MAKÜFEBED

Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi
The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University
Volume: 15 Issue: 1 - 2024 | Cilt: 15 Sayı 1 - 2024

Environmental Impacts of Geothermal Fields on Water Resources in the Central Anatolia Region, Türkiye

Türkiye, İç Anadolu Bölgesindeki Jeotermal Sahaların Su Kaynakları Üzerindeki Çevresel Etkileri

Eda AYDEMİR POLAT [1], Şehnaz ŞENER [1*]

[1] Süleyman Demirel University, Faculty of Engineering, Department of Geological Engineering, Isparta, Türkiye

Article Info

Research Article

DOI: 10.29048/makufebed.1416438

Corresponding Author

Şehnaz ŞENER

Email:sehnazsener@sdu.edu.tr

Article History

Received: 08.01.2024

Revised: 03.04.2024

Accepted: 04.04.2024

Available Online:15.06.2024

To Cite

Aydemir Polat, E., & Şener, Ş. (2024). Environmental impacts of geothermal fields on water resources in the Central Anatolia region, Türkiye. *The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University*, *15*(1), 42-60. https://doi.org/10.29048/makufebed.1416438

This article was produced from Eda AYDEMİR POLAT's doctoral thesis titled "Boğazlıyan (Yozgat) Termal ve Soğuk Su Kaynaklarının Hidrojeokimyasal ve İzotopik Yöntemlerle İncelenmesi"

ABSTRACT: Hot and mineral waters in thermal areas may interact with other water resources in the region. When such a situation occurs, it is possible for hot water to negatively affect the chemical structure and quality of cold-water resources. This limits the use of drinking and/or irrigation water in water resources. In the scope of this study, geothermal fields in the Central Anatolia region of Türkiye were examined in detail and the quality and usability characteristics of the water resources in these fields were examined. Thus, the environmental effects of geothermal in terms of water resources were tried to be revealed. The geological, hydrogeological and hydro geochemical properties of 18 different geothermal fields located in 5 different cities (Aksaray, Yozgat, Kırşehir, Niğde, and Nevşehir) were examined and their similarities and differences with each other were revealed. In addition, the quality and usability features of hot and cold-water resources in each field were examined and the possible negative effects of these geothermal fields on water resources were investigated. According to the results obtained, thermal energy causes pollution of both freshwater resources and soil, especially due to their high ion content.

Keywords: Geothermal, groundwater, drinking water, environmental effects, Central Anatolia Region

ÖZ: Termal alanlardaki sıcak ve mineralli sular bölgedeki diğer su kaynaklarıyla etkileşime girebilmektedir. Böyle bir durum oluştuğunda sıcak suyun, soğuk su kaynaklarının kimyasal yapısını ve kalitesini olumsuz etkilemesi mümkündür. Bu durum su kaynaklarında içme ve/veya sulama suyunun kullanımını sınırlamaktadır. Bu çalışma kapsamında Türkiye'nin İç Anadolu bölgesindeki jeotermal sahalar detaylı bir şekilde incelenerek bu sahalardaki termal suların kalite ve kullanılabilirlik özellikleri incelenmiştir. Böylece termal akışkanın su kaynakları açısından çevresel etkileri ortaya koyulmaya çalışılmıştır. Beş farklı ilde (Aksaray, Yozgat, Kırşehir, Niğde ve Nevşehir) yer alan 18 farklı jeotermal sahanın jeolojik, hidrojeolojik ve hidrojeokimyasal özellikleri incelenerek birbirleriyle benzerlik ve farklılıkları incelenmiştir. Ayrıca her sahadaki sıcak ve soğuk su kaynaklarının kalite ve kullanılabilirlik özellikleri tespit edilerek bu jeotermal sahaların su kaynakları üzerindeki olası olumsuz etkileri araştırılmıştır. Elde edilen sonuçlara göre termal sular, özellikle iyon içeriğinin yüksek olması nedeniyle hem tatlı su kaynaklarının hem de toprağın kirlenmesine neden olmaktadır.

Anahtar Kelimeler: Jeotermal, yeraltı suyu, içme suyu, çevresel etkiler, İç Anadolu Bölgesi

Burdur Mehmet Akif Ersoy University Press
E ISSN: 1309-2243

1. INTRODUCTION

In behalf of fulfill the rapidly increasing energy requirement as a result of the increase in the world population, the demand for developing industry and technology, the countries of the world are in search of new energy sources. While most of the energy needs are met by fossil fuels in the current order, knowing that these fuels will run out faster and the environmental problems they cause has led us to seek cleaner, renewable and more economical energy sources. Research and use of geothermal energy resources are rapidly becoming widespread in the world because it is environmentally friendly and renewable, a resource that can be used without being dependent on foreign sources and being economical, and most importantly, its utilization is wide.

Geothermal energy, which is a cleaner and more sustainable energy source than the other types of energy, has some effects on the environment. It is a benign energy source compared to nuclear and fossil fuels, but it does cause some gas and wastewater emissions that must be disposed of. Geothermal energy is about the same size as most other renewable energy sources such as hydro and solar energy. The main environmental problems related to this energy source are surface degradation, consequences of liquid extraction on a physical level, noise pollution, heat effects, biological and chemical effects and degradation of natural structure. Hence, a comprehensive examination of the environmental impacts associated with the utilization of geothermal energy is warranted, and power conversion and geothermal area selection should be made carefully (Kristmannsdóttir and Ármannsson, 2003). Reinjection, which is an important process for reservoir pressure and the environment, has a very important role in reducing the mentioned problems. In addition, the availability of the resource in different processes at gradually decreasing temperature steps increases sustainability: for example; such as industrial uses, heating for buildings, agricultural utilization, and aquaculture respectively. Many countries are at different stages in terms of legislation related to environmental protection during geothermal development (Rybach, 2003).

When taking into account the geological diversity of Türkiye, it becomes apparent that geothermal resources are situated in particular regions. Geothermal systems primarily form as a result of young tectonic movements and volcanic activities. Türkiyes geothermal resources are especially concentrated in Western Anatolia. After that Central Anatolia comes, followed by the Marmara, Eastern Anatolia, Southeastern Anatolia, Black Sea, and Mediterranean regions. Western Anatolias graben systems host high-temperature geothermal fields in Türkiye, Different from the geothermal fields in Western Anatolia, Central and Eastern Anatolia have regions falling into the low and medium-temperature categories (Akkuş and Alan, 2016; Şener and Baba, 2019). The distribution of geothermal systems in Central Anatolia closely aligns with the pattern of faults (Şener, 2019). In terms of potential, geothermal fields in the Central Anatolia Region come after the geothermal fields in Western Anatolia in the country. However, with the increase in the need for energy and the advancement of technology, geothermal studies in this region have also accelerated. This study encompasses geological, hydrogeological structure and hydro geochemical features of the important geothermal area in the Central Anatolia Region, which are increasing in importance day by day have been compiled using previous studies and the similarities and /or differences of these fields have been examined. In the evaluations, samples from cold water, springs and wells as well as hot and mineral groundwater were also surveyed. Furthermore, possible negative effects of geothermal formations on the quality and usage characteristics of existing water resources were discussed.

2. MATERIALS and METHODS

In Central Anatolia, which constitutes 9% of Türkiyes geothermal potential, geothermal systems are associated with volcanic and tectonic activities (Davraz et al., 2022). The existence of recent tectonic activity in the area suggests that the thermal gradient in the region is higher compared to other areas (Yılmaz Turalı et al., 2016). In the present study, geological, hydrogeological and hydro geochemical characteristics of the different geothermal fields in Yozgat, Kırşehir, Niğde, Nevşehir and Aksaray regions are discussed in detail, along with the general characteristics such as location, potential and intended use (Figure 1). In addition, the stratigraphic column cross-section of the geological units cropping out in the examined regions is given in Figure 2.

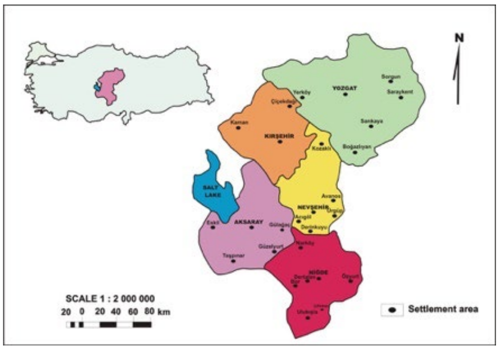

Figure 1. Location of the study area

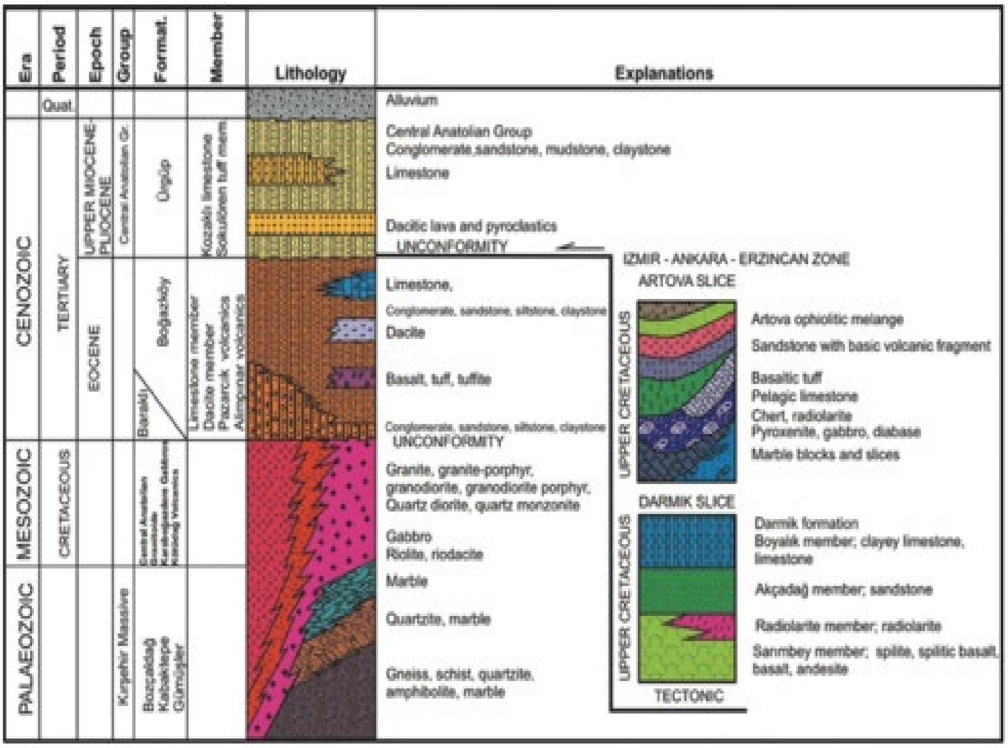

Figure 2. Stratigraphic column cross-section of the study area (Akçay et al., 2008)

3. RESULTS and DISCUSSION

3.1. Geothermal Fields in the Central Anatolia Region

3.1.1. Yozgat region

In Yozgat region, there are 28 production wells, 2 reinjection wells and 10 natural springs operating in 7 geothermal fields, namely Sorgun, Saraykent, Sarıkaya, Boğazlıyan, Yozgat–Merkez, Yerköy, Akdağmadeni (Davraz et al., 2022).

Sorgun Geothermal Field: In the Sorgun geothermal field, located in the Sorgun district, 40 km east of Yozgat, wells were drilled for the first time by General Directorate of Mineral Research and Exploration (MTA) in 1988 for geothermal research, and geothermal research in the region is still being carried out by private companies in the following years. However, some wells were closed due to some technical problems caused by the coal mines. Today, there are 12 geothermal wells with depths ranging from 90 m to 444 m in the field. After 2005, 5 production wells and 1 reinjection well were drilled.

As of 2007, the water extracted from the region is used for residential heating, thermal tourism, greenhouse cultivation and balneological purposes. The water temperature in the region varies between 50 and 85.4°C (Yılmaz Turalı, 2017). The geothermal wells in the field meet the thermal water needs of 1,000 houses and thermal facilities and the greenhouses of 10,000 m^2 (Şimşek et al., 2003). Some of the water returning from the heating is transferred to thermal spas and greenhouses, and the remaining part is injected underground through the reinjection well (Yılmaz and Şimşek, 2013). According to the data obtained, Sorgun geothermal system is a shallow and low temperature geothermal system. Since the level has decreased due to too many wells of coal mine in the region, thermal resources are extracted by drilling (Şimşek, 1993). Geothermal reservoir units are Paleocene granodiorites in the area (Şimşek 1993). Fracture, fault and altered zones of granodiorites are permeable. Geothermal water accumulated in the fractured and altered parts of granodiorite and Eocene conglomerates rises along the faults. While the lower boundary of the granodiorites is unclear, the upper boundary is formed by the Eocene cover rock. Normal and strike-slip faults have developed in the region depending on the tension tectonics in the Neogene and Quaternary (Yılmaz and Şimşek, 2013).

The bedrock (granodiorites) in the upper 30–50 meters and the deep fault/joint zones are permeable. The units in the lower parts have tight fracture intervals and are compacting. The alluvium covering surrounding of Eğriöz and Domuz Stream and containing fluvial sediments (clay, sand and gravel) is an important aquifer for thermal and cold waters with its bed thickness reaching 40 m. Pliocene sediments, which are mostly impermeable, consist of conglomerate, marl, sandstone and claystone. Permeable loose cemented sandstone and conglomerate units are of local importance as aquifers. Eocene deposits, consisting of claystone, marl, limestone, and clay levels, are mostly impermeable and form the cover rock of the region. However, the fracture zones of the units and the basal conglomerate may be permeable (Şimşek et al., 2003). When the chemical characteristic of water samples taken from the geothermal field were examined, it was determined that hot waters were NaCl water type, cold waters were $CaHCO_3$ water type and mineral spring waters were $CaSO_4$ water type (Table 1). When the semi-logarithmic Schoeller diagram is examined, it is seen that the chemical properties of hot water samples with relatively high Na and Cl ions are similar. According to the Cl–SO_4–HCO_3 diagram (Giggenbach, 1988), hot waters are located in the Cl region and cold waters are located in the HCO_3 region. When the mineral saturation index is examined, it indicates that the hot waters are highly saturated with carbonate minerals such as calcite and dolomite. Therefore, the thermal waters that come out have a corrosive effect (Yılmaz Turalı and Şimşek, 2017). According to KOP (2021a), the reservoir temperature was calculated using a cation geothermometers and a temperature between 79 and 155°C was determined. Considering the environmental isotope values, it is seen that the hot waters are of meteoric origin and are more dilute than the cold spring waters (Table 2). Like cold water sources, hot waters are fed by precipitation from higher elevations. In the Sorgun geothermal field, meteoric waters infiltrate underground and the groundwater infiltrating deep is heated by the heat source and thermal gradient. Periodic changes in environmental isotope values and the presence of tritium show that thermal water with a long circulation time mixes with relatively shallow cold spring water (Şimşek, 2003; Yılmaz Turalı and Şimşek, 2017).

Saraykent Geothermal Field: In Saraykent geothermal field in Saraykent district, 70 km east of Yozgat, there are 4 geothermal wells, only one of which is operational (KOP, 2021a). According to the geological characteristics of the area, the basement rocks are Paleozoic–Mesozoic metamorphic, also called Kırşehir Metamorphic, which are mainly composed of marble, schist, gneiss and Upper Cretaceous−Paleocene-aged ophiolite unit. Metamorphoses are overlain by Eocene aged sedimentary units and volcanic units (Şimşek, 1993; Burçak et al., 2002; Akçay et al., 2008; Dalkılıç et al., 2008). These Eocene units are unconformable overlain by Middle Miocene − Pliocene-aged terrestrial sediments, Pliocene volcanic and Plio-Quaternary clastic units. The Upper Cretaceous ophiolitic unit (mélange) located in the north of the study area was emplaced with a tectonic contact on the Eocene sedimentary unit. All of these lithological units are unconformable covered by the Quaternary aged alluvium, which is the youngest unit in the study area and located in the center of the geothermal field along the Saray Stream (Özulukale and Şimşek, 2016). In order to determine the hydrogeochemical properties of the field samples were taken from precipitation, surface water, geothermal and cold water resources in the Saraykent geothermal field; the major ion analysis results of the geothermal and cold water sources were evaluated using Schoeller (Schoeller, 1977) and Piper Diagrams (Piper, 1944) (Table 1). According to these diagrams, cold water samples are Ca−HCO_3 and Ca−SO_4 water type, geothermal water samples are Na−Cl and Na−SO_4 water type (Özulukale and Şimşek, 2015, 2016). The reason why the thermal waters in the Saraykent geothermal field are rich in Na, K, Cl, SO_4 ions is due to a deep circulation or the interaction of the marble orlimestone in the field and the water.

$\delta^{18}O$, $\delta^{2}H$ and $\delta^{3}H$ analyzes were made in thermal and cold water samples in order to make the origin interpretations of the waters in the Saraykent geothermal field (Table 2). The cold water sampling points are located along the Local Meteoric Waterline (LMWL), while the geothermal waters have a significant $\delta^{18}O$ shift from the LMWL. This shows that the geothermal system is fed by meteoric precipitation and has deep circulation of groundwater with high temperatures in the study area. Saraykent geothermal waters have almost zero tritium content. The low tritium contents of geothermal waters indicate that the springs are fed by groundwater with a relatively long transit time and have a deep circulation groundwater flow system in the study area (Özulukale and Şimşek, 2016). According to the mineral saturation index values calculated with the PhreeqC (Parkhurst and Appelo, 2013) program, it has been determined that Saraykent geothermal waters are saturated with aragonite, calcite, dolomite, quartz, chalcedony, and talc minerals. It is seen that these minerals, which tend to precipitate, cause crusting, and tend to dissolve anhydrite, gypsum, halite, and sylvan minerals. This situation suggests that the waters came into contact with the marbles and volcanites belonging to the metamorphic for a long time during their circulation. According to these results, it has been determined that the hot waters coming to the surface have crusting properties. Heat transfer takes place between geothermal fluids and the rock until the geothermal fluids rise to the surface. Consequently, the reservoir temperature is higher in geothermal systems. The probable reservoir temperature in Saraykent geothermal field is calculated as 108−132°C according to the chalcedony geo thermometer (Özulukale and Şimşek, 2015).

Sarıkaya Geothermal Field: Sarıkaya district is located at 80 km southeast of Yozgat province. In the Sarıkaya geothermal field, 9 wells were drilled for thermal heating, but cooling occurred in many wells due to too much water withdrawal. Inefficient wells are not used. Active wells in Sarıkaya-Center are used for thermal tourism purposes. The most important unit forming the aquifer in the study area is the Kalkanlıdağ and Bozçaldağ formations, which contain Paleozoic-aged marble and quartzite forming the foundation. Fault and fracture zones are hydro-geologically permeable and are of great importance for the geothermal system. Alluviums, consisting of gravel, sand and clay and reaching up to 40 m in thickness, located in the Boğazlıyanözü stream and Domuz stream bed, are an important aquifer for both thermal and cold waters. The sediments forming the Eocene-aged Beycedere formation in the region are composed of impermeable units containing succession of claystone, marl, clayey limestone, and sandstone. However, it is thought that the conglomerate and limestone at the base and the fault and fracture zones may be permeable. The units that make up the Pliocene-aged Kızılırmak formation consist of succession of sandstone, claystone and conglomerate, and these units are generally impermeable. However, loosely cemented sandstone and conglomerate levels may have aquifer characteristics of local hydrogeological importance (Seymen, 1981, 1982; Tolluoğlu, 1986; Kurt et al., 1991; Özen Türker, 2006). Özen Türker (2006) examined hot and mineral water sources and wells, cold water springs and wells and precipitation waters by sampling for 2 periods in order to reveal the physical and chemical properties of underground and surface waters in the Sarıkaya geothermal field and to understand the groundwater system to which they are connected. The temperatures of hot and mineral water springs and wells in Sarıkaya geothermal field vary between 25–50.9°C. The periodic temperature changes of the hot water springs in the study area are between 2−4°C. These temperature differences are due to the seasonal variation of the local groundwater level as a result of the change in the proportion of cold water mixed with hot water. While the pH values of the hot and mineral water sources in the study area are slightly acidic in the range of 6.19-6.95, the cold waters have pH values in the range of 6.90-7.87. Hot and mineral waters are of $CaCO_3$ type according to cation (Ca>Na+K>Mg) and anion (HCO_3>Cl>SO_4) sequences and it is thought that the dominant water type is related to Paleozoic marbles. On the other hand, cold water sources are generally in the category of Ca+Mg−HCO_3 type waters (Table 1). The low ion content of cold waters indicates shallow circulation groundwater. When the hot springs, cold water springs and surface waters in Sarıkaya geothermal area are evaluated, according to Wilcox diagram, cold spring and well waters have low salinity (EC: 200−800 µS/cm) and low sodium percentage, therefore Very Good – Good as irrigation water feature has been determined. However hot water spring take place in class of Good waters with relatively high EC and sodium percentages. According to the saturation index calculations of the minerals (Parkhurst and Appelo, 1999), it was determined that the hot water resources in the region were not saturated with carbonate minerals, but were oversaturated with iron minerals. According to this result, it has been determined that the hot waters coming to the surface are not in crusting feature. According to the environmental isotope values, the isotopic displacement process, which is an indicator of the high temperature in the hot water sources, was observed in which the geothermal system was fed by meteoric precipitation. The low tritium content of hot water springs indicates that the waters are fed by groundwater with a relatively long-term (30−40 years) circulation time (Table 2). According to chalcedony geothermal calculations and drilling studies, the reservoir temperature in Sarıkaya geothermal area is expected to be between 53 and 69°C (Özen Türker, 2006).

Boğazlıyan Geothermal Field: Boğazlıyan geothermal area is located at 110 km southeast of Yozgat province. The geothermal wells and springs in the region are located in the Cavlak locality of Bahariye village, to the west of Boğazlıyan district center. Meteoric origin waters leaking underground in the region are stored in Bozçaldağ formation, which is the reservoir unit of the system, after being heated in the depths. The heat source of the geothermal system in the region is geothermal gradient and magmatic rock intrusions. The cover unit of the system consists of impermeable Eocene, Miocene, and Pliocene units (Baraklı, Çayraz, İncik formations and Central Anatolia group). According to the hydro geochemical studies, the dominant cations in the Boğazlıyan geothermal field are sodium (Na^+) and calcium (Ca^{+2}), respectively (Table 1). Na increase is associated with rock−water interaction with minerals such as alkali feldspars and plagioclase in schists and granites. Dominant anions are listed as Cl, HCO_3 and SO_4 respectively (KOP, 2021a). According to Fournier (1977), Arnorsson et al. (1983), D’Amore and Arnorsson (2000) calculations, the reservoir temperature of the Boğazlıyan geothermal field was calculated as 92°C with a chalcedony thermometer and 85°C with a quartz geo thermometer, respectively. There are many geothermal wells in Boğazlıyan geothermal area. However, since the log information of these wells is not available, the depth of the well and the units cut by the well are not known. For this reason, uncertainties about the field are quite high. In order to evaluate the field correctly, first of all, this information must be obtained, and in the light of this information it is necessary to carry out geological, active tectonic and geophysical researches in the areas. It is important to carry out Vertical Electric Drilling (DES) and MT studies in order to suggest new well locations (KOP, 2021a).

Yerköy Geothermal Field: Yerköy is located 35 km southwest of Yozgat, 5 km from the Ankara−Yozgat highway. Between 1992 and 1997, seven shallow wells with a depth of 59 to 262 m and a maximum temperature of 47°C were drilled in order to develop spa tourism. In addition, two exploration/production wells, varying between 550 m and 750 m, respectively, were drilled in 2006 to investigate the geothermal potential of the region and to develop district heating. The temperatures in these wells were measured between 67°C and 72°C, respectively (Şimşek et al., 2006). The reservoir units of the geothermal field are altered granodiorite, rhyolite and fractured/faulted zones. Eocene and Oligocene deposits are cover rocks and unconformable overlie rhyolites and granodiorites. Quaternary alluviums unconformable overlie these deposits. NW-SE and NE-SW oriented normal fault systems were developed in the region due to the tension tectonics in the Neogene and Quaternary. Thermal springs emerge from the intersection points of these faults.

In addition, sedimentary rocks in the fault zone and alluviums consisting of sand and clay in the Delice stream bed are important aquifers for cold water (Yılmaz Turalı et al., 2016). Thermal and cold waters in the geothermal field were investigated to determine the physical, chemical and isotopic compositions of the waters (Table 1). According to the chemical analysis results, thermal waters are of Na–Cl type. In cold waters, three types of water were determined, namely Na–Cl, Na –HCO_3 and Na–SO_4 types

(Yılmaz Turalı et al., 2016). According to the environmental isotope analyzes given in Table 2, thermal waters are of meteoric origin and are fed by precipitation from higher elevations than cold waters. The average tritium values of cold waters are 5.53 tritium units. These waters are modern waters. The tritium values of the thermal waters are close to zero, indicating that the thermal waters were fed by precipitation before 1952 (Clark and Fritz, 1997). In the KOP (2021a) report, cation geothermometers were used to calculate the reservoir temperatures and it was determined that the reservoir temperature was between 87 and 144.8°C.

3.1.2. Kırşehir region

Geothermal resources in Kırşehir are especially concentrated in the center of city, Çiçekdağı, Bulamaçlı, Mahmutlu, Savcılı, Karakurt, Akpınar and Kaman regions. The usage areas of geothermal resources in the city are for agriculture (greenhouse heating, drying of fruits and vegetables), tourism, health and energy (housing heating). Kırşehir geothermal fields are very important for Türkiye with approximately 1,800 residential heating and 226 decares greenhouse heating potential.

The base of the study area is formed by Paleozoic-aged metamorphic, ophiolitic, and plutonic rocks and comprises several distinct structural blocks, known as the Kırşehir Continent (Şengör and Yılmaz, 1981) / Kırşehir Massif (Seymen, 1981), or the Central Anatolian Crystalline Complex (Göncüoğlu et al., 1991). Metamorphic schists in the Kırşehir Massif are generally not permeable. Nevertheless, cracks, karstification, fractures and cracks in marbles provide permeability. For this reason, marbles are considered the primary reservoir where geothermal water can be stored (Pasvanoglu and Chandrasekharam, 2011). Kırşehir geothermal field, located in the Central Anatolia region, is controlled by NE-SW and NW-SE oriented faults belonging to the Seyfe fault zone, and all geothermal fields in Kırşehir are associated with young volcanic activity and block faulting (Koçyiğit and Beyhan, 1998; Şener, 2019). Şener (2019) pointed out that the hot and cold waters in the geothermal field in Kırşehir are of Ca–Na–HCO_3–Cl and Ca–Mg–HCO_3 water type, respectively. In the Giggenbach diagram, it is seen that cold waters are located in the partly equilibrated water region and hot waters are located in the immature water region. According to the semi-logarithmic Schoeller diagram, hot and cold waters come from different aquifers. According to cation and silica geothermometer calculations, the probable reservoir temperature is between 58 and 98°C. When environmental isotope values are examined, the $\delta^{18}O$ and $\delta^{2}H$ values of geothermal water are between the Mediterranean meteoric water line and the global meteoric water line. Therefore, geothermal water is of meteoric origin and is fed by precipitation at higher elevations than cold waters (Şener, 2019).

Terme and Karakurt Geothermal Field: Located at the center of Kırşehir, the Karakurt and Terme geothermal fields are found. 14 geothermal wells, including one reinjection well, were drilled in the Terme geothermal field. However, today, some wells are not used because their flow rates have decreased. The geothermal water in the field is used for residential heating, spa, and greenhouse heating. In the Karakurt geothermal field, there are 4 wells used for heating and drying purposes. The reservoir rocks of thermal water in Terme and Karakurt geothermal fields are Bozçaldağ marbles belonging to the Paleozoic-aged Kırşehir massif, as in the surrounding areas. Since the thermal and mineral waters coming to the surface from normal faults are supersaturated with calcite, these hydrothermal channels may have been completely closed by carbonate precipitation. These long-lasting events have led to the gradual decrease of resource drains and the depletion of some of them (Pasvanoğlu and Gültekin, 2012). The physicochemical properties of hot and cold waters in the field are given in Table 3. Terme and Karakurt waters are generally supersaturated with carbonate (Pasvanoğlu and Chandrasekharam, 2011). Thermal waters are rich in Ca–Mg–HCO_3, while cold waters are of Ca–HCO_3 type. The similarity of the chemical composition of the cold waters discharged along the contact between the metamorphic rocks and the sedimentary rocks above them and the thermal waters of Terme is remarkable. Current travertine accumulations around thermal wells and springs continue. In the KOP (2021b) report, the reservoir temperatures were calculated as 130–218°C in the Terme geothermal field and 109°C in the Karakurt geothermal field using silica geothermometry. The formation of carbonate minerals takes place at lower temperatures. The reason is that the water rebalances with this mineral in the upstream where it cools. Chemical results show that Terme and Karakurt geothermal waters are oversaturated with calcite and the water is not balanced. This shows that the geothermal fluid has a rapid circulation between fractures and cracks. While the hydrogeochemical composition of Karakurt hot and cold waters is different from each other, Terme waters are similar (Table 3). Environmental isotope values indicate that hot waters have a meteoric origin and are fed from higher elevations than cold waters (Table 2). The presence of carbon in low-temperature waters is attributed to organic matter, whereas in high-temperature waters, it results from the dissolution of marine carbonates. This indicates that cold waters interact with shallow carbonate rocks, while thermal waters interact with deep-sea carbonates and metamorphic rocks in the region (Pasvanoğlu and Chandrasekharam, 2011).

Table 1. Physicochemical properties of thermal and cold waters in Yozgat Region

Parameters	SORGUN Yılmaz Turalı and Şimşek (2017)		SORGUN Şimşek et al. (2010)	SARAYKENT Özulukale and Şimşek (2016)		SARIKAYA Özen Türker (2006)		SARIKAYA KOP (2021a)	BOĞAZLIYAN KOP (2021a)	YERKÖY Yılmaz Turalı et al. (2016)		YERKÖY KOP (2021a)
	*TW	**CW	*TW	*TW	**CW	*TW	**CW	*TW	*TW	*TW	**CW	*TW
T (°C)	75.2-80.0	5.5-15.5	59.5-80.0	48.2-73.6	15.6-22.1	25.0-50.9	15.6-16.6	50.3	52.5	41.2-56.2	13.0-22.0	40.6
pH	7.0-7.3	3.6-8.5	7.0-8.5	7.1-7.6	7.4-7.8	6.0-7.5	6.8-7.8	7.3	7.9	6.9-8.5	7.2-7.8	7.7
EC (µS/m)	2568-2785	88-3367	2510-3000	2950-3870	15-1071	400-1300	200-800	1042	5040	7160-19440	678-2360	19800
Na (mg/L)	393.0-467.0	5.2-788	351.4-570.5	458.8-607.5	0.2-43.9	9.45-78.2	2.8-48.7	73.5	554.5	1357.5-3745.4	70.9-282.3	3119.0
K (mg/L)	14.2-22.0	0.0-2.2	11.5-20.2	29.4-47	0.2-16.0	1.7-9.9	0.7-8.2	9.7	13.4	63.9-102.5	1.0-7.0	108.9
Ca (mg/L)	106.0-158.2	4.0-96.4	113.9-160.7	139.3-179.3	4.0-128.8	83.2-102.6	58.3-115.7	104.7	254.7	220.9-1673.8	60.8-174.9	1416.4
Mg (mg/L)	0.5-2.7	4.0-96.4	1.7-9.1	6.9-8.2	0.19-27.3	3.1-6.9	2.7-17.1	5.8	46.1	2.5-10.3	14.4-56.8	2.1
Cl (mg/L)	537.8-628.0	1.9-31.0	440.5-997.9	374.6-590.7	0.2-25.4	7.8-92.0	2.8-47.8	140.6	859.9	2062.3-9380.1	18.7-293.3	9459.5
SO_4 (mg/L)	294.7-333.6	4.2-1632	290.5-347.8	508.4-631.3	0.4-81.2	20.7-62.8	6.9-90.7	75.4	292.0	270.6-407.7	46.8-684.8	454.4
HCO_3 (mg/L)	114.4-169.4	0.0-355.8	18.9-185.9	244.0-273.7	15.2-499.9	220.6-311.2	191.1-325.3	252.1	630.4	11.5-817.4	222.9-410.7	298.8
SiO_2 (mg/L)	118.9-229.8	0.3-31.8	52.5-107.8	98.0-139.3	26.8-55.6	-	-	23.4	18.5	19.9-80.4	12.2-20.0	11.6

*:Thermal water; **:Coldwater

Table 5. Physicochemical properties of thermal and cold waters in Nevşehir Region

Parameters	KOZAKLI Pasvanoğlu and Chandrasekharam (2011)		KOZAKLI Şener and Baba (2019)	AVANOS-ÜRGÜP-GÖREME KOP (2021d)	ACIGÖL Şener et al. (2017)	ACIGÖL *Kara (2013)*	ACIGÖL Burçak (2006)		DERİNKUYU *Kara (2013)*	DERİNKUYU Şener et al. (2017)
	*TW	**CW	*TW	*TW	*TW	*TW	*TW	**CW	*TW	*TW
T (°C)	51-96	15	28.5-77.9	19-58	43.7	20.2-30.5	22.4-65	13.8-19.6	23.5	46.5
pH	6.7-7.4	7.6	6.46-7.26	6.6-7.8	7.1	6.1-6.9	6.7-7.0	7.6-8.0	6.5	6.9
EC (µS/m)	1650-3560	468	-	1344-4810	-	307-1278	-	-	439	-
Na (mg/L)	20.6-466.4	17.0	220.2-490.9	951.6-4140.5	182.5	18.3-134	138-195	11.9-12.2	26.6	213.79
K (mg/L)	16.9-22.9	2.0	12.0-29.7	115.1-221.6	62.31	4.33-14.1	60.5-73.1	1.4-5.12	7.91	52.7
Ca (mg/L)	218.5-251.8	57.9	159.3-679.4	66.3-439.8	275.01	27.3-68.6	92-351	30.7-45.7	44.8	87.56
Mg (mg/L)	25.4-30.7	12.3	21.1-24.4	28.5-41.9	29.9	11.4-46.5	13.9-53	1.85-5.1	11.9	35.41
Cl (mg/L)	500.0-740.5	8.6	24.6-1013.8	615.8-3393.3	273.5	3.7-61.9	247-300	2.49-4.97	5.6	318.4
SO_4 (mg/L)	412.0-652.1	8975.0	311.2-721.5	2.9-392.6	86.29	3.2-19.4	80.2-160	3.36-61	5.87	215.1
HCO_3 (mg/L)	222.3-778.0	176.7	270.6-875.1	307.5-3255.2	1122,6	178-728	537-1681	93-162	255	482.2
SiO_2 (mg/L)	50.9-88.0	34.4	70.9-181.4	-	196	82-122	106-202	54-69	92	183

*:Thermal water; **:Coldwater

Savcılı Geothermal Field : The Kaman–Savcılı geothermal field is located in Central Anatolia, approximately 150 km southwest of Ankara, 56 km west of Kırşehir. 5 geothermal water exploration wells were drilled by MTA between 1986 and 2005 in the Savcılı geothermal field. However, only one of these wells is productive today (Yurteri et al., 2015). The foundation of the study region is composed of Kırşehir Massif rocks from the Paleozoic era, including gneiss, schist, amphibolite, quartzite, and marble. Metamorphic rocks of the Kırşehir Massif are tectonically overlaid by ophiolitic mélange units consisting of Late Cretaceous pelagic sediments and intercalated mafic volcanoclastic rocks and these formations were cut by the Baranadağ granitoids (Late Cretaceous–Paleocene), which is assumed to be the primary reservoir rock. The Eocene units and Miocene–Pliocene-aged Kızılırmak formation, consisting of terrestrial sediments (intercalation of conglomerate and sandstone), unconformable overlie the Mesozoic units. The Tertiary sedimentary layers with low permeability serve as the overlaying strata for the Savcılı–Büyükoba geothermal system.

The physicochemical properties of hot and cold waters in the field are given in Table 3. The ion concentrations of the waters show that the thermal waters are of the NaCl type and the cold waters are of the Ca–HCO_3 type. The outcomes from mineral saturation index calculations indicate that thermal waters, in particular, exhibit saturation with respect to quartz, chalcedony, calcite, aragonite, and dolomite. Hence, the possibility of calcification in thermal waters is suggested. The reservoir temperature was determined to be within the range of 68 –74°C utilizing a silica geothermometer. The thermal waters in the field are located on the Local Meteoric Water Line (LMWL), suggesting that the geothermal waters have meteoric origin. The minimal tritium presence in the thermal waters suggests that the thermal aquifer in the Savcılı geothermal field is supplied by groundwater with an extensive and enduring circulation mechanism (Yurteri and Şimşek, 2017) (Table 2).

Table 2. Isotopic properties of thermal and cold waters in the Central Anatolia Region

	δ ^{18}O (‰ SMOW) *** (min – max)	**δ ^{2}H (‰ SMOW) ***** (min- max)	**Tritium unit (TU)** (min- max)
SORGUN - *TW *(Yılmaz Turalı, 2017)*	-11.06 _ -10.28	-84.36 _ -78.83	1.11 _ 3.01
SORGUN - **CW *(Yılmaz Turalı and Şimşek, 2017)*	-12.06 _ -7.17	-84.73 _ -61.35	4.75 _ 8.12
SARAYKENT - *TW *(Özulukule and Şimsek, 2016)*	-10.91 _ -9.85	-95.06 _ -91.15	0.00 _ 0.40
SARAYKENT - **CW *(Özulukule and Şimsek, 2016)*	-11.36 _ -10.3	-79.37 _ -77.67	6.67 _ 7.16
SARIKAYA - *TW *(Özen Türker, 2006)*	-11.42 _ -10.23	-80.68 _ -77.64	1.25 _ 3.45
SARIKAYA - **CW *(Özen Türker, 2006)*	-12.22 _ -9.28	-77.78 _ -69.36	5.91 _ 8.92
YERKÖY - *TW *(Yılmaz Turalı et al., 2016)*	-11.63 _ -9.34	-90.02 _ -78.09	0.39 _ 1.1
YERKÖY - **CW *(Yılmaz Turalı et al, 2016)*	-9.61 _ -8.73	-76.84 _ -64.22	3.81 _ 6.48
TERME-KARAKURT - *TW *(Pasvanoğlu and Gültekin, 2011)*	-11.12 _ -10.02	-83.9 _ -76.8	-0.52 _ 2.0
TERME-KARAKURT - **CW *(Pasvanoğlu and Gültekin, 2011)*	-8.91 _ -8.39	-74.7 _ -58	0.81 – 3.97
SAVCILI (KAMAN) - *TW *(Yurteri et al., 2015)*	-12.27 _ -12.07	-88.4 _ -8.37	0.18 _ 0.28
SAVCILI (KAMAN)- **CW *(Yurteri et al., 2015)*	-11.33 _ -7.13	-76.58 _ -55.77	5.57 _ 8.49
KOZAKLI - *TW (Pasvanoğlu and	-10.37_ -9.97	-74_ -59.2	0.14_ 0.62
KOZAKLI - **CW (Pasvanoğlu and	-8.91	-68.9	8.87
KOZAKLI - *TW (Şener and Baba, 2019)	-11.91 _ -10.89	-78.38_ -70.62	-
ACIGÖL - *TW *(Şener et al., 2017)*	-11.9	-79	-
ACIGÖL - *TW *(Burçak, 2006)*	-11.50 _ -9.41	-76.39 _ -65.60	0 _ 1.40 (±1.95)
ACIGÖL - **CW *(Burçak, 2006)*	-11.77	-78.10	3.20 ±2.0

Table 2. Isotopic properties of thermal and cold waters in the Central Anatolia Region (Continue)

	δ ^{18}O (‰ SMOW) *** (min – max)	**δ ^{2}H (‰ SMOW)** ***	**Tritium unit (TU)** (min- max)
DERİNKUYU - *TW *(Şener et al., 2017)*	-10.7	-76	-
DERTALAN - *TW *(Şener et al., 2017)*	-11.6	-74	-
DERTALAN – *TW Temel (2007)	-11.58	-76.33	0.04
ÇİFTEHAN - *TW Temel (2007)	-10.79	73.32	-0.06

:Thermal water; **:Coldwater; *:Standard Mean Ocean Water*

Çiçekdağ-Bulamaçlı Geothermal Field: Çiçekdağı is located approximately 70 km northeast of Kırşehir province. The Bulamaçlı geothermal field is located to the east of Çiçekdağı and to the south of Yozgat–Yerköy. There are two natural spring and two geothermal wells in the Bulamaçli geothermal area, but today, one of the spring has no flow.

The Central Anatolian group, which consists of similar lithology, and the İncikli Baraklı and Boğazköy formations are named under the same group. Sandstone and conglomerate levels in these units can contain groundwater in proportion to their thickness and spread. In addition, the limestone and travertine units of the Bozçaldağ formation serve as the aquifer of the system as they can contain groundwater due to karstic melting gaps and broken-cracked systems. On the other hand, alluvium has been determined as a granular aquifer due to its porous structure, which can contain a significant amount of groundwater (KOP, 2021b).

The physicochemical properties of the thermal and cold waters in the field are given in Table 3. In the Schoeller semi-logarithmic diagram, waters with similar origin, same reservoir and recharge area show similar changes. It is seen that Bulamaçlı spring and well waters have similar major ion contents in Schoeller diagram. The water type of Bulamaçlı thermal water is Na–Cl. Na increase is associated with rock–water interaction with minerals such as plagioclase and alkali feldspars in granites and schists. The increase in Cl is realized by ion exchange depending on the rock–water interaction with the evaporitic units in this region (Ünsal and Afşin, 1999). In the report of KOP (2021b), the reservoir temperature of the geothermal system was calculated between 82 and 147°C with silica thermometer.

Çiçekdağ–Mahmutlu Geothermal Field: Çiçekdağı–Mahmutlu geothermal field is located approximately 31 km northeast of Kırşehir. There are 3 natural springs in the north of Mahmutlu village. Today, Küçükhamam spring does not flow from these sources, whose flow rates vary between 1–5 l/s. On the other hand, the flow of other resources changes seasonally. In addition, there are 3 geothermal wells and one reinjection well in the Mahmutlu geothermal area, and the wells are discharging artesianly.
Incik, Çayrak, and Kızılırmak formations observed in the field and consisting of similar lithology (conglomerate, sandstone, claystone, mudstone, etc.) have been evaluated within the same hydrogeological unit because they have similar hydrogeological characteristics. Sandstone and conglomerate levels in these units can contain groundwater in proportion to their thickness and spread. Dulkadirli and Kozaklı limestone members observed in and around the Mahmutlu geothermal area were named as karstic aquifers (KOP, 2021b).

The physicochemical properties of the thermal waters in the field are given in Table 3. In the Mahmutlu geothermal field, the dominant cation is Na^{+} followed by Ca^{+}. Na increase is associated with the interaction of rock–water with minerals such as plagioclase and alkali feldspars in granites and schists (Ünsal and Afşin, 1999). The dominant anions are sulfate (SO_4) and chloride (Cl). The increase in Cl is realized by ion exchange depending on the rock–water interaction with the evaporitic units observed in this region just like in Bulamaçlı. High SO_4 contents can be explained by the dissolution of minerals such as gypsum in Neogene sediments. It is seen that Mahmutlu well waters have similar major ion content in the Schoeller diagram. The water class of Mahmutlu thermal waters was determined as Na–Ca–Cl–SO_4. In the KOP (2021b) report, the reservoir temperature of the geothermal system was calculated between 56 and 181°C with silica geothermometers.

Table 3. Physicochemical properties of thermal and cold waters in Kırşehir Region

Parameters	**Terme-Karakurt** Pasvanoğlu and Gültekin (2011)		**Savcılı (Kaman)** Yurteri et al. (2015)		**Bulamaçlı (Çiçekdağ)** KOP (2021b)	**Mahmutlu (Çiçekdağ)** KOP (2021b)
	*TW	**CW	*TW	**CW	*TW	*TW
T (°C)	44-60	13-20	30.0-33.5	7.2-13.6	39.6-43.7	73.1-78.3
pH	6.3-7.0	7.2-7.5	9.4-9.5	6.7-7.7	6.5-6.6	8.0-8.3
EC (µS/m)	1000-2400	478-883	513-527	179-1449	7400-7430	6008-6330
Na (mg/L)	36.6-170.4	9.3-32.3	111.2-111.8	1.5-172.0	1334.4-1497.9	1016.4-1077.6
K (mg/L)	4.5-12.2	0.7-2.4	1.2-1.3	0.4-12.3	0-123.0	0-45.5
Ca (mg/L)	118.1-255.7	64.9-91.8	9.1-9.3	26.7-126.1	257.7-286.8	318.4-349.3
Mg (mg/L)	18.3-38.4	10.4-24.3	0.1-0.3	1.9-35.7	9.7-11.7	46.1-51.4
Cl (mg/L)	47.4-279.3	13.4-45.1	88.2-88.9	1.5-256.5	2332,2-2337,9	1360.9-1434.2
SO_4 (mg/L)	49.8-269.3	9.9-65.5	48.9-49.3	5.9-388.6	499.5-503.0	1329.9-1438.1
HCO_3 (mg/L)	438.9-838.0	205.2-353.4	12.6-31.6	94.8-379.2	823.5-902.3	269.7-287.4
SiO_2 (mg/L)	19.4-50.7	16.9-25.5	47.0-47.4	8.5-28.5	43.4-55.7	25.9-30.6

**:Thermal water; **:Coldwater*

3.1.3. Niğde region

There are Narköy, Çiftehan, and Derdalan geothermal fields in Niğde province and the geothermal waters here are used for thermal tourism purposes. Apart from the existing wells, it is planned to drill new geothermal wells in two locations in Niğde center, one in Bor and two locations in Ulukışla.

Narköy Geothermal Field: In the Narköy geothermal field, 4 wells were drilled by MTA in 1990, but these wells with a temperature of around 65°C are not used due to the scaling problem. Today, only a well opened in 2016 is active and is used for thermal tourism purposes. There is no reinjection well in the Narköy geothermal area. For this reason, the discharge of geothermal waters to the natural environment after use may cause significant environmental problems.

Marbles belonging to Bozçaldağ formation at the basement of the Narköy geothermal area are reservoir rocks due to their secondary permeability. Travertines cropping out in small areas in the region have melting gaps and may contain groundwater. The heat source of the hydrothermal system is likely volcanic activity. The cover rock of the system is impermeable Upper Miocene–Pliocene and Quaternary-aged ignimbrite, tuff, pyroclastic and sediments formed in terrestrial lacustrine facies contemporaneous with them. It is thought that shallow reservoirs developed in the permeable zones within these units (Burçak, 2006).

The physicochemical properties of the thermal waters in the field are given in Table 4. The highest cation values in the NAR-2 well, which is the only active well in the field, were calcium (Ca^{+2}) and sodium (Na^{+}) ions, respectively, and the water type was determined as Ca–Na–Cl–HCO_3. The dominant anions are bicarbonate (HCO^{-}) and chloride (Cl^{-}), respectively. The reservoir rock of the geothermal system around Narköy is the marbles belonging to the Bozçaldağ formation. The predominance of Ca and HCO_3 contents of the thermal waters in this area is due to the interaction of the thermal water with the reservoir rock. The reservoir temperature of the geothermal system is maximum 145°C according to the silica geothermometer calculations. (KOP, 2021c).

Çiftehan Geothermal Field: Çiftehan geothermal field is located in Ulukışla district, 77 km southeast of Niğde city center. There are two natural resource discharges in the Çiftehan geothermal area. There are two wells drilled in the 1990s and 6 wells drilled in the 2000s in this region. These wells are used for thermal tourism purposes. The hot and mineral waters of Çiftehan are exposed in relation to the strike-slip and left-sided Ilıca fault and other fracture systems (Afşin et al., 2007).

Mesozoic and Cenozoic-aged rocks crop out in Çiftehan and its surroundings. The marbles, which are in the Bolkardağ group of Permo–Triassic age (Demirtaşlı et al., 1973) and which are located in the basement, have aquifer characteristics. The Late Cretaceous-aged (Ayan, 1968) Alihoca ophiolite overlying this unit is impermeable except for the fractured levels. Above this, the sandstone, limestone and unfilled cracked levels of Paleocene–Early Eocene-aged Çiftehan formation (İşler, 1988) are permeable, while the other levels are impermeable. The Çayırlıgedik formation is permeable except for the clayey limestone levels. Alluvium consisting of gravel, sand, silt and clay is observed along the Çiftehan stream valley. Gravel and sands in the unit are permeable, silts are semi-permeable, and clays are impermeable.

The physicochemical properties of the thermal waters in the field are given in Table 4. The ion sequence of Çiftehan thermal and mineral waters is Na+K>Ca+Mg, Cl+SO_4>HCO_3+CO_3, and they are non-carbonate waters with more than 50% alkalinity (Temel, 2007). The thermal waters in the Çiftehan geothermal field have a chemical composition belonging to the Na–Ca–SO_4–Cl water type. The constituents of these waters originate from the following sources: Na comes from the mineral albite, SiO_2 from tuff, SO_4 from the mineral barite ($BaSO_4$), Ca and HCO_3 from carbonate rocks. According to the results of environmental isotope analysis, Çiftehan thermal waters are of meteoric origin and their circulation times in the aquifer are relatively long and they are deep circulation sources (Table 2). According to the chalcedony geothermometer, the reservoir temperature was calculated as 69 °C (Temel, 2007).

Dertalan Geothermal Field: In the Dertalan geothermal area, there is a thermal spring with a flow rate of 8 l/s and a temperature of 29.5°C. Today, there is one operating well in Hamamlı–Kumluca in this geothermal area. The depth of the well opened in 2016 is 472 m, its flow rate is 25 l/s and its temperature is 32°C. The well is not currently used. In the Niğde–Derdalan geothermal area, the Paleozoic Niğde massif is the basement rock units. The fractured and karstic cavities of the marbles in these basement rocks are permeable and constitute the reservoir rock of the geothermal system. The heat sources of the geothermal system are the geothermal gradient and the granodiorite intrusions of the Niğde massif. Thermal water rises along the fault planes and rises to the surface. The cover rock of the geothermal system is Upper Miocene–Pliocene-aged volcanic and sedimentary units (KOP, 2021c).
The physicochemical properties of the thermal waters in the field are given in Table 4. According to the results of the chemical analysis of the waters, the thermal waters in the Dertalan geothermal field are of Ca–Mg–SO_4 type (Şener, 2015). If the Cl/SO_4 ratio of the waters is high, the aquifer temperature is high (Tarcan, 2002). When the thermal water in the region was examined, the Cl/SO_4 ratio was found to be high, although the aquifer was not at high temperature. This situation is explained by the fact that the Cl content originates from the salty units of the rocks at the base of the study area, rather than being related to the temperature (Şener, 2015). According to the chalcedony and quartz geothermometer calculations of Dertalan thermal waters, the maximum reservoir temperature that can be expected is in the range of 150–173°C (Fournier, 1977). In the research conducted by Afşin et al., (2007) and Temel (2007), it was determined that Dertalan thermal water source in Niğde Center is saturated with chalcedony, goethite, hematite and quartz minerals. The isotope contents of the hot water sample taken from the Dertalan geothermal field indicate that the waters are of meteoric origin (Table 2). Dertalan thermal water spring has a deep and medium-term circulation according to tritium and EC value.

Table 4. Physicochemical properties of thermal waters in Niğde Region

Parameters	**Çiftehan** KOP (2021c)	**Çiftehan** Şener et al. (2017)	**Çiftehan** Temel (2007)	**Narköy (Acıgöl)** KOP, (2021c)	**Dertalan** Şener et al. (2017)	**Dertalan** Temel (2007)
	*TW	*TW	*TW	*TW	*TW	*TW
T (°C)	32.2-55.1	44.5	52	60.1	29.5	28.5
pH	8.4-8.8	8.6	8.2	6.9	6.7	4.9
EC (µS/m)	2820-3010	-	2770	2740	-	705
Na (mg/L)	365.2-378.6	385	391.0	240.6	23.34	31.9
K (mg/L)	8.19-8.45	7.8	8.34	85.5	7.8	8.7
Ca (mg/L)	220.8-231.7	214	224.2	553.3	66.74	92.58
Mg (mg/L)	0.12-0.2	0.24	0.42	47.6	14.99	14.60
Cl (mg/L)	616.5-624.4	389	358.7	689.2	14.64	12.23
SO_4 (mg/L)	1165.0-1180.6	86.2	770.3	142.4	371.34	259.06
HCO_3 (mg/L)	19.8-21.4	12	15.33	768.4	11.16	104.22
SiO_2 (mg/L)	-	83	48.10	-	179	62.1

**:Thermal water*

3.1.4. Nevşehir region

Nevşehir has a great potential among the resources in the Central Anatolia region in terms of geothermal resources. Especially Kozaklı geothermal field is important as a thermal health and tourism center in the region.

Kozaklı Geothermal Region: Kozaklı geothermal field is one of the most important geothermal fields in Türkiye. Geothermal studies in this area have been continuing since 1963. The data obtained from the drillings show that it is a low temperature area and therefore geothermal fluid is used for regional and greenhouse heating and thermal tourism purposes. Due to the diversity of uses, geothermal waters are used in an uncontrolled manner in the region and this reduces the reservoir pressure (Pasvanoğlu et al., 2012). More than 23 wells with depths ranging from 90 to 205 m have been drilled by MTA, state and private institutions in the Kozaklı geothermal field. Most of these wells are of artesian type, but water is pumped from the wells during the summer months (Özkan and Koçak, 2006). The temperature range of the waters is 45-96 °C and their discharge is 2-0 l/s. It is thought that waters hotter than 90 °C coming out of a 150 m deep well may indicate the presence of magma chambers that are still cooling under the Kozaklı Region. (Koçak, 1997). In addition, there is one reinjection well at a depth of 3016 m in the region.

The reservoir rock of the geothermal water in the Kozaklı geothermal area is the Bozçaldağ marbles belonging to the Paleozoic-aged Kırşehir crystal massif or the Central Anatolian Crystal Complex (Ketin, 1955; Seymen, 1982; Goncuoglu et al., 1992, 1993), which is the oldest unit in the region. Secondary pores formed by the cracked-fractured levels of Bozçaldağ marbles and Kozaklı limestone member form aquifers in the region (Canik and Pasvanoğlu, 1993). Oligocene aged clayey-marl units have low porosity and therefore act as cover rock. In the Kozaklı geothermal area and its vicinity, the geothermal fluid emerges from the intersection points of the NW-SE and NE-SW trending faults. The geothermal system in the area is tectonic controlled. Some of the meteoric water feeds the shallow aquifers and creates mineral water discharges in the region. Meteoric waters infiltrating deep by faults feed the fractured-cracked marbles, which is the reservoir rock of the geothermal system (Pasvanoğlu and Chandrasekharam, 2011; Pasvanoğlu et al., 2012). The physicochemical properties of the thermal and cold waters in the field are given in Table 5. The chemical properties of Kozaklı thermal waters are similar to each other and are represented by higher total ion concentrations and EC values. The Cl and SO4 concentrations of Kozaklı thermal waters are higher than their HCO3 content while cold waters are of Ca–HCO3 type (Pasvanoğlu et al., 2012).

In the Schoeller semi-logarithmic diagram it is seen that the waters have similar origin, the same reservoir and feeding area. In the Piper diagram, it is seen that Kozaklı geothermal waters represent non-carbonate waters with more than 50% alkalinity and the water classes are generally Na–Ca–SO4–Cl and Na–Ca–Cl–SO4 types (KOP,2021d). It has been determined that the cold water springs are also Ca+Mg HCO3 water type. Thermal waters from springs and wells have much higher salinity than groundwater and the water type is determined as Na–Cl (Pasvanoğlu and Chandrasekharam, 2011). According to the studies of Pasvanoğlu and Chandrasekharam (2011), the tritium contents of geothermal waters in Kozaklı geothermal field showed that the waters have a long circulation time in the reservoir rock. Hot waters from the geothermal reservoir rise to the surface in relation to the fracture system that acts as a channel. These waters mix with the current cold waters during their rise to the surface.

Although chemical geothermometers cannot predict the realistic temperatures of the reservoir, oxygen and hydrogen isotopes geothermometers show temperatures above 220°C and it is estimated that there is a high temperature reservoir under the Kozaklı geothermal region (Pasvanoğlu and Chandrasekharam, 2011). The probable reservoir temperature was calculated between 103 and 173°C using a quartz and chalcedony geo thermometer. δ18O and δ2H values for thermal waters indicate a deep circulating meteoric origin (Table 2). These waters are probably caused by rainwater seeping into the deep hot reservoir through fractures and faults (Pasvanoğlu and Chandrasekharam, 2011; Şener and Baba; 2019). According to the KOP (2021d) report, the saturation index values of thermal water samples show that Kozaklı well waters are saturated with aragonite, calcite, dolomite, goethite, hematite, and talc minerals. As a result, it has been determined that calcite, aragonite, and dolomite scaling may occur in the bearing systems where water is used in the Kozaklı well.

Avanos–Ürgüp–Göreme Geothermal Region: The majority of these wells are located in the north and northeast of Nevşehir city center. The reservoir rock of the geothermal water in the region is Bozçaldağ marbles belonging to the Paleozoic-aged Kırşehir massif. The unit acquires an aquifer character with the secondary porosity formed by the fractured-cracked levels of Bozçaldağ marbles. The heat source in the region is high geothermal gradient and magmatic rock intrusions in close relation with the Erciyes volcanism. The cover rock of the system is impermeable Upper Miocene–Pliocene and Quaternary-aged ignimbrite, tuff, pyroclastic, and sediments formed in terrestrial lacustrine facies contemporaneous with them (Canik and Pasvanoğlu, 1993; KOP, 2021d).

The physicochemical properties of the thermal and cold waters in the field are given in Table 5. The dominant cation in Nevşehir–Merkez-Avanos geothermal area is sodium (Na+). The highest potassium (K+), calcium (Ca+2), sulfate (SO4) and Cl values are found in Göreme spring. The highest anion in the region is chloride (Cl-). The high ion contents of Nevşehir–Merkez, Ürgüp and Göreme geothermal waters indicate that the geothermal waters are fed from the deep reservoir. In the Scholler semi-logarithmic diagram, it was determined that well and spring water samples were fed from a similar reservoir. Also, according to the Piper diagram, Nevşehir Merkez–Avanos thermal waters represent non-carbonate waters with an alkalinity of more than 50%. The water class of well and spring waters is determined as Na–Cl–HCO3 (KOP 2021d).

According to the saturation index calculations, it is observed that: the Ürgüp well water is saturated with aragonite, calcite, chalcedony, dolomite, goethite, hematite, quartz and talc minerals the Göreme spring is saturated with aragonite, calcite, dolomite, goethite, hematite, quartz and siderite minerals, the Nevşehir center is saturated with goethite-hematite, quartz, and siderite minerals. The reservoir temperatures calculated by quartz geo thermometers for the well in Nevşehir Merkez (Avanos) are between 48-75°C. The reservoir temperatures calculated by cation geo thermometers of Göreme spring water and Ürgüp well water vary between 93-217°C (KOP, 2021d).

Acıgöl–Derinkuyu–Gülşehir Geothermal Region: There are two boreholes around Acıgöl and one borehole in Derinkuyu. The drilling in Derinkuyu is the deepest well in the region, at 2,505 m (KOP, 2021d). Paleozoic aged metamorphic units, Upper Cretaceous ophiolite; fault zones within volcanic and magmatic units constitute the main reservoir of the system. Limestone and Plio-Quaternary basalts observed in places between the ignimbrite levels are also secondary reservoirs. The cover rock of the geothermal system is composed of clayey, ignimbrite and tuffy layers of Miocene, Pliocene, and Quaternary-aged volcano sedimentary succession. The feeding direction of the field is thought to be from the S and SW sections of the region (Kara, 2013). The heat sources of the geothermal system are young volcanism and Cretaceous-aged granite and granodiorite intrusions, which have regionally high geothermal gradients and are observed around Acıgöl springs (Şener, et al., 2017).

In the research carried out around Acıgöl, Derinkuyu and Gülşehir districts within the study area, it is thought that the main tectonic structures are N-S and NW-SE oriented, and synthetic and NE-SW direction antithetic fault systems developed depending on these main tectonic lines. It has been observed that the wells with high temperatures measured in and around the study area are also concentrated on these antithetic fault systems (Kara, 2013). It is thought that the Cappadocia volcanic complex is under the influence of the activity of the Tuzgölü and Ecemiş Fault systems. These fault systems almost perpendicularly cut the long axis of the Cappadocia region volcanic and consist of many faults developed in N-S, NW-SE and NE-SW directions (Toprak, 1998).

Physicochemical properties of thermal and cold waters in the field are given in Table 5. According to the results of chemical analysis of the waters, the cold waters in the area are Ca–Mg–HCO_3 and Ca–HCO_3 water types; In hot waters, while the waters in the first geothermal system are of the Ca-Na–SO_4 and Ca–Mg–SO_4 types, the waters in the second geothermal system are of the Na–Cl–HCO_3 and Ca–Na–HCO_3 types and are mineral-poor hot waters. $\delta^{18}O$ and δ^2H stable isotope analyzes were performed on the water taken from the study area and the results were evaluated with various graphs and diagrams (Table 2). Accordingly, it was observed that the water samples were almost above the Global Meteoric Water Line created by Craig (1961). Therefore, this shows that the waters are fed by meteoric waters of the same origin (Şener, 2015). The suitability of the waters in the Nevşehir area for geothermometer use was examined in the Na–K–Mg triangle diagram (Giggenbach, 1991) and it was determined that they were in the immature water group. Under these conditions, silica geothermometers give the appropriate reservoir temperature and the reservoir temperature is calculated between 90 and 140°C (Kara, 2013).

3.1.5. Aksaray region

In the studies conducted by MTA (2005) in Aksaray province, four geothermal areas are mentioned: Ziga–Yaprakhisar, Ilısu, Tuzlusu and Güzelyurt–Sivrihisar (Şahinkalesi). Today, in addition to these areas, there are geothermal areas in Bekdik village of Sarıyahşi district, in Sofular village of Gülağaç district and in Dikmen village, located in the north of Aksaray. The reservoir rocks of the geothermal system in Aksaray province are marbles belonging to the Bozçaldağ formation. The cover rocks of the geothermal system are lacustrine-continental sedimentary and volcanic rocks of Upper Miocene, Pliocene and Quaternary age. The heat source of the hydrothermal system is volcanic activity and geothermal gradient. Tectonism has an important place in the formation of hot water resources. Tectonic lineation in the region is grouped in two directions: NW-SE and NE-SW. Rainwater in the region filters underground through faults, fractures and permeable rocks, where it comes into contact with magmatic intrusions and gets heated (Burçak, 2006; KOP, 2021e).

Silica, chalcedony and quartz geothermometers were used in all areas in Aksaray province. According to these calculations, reservoir temperatures in the Ziga geothermal area are between 58.65–106.86°C, 162.6°C in the Güzelyurt–Şahinkalesi geothermal area, and 90.71°C in the Tuzlusu geothermal area (KOP, 2021e).

Ziga–Yaprakhisar Geothermal Region: Yaprakhisar Village and its surroundings, located on the border of Ihlara Valley, are called Ziga geothermal field. In the Ziga geothermal field, two wells, one with a depth of 400 m and the other with a depth of 250 m, are operated for active thermal tourism purposes. The temperature of both wells is stated as 47°C.

In the study area, Paleozoic aged Tamadağ gneisses and schists and Bozçaldağ marbles are permeable units that have gained secondary porosity along fractures and fissures due to faulting, and form the deep (primary) reservoir. The cap rock of the system is the tuff levels within the Göstük toffies; The Selime tuffs, the hydrothermally altered sections of the Gelveri and Kızılkaya ignimbrites and the Hasandağ ash formation constitute impermeable rocks (Burçak, 2006).

Physicochemical properties of thermal and cold waters in the field are given in Table 6. Two different thermal water types, Na–Ca–Cl and Na–Ca–Cl–HCO_3, were determined in the Ziga geothermal field. The cation and anion contents of group 1 waters are similar to each other. The most distinctive feature of this group is that the determining cation is Na and the determining anion is Cl. In the second group of waters in Ziga, the determining cation is Na+K and the determining anion is HCO_3. According to water chemistry studies, the cold waters in the area are Ca–Mg–HCO_3 and Ca–HCO_3 type waters (Burçak, 2006). According to the cation maturity diagram of Giggenbach (1988), thermal waters in the Ziga geothermal area are located in the immature waters zone. For this reason, since cation geothermometers would give incorrect results in calculating reservoir temperatures, silica geothermometers were used to calculate reservoir temperatures of waters in the Ziga geothermal area. According to chalcedony and quartz geothermometer calculations, reservoir temperatures in the Ziga geothermal area were determined between 58.65–106.86°C (KOP, 2021e). There is no reinjection well in the Ziga geothermal area. Discharging recycled water after use into the natural environment may cause significant problems for the environment.

Şahinkalesi–Ilısu (Güzelyurt) Geothermal Region: There are 2 thermal water wells in the Ilısu geothermal field, located within the borders of Ilısu village in Güzelyurt district, and the wells are used for tourism purposes. Thermal hotels have a very important capacity for the region.

The cap rock of the system is impermeable, Upper Miocene–Pliocene- and Quaternary-aged ignimbrite, tuff, pyroclastics and sediments formed in continental and lacustrine facies of the same age. It is thought that a shallow reservoir developed in the permeable zones within these units. Marbles of the Bozçaldağ formation, one of the underlying metamorphic rocks in the geothermal system, are reservoir rocks due to their secondary permeability. The heat source of the hydrothermal system is probably volcanic activity (Burçak, 2006). Physicochemical properties of thermal and cold waters in the field are given in Table 6. In the Piper diagram, it has been determined that all cold water samples taken from the working area, along with the hot waters of Şahinkalesi, fall into the Ca–Mg–HCO_3 type water category based on cations as Ca+Mg>K+Na and anions as $HCO_3+CO_3>Cl+SO_4$ (Burçak, 2006). In addition, it has been determined that the thermal waters in the Şahinkalesi geothermal area are saturated with quartz and chalcedony, but are not saturated with calcite, dolomite, aragonite, gypsum and anhydrite.

Tuzlusu–Aksaray (Center) Geothermal Region: In the Tuzlusu geothermal field, located approximately 5 km northwest of Aksaray city center, Tuzlusu thermal and mineral water resources are exposed at three points at an average altitude of 1,040 m above sea level, at the intersections of the NE-SW oriented main fault and the faults oblique to it. However, only one of these sources is active today (Afşin and Elhatip, 2000).

The fractured, fissured and karst-cavity units of the marbles belonging to the Bozçaldağ metamorphics located in the east of the Tuzlusu geothermal field are permeable and constitute the main reservoir of the geothermal system. The schists belonging to the Tamadağ metamorphite (Seymen, 1981) are impermeable and the evaporites and lacustrine sediments in the area are the cover rocks. Tuzlusu thermal water source emerges from the intersection point of the NE-SW oriented main fault and the fault that cuts obliquely to it. Tuzlusu springs reaches the earth by washing the granites and evaporite units intruding along the circulation path and lost their temperature to a certain extent (Afşin and Elhatip, 2000). Physicochemical properties of thermal and cold waters in the field are given in Table 6. In the study conducted by Afşin and Elhatip (2000), it was determined that Aksaray–Merkez Tuzlusu spring waters were in Na–Ca–Cl–HCO_3 and Na–Cl type water chemistry facies. In addition, it has been stated that this aquifer system, which has medium-deep circulation, generally contains groundwater that moves slowly and therefore has high ion content. It was determined that the Tuzlusu thermal water was saturated with calcite and quartz minerals, but not saturated with anhydrite, aragonite, chalcedony, dolomite, fluorite, gypsum, halite, quartz and talc minerals. This shows that calcite crusting may occur in carrier systems where spring waters are used. This content shows that the aquifer of hot waters is marble and that highly soluble evaporitic rocks along the circulation path also have an effect (Afşin and Elhatip, 2000; KOP, 2021e). There are generally two different interrelated circulatory systems in Tuzlusu hot springs. The first of these is the medium-deep circulation system in which Ca–Na–Cl–HCO_3 and Na–Ca–Cl–HCO_3 water facies are observed, where hot waters mix with cold waters during the rise of the Eski Hamam Spring to the surface. The second is a deep circulation system in which Na–Ca–Cl–HCO_3 and Na–Cl water facies are observed, where the Hamam source mixes less with cold waters. These waters are underground waters with slow circulation and increased ion content as a result of prolonged contact with the rock. Silica geothermometers were used to calculate reservoir temperatures of Tuzlusu spring waters. According to chalcedony and quartz geothermometer calculations, the maximum reservoir temperature that can be expected in the Tuzlusu geothermal area has been determined as 90.71°C.

Table 6. Physicochemical properties of thermal and cold waters in Aksaray Region

Parameters	**Şahinkalesi-Güzelyurt** Burçak (2006)		**Ilısu-Güzelyurt** KOP (2021e)	**Ziga- Yaprakhisar** Burçak (2006)		**Ziga** KOP (2021e)	**Tuzlusu** Afşin and Elhatip (2020)	
	*TW	**CW	*TW	*TW	**CW	*TW	E. Hamam (*TW)	H. Kaynağı (*TW)
T (°C)	21-44.1	10.9-12	34.1	29.6-51	14.3-16.8	54.2	21.6	32
pH	6.8-8.3	7.3-7.8	7.1	6-7.4	7.6-8.8	6.64	6.6	6.6
EC (µS/m)	-	-	485	-	-	6720	4800	19800
Na (mg/L)	12.2-47.5	2.9-7.7	48	49.2-1225	11.7-12.7	803.8	24.96	256.2
K (mg/L)	0.8-16.5	1.1-6.6	19	17.9-174	2.0-8.6	128.5	0.64	5.5
Ca (mg/L)	22-52	12.9-26	30	31.2-361	59.1-65.9	561	14.5	26.5
Mg (mg/L)	3.2-8.3	1.6-5.0	10	36-162	12.2-19.4	48.5	2.8	9.29
Cl (mg/L)	3.2-14.6	1.2-2.8	24.4	20.9-1907	7.1-7.4	1473.0	22.8	260
SO_4 (mg/L)	1.79-16.8	1.7-7.6	16.5	0.9-78	6.7-11	74.44	1.36	6.37
HCO_3 (mg/L)	140-296	58-134	201.9	273-2087	244-336	1590.2	18.9	30.97
SiO_2 (mg/L)	70-146	30-77	-	47-114	52	-	-	-

**:Thermal water; **:Coldwater*

3.1.6. Evaluation of the usability and environmental impacts of water in geothermal fields

In order to determine the effect of geothermal waters on underground and surface waters in terms of their usability as drinking water, according to their chemical structures, the analysis results of the waters were compared with the drinking water limit values determined by TS266 (2005) and WHO (2017). According to the permissibility limits of the World Health Organization (WHO, 2017) Drinking Water Quality Guidelines in the Sorgun and Saraykent geothermal fields, thermal waters and mineral spring waters are not suitable for drinking, while cold waters in the geothermal field are suitable. In addition, according to the USA Salinity Laboratory irrigation water classification, thermal waters are not suitable for irrigation due to their high sodium and high salinity values (McGeorge, 1954).

Major ion analysis results detected in thermal waters in Boğazlıyan, Sorgun and Yerköy geothermal areas were compared with the limits set by TS266 (2005) and WHO (2017). According to these evaluations, it was determined that the EC, Na, SO_4 and Cl values of the well water exceeded the limit values. In Sarıkaya geothermal area, the major ion contents of thermal and cold waters are suitable according to TS266 (2005) and WHO (2017) limit values. As, Br and F contents in Boğazlıyan geothermal area, B, F, and Mn contents of Sorgun thermal waters, As, F, Mn, and Fe contents of Sarıkaya well and spring waters, B, Br, Fe and Mn elements of Yerköy well waters are above the TS266 (2005) limit values. The EC, Na, Cl and SO_4 values of the thermal waters in the Bulamaçlı (Çiçekdağ) and Mahmutlu (Çiçekdağ) geothermal fields in Kırşehir are not suitable for use as drinking water because they are above the TS266 (2005) and WHO (2017) permissible limit values for drinking water.

When the major ion values of Terme and Karakurt thermal waters are compared with the limit values of TS266 (2005) and WHO (2017), the Cl and SO_4 contents are higher than the threshold value. Therefore, while thermal waters are not suitable for drinking water, the ion values of cold waters in the field are within the appropriate range according to TS266 (2005) and WHO (2017) values. While Savcılı (Kaman) thermal waters are suitable for use according to both TS266 (2005) and WHO (2017) limit values, some of Savcılı (Kaman) cold waters are not suitable because they contain large amounts of Cl and SO_4. Considering the major ion and heavy metal contents of the thermal waters of Kırşehir province, it is seen that health problems may occur if the water is used as drinking water for a long time.

When the major ion analysis results of water samples in the Niğde geothermal field are compared with the limit values given in TS266 (2005) and WHO (2017); while the EC, Na and Cl values of Narköy and Dertalan thermal well waters are high, in addition to these values, the amount of SO_4 in Çiftehan thermal waters is also high. Therefore, none of the thermal waters in the Niğde geothermal field are suitable for use as drinking water. When the major ion values of water samples collected from Nevşehir geothermal field are compared with the values given in TS266 (2005) and WHO (2017); It has been determined that the EC, Na and Cl values of thermal water from the Kozaklı and Avonos–Ürgüp–Göreme wells exceed the limit values. In addition, the sulfate content in Göreme spring water is above the limit values. Since the cold waters in the Kozaklı geothermal field contain high amounts of SO_4, they are not suitable for use as drinking water according to both TS266 (2005) and WHO (2017) limit values.

While the EC, Na and SO_4 values of Nevşehir–Acıgöl thermal waters are suitable according to TS266 (2005) and WHO (2017) limit values, some thermal well waters are not suitable for use as drinking water due to high Cl content. When the major ion values of cold water samples taken from the Acıgöl thermal area are examined, they are suitable for use as drinking water according to the limit values of TS266 (2005) and WHO (2017). According to the values given in Kara (2013), the EC, Na, Cl and SO_4 values of the thermal waters in the Derinkuyu geothermal field are below the limit values given in TS266 (2005) and WHO (2017), while according to the values given in Şener et al. (2017), the Cl content is above the limit value. Major ion analysis results of samples taken from wells and springs in geothermal areas in Aksaray province were compared with the limit values given in TS266 (2005) and WHO (2017). According to the ion values given in Burçak (2006), Şahinkalesi thermal and cold waters are suitable for both limit values, while the EC, Na, Cl values of Ziga–Yaprakhisar thermal waters were determined above the limit values. In addition, especially high boron, iron and arsenic contents of the waters in the Ziga geothermal area may cause pollution of both fresh water resources and soil. For this reason, water returning from use should not be discharged into nature (KOP, 2021e). The cold waters of the Ziga–Yaprakhisar geothermal field are drinkable according to TS266 (2005) and WHO (2017) limit values. Although the Na, Cl and SO_4 values of Tuzlusu thermal waters are below the limit values, they are not suitable for drinking water because their EC values are quite high. KOP (2021e) determined that the As content of thermal waters in Aksaray province is between 3 and 1,087 µg/l. This value is well above the TS266 (2005) drinking water standards. Significant health problems may occur in long-term use of this water as drinking water. In addition, discharging the recycling waters resulting from the use of thermal waters into the natural environment may cause significant problems for the environment.

4. CONCLUSIONS

In geothermal fields, more effective changes in the chemical composition of the water are observed because the water with higher temperature interacts more easily with rocks and minerals. These changes can occur either through water dissolving minerals or by precipitating these minerals into the water. This may also affect groundwater quality. Geothermal fluids in the study areas are used for thermal tourism, greenhouse cultivation, residential heating and balneological purposes. Greenhouse activities are especially common in Boğazlıyan, Sorgun, Terme, Kozaklı, and Ilısu geothermal fields. The geothermal fluid in the Niğde region is currently used only for thermal tourism purposes. Kozaklı geothermal field is the largest geothermal field in the region with 31 wells, 1 of which is a reinjection well, and meets 50% of the region's needs with its thermal tourism and bed capacity. Since the Kozaklı geothermal system is suitable for integrated use, both greenhouse cultivation and thermal tourism activities are quite common. Geothermal fluids in the study area are used for thermal tourism, greenhouse cultivation, residential heating and balneological purposes. Greenhouse activities are especially common in Boğazlıyan, Sorgun, Terme, Kozaklı, and Ilısu geothermal fields. The geothermal fluid in the Niğde region is currently used only for thermal tourism purposes. Kozaklı geothermal field is the largest geothermal field in the region with 31 wells, 1 of which is a reinjection well, and meets 50% of the region's needs with its thermal tourism and bed capacity. Since the Kozaklı geothermal system is suitable for integrated use, both greenhouse cultivation and thermal tourism activities are quite common.

According to the geological and stratigraphic characteristics of the study area, the oldest unit in the region is the Kırşehir Massif, which consists of Paleozoic metamorphic, ophiolitic and plutonic rocks. The metamorphic schists of the Kırşehir Massif are mostly impermeable. However, the fractured, fissured and karst-cavity units of the marbles, which are among the Bozçaldağ metamorphites belonging to the Kırşehir Massif, are permeable and constitute the main reservoir of the geothermal system. In the geothermal systems in the region, impermeable Upper Miocene–Pliocene and Quaternary-aged ignimbrite, tuff, pyroclastics and sediments formed in terrestrial and lacustrine facies coeval with these are cover rocks. The heat source in the region is the high geothermal gradient and magmatic rock intrusions, closely related to the Erciyes volcanism, which is a young tectonism. Geothermal systems in the region are shallow and have lower temperatures, unlike the systems common in Western Anatolia. The deepest production well of the region is located in the Nevşehir–Derinkuyu geothermal field with 2,505 m, and the deepest reinjection well is located in the Nevşehir–Kozaklı geothermal field with 3,016 m. The highest geothermal fluid temperature in the region is Kozaklı geothermal field, with 96°C. Thermal waters vary from region to region with their hydrogeochemical properties. Most of the geothermal waters in the region are classified as NaCl, $Na–Ca–Cl–SO_4$, $Ca–Mg–HCO_3$, Na–Ca–Cl and $Ca–Na–SO_4$ type waters. Cold waters are generally $Ca–HCO_3$, $Ca–SO_4$ and $Ca–Mg–HCO_3$ type waters.

According to Giggenbach (1988) cation maturity diagram, cation geothermometer gives incorrect results in immature waters where water–rock balance is not established. Therefore, silica geothermometers were generally used to calculate the possible reservoir temperature of the geothermal system. The highest reservoir temperatures by region have been determined as follows: 155°C in the Yozgat–Sorgun geothermal field, 181°C in the Kırşehir–Mahmutlu geothermal field, 173°C in the Niğde–Dertalan geothermal field, 217°C in the Nevşehir–Göreme geothermal field, and 162°C in the Aksaray–Güzelyurt geothermal field. Compared to thermal waters in other geothermal fields in Central Anatolia, trace element content, especially Sr and As contents in Kozaklı thermal waters are generally high (Gemici and Tarcan, 2002; Şimşek, 2003; Aksoy et al., 2009; Karakuş and Şimşek, 2009). The reason for this is thought to be the rock–water interaction between rising thermal waters and Miocene sedimentary formations (Pasvanoğlu and Chandrasekharam, 2011). Kozaklı geothermal field is significantly different from other geothermal fields because it contains more sea water than the geothermal systems in Western and Central Anatolia (Canik and Pasvanoğlu, 2005).
The reinjection of geothermal fluids back into the geothermal system is crucial for both environmental conservation and the sustainability of the geothermal system. It is noteworthy that there are insufficient reinjection wells in the region to maintain reservoir pressure. In this context, having 1 reinjection well in the Kozaklı geothermal field, which has 30 production wells, is quite risky in terms of the sustainability of the geothermal system and the environment. Geothermal waters cause pollution of both fresh water resources and soil due to their high ion content. For this reason, water returning from use should be conveyed to the reservoir by reinjection instead of being discharged into nature. Due to the opening of too many wells and withdrawal of water in the region in recent years, many geothermal wells have become inefficient and have been closed. Especially in recent years, the number of production wells in Yozgat, Aksaray and Kırşehir regions has decreased compared to previous years. However, it is also planned to open new wells in different locations after the closed wells. It is planned to open 2 more geothermal wells in the Yozgat–Boğazlıyan geothermal field, 2 in Niğde–Merkez, 1 in Bor and 2 in Ulukışla.

Acknowledgement

The authors would like to thank Scientific Research Projects of Suleyman Demirel University which supported this work with the doctorate project (Projects No: FDK-2022-8804).

Author Contribution

Eda AYDEMİR POLAT: (b) Study Design, Methodology, c. Literature Review, f. Data Collection, Processing, (h) Writing Text

Şehnaz ŞENER: (a) Idea, Concept, (b) Study Design, Methodology (d) Supervision, (h) Writing Text (i) Critical Review

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions against Scientific Research and Publication Ethics" are not carried out.

Conflict of Interest

No conflict of interest was declared by the authors.

REFERENCES

Afşin, M., & Elhatip, H. (2000). Hydrogeochemistry and isotopic study of the travertine deposition of the Tuzlusu (Aksaray) thermal-mineral springs. *Bulletin For Earth Sciences*, *21*(22), 63-77.

Afşin, M., Erdoğan, N., Gürdal, H., Gürel, A., Onak, A., Oruç, Ö., Kavurmacı, M., & Durukan, G., (2007). *Hydrogeochemical and isotopic investigation of hot and mineral waters and travertines in central anatolia and medical and bioclimatic evaluation of waters* (Project report no. 104Y197). TÜBİTAK.

Akçay, A.E., Donmez, M., Kara, H., Yergok, A.F., & Esenturk, K. (2008). *Geological maps of Turkey in 1: 100.000 scale, Yozgat I-34 sheet* (No. 81). MTA Publications.

Akkuş, İ., & Alan, H. (2016). *Turkey's geothermal resources, projections, problems and suggestions report* (Report No. 123). TMMOB Chamber of Geological Engineers.

Aksoy, N., Şimşek, C., & Gunduz, O. (2009). Groundwater contamination mechanism in a geothermal field: a case study of Balcova, Turkey. *Journal of Contaminant Hydrology*, *103*(1-2), 13-28.

Arnórsson, S., Gunnlaugsson, E., & Svavarsson, H. (1983). The chemistry of geothermal waters in Iceland. III. Chemical geothermometry in geothermal investigations. *Geochimica et Cosmochimica Acta*, *47*(3), 567-577.

Ayan, T. (1968). *Geological investigation of Çiftehan and its surroundings* (Report No. 2113). MTA Compilation.

Burçak, M., Yucel, B., Kucuk, M., & Akin, U. (2002). Hydrothermal alteration of the Yozgat Saraykent (Karamagara) geothermal field. In M. Afşin, M. Kavurmacı & R. Demircioğlu (Eds.), *I. Central Anatolian Geothermal Energy and Environmental Symposium* (pp. 13-21). Niğde University Press.

Burçak, M. (2006). *Investigation of geothermal heat sources in Aksaray geothermal fields* [Master's thesis, Niğde University]. Bulletin of the Mineral Research and Exploration. https://dergipark.org.tr/en/download/article-file/44733.

Canik, B., & Pasvanoğlu, S. (1993). Hydrogeological investigation of the Mineralized and thermal water of the karstic aquifers around Kırsehir and the possibility of utilization in thermal spas international symposium on water resources in Karst with special emphasis on arid and semiarid zones. In A. Afrasiabian (Ed.), *International Symposium on Water Resources in Karst With Special Emphasis on Arid and Semiarid Zones, Shiraz* (pp. 153-167). Islamic Republic of Iran.

Canik, B., & Pasvanoğlu, S. (2005, September 26–28). *Hydrogeochemical investigation of Sarıot (Bolu-Mudurnu) thermal spring waters*. [Paper presentation]. II. National Isotope Techniques in Hydrology Symposium, İzmir, Türkiye.

Clark, I.D., & Fritz, P. (1997). *Environmental isotopes in hydrogeology*. Lewis Publishers.

Craig, H. (1961). Isotopic variations in meteoric waters. *Science, 133*, 1702-1703.

D'Amore F., & Arnorsson, S. (2000). Geothermometry in isotopic and chemical techniques in geothermal exploration, development and use. In S. Arnorsson (Ed.), *Isotopic and Chemical Techniques in Geothermal Exploration, Development and Use* (pp. 152-199). International Atomic Energy Agency.

Dalkilic, H., Donmez, M., & Akcay, A.E. (2008). *Geological Maps of Turkey in 1: 100.000 scale, Yozgat I-35 Sheet* (No. 82). MTA Publications.

Davraz, A., Nalbantçılar, M.T., & Önden, İ. (2022). Hydrogeochemical characteristics and trace element of geothermal systems in Central Anatolia, Turkey. *Journal of African Earth Sciences*, *195*, 104666.

Demirtaşlı, E., Bilgin, Z., Erenler, F., Işıklar, S., Sanlı, D., Selim, M., & Turan, N. (1973, December 17-19). *Geology of Bolkar Mountains* [Paper presentation]. 50th Anniversary of the Republic Earth Sciences Congress Ankara, Türkiye.

Fournier, R.O. (1977). Chemical geothermometers and mixing models for geothermal systems. *Geothermics*, *5*(1-4), 41-50.

Robert, W., & Potter, I.I. (1982). A revised and expanded silica (quartz) geothermometer. *Bulletin of Geothermal Resources Council*, *11*, 3-12.

Gemici, Ü., & Tarcan, G. (2002). Hydrogeochemistry of the Simav geothermal field, Western Anatolia, Turkey. *Journal of Volcanology and Geothermal Research*, *116*(3-4), 215-233.

Giggenbach, W.F. (1988). Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators. *Geochimica et Cosmochimica Acta*, *52*(12), 2749-2765.

Giggenbach, W.F. (1991). Chemical techniques in geothermal exploration. In F. D'Amore (Ed.), *Application of Geochemistry in Geothermal Reservoir Development: Series of Technical Guides on the Use of Geothermal Energy* (pp. 119-144). United Nations Digital Library.

Göncüoğlu, M., Toprak, V., Kuşçu, I., & Olgun, E. (1991). *Geology of the western part of the Central Anatolian Massif, Part 1: Southern Section*. TPAO.

Goncuoglu, C.M., Erler, A., Toprak, V., Yalnız, K., Olgun, E., & Rojay, B. (1992). *Geology of the western part of the Central Anatolian Massif. Part 2: Middle section* (Report No. 3155). Turkish Petroleum Corporation.

Goncuoglu, C.M., Erler, A., Toprak, V., Olgun, E., Yalnız, K., Kuşçu, I., Koksal, S., & Dirik, K. (1993). *Geology of the central part of the Central Anatolian Massif. Part 3: Geological evolution of the Central Kızılırmak Tertiary basin* (Report No. 3313). Turkish Petroleum Corporation.

İşler, F. (1988). Mineralogic-petrographic and geochemical ınvestigation of the Çiftehan (Niğde) volcanics. *Geological Bulletin of Turkey*, *31*, 29-36.

Kara, İ. (2013). *Hydrogeochemical properties of Nevşehir/Acıgöl-Derinkuyu-Gülşehir hot and mineral waters*. https://www.mta.gov.tr/dosyalar/images/dogalkaynaklar/makaleler/236/tr_20221012101113_236_4_4f1227ea.pdf

Karakus, H., & Simsek, S. (2008). Hydrogeological and geochemical studies of the Efteni and Derdin geothermal areas, Turkey. *Geothermics*, *37*(5), 510-524.

Ketin, I. (1955). On the geology of Yozgat region and the tectonic features of the Central Anatolian Massif (Kırşehir Crystallines). *Bulletin of the Geological Society of Turkey, 6*(1), 1-20.

Koçak, A. (1997). *Investigation of water chemistry and reservoir temperature of Kozaklı (Nevşehir) geothermal area.* [Unpublished doctoral thesis]. Hacettepe University.

Koçyiğit, A., & Beyhan, A. (1998). A new intracontinental transcurrent structure: the Central Anatolian Fault Zone, Turkey. *Tectonophysics*, *284*(3-4), 317-336.

KOP Regional Development Administration. (2021a). *Evaluation of geothermal resources project, Yozgat province* report. http://kop.gov.tr/upload/dokumanlar/240.pdf

KOP Regional Development Administration. (2021b). *Evaluation of geothermal resources project, Kırşehir province* report. http://kop.gov.tr/upload/dokumanlar/244.pdf

KOP Regional Development Administration. (2021c). *Evaluation of geothermal resources project, Niğde province* report. http://kop.gov.tr/upload/dokumanlar/241.pdf

KOP Regional Development Administration. (2021d). *Evaluation of geothermal resources project, Nevşehir province* report. http://kop.gov.tr/upload/dokumanlar/242.pdf

KOP Regional Development Administration. (2021e). *Evaluation of geothermal resources project, Aksaray province* report. http://kop.gov.tr/upload/dokumanlar/245.pdf

Kristmannsdóttir, H., & Ármannsson, H. (2003). Environmental aspects of geothermal energy utilization. *Geothermics*, *32*(4-6), 451-461.

Kurt, Z., Altun, E.İ., Keskin, H., Şengün, M., Sütçü, Y.F., Tekin, F., Özay, R., Erkan, M., & Örçen, S. (1991). *Geology of Boğazlıyan (Yozgat) area* (Report No. 9424). MTA Publications.

McGeorge, W.T. (1954). *Diagnosis and Improvement of Saline and alkali soils*. https://doi.org/10.2136/sssaj1954.03615995001800030032x

MTA. (2005). 1: 100 000 Ölçekli Türkiye Jeoloji Haritaları, No: 48. Yozgat J-34 Paftası.

Özen Türker, H. (2006). *Hydrogeochemical investigation of Sarıkaya (Yozgat) hot and mineral waters* [Unpublished master's thesis]. Hacettepe University].

Özkan, H., & Koçak, A. (2006). *Evaluation report of geothermal resources in Nevşehir province* (Report No. 10869). MTA Publications.

Özulukale, S., & Şimşek, Ş. (2015, September 3-5). *Hydrogeochemical evaluation of Saraykent Yozgat geothermal waters* [Paper presentation]. National Engineering Geology Symposium, Trabzon, Türkiye.

Özulukale, S., & Şimşek, Ş. (2016, September 19-24). *Hydrogeochemical and environmental isotopic survey in Saraykent Yozgat geothermal field Central Anatolia* [Paper presentation]. European Geothermal Congress, Strasbourg, France.

Parkhurst, D.L., & Appelo, C.A.J. (1999). *User's guide to PHREEQC (Version 2): A computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations* (No. 99-4259). US Geological Survey.

Parkhurst, D.L., & Appelo, C.A.J. (2013). *Description of input and examples for PHREEQC version 3—a computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations*. https://pubs.usgs.gov/tm/06/a43/

Pasvanoğlu, S., & Chandrasekharam, D. (2011). Hydrogeochemical and isotopic study of thermal and mineralized waters from the Nevşehir (Kozakli) area, Central Turkey. *Journal of Volcanology and Geothermal Research*, *202*(3-4), 241-250. https://doi.org/10.1016/j.jvolgeores.2011.03.003

Pasvanoğlu, S., & Gültekin, F. (2012). Hydrogeochemical study of the Terme and Karakurt thermal and mineralized waters from Kirşehir Area, central Turkey. *Environmental Earth Sciences*, *66*, 169-182. https://doi.org/10.1007/s12665-011-1217-3

Pasvanoğlu, S., Güner, A., & Gültekin, F. (2012). Environmental problems at the Nevşehir (Kozakli) geothermal field, central Turkey. *Environmental Earth Sciences*, *66*, 549-560.

Piper, A.M. (1944). A graphic procedure in the geochemical interpretation of water-analyses. *Eos, Transactions American Geophysical Union*, *25*(6), 914-928.

Rybach, L. (2003). Geothermal energy: sustainability and the environment. *Geothermics*, *32*(4-6), 463-470.

Schoeller, H. (1977). *Geochemistry of groundwaters in groundwater studies and international research and practice*, UNESCO.

Seymen, İ. (1981). Stratigraphy and metamorphism of the Kırşehir massif around Kaman (Kırşehir). *Bulletin of the Geological Society of Turkey*, *24*, 7-14.

Seymen, İ. (1982). *Geology of Kırşehir massif around Kaman* [Unpublished associate professor dissertation]. Istanbul Technical University.

Şener, M.F. (2015). *Geothermal resource potential of Cappadocia geothermal province* [Unpublished doctoral thesis]. Niğde University.

Şener, M.F., Şener, M., & Uysal, I.T. (2017). The evolution of the Cappadocia Geothermal Province, Anatolia (Turkey): geochemical and geochronological evidence. *Hydrogeology Journal*, *25*, 2323-2345. https://doi.org/10.1007/s10040-017-1613-1.

Şener, M.F. (2019). A new approach to Kırşehir (Turkey) geothermal waters using REY, major elements and isotope geochemistry. *Environmental Earth Sciences*, *78*(3), 75. https://doi.org/10.1007/s12665-019-8068-8

Şener, M.F., & Baba, A. (2019). Geochemical and hydrogeochemical characteristics and evolution of Kozaklı geothermal fluids, Central Anatolia, Turkey. *Geothermics*, *80*, 69-77. https://doi.org/10.1016/j.geothermics.2019.02.012

Şengör, A. C., & Yilmaz, Y. (1981). Tethyan evolution of Turkey: A plate tectonic approach. *Tectonophysics*, *75*(3-4), 181-241. https://doi.org/10.1016/0040-1951(81)90275-4

Şimsek, Ş. (1993). *Isotope and geochemical survey of geothermal systems of Yozgat province in Central Anatolia, Turkey*. https://inis.iaea.org/collection/NCLCollectionStore/_Public/26/044/26044462.pdf?r=1

Şimsek, Ş. (2003). Hydrogeological and isotopic survey of geothermal fields in the Buyuk Menderes graben, Turkey. *Geothermics*, *32*(4-6), 669-678.

Şimsek, Ş., Koc, K., & Yilmaz E. (2006). *Geology, hydrogeology, drilling and testing consultancy report of YK-2 and YK-3 Wells in Yerköy, Hacettepe University*. Yozgat Governorship Office and District Governorship of Yerkoy.

Şimsek, Ş., Yılmaz, E., Koc, K.,Turker, O.,Karakus, H., Bakir, N., Gulgor, A., Simsek, Z.N., Bulus, G., Girbalar, E.,Bektas I.,Savaci, T., & Oguz, H. (2010, April 25-30). *Geothermal exploration survey of Sorgun geothermal field (Yozgat-Turkey)* [Paper presentation]. World Geothermal Congress, Bali, Indonesia.

Tarcan, G. (2002). *Geothermal Water Chemistry*. JENARUM Summer School Lecture Notes.

Temel, D. (2007). *Comparison of the hot and mineral waters of Çiftehan, Kemerhisar and Dertalan (Niğde) with water chemistry and isotopic methods, medical and bioclimatic evaluation* [Unpublished master's thesis]. Niğde University.

Tolluoğlu, Ü. (1986). *Petrographic and petrotectonic investigations in the southwest of the Central Anatolian massif (in Kırşehir region)* [Unpublished doctoral thesis]. Hacettepe University.

Toprak, V. (1998). Vent distribution and its relation to regional tectonics, Cappadocian Volcanics, Turkey. *Journal of Volcanology and Geothermal Research*, *85*(1-4), 55-67.

TS266, (2005). *Regulation on water for human consumption, TS-266* (Official Gazette No. 25730). Turkish Standards Institute.

Ünsal, N., & Afşin, M. (1999). Hydrochemical and isotopic properties of the Mahmutlu and Bağdatoğlu mineralized thermal springs, Kırşehir, Turkey. *Hydrogeology Journal*, *7*, 540-545. https://doi.org/10.1007/s100400050227

WHO. (2017). *Guidelines for drinking-water quality*. https://iris.who.int/bitstream/handle/10665/254637/9789241549950-eng.pdf?sequence=1

Yılmaz, E., & Şimsek, S. (2013, June 3-7). *Observation studies of wells in Sorgun geothermal field (Yozgat-Turkey)* [Paper presentation]. European Geothermal Congress, Pisa, Italy.

Yılmaz Turalı, E., Şimşek, Ş., & Koç, K. (2016, September 19-24). *Hydrogeochemical investigation of Yerköy (Yozgat-Turkey) geothermal waters.* [Paper presentation]. European Geothermal Congress, Strasbourg, France.

Yılmaz Turalı, E., & Şimşek, Ş. (2017). Conceptual and 3D simulation modeling of the Sorgun hydrothermal reservoir (Yozgat, Turkey). *Geothermics, 66*, 85-100.

Yurteri, C., Şimşek, Ş., Koç, K., & Yılmaz, E. (2015, April 19-24). *Hydrogeological survey of Savcılı Büyükoba geothermal field (Kaman, Kırsehir-Central Anatolia, Turkey)* [Paper presentation]. World Geothermal Congress, Melbourne, Australia

Yurteri, C., & Şimsek, Ş. (2017). Hydrogeological and hydrochemical studies of the Kaman-Savcili-Büyükoba (Kirsehir) geothermal area, Turkey. *Geothermics*, *65*, 99-112.