Fikret Kaçaroğlu

Abstract

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Fikret Kaçaroğlu: Hydrogeology of the Gökpınar 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 allochthonous and autochthonous 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 $141 \times 10^6$ m$^3$ and $98 \times 10^6$ m$^3$, and $2.71 \times 10^{-3}$ day$^{-1}$ and $2.98 \times 10^{-3}$ 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$_3^-$.

Izvleček

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Fikret Kaçaroğlu: Hidrogeologija kraških izvirov Gökpınar, 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. Ob močje prekrivajo številne škraplje, vrtače, ponori, podzemni kanali in jame. V prispevku je bila izvedena analiza zmanjševanja pretoka na izviroh Gökpınar, izračunani sta bila količnik uskladiščenja in upadanja pretoka obeh glavnih izvirov. Količnik uskladiščenja je $141 \times 10^6$ m$^3$, količnik upadanja pretoka pa $2.71 \times 10^{-3}$ day$^{-1}$ in $2.98 \times 10^{-3}$ day$^{-1}$, rešpektivno. 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: $T=10.8–11.1^\circ C$, 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, 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.

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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).

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 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.

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 Tophma 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.
The study area is located within the Eastern Taurid Belt (Kurtman 1978; Atabey et al. 1994). In the area allochtonous and autochthonous 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 autochthonous 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 serpentine, serpantinized peridotite, piroxenite, harzburgite, dunite and gабро.

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, gray-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 Gümüşalı 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, agglomerate 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 thrust over autochthonous 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 chanel 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 flatly 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 scarce 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: Springs in the study area.

<table>
<thead>
<tr>
<th>Spring no.</th>
<th>Name of the spring</th>
<th>Aquifer lithology (formation)</th>
<th>Altitude a.s.l. (m)</th>
<th>Discharge (L/s)</th>
<th>Date of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>GK-3</td>
<td>Serkiz Dere</td>
<td>Limestone (Gürün fm.)</td>
<td>1,920</td>
<td>1.0</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-4</td>
<td>Kale Dere</td>
<td>Limestone – Clayey limestone (Gürün fm.)</td>
<td>1,890</td>
<td>3.0</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-5</td>
<td>Büyük çeşme (Kavak)</td>
<td>Clayey limestone (Gürün fm.)</td>
<td>1,820</td>
<td>2.0</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-6</td>
<td>Körpınar</td>
<td>Limestone (Gürün fm.)</td>
<td>1,880</td>
<td>2.0</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-7</td>
<td>Dönumpınar</td>
<td>Limestone (Gürün fm.)</td>
<td>1,870</td>
<td>0.5</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-8</td>
<td>Küçükyazılı</td>
<td>Limestone (Gürün fm.)</td>
<td>1,880</td>
<td>1.0</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-9</td>
<td>Halacoğlu</td>
<td>Limestone (Gürün fm.)</td>
<td>1,850</td>
<td>0.5</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-10</td>
<td>Akpınar</td>
<td>Limestone (Gürün fm.)</td>
<td>1,820</td>
<td>0.5</td>
<td>04.08.1995</td>
</tr>
<tr>
<td>GK-11</td>
<td>Yelken</td>
<td>Limestone (Yüceyurt fm.)</td>
<td>1,650</td>
<td>1.0</td>
<td>04.08.1995</td>
</tr>
</tbody>
</table>

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.
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.

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 corrosively 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. Hezanalı 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) 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.

**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
The composition of groundwater. Rocks made of carbonate minerals, 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 with the hydrogeological characteristics 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...
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, 2.3 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=270–435 mS/cm, TDS=180–230 mg/L, Na\(^+\)=1.4–4.2 mg/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.

<table>
<thead>
<tr>
<th>Samp. no.</th>
<th>Spring no.</th>
<th>Name of the spring</th>
<th>Date of sampling</th>
<th>( T(°C) )</th>
<th>( pH )</th>
<th>( EC ) (μS/cm)</th>
<th>( TDS ) (mg/L)</th>
<th>Cations (mg/L)</th>
<th>Anions (mg/L)</th>
<th>Hardness (mg/L CaCO(_3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>GK-3</td>
<td>Serkiz dere</td>
<td>04.08.1995</td>
<td>9.4</td>
<td>7.65</td>
<td>295</td>
<td>190</td>
<td>1.4</td>
<td>0.5</td>
<td>42.0</td>
</tr>
<tr>
<td>7</td>
<td>GK-4</td>
<td>Kaledere</td>
<td>04.08.1995</td>
<td>10.0</td>
<td>8.25</td>
<td>270</td>
<td>180</td>
<td>1.4</td>
<td>0.7</td>
<td>46.0</td>
</tr>
<tr>
<td>8</td>
<td>GK-5</td>
<td>Büyük çeşme</td>
<td>04.08.1995</td>
<td>9.5</td>
<td>7.55</td>
<td>345</td>
<td>230</td>
<td>2.1</td>
<td>3.4</td>
<td>50.0</td>
</tr>
<tr>
<td>9</td>
<td>GK-6</td>
<td>Körpinar</td>
<td>04.08.1995</td>
<td>10.6</td>
<td>7.90</td>
<td>335</td>
<td>220</td>
<td>3.5</td>
<td>0.8</td>
<td>50.0</td>
</tr>
<tr>
<td>10</td>
<td>GK-7</td>
<td>Dönişpınar</td>
<td>04.08.1995</td>
<td>9.4</td>
<td>7.70</td>
<td>335</td>
<td>220</td>
<td>2.0</td>
<td>1.3</td>
<td>50.0</td>
</tr>
<tr>
<td>11</td>
<td>GK-8</td>
<td>Küçükyazılı</td>
<td>04.08.1995</td>
<td>8.5</td>
<td>7.55</td>
<td>300</td>
<td>200</td>
<td>1.8</td>
<td>1.0</td>
<td>45.0</td>
</tr>
<tr>
<td>12</td>
<td>GK-9</td>
<td>Halacoğlu</td>
<td>04.08.1995</td>
<td>8.3</td>
<td>7.70</td>
<td>295</td>
<td>190</td>
<td>1.4</td>
<td>0.8</td>
<td>38.0</td>
</tr>
<tr>
<td>13</td>
<td>GK-10</td>
<td>Akpınar</td>
<td>04.08.1995</td>
<td>8.3</td>
<td>7.80</td>
<td>285</td>
<td>190</td>
<td>1.4</td>
<td>0.7</td>
<td>40.0</td>
</tr>
<tr>
<td>14</td>
<td>GK-11</td>
<td>Yelken</td>
<td>04.08.1995</td>
<td>11.7</td>
<td>7.65</td>
<td>435</td>
<td>290</td>
<td>4.2</td>
<td>1.2</td>
<td>60.0</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Samp. no.</th>
<th>SAMP. point</th>
<th>Date of sampling</th>
<th>Anhydrite</th>
<th>Aragonite</th>
<th>Calcite</th>
<th>Dolomite (d)</th>
<th>Dolomite (c)</th>
<th>Gypsum</th>
<th>Halite</th>
</tr>
</thead>
</table>

Sampling point: Gökpınar-1 spring (GK-1)

<table>
<thead>
<tr>
<th>Samp. no.</th>
<th>SAMP. point</th>
<th>Date of sampling</th>
<th>Anhydrite</th>
<th>Aragonite</th>
<th>Calcite</th>
<th>Dolomite (d)</th>
<th>Dolomite (c)</th>
<th>Gypsum</th>
<th>Halite</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GK-1</td>
<td>02.08.1995</td>
<td>-2.908</td>
<td>-0.345</td>
<td>-0.190</td>
<td>-1.505</td>
<td>-0.894</td>
<td>-2.653</td>
<td>-9.399</td>
</tr>
<tr>
<td>22</td>
<td>GK-1</td>
<td>29.09.1995</td>
<td>-2.805</td>
<td>-0.032</td>
<td>0.122</td>
<td>-0.959</td>
<td>-0.349</td>
<td>-2.550</td>
<td>-9.285</td>
</tr>
<tr>
<td>32</td>
<td>GK-1</td>
<td>31.10.1995</td>
<td>-2.824</td>
<td>0.002</td>
<td>0.157</td>
<td>-0.939</td>
<td>-0.329</td>
<td>-2.569</td>
<td>-9.246</td>
</tr>
<tr>
<td>43</td>
<td>GK-1</td>
<td>24.04.1996</td>
<td>-2.650</td>
<td>-0.104</td>
<td>0.050</td>
<td>-1.291</td>
<td>-0.681</td>
<td>-2.395</td>
<td>-9.367</td>
</tr>
<tr>
<td>52</td>
<td>GK-1</td>
<td>30.05.1996</td>
<td>-2.635</td>
<td>-0.002</td>
<td>0.153</td>
<td>-1.198</td>
<td>-0.588</td>
<td>-2.380</td>
<td>-9.599</td>
</tr>
<tr>
<td>62</td>
<td>GK-1</td>
<td>17.07.1996</td>
<td>-2.793</td>
<td>-0.172</td>
<td>-0.017</td>
<td>-1.531</td>
<td>-0.922</td>
<td>-2.538</td>
<td>-9.479</td>
</tr>
<tr>
<td>72</td>
<td>GK-1</td>
<td>13.08.1996</td>
<td>-2.828</td>
<td>-0.083</td>
<td>0.071</td>
<td>-1.292</td>
<td>-0.683</td>
<td>-2.573</td>
<td>-9.566</td>
</tr>
<tr>
<td>82</td>
<td>GK-1</td>
<td>27.09.1996</td>
<td>-2.747</td>
<td>-0.083</td>
<td>0.071</td>
<td>-1.231</td>
<td>-0.621</td>
<td>-2.492</td>
<td>-9.500</td>
</tr>
</tbody>
</table>

Sampling point: Gökpınar-2 spring (GK-2)

<table>
<thead>
<tr>
<th>Samp. no.</th>
<th>SAMP. point</th>
<th>Date of sampling</th>
<th>Anhydrite</th>
<th>Aragonite</th>
<th>Calcite</th>
<th>Dolomite (d)</th>
<th>Dolomite (c)</th>
<th>Gypsum</th>
<th>Halite</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>GK-2</td>
<td>02.08.1995</td>
<td>-2.891</td>
<td>-0.214</td>
<td>-0.059</td>
<td>-1.194</td>
<td>-0.583</td>
<td>-2.636</td>
<td>-9.382</td>
</tr>
<tr>
<td>21</td>
<td>GK-2</td>
<td>29.09.1995</td>
<td>-2.843</td>
<td>-0.004</td>
<td>0.150</td>
<td>-0.815</td>
<td>-0.205</td>
<td>-2.588</td>
<td>-9.285</td>
</tr>
<tr>
<td>31</td>
<td>GK-2</td>
<td>31.10.1995</td>
<td>-2.806</td>
<td>-0.026</td>
<td>0.128</td>
<td>-0.970</td>
<td>-0.359</td>
<td>-2.551</td>
<td>-9.334</td>
</tr>
<tr>
<td>42</td>
<td>GK-2</td>
<td>24.04.1996</td>
<td>-2.649</td>
<td>-0.254</td>
<td>-0.100</td>
<td>-1.593</td>
<td>0.983</td>
<td>-2.394</td>
<td>-9.384</td>
</tr>
<tr>
<td>51</td>
<td>GK-2</td>
<td>30.05.1996</td>
<td>-2.723</td>
<td>0.000</td>
<td>0.154</td>
<td>-1.195</td>
<td>-0.585</td>
<td>-2.468</td>
<td>-9.532</td>
</tr>
<tr>
<td>61</td>
<td>GK-2</td>
<td>17.07.1996</td>
<td>-2.785</td>
<td>0.007</td>
<td>0.161</td>
<td>-1.067</td>
<td>-0.457</td>
<td>-2.531</td>
<td>-9.598</td>
</tr>
<tr>
<td>71</td>
<td>GK-2</td>
<td>13.08.1996</td>
<td>-2.953</td>
<td>-0.005</td>
<td>0.150</td>
<td>-1.004</td>
<td>-0.394</td>
<td>-2.698</td>
<td>-9.544</td>
</tr>
<tr>
<td>81</td>
<td>GK-2</td>
<td>27.09.1996</td>
<td>-2.716</td>
<td>0.036</td>
<td>0.191</td>
<td>-1.091</td>
<td>-0.481</td>
<td>-2.461</td>
<td>-9.460</td>
</tr>
</tbody>
</table>
conduit springs were very variable in hardness throughout 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.

$\text{Ca}^{2+}$, $\text{HCO}_3^-$ and hardness concentrations of the Gökpınar springs do not change markedly with time while $\text{Mg}^{2+}$ concentrations exhibit significant change in time. On an equivalent basis (meq/L) $\text{Ca}^{2+}/\text{Mg}^{2+}$ 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 $\text{Ca}^{2+}/\text{Mg}^{2+}$ ratio provides information on the rock type through which the groundwater has passed. The $\text{Ca}^{2+}/\text{Mg}^{2+}$ 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).

$\text{HCO}_3^-$ is the dominant dissolved anion in the waters of the study area. $\text{HCO}_3^-$ concentrations of the Gökpınar springs varies between 144 and 158 mg/L. In low yield springs $\text{HCO}_3^-$ contents range from 134 to 198 mg/L. On an equivalent basis (meq/L), $\text{HCO}_3^-$ 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 $\text{HCO}_3^-$ 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.

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 $\text{Ca}^{2+}$ and $\text{HCO}_3^-$. 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-

![Fig. 9: Classification of the spring waters in the Piper diagram.](image)
Tab. 8: Saturation indices of the water samples from low yield springs in the Gökpinar basin for August 1995 period.

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

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, gypsum and halite minerals were calculated using WATEQ4F computer program (Plummer et al. 1984). The values of the saturation indices for dolomite and calcite are included in Tabs. 7 and 8. Positive values of SI indicate supersaturation dissolution, while negative ones indicate undersaturation. Saturation state indicates the direction of the processes; for undersaturation dissolution is expected, and supersaturation suggests precipitation. All spring waters in the study area are undersaturated with respect to anhydrite, gypsum and halite minerals (Tabs. 7 & 8). Gökpinar springs (GK-1 and GK-2) were generally undersaturated or slightly saturated with respect to aragonite, slightly undersaturated for calcite, and undersaturated for dolomite. In August 1995 period, low yield springs in the study area are undersaturated with respect to anhydrite and dolomite. Saturation with respect to calcite and undersaturation to dolomite of the Gökpinar springs is in consistence with the mineralogical composition of the karst aquifer lithology. While (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, precipitation of calcite is 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.

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