hydraulics Works; the structural properties of the basin and formation thicknesses were taken from a study by Önder (1994), who used surficial resistivity. The names of the formation and other lithologic information about the region were taken from Umut et al. (1991).

Geology and hydrogeology

The Günyüzü basin is a small basin, exhibiting semi-arid climatic conditions. The average rainfall is 396 mm/year (Demiroğlu 2008). The basin occupies a surface area of 548 km^2, ranging from a minimum elevation of 800 m to summits of 1,814 meter (Arayit Mountain) above sea level. The surficial outflow of the catchment discharges to the Sakarya River, and then into the Black Sea (Fig. 1a). Lithology in the higher areas of the basin is represented mainly by schists, marbles and granitic rocks. The basin is drained by a number of ephemeral and intermittent streams. Groundwater flows principally toward the Sakarya River.

Five main lithostratigraphic units are recognized in the study area: Permo-Carboniferous Kertek metamorphic units, which form the basement of the Günyüzü basin, Eocene Sivrihisar granodiorite, Miocene sedimentary units, Pleistocene terrestrial clastics and Holocene alluvium. A simplified stratigraphic columnar section of the study area is as given in Fig. 3. There exist a number of previous studies on regional geology, geomorphology, and tectonics for the study area (Weingart 1954; Altınlı 1973; Erdinç 1978; Kulaksız 1981; Gautier 1984; Umut et al. 1991; Kibici et al. 1993; Gözler et al. 1996; Göncüoğlu et al. 1996; Whitney 2002; Örgün et al. 2004, 2005; Yaltirak et al. 2005; Whitney and Davis 2006).

Based upon these studies and our observations, it is understood that the study area was influenced by four different tectonic activities: The Kertek metamorphic units gained their existing structural features in the first tectonic stage (in Permo-Carboniferous period). The second tectonic stage is represented by intrusion of the Sivrihisar granodiorite into the Kertek metamorphic units. This event intensively modified the structural features of the basement in Paleocene-Eocene period. Uplifting and faulting of Kertek metamorphic units and Sivrihisar granodiorite (Oligocene–Miocene period) represent the third stage of the tectonic activities. The last stage is represented by current seismic activity which occurred by reactivation of old faults.

Based on structural features and hydrogeological characteristics, such as permeability and porosity, all the rocks in the basin may be classified as locally rich, medium, and poor aquifers and aquicludes (Fig. 2).

Permo-Carboniferous marbles within the Kertek metamorphic unit represent the higher parts of the aquifer system. The thickness of the marbles is more than 100 m (Fig. 3). The marbles, mapped as locally rich and medium aquifers both contain and conduct considerable amounts of groundwater. Also, the marbles play a significant role in recharge of the basin. The K3 and K2 springs are recharged, circulate, and discharge through these marbles. This circulation happens at shallow depths and the uniform chemical properties of the springs imply laminar flow conditions. Karstic springs and aquifer systems are illustrated in a conceptual model (Fig. 4). Pump tests in the marbles yielded hydraulic conductivities from 1.19 to 98.9 m/day and specific capacity ranges from 0.64 to 75 l/s/m. The highest hydraulic conductivity and specific capacity were associated with karstic structures. Other shallow circulated water (K6, K8, and K9) mostly are recharged from the marbles, but discharge from Miocene units such as limestone, conglomerate and sandstone. These values indicate that the system is heterogeneous.

Recharge is greatest where the marbles are exposed in the highest elevations. Karstic conditions permit deep circulation of this recharged water and faults in the marble permit significant vertical movement and discharge at springs (K1, K4, K5, and K7). Shallow circulation occurs in partly developed conduits, with infiltration in old karstic

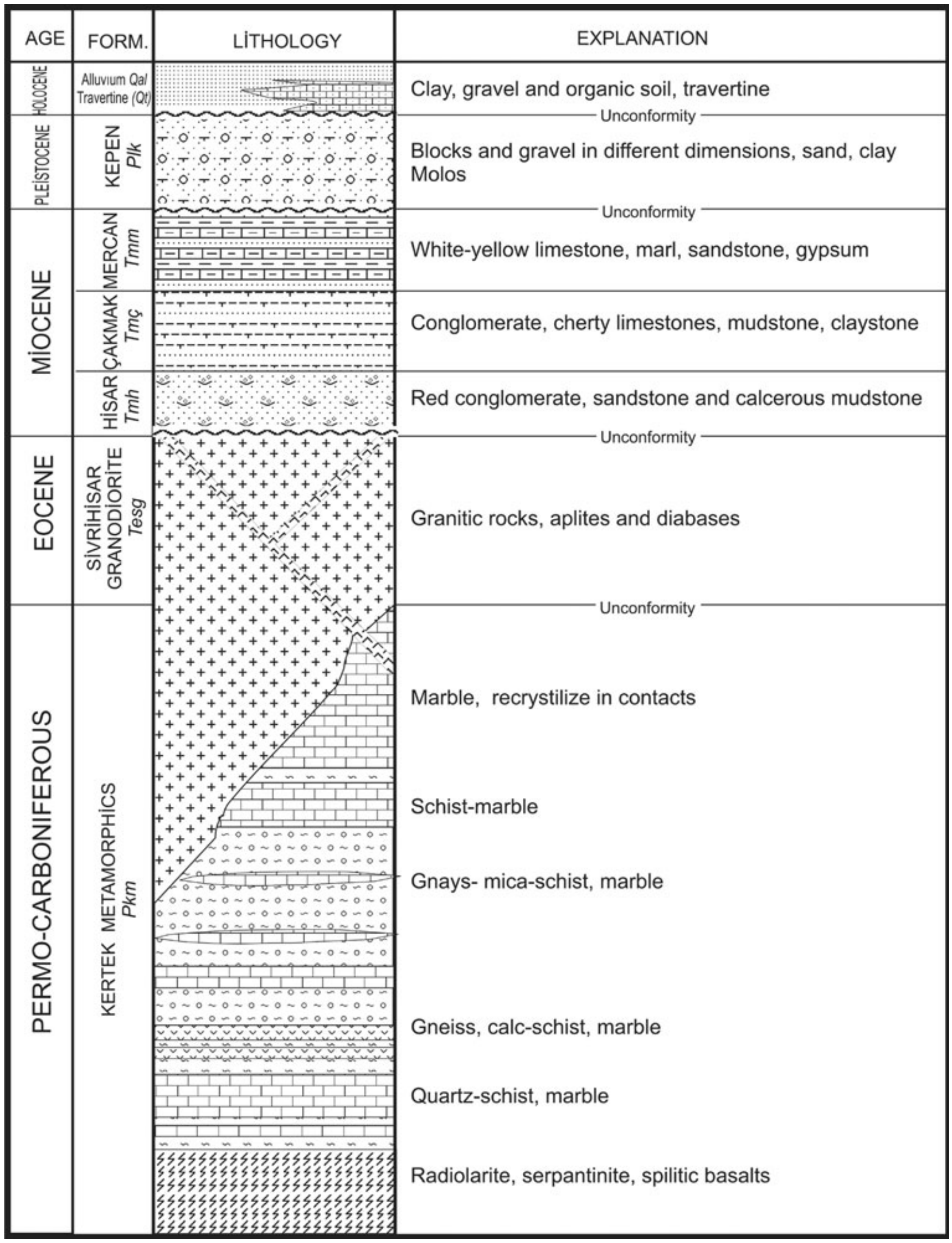

Fig. 3 Simplified stratigraphic columnar section of the study area (Demiroğlu 2008)

structures such as sinkholes, fractures and joints. Turbulent flow in the vadose zone is inferred from the discharge rates of the K5 spring (Demiroğlu 2008).

Miocene limestones constitute the second important aquifer in the basin and they are mapped as local medium aquifers (Fig. 2). According to the data obtained from pump tests carried out at wells drilled in these unit, the hydraulic conductivity values vary between 1.39 and 4.1 m/day and specific capacity varies from 1.8 to 2.9 l/sec/m. The hydraulic conductivity and specific capacity values of the Miocene conglomerates vary from 0.27 to 0.39 m/day and 0.38 to 0.55 l/s/m, respectively. The ultrabasic rocks and schists of the Kertek metamorphic unit, Eocene granitic rocks and diabases, and Miocene marl and clays are impermeable (Demiroğlu 2008).

The following precipitation stations were used to estimate the input to the water budget: Sivrihisar (1929–2005), Günyüzü (1969–2000) meteorological stations, Gümüşkonak (1969–2001) and Ahiler (1964–2005) DSİ (State Hydraulic Works) stations (Fig. 1b). The main factors that influence of the recharge are altitude, season, rainfall type, and intensity**.** As expected, the amount of precipitation increases with altitude and the precipitation–altitude relationship was used within the 3D analyst-surface tool of Arc-Map 9 to assign precipitation. Precipitation by area from highest to lowest elevation is 40×10^6 m^3/year

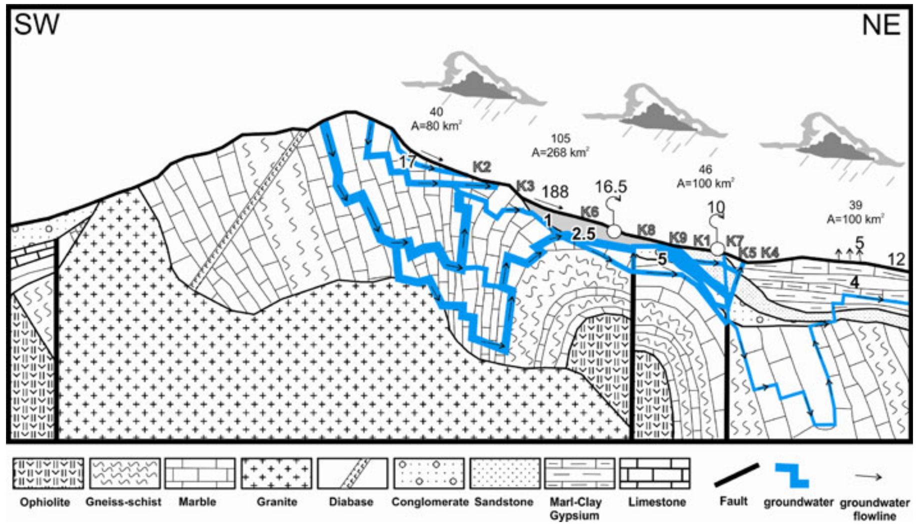

Fig. 4 Schematic illustration the hydrogeological conceptual model of the Günyüzü basin (The water budget units are expressed as million m^3/year)

(80 km^2), 105 × 10^6 m^3/year (268 km^2), 46 × 10^6 m^3/year (100 km^2), 39 × 10^6 m^3/year (100 km^2). Short-lived and intense rainfalls and snowmelts directly affect the recharge in that karstic area. The influence of precipitation of those types has been observed on spring discharge rates in the basin. Total precipitation of 215–230 × 10^6 m^3/year was estimated. The mean annual precipitation rate was found to be 500 mm for the karstic area. Cumulative deviation from the mean annual precipitation plots revealed that the period from 1991 to 1995 was a dry, 1995 to 2000 was wet and 2000 to 2007 was a dry again.

In the study area and its vicinity, there exist flow-gauging stations operated by EIE (Electrical Survey and Administration). The regional evapotranspiration (ET), surface runoff and base flow were calculated by using Sakarya River's flow data provided by that administration. Potential and real ET values were calculated by Penman and Turc methods and it was revealed that 84–89 % of the total annual precipitation (~188 × 10^6 m^3/year) is returned to the atmosphere through ET, and the remaining 11–16% either flows as surface water runoff (12 × 10^6 m^3/year) or percolates into depths to recharge groundwater (Fig. 4).

Groundwater boundaries in the Günyüzü basin are not coincident with the topographic boundaries. Instead, the groundwater boundaries depend upon the extent of the lithologies such as the marble.

Recharge for the basin was estimated to be 29.5 × 10^6 m^3/year. This included percolation from local permeable (~17 × 10^6 m^3/year), semi-permeable ((5 + 4) × 10^6 m^3/year) and impermeable (~1 × 10^6 m^3/year) formations plus irrigation water (~2.5 × 10^6 m^3/year). Total discharge from the basin was estimated to be 31.5 × 10^6 m^3/year. Discharge from the springs was estimated to be 16.5 × 10^6 m^3/year, and groundwater evaporation was estimated to be 5 × 10^6 m^3/year. Well discharge was estimated to be 10 × 10^6 m^3/year (Fig. 4). These results suggest that recharge is less than discharge in the Günyüzü Basin. However, this lack of balance can be explained by the following: (1) rainfall and discharge were estimated for different periods, (2) the recharge was under-estimated because of rapid infiltration in karstic structures, and (3) the recharge from snow melt was under-estimated.

The water recharged into karst aquifers moves down–gradient through highly anisotropic pathways. Such aquifers are usually discussed in terms of a triple porosity model or triple permeability model (White 2002). High discharges ratios (Q_{max}/Q_{min}) and rapidly changing chemical composition reveals turbulent flow conditions. On the other hand, low discharge rates and nearly constant chemical composition characterize fractured system, long residence time and diffuse infiltration in the aquifer system (Aydin 2005). The conduit type system is typified by significant temperature variations, whereas a spring with the diffuse type of flow is typified by steady temperatures (Mazor 1991). Springs in Günyüzü basin mostly displayed nearly constant temperature, slight variations in chemical composition and low variation of the measurements (coefficient of variation = SD/mean) performed at both dry and wet season (Tables 2, 3).

As seen in Table 3, there is almost no change in temperature for springs K3, K5, K6, K7, K8, and K9. Spring K2 however, was variable in temperature related to weather conditions. Spring K1 was not sampled in September 2005, March and April 2006, as it was dry because of new wells. Q_{max}/Q_{min} values of the samples were given in Table 3. As seen in the table, discharge rates are low. Also, the coefficient of variation for EC and Ca^{2+} were given in Table 2. These features imply a fractured system with a long residence time and diffuse infiltration.

Table 2 Springs Q_{max}/Q_{min} and variation of the measurements

Spring no.	Spring name	Q_{max} (l/s)	Q_{min} (l/s)	Q_{max}/Q_{min}	CV_{ec}	CV_{ca}	Observation date
K1	Yeniçıktı	108	49	2.2	10.3	8.04	1986–2006
K2	Musluk çeşmesi	0.5	0	∞	–	–	2004–2006
K5	Subaşı	181	112	1.61	11.9	8.9	2000–2006
K6	Atlas	91	50	1.82	19.07	0.21	1998–2006
K7	Çardak hamamı	140	39	3.58	26.6	4.2	1991–2006
K8	Nasrettin hoca	219	152	1.44	3.96	6.63	1994–2006
K9	Babadat	100	68	1.47	4.95	6.01	1979–2006

CV coefficient of variation

Table 3 Springs temperatures (*T*, °C)

Spring no.	Spring name	Agust 2005 (*T*, °C)	Sept. 2005 (*T*, °C)	March 2006 (*T*, °C)	April 2006 (*T*, °C)	May 2006 (*T*, °C)
K1	Yeniçıktı	22.82	–	–	22.91	–
K2	Musluk çeşmesi	24.88	–	5.35	10.39	12.31
K3	Çukurçeşme	13.95	14.09	13.44	13.36	13.56
K5	Subaşı	29.90	29.76	31.07	31.06	31.06
K6	Atlas	18.96	19.02	18.80	18.94	18.97
K7	Çardak hamamı	35.00	34.50	33.70	34.82	34.81
K8	Nasrettin hoca	22.70	22.80	22.07	22.25	22.21
K9	Babadat	20.50	20.50	20.46	20.46	20.46

Spring temperatures are used to provide initial information on the depth of circulation (Mazor 1991; Linan et al. 2009) and the hydrochemical, isotopic values are used to confirm this result. Circulation depth values are given in Table 4, together with discharge elevation and average temperature of the samples.

Table 4 Geographic coordinate, discharge elevation, circulation depth and average temperature of the samples (Coordinates UTM 35)

Sample	Spring name	*X* (N) m	*Y* (E) m	Elv. (m)	Depth (m)	*T* (°C)
K1	Yeniçıktı	43,419,80	3,993,53	887	382	22.8
K2	Musluk çeşmesi	43,476,58	3,95,851	1,068	12	13.2
K3	Çukurçeşme	4,35,1171	3,967,69	1,011	88	14.0
K5	Subaşı	4,35,3611	3,992,17	961	622	30.0
K6	Atlas	4,35,6938	3,934,66	1,055	255	19.0
K7	Çardak hamamı	4,36,6839	3,901,27	925	788	35.0
K8	Nasrettin hoca	4,37,3481	3,852,92	943	378	22.7
K9	Babadat	4,37,4508	3,805,58	917	305	20.5

Hydrogeochemistry

Data on measured physicochemical characteristics (pH, Eh, EC, TDS, DO, HCO, SO, Cl, Ca, Mg, Na, K) of groundwater samples from Günyüzü basin are summarized in Tables 5 and 6. The dissolved oxygen (DO) values did not display differences between sampling seasons. The DO concentrations of the samples were plotted with respect to the circulation depths (Fig. 5). There exists a negative correlation between DO values and the circulation depths ($r^2 = 0.9147$). DO values tend to increase with the decrease in circulation depths. In the same way, EC and TDS values tend to increase with the increase in circulation depth. However, both the EC values and TDS values of some samples taken in wet season were generally higher than that of dry season. The other parameters of the samples, taken during both seasons individually, exhibit no salient variations (see Tables 5, 6). So it may be concluded that both the shallow- and deeply-circulated waters have not been exposed to different hydrogeochemical evolving processes during circulation.

Hydrochemical compositions of the groundwater samples were plotted in trilinear equivalence diagrams (Fig. 6). These plots did not vary by season. The samples were identical in cation contents and the waters are often

Table 5 Physicochemical data of samples in wet season

No.	EC (μs/cm)	TDS (mg/l)	DO (mg/l)	pH	Asidite (mmol/l)	Alkalinite (mmol/l)	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	HCO_3^{-2}
K1	603.00	464.00	4.90	6.96	0.80	4.90	3.58	2.07	0.47	0.04	0.18	1.12	4.23
K2	309.50	272.00	10.52	7.34	0.20	4.30	3.74	0.36	0.21	0.02	0.09	0.27	3.51
K3	331.50	276.00	8.89	7.21	0.30	3.90	2.60	1.55	0.26	0.23	0.29	0.34	3.44
K4	803.00	467.50	4.69	6.87	1.05	6.60	5.32	2.65	0.55	0.07	0.21	2.85	5.10
K5	798.00	474.00	4.46	6.86	1.20	6.40	4.65	2.05	0.55	0.06	0.19	0.88	5.51
K6	440.00	323.50	7.96	6.68	0.65	5.75	3.88	1.08	0.2	0.03	0.06	0.15	4.58
K7	958.50	525.00	2.21	7.02	1.40	7.45	3.89	1.23	1.37	0.06	0.8	0.32	5.03
K8	404.50	278.50	7.36	7.16	0.35	4.55	3.21	1.04	0.25	0.02	0.09	0.23	3.73
K9	415.50	296.00	7.75	7.09	0.35	4.50	3.11	1.14	0.33	0.03	0.15	0.22	3.73

Table 6 Physicochemical data of samples in dry season

No.	EC (μs/cm)	TDS (mg/l)	DO (mg/l)	pH	Asidite (mmol/l)	Alkalinite (mmol/l)	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	HCO_3^{-2}
K1	590	400	7.49	7.08	0.60	6.20	3.89	2.34	0.48	0.04	0.19	0.70	4.69
K2	411	268	8.90	8.27	0.40	4.00	3.83	0.48	0.23	0.01	0.09	0.17	3.89
K3	346	286	9.11	7.15	0.30	4.00	2.54	1.72	0.32	0.29	0.37	0.42	3.54
K4	1,216	724	4.12	6.98	1.70	6.50	4.66	2.19	0.54	0.06	0.18	0.57	5.97
K5	778	456	4.81	6.94	1.50	7.10	4.69	2.18	0.52	0.06	0.19	0.66	5.92
K6	418	304	8.13	6.80	1.30	5.50	3.84	1.19	0.2	0.03	0.07	0.10	4.95
K7	935	512	2.89	6.93	1.50	7.90	4.70	1.68	1.82	0.07	1.07	0.38	6.68
K8	403	274	7.68	7.17	0.30	4.50	3.12	1.09	0.27	0.02	0.12	0.27	3.87
K9	405	288	8.06	6.92	0.40	4.60	3.18	1.26	0.32	0.02	0.17	0.31	4.03

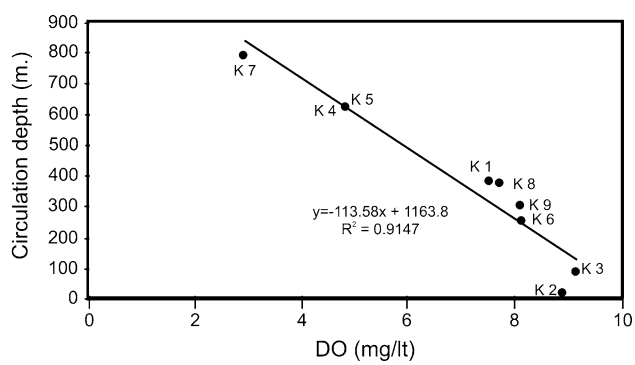

Fig. 5 Plot of DO versus circulation depth for the water samples

characterized by being rich in Ca. With respect to anion, the waters were enriched in bicarbonate (HCO_3^-). Thus, the groundwater is involved in (Ca + Mg)–HCO_3 type, except sample K7. K7 represents hot water and is enriched in Na^+, slightly. That sample characterizes the (Ca + Na + Mg)–HCO_3 type.

The groundwater samples are moderately alkaline and reflect the moderately hard and hard water characteristics. The decreasing abundances of major ions in the waters figures Ca > Mg > Na > K and HCO_3 > SO_4 > Cl alignment, whereas it displays as Ca > Na > Mg > K and HCO_3 > Cl > SO_4 order in hot water (K7). Based on these hydrochemical characteristics along with observed lithological and mineralogical data, it is inferred that the waters evolved largely through preferential dissolution of carbonate minerals with a lesser degree of silicates (Fig. 7).

Some trace elements in water samples were analyzed to identify existing contaminants. The concentrations of the most toxic elements such as Al, Cd, Co, Fe, Mn, Ni, Pb, and Zn are found to be less than limits for drinking water of World Health Organization (WHO 1996) and US Environmental Protection Agency (US EPA 2000a). The F, NO_2, and NO_3 values in the waters vary from 0.001 to 0.25, 0.08 to 0.16, and 2.5 to 35 mg/l, respectively (Demiroğlu 2008).

Stable oxygen is plotted versus stable hydrogen in Fig. 8. All groundwater samples plotted between the local (Ankara) meteoric line ($\delta^2H = 8 \times \delta^{18}O + 14.5$) and the global meteoric line ($\delta^2H = 8 \times \delta^{18}O + 10$), except for the sample from spring K3. This sample was influenced by evaporation because the spring is stored in the cistern before it is discharged from an old fountain.

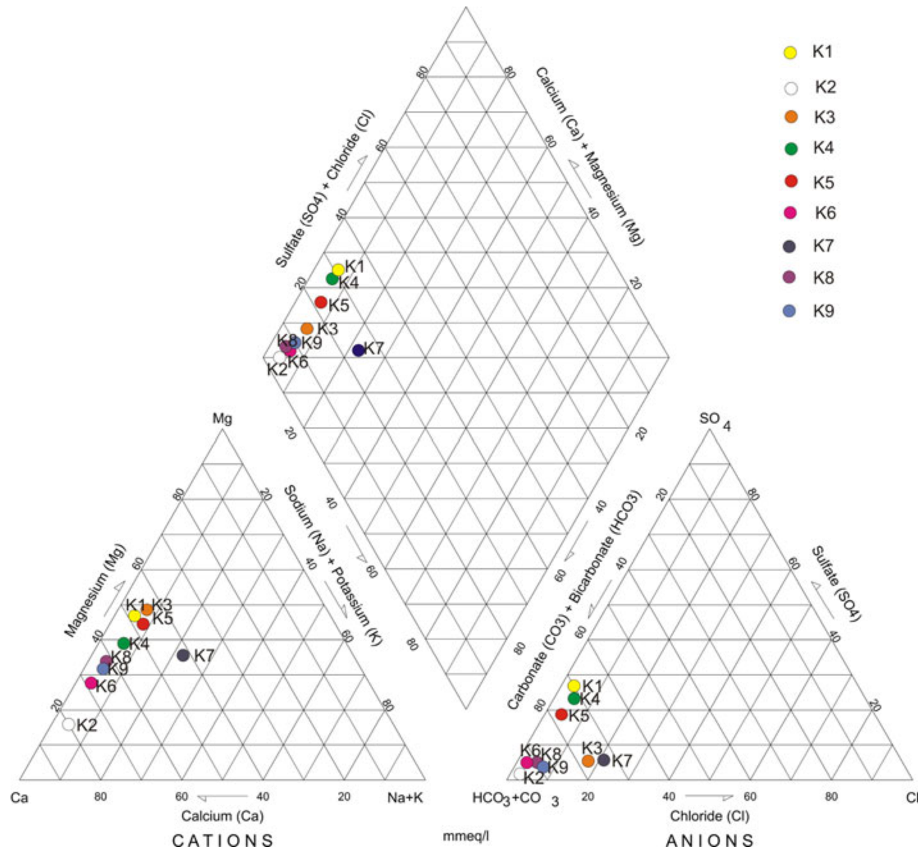

Fig. 6 Piper diagram of the sampling points

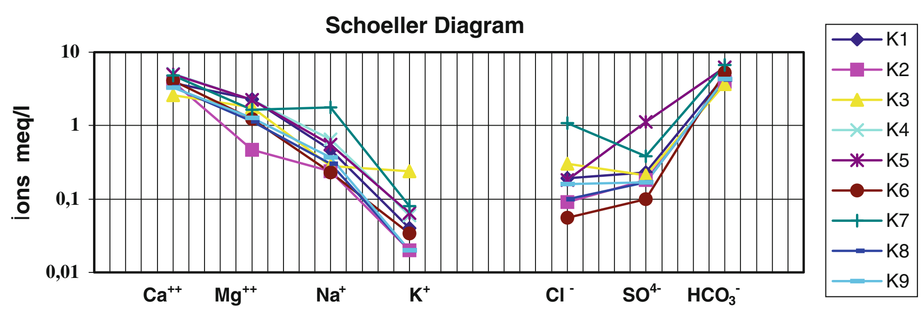

Fig. 7 Schoeller diagram of the sampling points

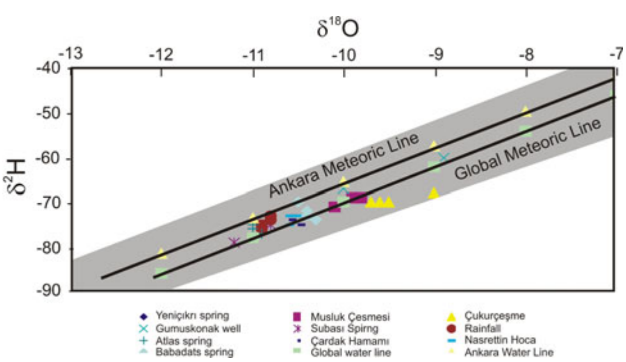

Fig. 8 δ^{18}O–δ^{2}H relationship of the waters from the study area

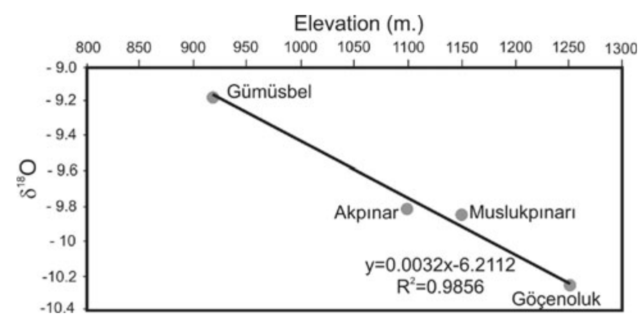

Fig. 9 Plot of δ^{18}O versus elevation for the water samples from the study area

Isotope hydrology studies have shown that an elevation effect in weighted mean precipitation exists of between −0.15 and −0.50‰ δ^{18}O per 100 m elevation (Clark and Fritz 1997). For the Günyüzü basin, δ^{18}O was found to be −0.32‰ per 100 m elevation. Four sample points were chosen to represent precipitation from different altitudes in

Table 7 Averages recharge elevations of the water samples as defined by their oxygen-18 isotope contents

Sample	Sample name	$\delta^{18}O$	Discharge elevation (m)	Recharge elevation (m)
K1	Yeniçıkrı spring	−10.90	887	1,465
K3	Çukurçeşme spring	−9.40	991	996
K4	55886/A well	−10.95	910	1,480
K5	Subaşı spring	−10.85	951	1,450
K6	Atlas spring	−11.00	1,065	1,497
K7	Çardak hamamı	−10.55	919	1,356
K8	Nasrettin Hoca	−10.55	934	1,356
K9	Babadat spring	−10.40	904	1,309

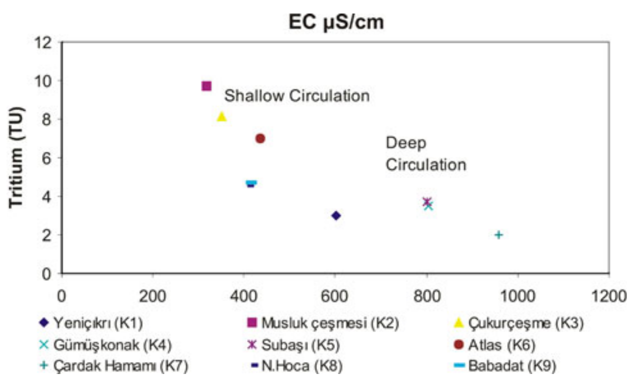

Fig. 10 Tritium–EC relationship of the water samples from the study area

Günyüzü (K2) and nearby basin (Günay 2006) (Fig. 9). Two samples were collected at the Göcenoluk, Akpınar and Gümüşbel springs respectively. Four samples were collected at the Musluk çeşmesi (K2) spring. The recharge elevation of the springs was found using $\delta^{18}O$—elevation relationship and given together with the discharge elevations in Table 7.

The EC–tritium relationship indicates the existence of waters with different circulating depth (Fig. 10). The samples can be divided into two main groups based on the EC and tritium (^3H) conditions: the waters with high EC (590–1216 µS/cm) and low ^3H (0–4 TU) and the waters with low EC (309–440 mg/l) and high ^3H (4–10 TU). The first group represents the deep circulating water (K5, K4, and K7). The second group represents the shallow circulating waters (K2, K3, K6, K8, and K9) and physicochemical properties of these waters are likely to reflect the effects of mixing of the shallow waters and the deep waters (cool groundwater) in various proportions during their ascent to the surface or during storm events (Demiroğlu et al. 2007).

Conclusions

The study area with annual average precipitation of 393 mm/year is a semi-arid region. Thus the water budget is dominated by evapotranspiration. Less than 20 % of the annual input becomes either stream flow or groundwater. The largest groundwater discharge is from karstic springs. Chemical and isotopic analyses reveal the existence of two groundwater flow systems, a deep thermal system and a shallow system. Both systems are meteoric.

The waters are dominantly characterized by rich Ca and HCO_3 ion contents and reflect the (Ca + Mg)–HCO_3 type. Decreasing orders of the absolute abundances of major ions in the waters are Ca > Mg > Na > K and HCO_3 > SO > Cl and these orders imply that the waters evolved largely through preferential dissolution of carbonate minerals with a lesser degree of silicate minerals. Major (Ca, Mg, Na, K, SO_4, Cl, HCO_3, NO_2, NO_3) and trace element (Cd, Co, Cu, F, Fe, Mn, Ni, Pb, Zn) concentrations in the waters do not show any potential contamination and their values fall below the standards for fresh water.

During recent years, there has been a shift from agricultural to domestic land use within the study area. This shift has led to an increased need for groundwater supplies. Thus the concept of sustainable water management is important because of the increased pumping of groundwater within Günyüzü basin. In this study, a conceptual model of aquifer behavior has been constructed, but defining the safe yield is not possible because of the existence of old static water. However, water level drawdown can be controlled by limited pumping rates and by avoiding new drilling in the Gümüşkonak and Yeniçikri areas (Demiroğlu 2008). During the studies, it was observed that water from the new wells dug near Yeniçikri and Subaşi springs caused a change in the groundwater levels (as of June 3, 2007 a drop of 5–7 m in the water level of the wells) and Yeniçıkrı spring had dried up. If this trend of increased use continues, it will cause the existing springs to dry, the water levels in the wells to drop, and the discharge to the Sakarya River to decrease.

Acknowledgments This work was supported by TUBİTAK-ÇAYDAG (Project No: 105Y145) and İTÜ-BAP (Project no: 31880). We would like to thank Tolga Yalçın for he manages the TUBİTAK

Project. We also acknowledge to Mehmet Ekmekçi from Hacettepe University for commentaries.

References

Altınlı E (1973) Orta Sakarya Jeolojisi (Geology of middle Sakarya) Cumhuriyetin 50. Yılı Yerbilimleri Kongresi, Bildiriler Kitabı, 159–192

Aquilina L, Ladouche B, Dölfliger N (2005) Recharge processes in karstic systems investigated through the correlation of chemical and isotopic composition of rain and spring waters. Appl Geochem 20:2189–2206

Aydın H (2005) Harmanköy-Belyayla (Bilecik) Investigation of morphology-hydrogeology relations in Harmankoy-Beyyayla (Bilecik) karst system, PhD Thesis, Hacettepe University, Institute of Science and Technology (In Turkish with English summary)

Clark D, Fritz P (1997) Environmental ısotopes in hydrogeology. CRC Press, Boca Raton, p 312

Demiroğlu M (2008) Hydrogeology and hydrochemistry of Eskişehir-Sivrihisar-Günyüzü Basin. PhD Thesis, Istanbul Technical University, Institute of Science and Technology (In Turkish with English summary)

Demiroğlu M, Yalçın T, Örgün Y, Yaltırak C, Akdeniz U (2007) Hydrogeochemical characteristics of groundwater in Günyüzü basin (Sivrihisar-Eskişehir) Western Turkey. In: The 23rd International Applied Geochemistry Symposium, Extended Abstracts, Oviedo, Spain, p 129

Dennis PC, Murray BS (2002) Karst groundwater basin delineation, Fort Knox. Ky Eng Geol 65:125–131

Erdinç H (1978) Sivrihisar kristalin masifinin jeolojisi ve petrolojisi, İstanbul Üniversitesi, Fen Fakültesi, Mineraloji ve Petrografi Kürsüsü, PhD Thesis (Unpublished)

Gautier Y (1984) Deformations et Metamorphismes Associes a la Suture Tethysienne en Anatolie Centrae, (Region de Sivrihisar, Turquie), PhD Thesis, University de Paris-Sud Centre D'Orsay, p 236

Gieske A, De Vries JJ (1990) Conceptual and computational aspects of the mixing cell method to determine groundwater recharge components. J Hydrol 121:277–292

Göncüoğlu MC, Turhan N, Şentürk Ş, Uysal Ş, Özcan A (1996) Orta Sakarya'da Nallıhan- Sarıcakaya arasındaki yapısal birimlerin jeolojik özellikleri, MTA Derleme, No: 9973, Ankara (Unpublished report)

Gözler MZ, Cevher F, Ergül E, Asutay HJ (1996) Orta Sakarya ve güneyinin jeolojisi, MTA Derleme No: 9973, Ankara (Unpublished report)

Günay G (2006) Hydrology and hydrogeology of Sakaryabaşı karstic springs, Çifteler, Turkey. Env Geol 51:229–240

Kaçaroğlu F (1999) Review of groundwater polltion and protection in karst areas. Water Air Soil Pollut 113:337–356

Kibici Y, Dağ N, Özgenç İ (1993) Sivrihisar-Günyüzü (Eskişehir) granitoyid kuşağının mineralojik ve petrografik özellikleri. Yerbilimleri 23:97–112

Kulaksız S (1981) Sivrihisar kuzeybatısının jeolojisi. Yerbilimleri 8:103–124

Linan C, Andreo B, Mudry J, Carrasco F (2009) Groundwater temperature and electrical conductivity as tools to characterize flow patterns in carbonate aquifers: The Sierra de las Nieves karst aquifer, Southern Spain. Hydrogeol J 17:843–853

Mazor E (1991) Applied chemical and isotopic groundwater hydrology. Halsted Press, New York

Önder İ (1994) Turkiye Rejyonal Jeoelektrik Haritalar Projesi Eskişehir-Sivrihisar-Günyüzü-G.konak Sahaları Rezistivite Etüt Raporu (Geophysical study of the Eskişehir-Sivrihisar-Günyüzü-G.konak fields), MTA Derleme No: 9921, Ankara (Unpublished report)

Örgün Y, Gültekin AH, Altınsoy N, Çelebi N, Karahan G (2004) Hydrogeochemical characteristics and radioactivity levels of some of the groundwater from western Anatolia. In: Proceedings of ınternational symposium on earth system sciences, 8–10 September, Istanbul, pp 643–650

Örgün Y, Altinsoy N, Gültekin AH, Karahan G, Çelebi N (2005) Natural radioactivity levels in granitic plutons and groundwater in southeast part of Eskisehir, Turkey. Appl Radiat Isot 63:267–275

Özaydın V, Şendil U, Altınbilek D (2001) Stable isotope mass balance method to find water budget of a lake. Turk J Eng Env Sci 25:329–344

Shaban A, Khawlie M, Chadi A (2006) Use of remote sensing and GIS to determine recharge potential zones: the case of Occidental Lebanon. Hydrogeol J 14:433–443

Shurbaji AR, Campbell AR (1997) Study of evaporation and recharge in desert soil using environmental tracers, New Mexsico, USA. Env Geol 29:147–151

Tezcan L (1993) Karst Akifer Sistemlerinin Trityum İzotopu Yardımıyla Matematiksel Modellemesi (Mathematical model of karst aquifer systems by tritium isotope), PhD Thesis, Hacettepe University, Institute of Science and Technology (In Turkish with English summary)

Umut M, Acarlar M, Gedik İ, Güner E, Saçlı L, Şen AM (1991) Çifteler-Holanta (Eskişehir ili) Çeltik (Konya ili) ve dolayının jeolojisi. MTA Derleme No: 9204 (Unpublished report)

US EPA (US Environmental Protection Agency) (2000a) Drinking water regulations and health advisories. US EPA, Washington DC

Weingart W (1954) 56/4 (Sivrihisar) ve 57/1, 57/3 (Ankara) paftalarının jeoloji haritası hakkında. MTA rapor No: 2248 (Unpublished report)

White WB (2002) Karst hydrology; recent developments and open questions. Eng Geol 65:85–105

Whitney DL (2002) Coexisting andalusite, kyanite, and sillimanite: sequential formation of three Al_2SiO_5 polymorphs during progressive metamorphism near the triple point, Sivrihisar, Turkey. Am Min 87:405–416

Whitney DL, Davis PB (2006) Why is lawsonite eclogite so rare? Metamorphism and preservation of lawsonite eclogite, Sivrihisar. Turk Geol Soc Am 34:473–476

World Health Organization (WHO) (1996) Guidelines for drinking water quality. recommendations. Health criteria and other supporting ınformation, vol 2. WHO, Geneva

Yaltirak C, Yalçın T, Yüce G, Bozkurtoğlu E (2005) Water-level changes in shallow wells before and after the 1999 İzmit and Düzce earthquakes and comparison with long-term water-level observations (1999–2004), NW Turkey. Turk J Earth Sci 14:281–309

Zuber A (1983) On the environmental isotope method for determining the water balance components of some lakes. J Hydrol 61:409–427