COBISS: 1.01

HYDROGEOLOGY OF THE GÖKPINAR KARST SPRINGS, SIVAS, TURKEY

HIDROGEOLOGIJA KRAŠKIH IZVIROV GÖKPINAR, SIVAS, TURČIJA

Fikret KAÇAROĞLU[1]

Abstract UDC 556.36:551.44(560)

Fikret Kaçaroğlu: Hydrogeology of the Gökpinar karst springs, Sivas, Turkey

Gökpınar karst springs are located 8 km to the south of the Gürün district centre, Sivas, Turkey. The springs have two main outlets (Gökpınar-1 and Gökpınar-2) and outflow from Jurassic-Cretaceous Yüceyurt formation (limestone). The total discharge of the springs ranges between 4.5 and 7.8 m^3/s. The study area is formed of allocthonous and autocthonous lithological units whose ages range from Upper Devonian to Quaternary. These lithologies are mostly formed of limestones. Yüceyurt formation (limestone), from which Gökpınar karst springs outflow, constitute the main aquifer in the study area and is karstified. The unit has a well developed karst system comprising karren, dolines, ponors, underground channels and caves. The recession (discharge) analysis of the Gökpınar springs was carried out and the storage capacities and discharge (recession) coefficients of the Gökpınar-1 and Gökpınar-2 springs were calculated as 141×10^6 m^3 and 98×10^6 m^3, and 2.71×10^{-3} day^{-1} and 2.98×10^{-3} day^{-1}, respectively. The storage capacities and discharge (recession) coefficients obtained suggest that the karst aquifer (Yüceyurt limestone) has large storage capacity, and drainage occurs very slow. The major cations in the study area waters are Ca^{2+} and Mg^{2+}, and anion is HCO_3^-. The waters are calcium bicarbonate type. Some of the water chemistry parameters of the Gökpınar springs range as follows: T=10.8–11.1°C, pH=7.65–7.95, EC=270–310 μS/cm, TDS=170–200 mg/L, Ca^{2+}=40.0–54.0 mg/L, Mg^{2+}=4.5–10.0 mg/L, HCO_3^-=144.0–158.0 mg/L. Temperature, EC, TDS, and Ca^{2+} and HCO_3^- concentrations of the Gökpınar springs did not show significant variations during the study period.

Keywords: hydrogeology, karst, groundwater, Gökpınar springs, Sivas.

Izvleček UDK 556.36:551.44(560)

Fikret Kaçaroğlu: Hidrogeologija kraških izvirov Gökpinar, Sivas, Turčija

Kraški izviri Gökpınar se nahajajo 8 km južno od regijskega središča Gürün, Sivas, Turčija. Voda izvira iz dveh glavnih izvirov (Gökpınar 1 in Gökpınar 2) in izteka iz jursko kredne Yüceyurt formacije (apnenec). Skupni pretoki nihajo med 4,5 in 7,8 m^3/s. Prispevno območje pokriva alohtone in avtohtone litološke enote, katerih starost sega od zgornje devonskih do kvartarnih kamnin, večinoma apnencev. Formacija Yüceyurt (apnenec) sestavlja glavni vodonosni sistem in je močno zakrasela. Območje prekrivajo številne škraplje, vrtače, ponori, podzemni kanali in jame. V prispevku je bila izvedena analiza zmanjševanja pretoka na izvirih Gökpınar, izračunani sta bila količnika uskladiščenja in upadanja pretoka obeh glavnih izvirov. Količnik uskladiščenja je 141×10^6 m^3 oziroma 98×10^6 m^3, količnik upadanja pretoka pa 2.71×10^{-3} dan^{-1} oziroma 2.98×10^{-3} dan^{-1}. Dobljeni rezultati kažejo, da ima obravnavani vodonosnik Yüceyurtskega apnenca veliko zmogljivost uskladiščenja in zato je odvodnjavanje precej počasno. Glavni kationi v vodah na obravnavanem območju so Ca^{2+} in Mg^{2+}, med anioni pa prevladuje HCO_3^-. Vode so kalcij-bikarbonatnega tipa. Nekateri kemijski parametri v vodah izvirov Gökpınar se gibljejo med naslednjimi vrednostmi: T=10.8–11.1°C, pH=7.65–7.95, EC=270–310 μS/cm, TDS=170–200 mg/L, Ca^{2+}=40.0–54.0 mg/L, Mg^{2+}=4.5–10.0 mg/L, HCO_3^-=144.0–158.0 mg/L. Temperatura, EC, TDS, Ca^{2+} in HCO_3^- koncentracije niso v času opazovanja pokazale značilnih variacij.

Ključne besede: hidrogeologija, kras, podzemna voda, izviri Gökpınar, Sivas.

[1] Muğla Sıtkı Koçman University, Department of Geological Engineering, TR-48000 Muğla, Turkey, e-mail: fkacaroglu@mu.edu.tr

Received/Prejeto: 29.3.2010

INTRODUCTION

Karst terrains in the world are mostly composed of carbonate rocks. About one third of Turkey is covered by carbonate rocks, and most of these rocks are karstified. Karst groundwater is a major water resource for many settlements (e.g. Antalya, İskenderun) in the karstic regions of Turkey (Kaçaroğlu 1999). Carbonate rocks (limestone, dolomitic limestone) cover a large area in the vicinity of Gürün, south of Sivas, Turkey. Karstification has developed in most of these rocks. High-yield karst springs outflow from these karstified lithologies. Karstification also occurs in the gypsum in the region extending from the west to the east of Sivas, Turkey, and there are some large capacity gypsum karst springs (Kaçaroğlu *et al.* 1997, 2001).

Fig. 3: Gökpınar-2 spring (Photo: F. Kaçaroğlu).

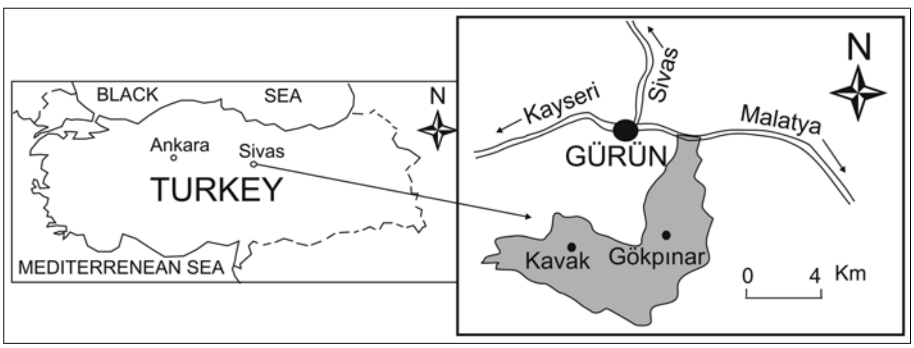

Fig. 1: Location map of the study area.

The water is used for fish production, power (electricity) generation and irrigation. This study was conducted to identify the hydrogeological and hydrogeochemical properties of the Gökpınar karst springs and karstic features of the study area. The study is the first hydrogeological investigation conducted on Gökpınar karst springs.

Fig. 2: Gökpınar-1 spring (Photo: F. Kaçaroğlu).

Fig. 4: Gökpınar stream (downstream of the Gökpınar springs, GD-1) (Photo: F. Kaçaroğlu).

Gökpınar karst springs are located 8 km to the south of Gürün district centre, Sivas, Turkey (Fig. 1). The springs discharge the groundwater in the karstified Jurassic-Cretaceous Yüceyurt formation (limestone) and have two main outlets. Gökpınar springs (Gökpınar-1 and Gökpınar-2) form two ponds at the discharge points (Figs. 2 & 3). The study area covers an area of about 200 km^2 which is drained by Gökpınar stream. Gökpınar stream (Fig. 4), mainly fed by Gökpınar karst springs, discharges into Tohma river (Fig. 5) which is a tributary of the Euphrates river. The Euphrates river and its tributaries constitute one of the largest trans-boundary river system in the Middle East and lie in Turkey, Syria and Iraq.

Fig. 5: Tohma river (upstream of the Gökpınar stream connection, TÇ-1) (Photo: F. Kaçaroğlu).

Field observations and mapping, discharge measurement on the streams and springs, water sampling and analyses were performed in order to achieve the purposes of the study. The flow measurement of the springs and streams were carried out by means of current meter. Temperature (T), pH, electrical conductivity (EC), and total dissolved solids (TDS) of the waters were measured at the time of the sample collection using portable (field-type) instruments. EC values were reported at 25°C. The measurement and analysis procedures given by APHA-AWWA-WPCF (1995) and Hem (1985) were followed during the field and laboratory work. The field work of the study were carried out between August 1995 and October 1996.

GEOLOGY

The study area is located within the Eastern Taurid Belt (Kurtman 1978; Atabey *et al.* 1994). In the area allochtonous and autochtonous sedimentary, ophiolitic and volcanic rocks crop out. The geological ages of these rocks range from Upper Devonian to Quaternary (Fig. 6). The geological setting of the area is described in the following paragraphs based on the studies of Kurtman (1978), Atabey (1993, 1996) and Atabey *et al.* (1994).

STRATIGRAPHY

Allochtonous lithological units (Fig. 6) consist of Munzur limestone (Triassic) and Pınarbaşı ophiolite (Jurassic-Cretaceous), whereas autocthonous units are Gümüşali (Upper Devonian), Yüceyurt (Jurassic-Cretaceous), Demiroluk (Eocene), Gövdelidağ (Upper Eocene-Lower Miocene), Gürün (Miocene) formations and Alluvium (Quaternary).

Munzur limestone (Mzm) is exposed in the eastern part of the area, and consists of medium-thick bedded, gray-white, yellowish coloured, fractured, partially karstified limestone. The thickness of the unit ranges between 400–750 m. Pınarbaşı ophiolite (Kp) crops out in a small area in the east, and formed of serpantine, serpantinized peridotite, piroxenite, harzburgite, dunite and gabro.

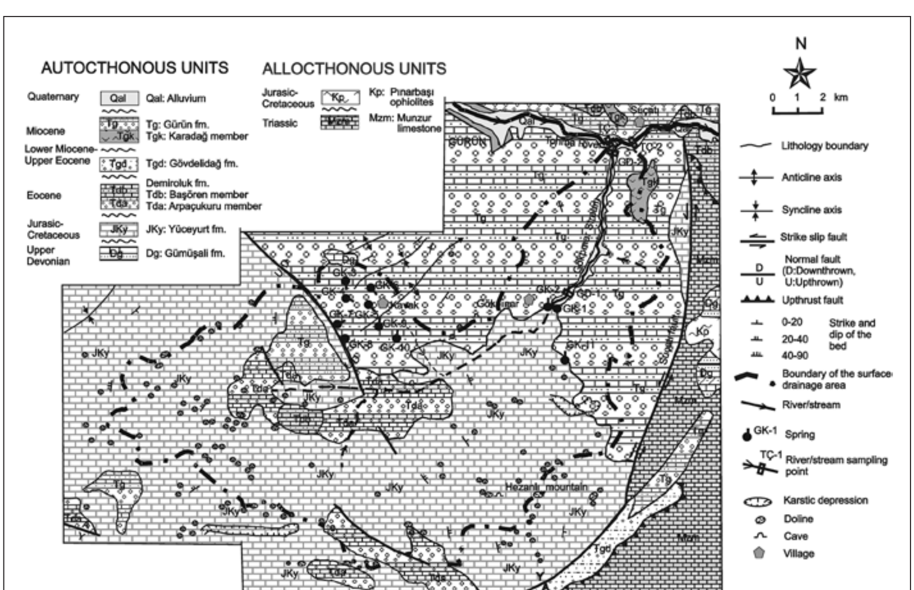

Fig. 6: Hydrogeological map of the study area (modified from Atabey et al. 1994 and Kaçaroğlu 2006).

Gümüşali formation (Dg) crops out in the eastern part of the area. It consists of algae, gastropoda, echinide, brachiopoda containing thin-medium bedded limestone, and alternating shale, mudstone and thin bedded sandstone. The thickness of the formation ranges between 200–250 m.

Yüceyurt formation (Jky) covers the largest part of the area. It comprises medium-thick bedded, grey-white, yellowish coloured limestone and dolomitic limestone at lower and middle parts of the sequence. The upper part of the unit consists of partially massive, white and pinkish coloured limestone. The unit is densely fractured, jointed and karstified. The thickness of the formation ranges between 400–1,100 m. The unit overlies Gümüşali formation and is overlain by Demiroluk formation unconformably.

Demiroluk formation (Td) is exposed at the central and southern parts of the study area. It comprises conglomerate, calcarenite, sandstone, limestone, marl and clayey limestone. The formation is divided into two members (Atabey *et al.* 1994) as Arpaçukuru member (Tda) and Başören member (Tdb). Arpaçukuru member consists of thick bedded conglomerate, calcarenite, thick bedded and massive limestone. The thickness of the member ranges between 50–200 m. Başören member is formed of alternating grey-greenish marl, thin layered calcarenite, clayey limestone, and very thick bedded (2–3 m) calcarenite and sandstone. The thickness of the member ranges between 200–400 m.

Gövdelidağ formation (Tgd) crops out in a small area at the southeast of the study area. The unit is formed of red, thick bedded and massive conglomerate and interlayers of thick bedded (0.5–1.0 m) sandstone, and brown, yellow coloured mudstone. The thickness of the formation ranges between 200–350 m. The unit overlies Demiroluk formation and overlain by Gürün formation unconformably.

Gürün formation (Tg), which was named by Kurtman (1978) is exposed at the north and northwest of the study area. The unit consists from the bottom to the top of conglomerate, sandstone, calcarenite, marl, mudstone, tuf, tufite, marl interlayered thin layered clayey limestone and medium-thick bedded or massive limestone (Atabey *et al.* 1994). This rock sequence is crossed by volcanic rocks or contain their interlayers at some localities. These volcanic rocks comprise tracky andesite, andesite, tuf, aglomerate and lava, and were identified as Karadağ member (Tgk) by Kurtman (1978). Tracky andesite has columnar and jointed structure.

Alluvium (Qal) is exposed along the Tohma river and Gökpınar stream valleys. It consists of loose gravel, sand, silt, and clay. Locally clay lenses and cross-bedding is present in the alluvium.

TECTONICS

The study area is located in the Taurid Tectonic Belt (Kurtman 1978). The geological evolution of the region was completed between Upper Devonian and Quaternary. Pınarbaşı ophiolite replaced over the carbonate rocks (Munzur limestone) during pre-Maestrichtian. Due to the compressional regime which initiated in Upper Paleocene period folds, overthrusts, strike slip and normal faults have developed (Fig. 6). Munzur limestone thrusted over autochtonous lithological units. The folds (anticlines and synclines) developed in Gürün formation strike in NE–SW direction. In Miocene N–S directed Suçatı strike-slip fault formed, and crossed pre-Pliocene aged rocks (Atabey *et al.* 1994). The rocks in the study area have gained fractured and jointed character at different degrees depending on the lithological and physical properties. Jointed structure is apparent especially in limestones.

KARST HYDROGEOLOGY

KARST FEATURES

Karst areas are characterized by the occurrence of the various type and size karst features and karst landforms. In the study area (Fig. 6), small scale solution sculpture and large scale karst landforms and features have developed mostly in the Yüceyurt limestone. Small scale solution sculpture consists of microkarren, karren, solution pits and solution pans. Large scale karst landforms in the study area are dolines (sinkholes), ponors (swallow holes), and closed depressions. Some caves were also observed in the study area.

Karren are the most developed karst landforms in the study area. The dimensions of the karren range in general from a few centimeters up to 10 meters in length, and from a few centimeters to 1 meter in width and depth. Some karren chanels are filled by excess soil. They are dominantly of "rundkarren" type (Bögli 1980; Ford & Williams 2007) which have rounded cross section.

On the Yüceyurt formation which mostly consists of thick bedded or massive limestone, karren form limestone pavements in some bare areas. The dimensions of the pavement areas in the study area extend up to a few hundred meters. Limestone pavements develop best upon thick to massive bedded strata where strata are flat-lying or gently dipping (Ford & Williams 2007). Alpine relief and climate particularly encourages bare-pavement karst, with joint enlargement (kluftkarren) and little soil cover (LaFleur 1999).

Solution pits which are among the observed karst landforms in the study area have circular, elliptical or irregular plan view, and their diameter range from a few centimetres to several decimetres. Some pits are aligned, and located along the joints. Solution pans have flat or nearly flat bottoms, and are generally observed on bare rock.

Dolines are among the karst landforms that give karst topography its particular character, and are caused by dissolution, collapse, suffosion, or subsidence processes. In the study area dolines are widely distributed karst landforms. The dolines in the study area which were probably caused by dissolution or collapse, are mostly distributed in the south and west parts of the area at high altitudes, and often follow structural trends and lineaments. They are usually circular to subcircular in plan view and have diameters ranging from a few meters to some hundred meters.

Ponors (swallow holes) are the places where the water from allogenic sources inflows into karst aquifer and make important contribution to the karst groundwater recharge process. The water goes underground via a ponor as a sinking stream, concentrated recharge, or from ponded water. Ponors observed in the study area are generally located at the bottom or along the periphery of the closed depressions, along the fault and fracture zones, and along the stream beds. They have irregular or subcircular shape and the dimensions reach up to a few meters.

Large scale closed depressions are scarse in the study area in comparison to the number of dolines. Closed depressions tend to be broad and shallow. Their length in the study area reach up to several hundred meters.

KARST SPRINGS

The groundwater flow system in the karst aquifer of the Gökpınar springs (Yüceyurt formation) is characterized by relatively uniform flow and reasonably uniformity of the hydrochemistry of the springs. In the study area two large capacity karst springs, named Gökpınar-1 (GK-1) (Fig. 2) and Gökpınar-2 (GK-2) (Fig. 3) springs, outflow from the Jurassic-Cretaceous Yüceyurt formation (Fig. 6 & Tab. 1). These springs constitute two main discharge points of the karstic aquifer, and are located on the boundary of the Yüceyurt and Gürün formations. There are also nine low yield (0.5 to 3.0 L/s) springs (Tab. 1) in the study area outflowing from Yüceyurt and Gürün formations (Kaçaroğlu 2001, 2006). Karst springs commonly appear at the contact between a carbonate-rock massif and low-permeability layers (Bonacci 2001).

Gökpınar-1 spring (Fig. 2) is located in the east part of the study area. It outflows through the bottom of a funnel-shaped depression (approximately 100 m in length, 40 m in width), forms a "rise pond" (White 2002), with a maximum depth of 15 m, and discharges its water into Gökpınar stream via a channel. Discharge of the spring ranges between 2,415–4,425 m^3/s (Tab. 1).

Gökpınar-2 spring (Fig. 3) is located about 100 m to the west of the Gökpınar-1 spring and issues from the limestone aquifer through solution channels. The spring forms a pond (approximately 40 m in length, 15 m in width, and maximum depth is 2 m), and discharges its water into Gökpınar stream via a channel. Discharge of the spring ranges 2,175–3,395 m^3/s.

The discharges of the Gökpınar-1 and Gökpınar-2 springs does not have considerable variations between wet and dry months. This situation may be attributed to slow response character of the karst aquifer (Yüceyurt formation). In slow response aquifers the throughput time is sufficiently long to completely flatten the individual hydrographs, and a broad rise and fall relating to wet and dry seasons is observed (White 1999). Hershey *et al.* (2010) claimed that large and consistent spring discharges suggest a supporting groundwater system that is recharged over a large area where natural small-scale variations in recharge are smoothed.

Tab. 1: Springs in the study area.

Spring no.	*Name of the spring*	*Aquifer lithology (formation)*	*Altitude a.s.l. (m)*	*Discharge (L/s)*	*Date of measurement*
GK-1	Gökpınar-1	Limestone (Yüceyurt fm.)	1,445	2,415 4,425	22.04.1996 16.07.1996
GK-2	Gökpınar-2	Limestone (Yüceyurt fm.)	1,450	2,176 3,395	31.10.1995 16.07.1996
GK-3	Serkiz Dere	Limestone (Gürün fm)	1,920	1.0	04.08.1995
GK-4	Kale Dere	Limestone – Clayey limestone (Gürün fm.)	1,890	3.0	04.08.1995
GK-5	Büyük çeşme (Kavak)	Clayey limestone (Gürün fm.)	1,820	2.0	04.08.1995
GK-6	Körpınar	Limestone (Gürün fm)	1,880	2.0	04.08.1995
GK-7	Dönükpınar	Limestone (Gürün fm.)	1,870	0.5	04.08.1995
GK-8	Küçükyazılı	Limestone (Gürün fm.)	1,880	1.0	04.08.1995
GK-9	Halacoğlu	Limestone (Gürün fm.)	1,850	0.5	04.08.1995
GK-10	Akpınar	Limestone (Gürün fm.)	1,820	0.5	04.08.1995
GK-11	Yelken	Limestone (Yüceyurt fm.)	1,650	1.0	04.08.1995

A parallel trend exists between spring discharges and temperatures (Fig. 7). During high discharges, in general, the temperatures are also high. High values of discharge and temperature are observed during hot months. The water temperature of the Gökpınar springs ranges between 10.8–11.1°C, and variation is only 0.3°C. Based on Gürün meteorological station data (1973–1995), mean monthly temperature ranges between -3.5°C (January) and 21.4°C (July), and the mean annual temperature is 9.2°C. High water temperatures of the Gökpınar springs, greater than the mean air temperature, are likely to be the consequence of the groundwater circulation system within the karst aquifer.

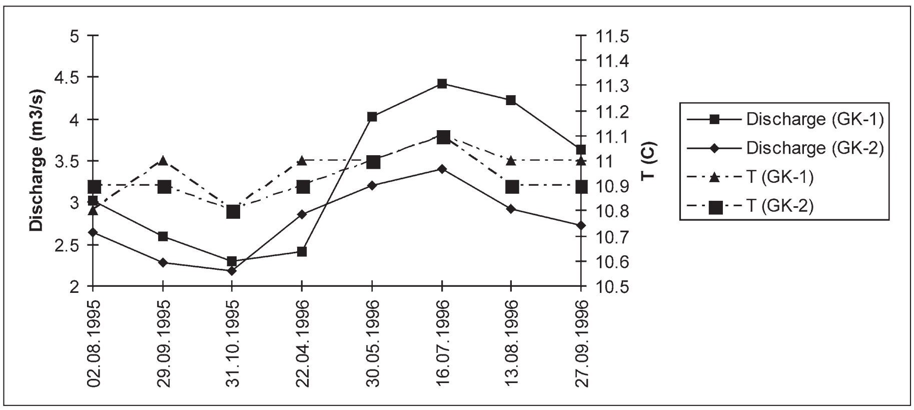

Fig. 7: Variation of the discharge and temperature of the Gökpınar springs in time.

RECHARGE OF THE KARST AQUIFER

In karst areas "localized recharge" (Lerner 1997; Hendrickx & Walker 1997) type of groundwater recharge is generally dominated. During localized recharge, the water percolates rapidly into karst aquifer through cracks, fissures or solution channels (De Vries & Simmers 2002). In dry season, the recharge of the karst aquifer is much smaller. High-intensity winter precipitation is highly effective in enhancing recharge. During the wet season (between November and May in the Mediterranean region) 70–90% of the precipitation recharges the karst aquifer (Milanovic 1981). Hoetzl (1995) reported that on an exposed karst area in Saudi Arabia, 45% of the average rainfall disappears into sinkholes and corrosionally extended joints. Günay & Yayan (1979) calculated the infiltration percent of the precipitation as 45% for Kırkgöz karst springs (Antalya, Turkey) using discharges of the springs.

The movement of the water through the karst aquifer depends upon matrix (intergranular), fracture and solution (conduit) permeability. In karst aquifers the water flow through the karst conduits is dominated. The karst aquifer in the study area (Yüceyurt limestone) is fed mainly from infiltration of the precipitation. The precipitation falling over the karstified limestone outcrops easily infiltrates through a great number of joints, fractures, solution channels, sinkholes, and ponors. In addition, there is indirect recharge from infiltration of temporary surface waters. The drainage of the Yüceyurt formation is almost entirely underground.

The study area is located in a transition zone between typical semi-arid climate of Central Anatolia and Mediterranean climate. The climate is characterised by dry and warm summers and a cold and wet period that occurs during autumn, winter and spring. Precipitation distribution over the year is irregular. The monthly precipitation reaches a maximum during April and a minimum in August. Precipitation primarily occurs during cold seasons, and its distribution among the months allows a higher infiltration into the karst aquifer. The precipitation occurs mostly as snow during winter (December–March), which can have a significant effect on the recharge of the groundwater in the karst aquifer. According to Fiorillo (2009), in Mediterranean climates, the precipitation that occurs up to March–April of each hydrological year recharges karst aquifers, and subsequent precipitation, up to September–October, generally does not recharge the aquifers.

In the flow systems of the carbonate rock province, recharge is commonly derived from precipitation in the mountains. The higher mountains receive larger amounts of precipitation and generate the higher portion of recharge (Hershey *et al.* 2010). The mean annual precipitation values of the meteorological stations in the vicinity of the study area range between 306 mm and 740 mm (Tab. 2). The precipitation generally increases with altitude of the station. Kandil, Sevdili and Adatepe stations are situated to the south of the study area and receive the precipitation mainly under the influence of the moist air front coming from Eastern Mediterranean Sea. The meteorological data of the above mentioned stations are limited and there is no meteorological station at high altitudes (above 1,500 m a.s.l.) in the vicinity of the study area. Hezanlı Mountain (2,283 m a.s.l.) constitutes an important part of the Gökpınar Springs' recharge area which lies between 1,450 m and 2283 m a.s.l. The precipitation amounts recorded at meteorological stations

Tab. 2: Mean annual precipitations of the meteorological stations in the vicinity of the study area.

Station name	***Operating organization***	***Altitude of the station (m)***	***Gauging period***	***Mean annual precipitation (mm)***
Gürün	DMİ	1,250	1980–1995	306
Kandil	DSİ	1,280	1981–1995	411
Sevdili	DSİ	1,470	1981–1995	355
Adatepe	DSİ	1,330	1981–1995	740

Tab. 3: Discharges of the Gökpınar springs (m^3/s), and discharge coefficients (α) and storage capacities (V_s) calculated from spring discharge hydrograph.

Date of measurement	***Gökpınar-1 spring (GK-1)***	***Gökpınar-2 spring (GK-2)***	***Total of the GK-1 and GK-2***
02.08.1995	3.015	2.650	5.665
29.09.1995	2.595	2.280	4.875
31.10.1995	2.295	2.175	4.470
22.04.1996	2.415	2.865	5.280
30.05.1996	4.025	3.200	7.225
16.07.1996	4.425	3.395	7.820
13.08.1996	4.225	2.925	7.150
27.09.1996	3.630	2.730	6.360
Average discharge	3.320	2.780	6.100
Discharge coefficient, α (day^{-1})	2.71×10^{-3}	2.98×10^{-3}	
Storage capacity, V_s (m^3)	141×10^{6} (141,000,000)	98×10^{6} (98,000,000)	

(Tab. 2) may easily increase by a factor of two or more at higher elevations of the recharge area. Because of the scarcity of the meteorological data, calculation of a complete water budget could not be performed.

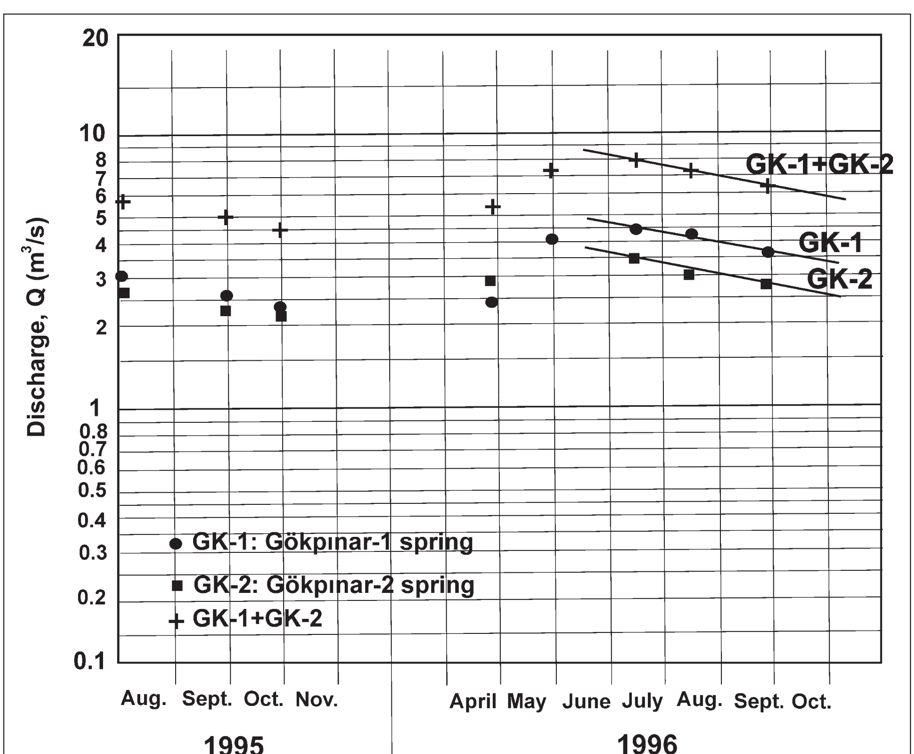

Fig. 8: Discharge graph of the Gökpınar springs (modified from Kaçaroğlu 2006).

DISCHARGE OF THE SPRINGS

The discharges of the Gökpınar springs, Gökpınar stream and Tohma river measured during the field work of this study are given in Tab. 3 and Tab. 4. In springs the minimum discharges were measured in September 1996 and October 1995, and the maximum in July 1996. The minimum discharge in Gökpınar stream is in October, and maximum discharge is in July. Gökpınar stream is mainly fed by the water discharged via Gökpınar springs. The upstream segment of the Gökpınar stream is an intermittent stream which is dry during a long period of the year. Gökpınar stream makes a great contribution to the discharges of the Tohma river (Tab. 4).

Analysis of the spring recession hydrograph offers considerable potential insight into the nature and operation of the karst drainage system and provide information on the volume of water held in storage (Bonacci 1993). It also allows calculating the amount of the water drained through a particular spring from the beginning of the recession. These characteristics are important for evaluating water resources, especially in water deficient regions (Amit *et al.* 2002).

The period after the spring rains, in some precipitation regimes, when the water input into the aquifer is practically zero (recession period) is the most suitable

Tab. 4: Discharges of Gökpınar stream and Tohma river (m³/s).

Stream/river/ measurement point	*Location of the measurement point*	*Date of measurement*							
		Aug 1995	*Sep 1995*	*Oct 1995*	*Apr 1996*	*May 1996*	*July 1996*	*Aug 1996*	*Sep 1996*
Gökpınar stream GD-1	Downstream of the Gökpınar springs	5.665	4.875	4.475	5.410	7.275	7.820	7.155	6.060
Gökpınar stream GD-2	Suçatı-Upstream of the Tohma river connection	6.250	5.100	5.250	5.850	7.850	8.350	8.085	6.665
Tohma river TÇ-1	Suçatı-Upstream of the Gökpınar stream connection	0.950	1.510	1.815	6.905	3.180	2.570	1.925	2.245
Tohma river TÇ-2	Suçatı-Downstream of the Gökpınar stream connection	7.100	6.650	7.050	13.00	11.25	10.92	10.10	8.910

for this analysis (Milanovic 1981; Ford & Williams 2007; Bonacci 2001; White 2002). Maillet (1905) provided the first mathematical characterization of the baseflow recession. This interpretation is based on the drainage of a simple reservoir (Kovacs *et al.* 2005).

In dry period, during which there is no water input into the aquifer, the dynamic water reserve in the aquifer from which the spring outflows decreases as a function of time, and the groundwater level declines. Maillet (1905) proposed that the discharge of a spring is a function of the water volume held in storage and described it by the simple exponential relation (Milanovic 1981; Ford & Williams 2007):

$$Q_t = Q_o.e^{-\alpha t} \text{ or } Q_t = Q_o.e^{-\alpha(t-to)} \qquad (1)$$

where Q_t is the discharge (m³/s) at time t; Q_o is previous discharge at time zero (t_o); t (or t-t_o) is the time elapsed (usually expressed in days) between Q_t and Q_o; e is the base of the natural logarithm; and α is termed recession (discharge) coefficient [T^{-1}].

Maillet's (1905) equation recession analysis of the discharges of the Gökpınar springs (Tab. 3 & Fig. 8) were performed, and recession coefficients (α) and dynamic volume (storage capacity, V_s) of the aquifer were calculated. The recession (discharge) coefficients of the Gökpınar-1 (GK-1) and Gökpınar-2 (GK-2) springs are α_{GK-1}= 2.71×10⁻³ day⁻¹ and α_{GK-2}= 2.98×10⁻³ day⁻¹, and dynamic volume (storage capacity) values are $V_{s(GK-1)}$= 141×10⁶ m³ and $V_{s(GK-2)}$= 98×10⁶ m³.

The value of the recession coefficient derives from the hydrogeological characteristics of the aquifer, especially effective porosity and transmissivity. It represents the capability of the aquifer to release water. Small values of α indicate very slow drainage of the karst aquifer with a large storage capacity. The springs of this type of aquifer are mostly permanent. Large values of α (the recession curve is steep) indicate rapid drainage of conduits and little underground storage (Milanovic 1981; Ford & Williams 2007).

The values of the recession coefficients calculated for Gökpınar springs and little changes in the discharge through the year indicate that the Yüceyurt limestone karst aquifer has a large storage capacity and the drainage occurs very slowly. The discharge of the springs are not being directly affected by the monthly variations of the precipitation.

Recession coefficients were calculated using Maillet (1905) approach for some large karst springs in Taurid Karst Belt (Turkey) by various researchers. Çelik & Afşin (1996) obtained a mean value of 6.92×10^{-3} day^{-1} for Kazanpınarı karst spring in Elmalı Polje, Antalya. Günay & Yayan (1979) calculated recession coefficients rangin from 3.1×10^{-3} day^{-1} to 6.2×10^{-3} day^{-1} for Kırgöz karst springs, north of Antalya. Yevjevich (1985) obtained a recession coefficient of 2.6×10^{-3} day^{-1} for Dumanlı spring, Manavgat river basin-Antalya. Similar recession coefficient values of the Gökpınar springs and the above mentioned springs may be interpreted as karst aquifer of the Gökpınar springs (Yüceyurt limestone) has similar hydrogeological characteristics that of the karst aquifers in the Antalya region. As mentioned before the study area is located in the eastern part of the Taurid Karst Belt.

HYDROCHEMISTRY

CHEMICAL CHARACTER OF THE WATERS

Carbonate reactions are very important in controlling the composition of groundwater. Rocks made of carbonates, such as limestones and dolomites, are often aquifers that have a high productivity. The main minerals in these rocks are Ca- and Mg- carbonates which react

Tab. 5: Water analyses data of the Gökpınar springs.

Samp. no.	Date of sampling	T (°C)	pH	EC (μS/cm)	TDS (mg/L)	Cations (mg/L)				Anions (mg/L)				Hardness (mg/L $CaCO_3$)	Ca/Mg
						Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4		
Sampling point: Gökpınar-1 spring (GK-1)															
1	02.08.1995	10.8	7.65	280	180	2.4	1.0	40.0	9.0	0.0	150.0	5.5	11.0	137	2.695
22	29.09.1995	11.0	7.90	295	190	2.3	0.9	46.0	8.5	0.0	153.0	7.5	12.5	150	3.281
32	31.10.1995	10.8	7.92	305	180	2.1	1.0	48.0	8.0	0.0	153.0	9.0	11.5	155	3.638
43	24.04.1996	11.0	7.80	310	200	2.6	1.2	50.0	6.0	0.0	150.0	5.5	16.5	150	5.053
52	30.05.1996	11.0	7.85	298	190	2.4	1.1	54.0	5.0	0.0	158.0	3.5	16.0	156	6.548
62	17.07.1996	11.1	7.75	270	180	2.2	1.0	48.0	4.5	0.0	147.0	5.0	12.0	139	6.467
72	13.08.1996	11.0	7.85	285	180	2.0	0.9	46.0	5.0	0.0	150.0	4.5	11.5	136	5.578
82	27.09.1996	11.0	7.85	280	180	2.1	1.0	48.0	6.0	0.0	145.0	5.0	13.5	145	4.851
Minimum		10.8	7.65	270	180	2.0	0.9	40.0	4.5	0.0	145.0	3.5	11.0	136	2.695
Maximum		11.1	7.92	310	200	2.6	1.2	54.0	9.0	0.0	158.0	9.0	16.5	156	6.548
Mean		11.0	7.82	290	185	2.3	1.0	47.5	6.5	0.0	151.0	5.7	13.1	146	4.431
Sampling point: Gökpınar-2 spring (GK-2)															
2	02.08.1995	10.9	7.80	285	190	2.5	1.1	40.0	10.0	0.0	144.0	5.5	11.5	141	2.425
21	29.09.1995	10.9	7.95	307	200	2.3	1.0	44.0	10.0	0.0	153.0	7.5	12.0	151	2.668
31	31.10.1995	10.8	7.90	306	200	2.2	0.9	48.0	8.5	0.0	150.0	7.0	12.0	155	3.424
42	24.04.1996	10.9	7.65	310	200	2.5	1.3	50.0	6.0	0.0	150.0	5.5	16.5	150	5.053
51	30.05.1996	11.0	7.85	298	190	2.8	1.2	54.0	5.0	0.0	158.0	3.5	13.0	156	6.548
61	17.07.1996	11.1	7.90	285	190	2.4	1.1	50.0	6.0	0.0	153.0	3.5	12.0	150	5.053
71	13.08.1996	10.9	7.95	270	170	2.1	1.0	44.0	6.5	0.0	150.0	4.5	9.0	137	4.104
81	27.09.1996	10.9	7.95	285	180	2.3	1.1	50.0	5.0	0.0	147.0	5.0	14.0	146	6.063
Minimum		10.8	7.65	270	170	2.1	0.9	40.0	5.0	0.0	144.0	3.5	9.0	137	2.425
Maximum		11.1	7.95	310	200	2.8	1.3	54.0	10.0	0.0	158.0	7.5	16.5	156	6.548
Mean		10.9	7.87	293	190	2.4	1.1	47.5	7.1	0.0	151.0	5.3	12.5	148	4.056

easily with groundwater and give water its "hard" character (Appello & Postma 1996). The physico-chemical characteristics of groundwaters in karstic systems are determined by the lithology of the rocks that they cross, the physico-chemical processes that predominate, the residence time of water and the various conditions and modes of circulation that coexist within them (Lopez-Chicano *et al.* 2001).

In order to identify the chemical character of the waters of the karst springs, field measurements and laboratory analyses were carried out on the water samples collected between August 1995–September 1996 (Tabs. 5 & 6).

The waters of the Gökpınar springs and the other low yield springs are not rich (Tabs. 5 & 6) in major ions and total dissolved solids. Total dissolved solids (TDS) are moderate according to the classification proposed by Smith *et al.* (1993). The order of predominance of ions of the spring waters is Ca^{2+}>Mg^{2+}>Na^{+} for cations and HCO_3^->SO_4^{2+}>Cl^- for the anions. Ca^{2+} and HCO_3^- are dominant dissolved species in the waters of the Gökpınar springs and low yield springs due to the mineralogical composition of the karst aquifer. This also indicate the dissolution and precipitation of the predominant carbonate rocks in the aquifer.

The mean values of the water quality parameters in Gökpınar-1 (GK-1) spring waters are as follows (Tab. 5): T=11.0°C, pH=7.82, EC=290 mS/cm, TDS=185 mg/L, Na^+=2.3 mg/L, K^+=1.0 mg/L, Ca^{2+}=47.5 mg/L, Mg^{2+}=6.5 mg/L, HCO_3^-=151.0 mg/L, Cl^-=5.7 mg/L, SO_4^{2+}=13.1 mg/L, Hardness=146 mg/L $CaCO_3$. The mean values of the same parameters for Gökpınar-2 (GK-2) spring waters are 10.9°C, 7.87, 293 mS/cm, 190 mg/L, 2.4 mg/L, 1.1 mg/L, 47.5 mg/L, 7.1 mg/L, 151.0 mg/L, 5.3 mg/L, 12.5 mg/L, 148 mg/L $CaCO_3$, respectively. In both springs these parameters and the amounts of the dissolved ions do not change significantly between wet and dry seasons. EC, TDS, and cation and anion concentrations of the Gökpınar springs have lower values which may be attributed to the short residence time of the water in the karst aquifer.

The ranges of the water quality parameters of the low yield springs are as follows (Tab. 6): EC=270–435S/cm,TDS=180–230mg/L,Na^+=1.4–4.2mg/L, K^+=0.5–3.4 mg/L, Ca^{2+}=38–60 mg/L, Mg^{2+}=4.5–10 mg/L, HCO_3^-=134–198 mg/L, Cl^-=3.5–10.5 mg/L, SO_4^{2+}=3.0–19.5 mg/L, Hardness=125–181 mg/L $CaCO_3$.

In a study of the carbonate springs in the central Appalachians, Shuster & White (1971) observed that

Tab. 6: Water analyses data of the low yield springs in the Gökpınar basin for August 1995 period.

Samp. no.	Spring no.	Name of the spring	Date of sampling	T (°C)	pH	EC (μS/cm)	TDS (mg/L)	Cations (mg/L)				Anions (mg/L)				Hardness (mg/L $CaCO_3$)
								Na	K	Ca	Mg	CO_3	HCO_3	Cl	SO_4	
6	GK-3	Serkiz dere	04.08.1995	9.4	7.65	295	190	1.4	0.5	42.0	5.0	0.0	147.0	7.5	3.0	126
7	GK-4	Kaledere	04.08.1995	10.0	8.25	270	180	1.4	0.7	46.0	5.0	3.0	134.0	7.0	7.0	136
8	GK-5	Büyük çeşme	04.08.1995	9.5	7.55	345	230	2.1	3.4	50.0	8.5	0.0	189.0	7.5	8.5	160
9	GK-6	Körpınar	04.08.1995	10.6	7.90	335	220	3.5	0.8	50.0	6.0	0.0	177.0	10.5	9.5	150
10	GK-7	Dönükpınar	04.08.1995	9.4	7.70	335	220	2.0	1.3	50.0	5.5	0.0	168.0	9.0	9.0	148
11	GK-8	Küçükyazılı	04.08.1995	8.5	7.55	300	200	1.8	1.0	45.0	5.0	0.0	159.0	3.5	7.5	133
12	GK-9	Halacoğlu	04.08.1995	8.3	7.70	295	190	1.4	0.8	38.0	8.5	0.0	162.0	7.5	6.5	130
13	GK-10	Akpınar	04.08.1995	8.3	7.80	285	190	1.4	0.7	40.0	6.0	0.0	150.0	7.0	4.0	125
14	GK-11	Yelken	04.08.1995	11.7	7.65	435	290	4.2	1.2	60.0	7.5	0.0	198.0	9.0	19.5	181
Minimum				8.3	7.55	270	180	1.4	0.5	38.0	5.0	0.0	134.0	3.5	3.0	125
Maximum				11.7	8.25	435	290	4.2	3.4	60.0	10.0	3.0	198.0	10.5	19.5	181

Tab. 7: Saturation indices of the water samples from the Gökpınar springs.

Samp. no.	Samp. point	Date of sampling	Anhydrite	Aragonite	Calcite	Dolomite (d)	Dolomite (c)	Gypsum	Halite
Sampling point: Gökpınar-1 spring (GK-1)									
1	GK-1	02.08.1995	-2.908	-0.345	-0.190	-1.505	-0.894	-2.653	-9.399
22	GK-1	29.09.1995	-2.805	-0.032	0.122	-0.959	-0.349	-2.550	-9.285
32	GK-1	31.10.1995	-2.824	0.002	0.157	-0.939	-0.329	-2.569	-9.246
43	GK-1	24.04.1996	-2.650	-0.104	0.050	-1.291	-0.681	-2.395	-9.367
52	GK-1	30.05.1996	-2.635	-0.002	0.153	-1.198	-0.588	-2.380	-9.599
62	GK-1	17.07.1996	-2.793	-0.172	-0.017	-1.531	-0.922	-2.538	-9.479
72	GK-1	13.08.1996	-2.828	-0.083	0.071	-1.292	-0.683	-2.573	-9.566
82	GK-1	27.09.1996	-2.747	-0.083	0.071	-1.231	-0.621	-2.492	-9.500
Sampling point: Gökpınar-2 spring (GK-2)									
2	GK-2	02.08.1995	-2.891	-0.214	-0.059	-1.194	-0.583	-2.636	-9.382
21	GK-2	29.09.1995	-2.843	-0.004	0.150	-0.815	-0.205	-2.588	-9.285
31	GK-2	31.10.1995	-2.806	-0.026	0.128	-0.970	-0.359	-2.551	-9.334
42	GK-2	24.04.1996	-2.649	-0.254	-0.100	-1.593	0.983	-2.394	-9.384
51	GK-2	30.05.1996	-2.723	0.000	0.154	-1.195	-0.585	-2.468	-9.532
61	GK-2	17.07.1996	-2.785	0.007	0.161	-1.067	-0.457	-2.531	-9.598
71	GK-2	13.08.1996	-2.953	-0.005	0.150	-1.004	-0.394	-2.698	-9.544
81	GK-2	27.09.1996	-2.716	0.036	0.191	-1.091	-0.481	-2.461	-9.460

conduit springs were very variable in hardness throughout of the year (coefficient of variation 10–24%). Diffuse springs had a rather constant hardness (coefficient of variation <5%). The hardness of the Gökpınar streams do not show considerable changes in time. The coefficient of the variation of the hardness for GK-1 and GK-2 are 5.5% and 4.5%, respectively. Regarding the classification of the Shuster and White (1971) Gökpınar springs do not exhibit complete diffuse and conduit type character.

Jacobson & Langmuir (1974) investigated the discharge and geochemistry of the carbonate springs in central Pennsylvania. The researchers distinguished three types of karst springs as conduit, diffuse-conduit, and diffuse. The water chemistry data of the Gökpınar springs suggest that they are conduit type regarding to the EC values (EC 270–310 S/cm), and are diffuse type regarding to the coefficients of variation of the EC (4.8%) and discharge (26% for GK-1 and 15% for GK-2). The discharges of the Gökpınar springs show larger variation than the other chemical variables. Jacobson & Langmuir (1974) explains such a situation by buffering effect on the water quality relative to discharge.

Ca^{2+}, HCO_3^- and hardness concentrations of the Gökpınar springs do not change markedly with time while Mg^{2+} concentrations exhibit significant change in time. On an equivalent basis (meq/L) Ca^{2+}/Mg^{2+} ratios of the Gökpınar springs range from 2.7 to 6.6 for GK-1, and from 2.4 to 6.6 for GK-2 (Tab. 5). These ratios indicate mainly limestone dissolution and consistent with the fact that the springs issue from Yüceyurt formation which mainly consists of limestone and partially dolomitic limestone. The Ca^{2+}/Mg^{2+} ratio provides information on the rock type through which the groundwater has passed. The Ca^{2+}/Mg^{2+} ratio ranges from 1 to 1.5 for dolomite aquifers, and from 6 to 8 for limestone aquifers. Intermediate values indicate a dolomitic limestone or a mixed limestone-dolomite sequence (White 1999).

HCO_3^- is the dominant dissolved anion in the waters of the study area. HCO_3^- concentrations of the Gökpınar springs varies between 144 and 158 mg/L. In low yield springs HCO_3^- contents range from 134 to 198 mg/L. On an equivalent basis (meq/L), HCO_3 accounts for 85% to 86% of the anions in Gökpınar springs and 83% to 86% of the anions in low yield springs. The high concentrations of HCO_3^- in the water indicate intensive chemical weathering mainly carbonate dissolution occurring in the recharge area of the springs which is consistent with the lithological composition of the karst aquifer.

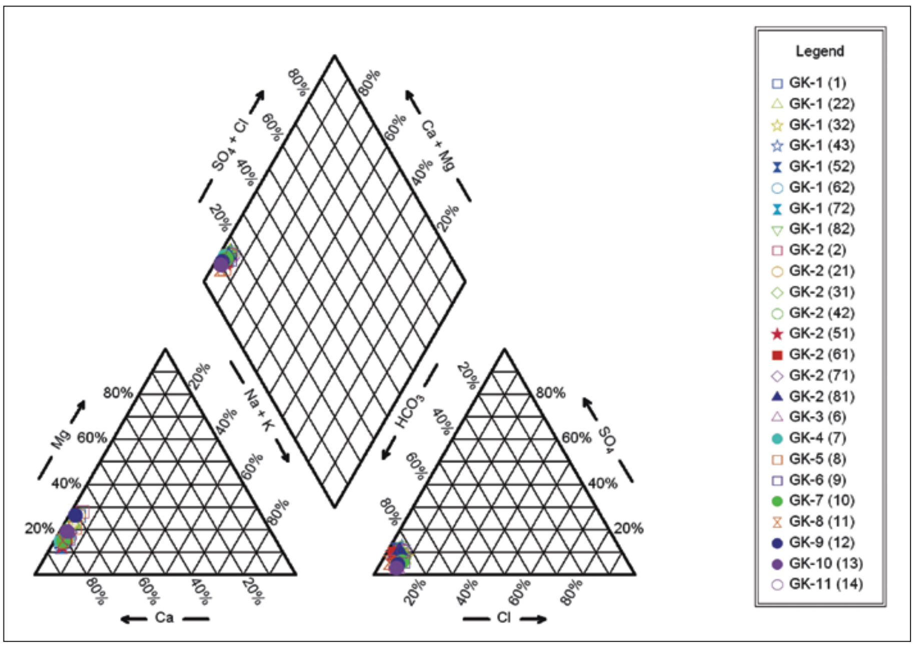

Fig. 9: Classification of the spring waters in the Piper diagram.

The water analyses are presented in a Piper diagram (Piper 1944) (Fig. 9). The diagram represents the concentrations as percentages. Using this diagram the water analyses can be classified into types or hydrochemical facieses (Back 1966). The diagram displays the relations between rock type and water composition, and evolution of the composition along its route (Appelo & Postma 1996; Drever 1997). The water samples plotted near the left corners of the cation and anion triangles, and are rich in Ca^{2+} and HCO_3^-. Therefore, with regard to the Piper diagram (Fig. 9), all waters are "calcium bicarbonate" type.

Regarding the limits in Turkish Drinking Water Standards (TSE 2005) all spring waters in the study area are suitable for drinking. The recharge area of the Gökpınar springs is sparsely populated and there is no industrial, mining and agricultural activity that may cause water pollution.

SATURATION STATE

The saturation indices (SI) describe quantitatively the deviation of water from equilibrium with respect to dis-

Tab. 8: Saturation indices of the water samples from low yield springs in the Gökpınar basin for August 1995 period.

Samp. no	Spring no	Name of the spring	Date of sampling	Anhaydrite	Aragonite	Calcite	Dolomite (d)	Dolomite (c)	Gypsum	Halite
6	GK-3	Serkiz dere	04.08.1995	-3.433	-0.346	-0.191	-1.814	-1.197	-3.177	-9.492
7	GK-4	Kaledere	04.08.1995	--3.037	0.247	0.402	-0.651	-0.037	-2.782	-9.525
8	GK-5	Büyük çeşme	04.08.1995	-2.945	-0.281	-0.125	-1.526	-0.910	-2.689	-9.324
9	GK-6	Körpınar	04.08.1995	-2.892	0.058	0.212	-0.975	-0.364	-2.637	-8.957
10	GK-7	Dönükpınar	04.08.1995	-2.907	-0.178	-0.023	-1.512	-0.895	-2.651	-9.263
11	GK-8	Küçükyazılı	04.08.1995	-3.013	-0.403	-0.247	-1.977	-1.356	-2.757	-9.714
12	GK-9	Halacoğlu	04.08.1995	-3.147	-0.323	-0.166	-1.517	-0.895	-2.890	-9.491
13	GK-10	Akpınar	04.08.1995	-3.327	-0.229	-0.073	-1.503	-0.882	-3.070	-9.519
14	GK-11	Yelken	04.08.1995	-2.534	0.136	0.290	-0.777	-0.171	-2.280	-8.953

solved minerals. If the water is exactly saturated with the dissolving mineral, saturation index equals to zero (SI=0). Positive values of SI indicate saturation, and negative ones indicate undersaturation. Saturation state indicates the direction of the processes; for undersaturation dissolution is expected, and supersaturation suggests precipitation.

Saturation indices for anhydrite, aragonite, calcite, dolomite, gypsum and halite minerals were calculated (Tabs. 7 & 8) using WATEQF computer program (Plummer et al. 1984). The values of the saturation indices for dolomite are given as dolomite (c) and dolomite (d) in Tabs. 7 & 8. "The (c) and (d) refer well-crystallized (ordered) and disordered dolomite respectively. Well-ordered crystals are always less soluble than disordered crystals. The WATEQ4F database includes separate solubilities for crystalline and disordered forms for some solids" (Drever 1977).

All spring waters in the study area are undersaturated with respect to anhydrite, gypsum and halite minerals (Tabs. 7 & 8). Gökpınar springs (GK-1 and GK-2) are generally undersaturated or slightly saturated with respect to aragonite, slightly saturated for calcite, and undersaturated for dolomite. In August 1995 period, low yield springs in the study area are undersaturated with respect to dolomite, and undersaturated or slightly saturated for aragonite and calcite minerals. Saturation with respect to calcite and undersaturation to dolomite of the Gökpınar springs is in consistence with the mineralogical composition of the karst aquifer lithology. White (1977) states that most chemical reactions occur near the recharge zone of the karst aquifer, and solution rates are highest in the initial stages of the flow paths and decreases considerably within short distances of the recharge zone.

Saturation index (SI) values for calcite calculated for Gökpınar springs are in the range -0.190 to +0.191. In the study area no calcite (carbonate tuffa) precipitation was observed around the outlets of the springs. Appello & Postma (1996) interpreted small SI values for calcite as "dissolution of carbonates generally fast enough to reach thermodynamic equilibrium, while precipitation of calcite in natural settings is sluggish when SI values are smaller than 0.3".

CONCLUSIONS

Gökpınar karst springs are potentially important water resources for water requirements in Gürün district centre, Sivas. At present the water of the springs is used for fish production, power (electricity) generation and irrigation. This study, as the first hydrogeological research in the area, aimed at determination of the hydrogeological and hydrogeochemical characteristics of the Gökpınar karst springs and karstic features of the study area.

The main aquifer in the study area is Jurassic-Cretaceous Yüceyurt formation which is made up of mainly limestone and partially dolomitic limestone. The aquifer exhibits a well developed karst system. Small scale solution sculpture and large scale karst landforms and features are developed in this formation. The groundwater in the karst aquifer (Yüceyurt formation) is discharged by Gökpınar springs which have two main outlets and a total discharge ranging between 4.5 m^3/s and 7.8 m^3/s.

The recession analysis of the discharges of the Gökpınar-1 and Gökpınar-2 springs has given the storage capacities as 141×10^6 m^3 and 98×10^6 m^3, and the recession (discharge) coefficients as 2.71×10^{-3} day^{-1} and 2.98×10^{-3} day^{-1}, respectively. These values indicate that the karst aquifer has a large storage capacity and the drainage of the aquifer occurs very slow. The recession coefficients of the Gökpınar springs have close values that of karst springs in the Antalya region which are located in the western part of the Taurid Karst Belt. Based on these it may be concluded that the karst aquifer in the study area has similar hydrogeological properties that of the karst aquifers in the Antalya region.

The waters of the study area are not rich in major ions and total dissolved solids (TDS). TDS concentrations are moderate. The major ions in the waters of the study area are Ca^{2+} and HCO_3^-, and all waters are of calcium bicarbonate type. Regarding maximum permissible limits in Turkish Drinking Water Standards all waters are suitable for drinking.

Gökpınar springs (GK-1 and GK-2) are undersaturated for anhydrite, dolomite, gypsum and halite minerals. The same springs are generally undersaturated for dolomite and slightly saturated for calcite. Low yield springs are undersaturated to dolomite, and undersaturated or slightly saturated for aragonite and calcite minerals.

As mentioned before, this study is first hydrogeological investigation concerning Gökpınar karst springs. More detailed investigations have to be carried out to determine the age, origin, recharge area and detailed hydrochemistry of the groundwater in the karst aquifer. For this purpose several different investigation methods must be used, including stable and radioactive isotope analyses together with inorganic geochemistry.

ACKNOWLEDGEMENT

This investigation was financially supported as research project by the Research Found of the Cumhuriyet University, Sivas, Turkey (Project code M-062).

REFERENCES

Amit, A., Lyakhovsky, V., Katz, A., Starinsky, A. & A. Burg, 2002: Interpretation of spring recession curves.- Groundwater, 40, 5, 543–551.

Appelo, C.A.J. & D. Postma, 1996: *Gechemistry, Groundwater and Pollution.*- Balkema, pp. 536, Rotterdam.

APHA-AWWA-WPCF, 1995: *Standart methods for the examination of water and wastewater (19th ed.).*- American Public Health Association, pp. 1140, Washington DC, USA.

Atabey, E., 1993: Gürün otoktonunun stratigrafisi (Gürün-Sarız arası), Doğu Toroslar-GB Sivas (Stratigraphy of the Gürün autochtonous units-The area between Gürün and Sarız, Eastern Torids, SW Turkey).- Türkiye Jeoloji Bült., 36, 99–113.

Atabey, E., 1996: The development of nummulites banks within the compressional tectonically controlled Tertiary basin of Gürün Autochthone, Eastern Taurus, SW Sivas (Turkey).- Turkish J. Earth Sci., 5, 99–108.

Atabey, E., Bağırsakçı, S., Canpolat, M., Gökkaya, K.Y., Günal, S. & N. Kılıç, 1994: *Gürün, Kangal (Sivas)-Darende, Hasançelebi (Malatya) arasının jeolojisi (Geology of the region between Gürün, Kangal (Sivas) and Darende, Hasançelebi (Malatya)).*- MTA Derleme, rep. no. 9760, pp. 20.

Back, W., 1996: *Hydrochemical facies and groundwater flow patterns in northern part of Atlantic Coastal Plain.*- U.S. Geological Survey, Professional Paper 498-A, pp. 42, Reston.

Bonacci, O., 1993: Karst springs hydrographs as indicators of karst aquifers.- Hydrol. Sci. J, 38, 1–2, 51–62.

Bonacci, O., 2001: Analysis of the maximum discharge of karst springs.- Hydrogeology Journal, 9, 4, 328–338.

Bögli, A, 1980: *Karst Hydrology and Physical Speleology.*- Springer Verlag, pp. 284, Berlin.

Çelik, M. & M. Afşin, 1996: The evaluation of karstic aquifer recharge from spring hydrographs; Kazanpınar springs (Elmalı polje, Antalya).- Yerbilimleri (Geosound), 28, 35–41.

De Vries, J.J. & I. Simmers, 2002: Groundwater recharge: an overview of processes and challenges.- Hydrogeology Journal, 10, 5–17.

Drever, J.I., 1997: *The Geochemistry of Natural Waters (3rd ed.).*- Prentice Hall, pp. 436, New Jersey.

Fiorillo, F., 2009: Spring hydrographs as indicator of droughts in a karst environment.- J. Hydrology, 373, 3–4, 290–301, DOI: 10.1016/j.hydrol.2009.04.034.

Ford, D. & P. Williams, 2007: *Karst Hydrogeology and Geomorphology.*- John Wiley & Sons, pp. 562, Chichester.

Günay, G. & T. Yayan, 1979: *Antalya-Kırkgöz Karst Kaynaklarının Hidrojeolojisi (Hydrogeological Investigation of the Antalya-Kırkgöz Karst Springs).*- DSİ-UNDP project (Tur/77/015) no. 32, pp. 118, Ankara.

Hendrickx, J.M.H. & G.R. Walker, 1997: Recharge from precipitation.- In: Simmers, I. (ed.) *Recharge of Phereatic Aquifers in (Semi-) Arid Areas.* IAH Publ. n. 19, Balkema, pp. 19–111, Rotterdam.

Hem, J.D., 1985: *Study and interpretation of the chemical characteristics of natural water.*- US Geological Survey, Water Supply Paper, n. 2254, pp. 263, Reston.

Hershey, R.L., Mizell, S.A. & S. Earman, 2010: Chemical and physical characteristics of springs discharging from regional flow systems of carbonate-rock province of the Great Basin, western United States.- Hydrogeology Journal, 18, 1007–1026.

Hoetzl, H., 1995: Groundwater recharge in an arid karst area (Saudi Arabia).- In: Adar, E.M. & C. Leibundgut (eds.) *Application of Tracers in Arid Zone Hydrology.* IAHS Publ., n. 232, pp. 195–207, Oxfordshire, UK.

Jacobson, R.L. & D. Langmuir, 1974: Controls on the quality variations of some carbonate spring waters.- Journal of Hydrology, 23, 247–265.

Kaçaroğlu, F., 1999: Review of groundwater pollution and protection in karst areas.- Water, Air and Soil Pollution, 113, 337–356.

Kaçaroğlu, F., 2001: *Gürün-Gökpınar kaynakları ve civarının hidrojeoloji incelemesi (Hydrogeological investigation of the Gürün-Gökpınar springs and their vicinity).*- Cumhuriyet Üniversitesi Araştırma Fonu Proje, n. M-062, pp. 29, Sivas.

Kaçaroğlu, F., 2006: Gökpınar karst kaynaklarının (Gürün-Sivas) hidrojeoloji incelemesi (Hydrogeological investigation of the Gökpınar karst springs (Gürün-Sivas)).- Yerbilimleri, 27, 3, 181–194.

Kaçaroğlu, F., Değirmenci, M. & O. Cerit, 1997: Karstification in Miocene gypsum: An example from Sivas, Turkey.- Environmental Geology, 30, 1–2, 88–97.

Kaçaroğlu, F., Değirmenci, M. & O. Cerit, 2001:Water quality problems of a gypsiferous watershed: Upper Kızılırmak Basin, Sivas, Turkey.- Water, Air and Soil Pollution, 128, 161–180.

Kovacs, A., Perrochet, P., Kiraly, L. & P-Y. Jeannin, 2005: A quantitative method for the characterisation of karst aquifers based on spring hydrograph analysis.- Journal of Hydrology, 303, 152–164.

Kurtman, F., 1978: Gürün bölgesinin jeolojik ve tektonik özellikleri (Geology and tectonics of the Gürün region).- MTA Dergisi, 91, 1–12.

LaFleur, R., 1999: Geomorphic aspects of groundwater flow.- Hydrogeology Journal, 7, 78–93.

Lerner, D., 1997: Groundwater recharge.- In: Saether, O.M. & P. De Caritat, (eds.) *Geochemical Processes, Weathering and Groundwater Recharge in Catchments.* Balkema, pp. 109–150, Rotterdam.

Lopez-Chicano, M., Bouamama, M., Vallejos, A. & A. Pulido-Bosch, 2001: Factors which determine the hydrogeochemical behaviour of karstic springs. A case study from the Betic Cordilleras, Spain.- Applied Geochemistry, 16, 1179–1192.

Maillet, E., 1905: *Essais d'Hydraulique souterraine et fluviale.*- Hermann, pp. 218, Paris.

Milanovic, P.T., 1981: *Karst Hydrogeology.*- Water Resources Publications, pp. 434, Littleton.

Piper, A.M., 1944: A graphical procedure in the geochemical interpretation of water analyses.- American Geophysical Union Transactions, 25, 914–923.

Plummer, L.N., Jones, B.F. & A.H. Truesdell, 1984: *WATEQF-A Fortran IV version of WATEQ, A Computer program for calculating chemical equilibria of natural waters.*- U.S. Geological Survey, Water Resources Investigation Report 76–13, Reston.

Shuster, E.T. & W.B. White, 1971: Seasonal fluctuations in the chemistry of limestone springs: A possible means for characterizing carbonate aquifers.- Journal of Hydrology, 14, 93–128.

Smith, R.A., Alexander, R.B. & K.J. Lanfear, 1993: Stream water quality in the conterminous United States-status and trends of selected indicators during the 1980's.- In: Paulson, R.W., Chase, E.B., Williams, J.S. & Moody, D.W. (comps.) *National water summary 1990–91- Hydrologic events and stream water quality.* U.S. Geological Survey, Water Supply Paper 2400, pp. 111–140, Reston..

TSE, 2005: TS 266 Sular-İnsani Tüketim Amaçlı Sular (TS 266 Water intended for human consumption).- Türk Standartları Enstitüsü (Turkish Standards Institution), pp. 10, Ankara.

White, B., 1977: Role of solution kinetics in the development of karst aquifers.- In: Tolson, J.S. & F.L. Boyle (eds.) *Karst Hydrogeology.* Int. Assoc. Hydrogeol. Mem., 12, pp. 503–517.

White, W.B., 1999: Groundwater flow in karst aquifers.- In: J.W. Delleur (ed.) *The Handbook of Groundwater Engineering.* CRC Press, chapter 18, 18/1-18/36, Boca Raton.

White, W.B., 2002: Karst hydrology: recent developments and open questions.- Engineering Geology, 65, 85–105.

Yevjevich, V., 1985: Specificities of karst water resources.- In: Günay, G. & A.I. Johnson (eds.) *Karst Water Resources, Proceedings of the Ankara-Antalya Symposium,* 8th–12th July 1985, Ankara. IAHS Publ., n. 161, 3–20, Ankara.