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Hydrogeochemical Properties of Geothermal Fluid and Its Effect on the Environment in Gediz Graben, Western Turkey

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ABSTRACT

In parallel to developing geothermal energy applications such as electricity generation and direct application in different part of Turkey, many sites experience environmental problems such as groundwater and surface water contamination. Currently, 2084 MWt is actually being utilized for direct applications and 322.39 MWe of electricity is being generated in Turkey. Most of this energy originates from the Menderes Massif (consisting of mica-schist, gneiss and marbles) which discharges along the rims of east–west-trending faults that form the Büyük Menderes, Küçük Menderes, Gediz, and Simav grabens in western Turkey. With a length of 140 km and a width of 3–40 km, Gediz Graben is one of the most important geothermal sites for geothermal energy in western Anatolia. The graben has a WNW–ESE trending structure bounded by two major active normal fault systems. Many geothermal fields occur along Gediz Graben from Alaşehir to Turgutlu districts. Within this region, geothermal energy is being actively used for green house and district heating as well as thermal tourism and balneology. More than 100 boreholes have been drilled for power generation in this graben during the last decade. The depth of these boreholes recently reached to 2954 m and the highest reservoir temperature (287 °C in 2750 m) ever achieved in Turkey was measured within this system.

The geothermal fluid in Gediz Graben is mostly dominated by Na and HCO_3 ions whereas groundwater is mostly dominated by Ca and HCO_3 ions. The chemical analyses further revealed very high levels of heavy metals such as arsenic and boron reaching to values of 350 µg/L and 67 mg/L, respectively. The results also indicated that uncontrolled discharge of geothermal fluid influence the quality of surface and subsurface water resources of the region where these resources are commonly used for agricultural irrigation and domestic water supply. In particular, the levels of arsenic and boron in surface and subsurface waters exceeded the maximum allowable limits given in national and international standards for drinking-water quality. Thus, strict re-injection practices need to be implemented in Gediz Graben in order to prevent contamination of the already scarce water resources of the region.

1. INTRODUCTION

Turkey is located within the Mediterranean Earthquake Belt, whose complex deformation results from the continental collision between the African and Eurasian plates (Bozkurt, 2001). The border of these plates constitutes seismic belts marked by young volcanics and active faults, while the latter allowing circulation of water, as well as heat. The distribution of hot springs in Turkey roughly parallels the distribution of the fault systems, young volcanism and hydrothermally altered areas (Simsek, 1997). There are a total of about 1500 thermal and mineral water spring groups in the country (MTA, 1980; Şimşek, 2009; Baba and Murathan, 2013) (Figure 1). Currently, 2084 MWt is actually being utilized for direct applications and 322.39 MWe of electricity is being generated (Table 1). In parallel to developing geothermal energy applications in Turkey, many sites experience problems associated with the geothermal fluid. Many geothermal power plants will be constructed in Turkey especially in Gediz Graben (Table 2).

Geothermal energy is generally accepted as being an environmentally benign energy source. However, geothermal development has shown that it is not completely free of environmental impacts. Generally, geothermal utilization can cause surface disturbances, physical effects due to fluid withdrawal, noise, thermal effects and emission of chemicals as well as affect the communities concerned socially and economically (Axtmann (1975); Ellis (1978); Ármannsson and Kristmannsdóttir (1992), Hunt (2001), Baba (2003) and Baba and Ármannsson (2006). In parallel to the developments (such as electricity generation, green house and district heating, industrial processes, thermal tourism and balneotherapy) experienced in geothermal field in different parts of Turkey, many sites are now experiencing problems associated with not only waste geothermal fluid disposal but also uncontrolled surface eruptions during drilling operations (Gunduz et al., 2013; Baba and Murathan, 2012; Baba and Murathan, 2013). This study focuses on hydrogeochemical properties of geothermal fluid and its effect on the environment in Gediz Graben which is one of the most important sites for geothermal energy in western Anatolia.

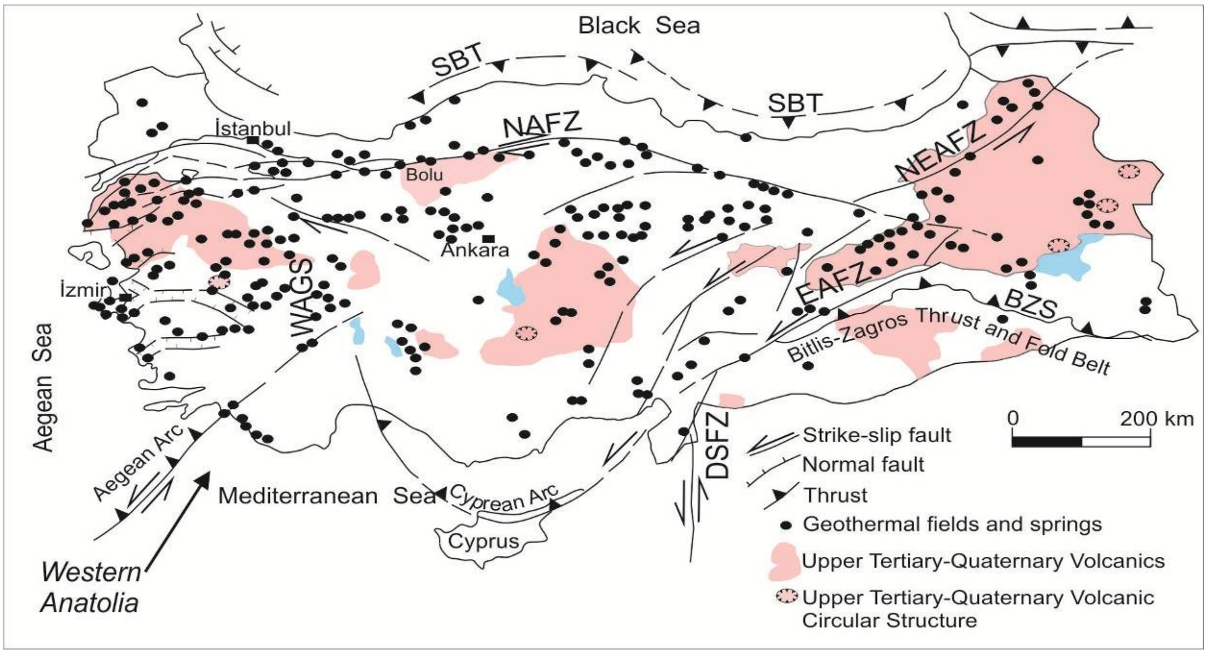

Figure 1: Tectonic map of the eastern Mediterranean region showing structures developed during the Miocene to Holocene time and distribution of geothermal areas around Turkey (compiled from; (Simsek el al., 2002; Yigitbas et al., 2004). (SBT, Southern Black Sea Thrust; NAFZ, North Anatolian Fault Zone; NEAFZ, Northeast Anatolian Fault Zone; EAFZ, Eastern Anatolian Fault Zone; WAGS, Western Anatolian Graben System; DSF, Dead Sea Fault Zone; BZS, Bitlis-Zagros Suture) (Baba ve Ármannsson, 2002).

Table 1: Power Generation in Turkey

City/Location	Field	Power plant	Types of GPPs	Startup date	Maximum resource temperature (°C)	Average resource temperature (°C)	Gross power capacity (MWe)
Denizli	Kizildere	Kizildere-1	Single flash	1984	242	217	17.40
	Sarayköy	Bereket	Binary cycle	2007	-	145	7.50
	Sarayköy	Jeoden	Binary Cycle	2012	-	101	0.84
	Kizildere	Kizildere-2	Triple flash	2013	-	-	80.00
Aydın/Sultanhisar	Salavatlı	Dora-1	Binary Cycle	2006	172	168	7.35
	Salavatlı	Dora-2	Binary Cycle	2010	176	175	11.20
	Salavatlı	Dora-3a	Binary Cycle	2013	-	170	17.00
Aydın/Germencik	Ömerbeyli	Gurmat	Double Flash	2009	232	220	47.40
	Hıdırbeyli	Irem	Binary Cycle	2011	190	170	20.00
	Bozkoy	Sinem	Binary Cycle	2012	-	180	24.00
	Bozkoy	Deniz	Binary Cycle	2012	-	180	24.00
	Gümüşköy	Gümüşköy-1	Binary cycle	2013	165	160	6.60
	Gümüşköy	Gümüşköy-2	Binary Cycle	2014	165	160	6.60
Aydın/Kuyucak	Pamukören	Çelikler-1	Binary Cycle	2013	-	170	22.50
	Pamukören	Çelikler-2	Binary Cycle	2013	-	170	22.50
Çanakkale	Tuzla	Tuzla	Binary Cycle	2010	174	160	7.50
						Total	**322.39**

Table 2: Power plants under constructed in Turkey

City/Location	Field	Power plant	Planned Capacity (MW)
Manisa	Merkez	Türkerler Sarıkız JES	10.00
	Alaşehir	Enerjeo Kemaliye JES	20.00
	Alaşehir	Türkerler Alaşehir JES	24.00
	Alaşehir	Maspo JES-1	35.00
	Alaşehir	Maspo JES-2	35.00
	Alaşehir - Erenköy	Alaşehir JES	30.00
	Salihli - Caferbeyli	Sanko JES	15.00
Denizli	Sarayköy	Gök JES	3.00
	Sarayköy - Tekke Hamam	Greeneco JES	20.00
Aydın	Salavatlı	Dora-3b JES	17.00
	Salavatlı	Dora-4 JES	17.00
	Sultanhisar	Çelikler Sultanhisar JES	9.90
	Sultanhisar-Atça	Alres JES	9.50
	Nazilli - Gedik	Kiper JES	20.00
	Köşk - Umurlu	Karkey Umurlu JES	12.00
	Germencik-Ömerbeyli	Efe JES	162.5
	Germencik-Hıdırbeyli	Kerem JES	24.00
	Yılmazköy	Ken Kipaş JES	24.00
	Kuyucak – Pamukören	Çelikler Pamukören JES-3	22.50
	Kuyucak – Pamukören	Çelikler Pamukören JES-4	22.50
Çanakkale	Ayvacık	Babadere JES	3.00
Bolu	Seben	Bolu JES	5.00
			378.40

2. STUDY AREA

The study area is located on Gediz Graben that has a total length of 140 km and a total width of 3–40 km. It is one of the most important geothermal sites for geothermal development in western Anatolia. The graben has a WNW–ESE trending structure bounded by two major active normal fault systems. Many geothermal fields occur along Gediz Graben from Alaşehir to Turgutlu districts. Within this region, geothermal energy is being actively used for green house and district heating as well as thermal tourism and balneotherapy. More than 100 boreholes have been drilled for power generation in this graben during the last decade (Figure 2). The depth of these boreholes recently reached a maximum depth of 2954 m. The highest reservoir temperature was measured as 287 °C at an elevation of 2750 m. This value was the highest temperature achieved in Turkey (Baba and Murathan, 2012a; Baba and Murathan, 2013).

3. GEOLOGICAL AND HYDROGEOLOGICAL OF STUDY AREA

Many studies have been conducted on the origin of the tectonic; as well as the associated seismic activity, widespread volcanism, mineralization and geothermal systems in Gediz Graben (Taymaz et al., 1991; Ambraseys and Jackson, 1998; Sarica, 1999; Koçyiğit et al., 1999; Sözbilir 2001, Ersoy and Helvaci, 2007; Karacik et al., 2007; Kocyigit and Deveci, 2007; Mutlu, 2007; Özsayin and Dirik, 2007; Sayin, 2007; Firuzan, 2008; Özkaymak and Sözbilir, 2008; Pamukcu and Yurdakul, 2008; Polat et al., 2008; Tan et al.,2008; Uzel and Sözbilir, 2008 and Çiftçi and Bozkurt, 2009; Baba and Murathan, 2012; Baba and Murathan, 2012a; Baba and Murathan, 2013). Western Anatolia forms one of the most seismically active and rapidly extending regions in the world and has been currently experiencing an approximate N–S continental extension since at least Miocene times. The N–S extension in the region has resulted in many Neogene to Quaternary continental basins trending mainly in the E–W and NE–SW directions (Şengör et al., 1985; Yılmaz et al., 2000). The activity of the bounding high-angle normal faults is shown via numerous earthquakes (Arpat and Bingol, 1969; Şengör et al., 1985; Seyitoglu et al., 1997; Bozkurt, 2003; Purvis and Robertson, 2004; Ersoy et al., 2008; Baba and Sözbilir, 2012). The footwall of the Gediz detachment comprises mylonitic gneiss, marble, and schist of the Menderes metamorphic core complex as well as Miocene synextensional granite. The hanging wall of the detachment fault comprises Miocene to Quaternary sedimentary units reaching up to 2500 m thick (Baba and Sözbilir, 2012).

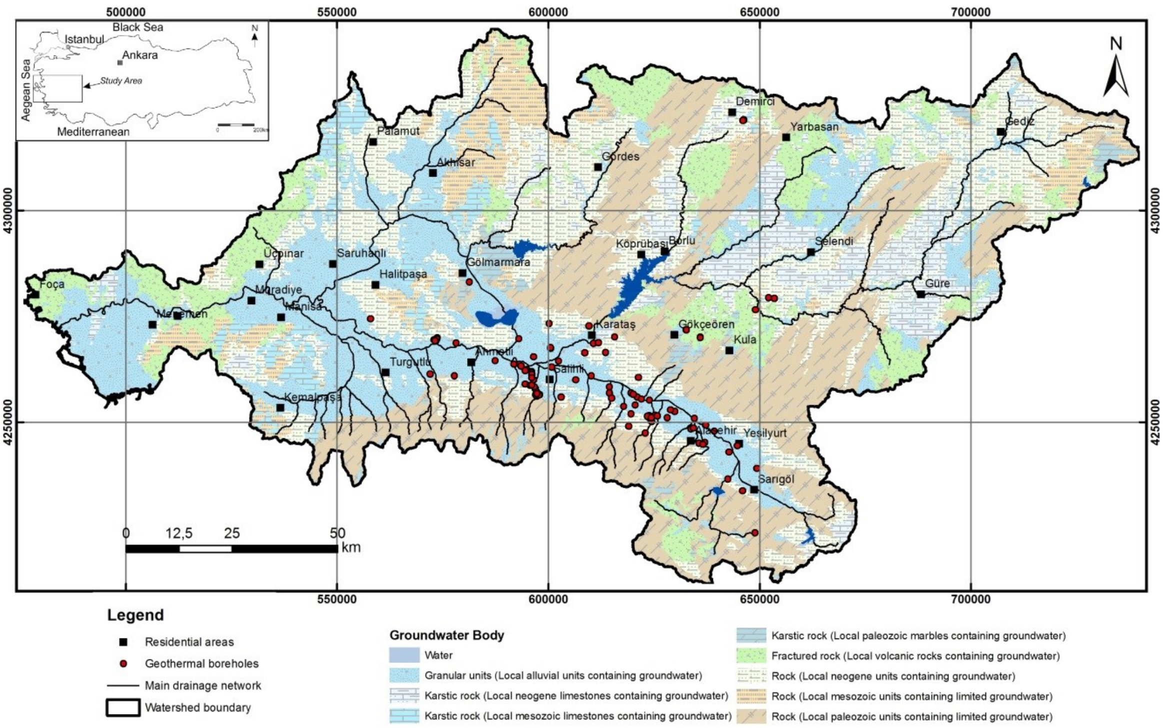

Figure 2: Geothermal drills in Gediz Graben

The carbonates of the Menderes Massif rocks are highly fractured and karstified and act locally as an aquifer for both cold groundwater and geothermal fluid. The permeability within the Menderes Massif rocks is highly variable. Schists and phyllites have relatively low permeability (see Figure 2). The Neogene terrestrial sediments, which are made up of alluvial fan deposits including poorly cemented clayey levels, have very low permeability as a whole and may locally act as cap rocks for the geothermal systems. Clayey levels of the Neogene sediments occur as impermeable barrier rocks. From sandstone to gravel and further to limestone levels of this Neogene unit, there are some minor aquifers. Alluvium is considered to be the most important and favorable unit for cold ground water production and it is possible to obtain 5-30 L/s groundwater from 120-150 m deep wells. Groundwater flows are typically towards west. There are numerous wells drilled in this unit by private companies (Özen et al., 2010). Many geothermal resources occur along the Gediz Graben starting from Alaşehir towards Turgutlu Region. The measured reservoir temperature was recorded to be as high as 287 °C in this area. The geothermal fluids of Gediz Graben are generally alkaline with carbonate alkalinity typically larger than non-carbonate alkalinity (Yılmazer et.al, 2010; Baba and Sözbilir, 2012).

4. MATERIALS AND METHOD

Water samples were collected from a number of geothermal wells in Gediz Graben. These samples were analyzed for physical parameters, major anions and cations and heavy metals and trace elements. Two samples were collected from each sampling point: one sample was used for the determination of major ions and another for heavy metals and trace elements. Samples were stored in pre-cleaned polyethylene bottles until laboratory analysis. Temperature and pH values of samples were determined in-situ by multiparameter probes.

Following sample collection, electrical conductivity (EC) measurements and chemical analyses were performed as quickly as possible in the laboratory. If immediate analysis was not possible, samples were stored at 4°C in a dark room. Major chemical constituents were determined using standard methods described in AWWA (1995). Bicarbonate (HCO_3) and chloride (Cl) ions were determined with neutralization and precipitation titrations, respectively. A gravimetric method was applied in the determination of sulphate (SO_4) and total dissolved solid (TDS). Fluoride ion was determined with an ion-selective electrode. Major cations (K, Na, Ca, Mg) and As and B were determined by inductively coupled plasma–mass spectroscopy (ICP-MS).

5. RESULTS AND DISCUSSION

5.1 Major Anion and Cation Parameters

Chloride and potassium concentrations reaching up to 3889 mg/L and 4706 mg/L was detected respectively in the geothermal fluid (P1, 12/09/2012) of Alan (Alasehir) geothermal field (Baba and Murathan, 2013). Also, sodium levels were found to be higher than 751 mg/L in the same geothermal fluid and it was clear that high sodium concentrations were associated with high chloride concentrations. These ions originated through dissolution from the parent rock. The results of groundwater quality analyses were presented graphically using Piper and Schoeller diagrams (Figure 3 and 4). These types of graph presentations have a major advantage of showing the analogies and dissimilarities between samples and are also suitable in classifying the types of water samples. They can also show chemical relationships among water samples. Schoeller diagram given in represents a comparable plot of major ion analyses. Figure 4 clearly shows that cold waters are classified as Ca-HCO_3 type waters whereas the concentration of sodium and bicarbonate, expressed in meq/L was found to be higher than the concentration of the rest of the major ions (Mg, Ca, SO_4, Cl) in the geothermal fluid. Piper diagram presented in Figure 3 plots the major ions as percentages in two base triangles setting the total cations and total anions equal to 100% while projecting the data points in the two base triangles to an adjacent grid. This demonstration was considered to be useful in showing the clustering of data points which indicate the similar compositions of samples. According to Piper diagram, cold groundwater in the study area was classified to be Ca-HCO_3 type. Furthermore, geothermal fluid lied in the Na-HCO_3 zone which was consistent with Schoeller diagram representation and was classified as Na-HCO_3 type waters.

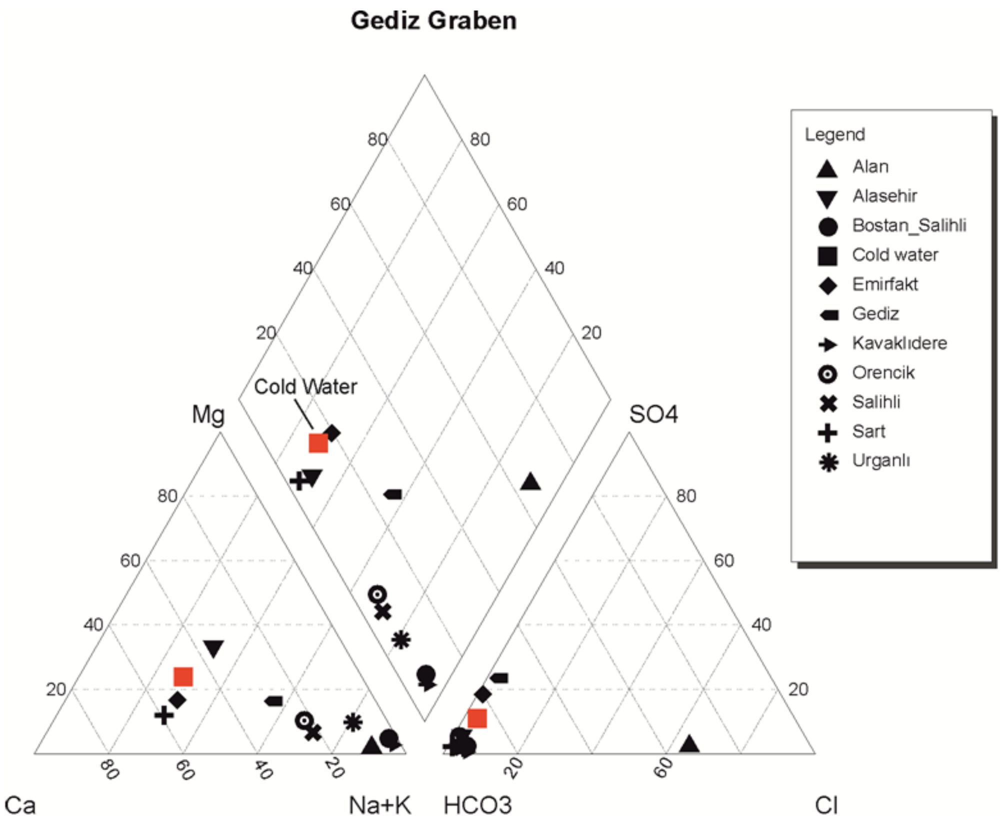

Figure 3: Piper diagram of water samples

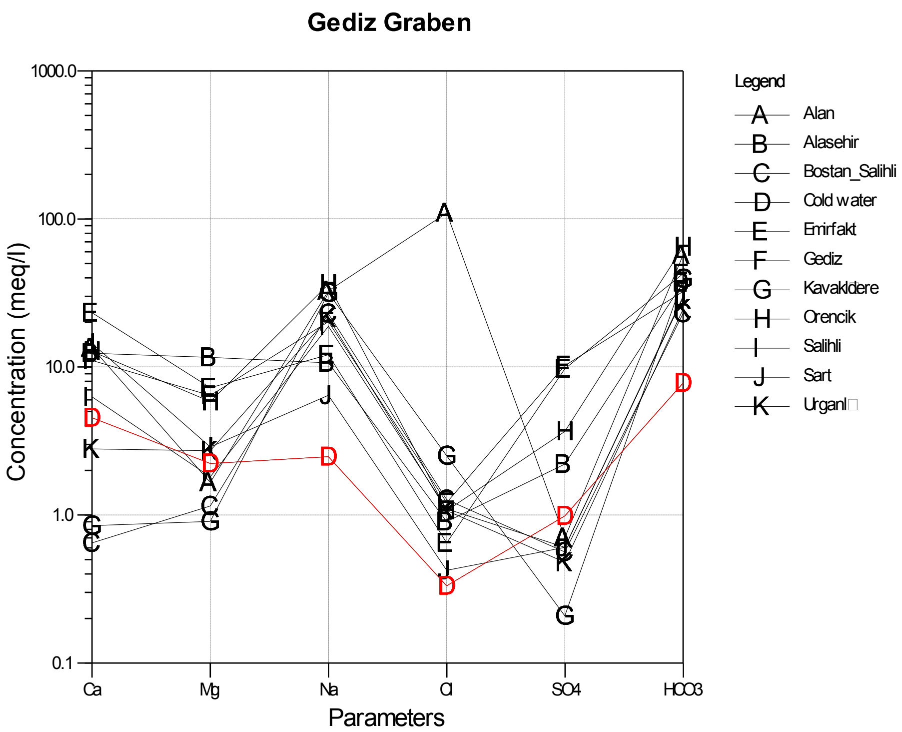

Figure 4: Schoeller diagram of water samples

5.2 Heavy metals

The results of arsenic and boron are presented in Figure 5 and Figure 6. The results showed that concentration of heavy metals in geothermal fluid were higher than that of groundwater in the study area. Especially, arsenic and boron values have exceeded national and international limits. The arsenic and boron concentrations reached to 350 µg/l and 67 mg/l, respectively. In Gediz Graben, arsenic is typically observed in the alteration zones of metamorphic rocks, in addition to its presence in some sedimentary rocks. Based on the tectonic characteristics and the geological structure, many parts of Turkey are likely to have arsenic-containing geological formations in which geothermal resources are also expected to contain high arsenic levels (Baba and Sozbilir, 2012). Generally, boron is high in some geothermal fluid in Gediz Graben. Its concentration is related to volcanic and sedimentary rocks, but may also be controlled by degassing of magma intrusive (Baba and Armmansson, 2006).

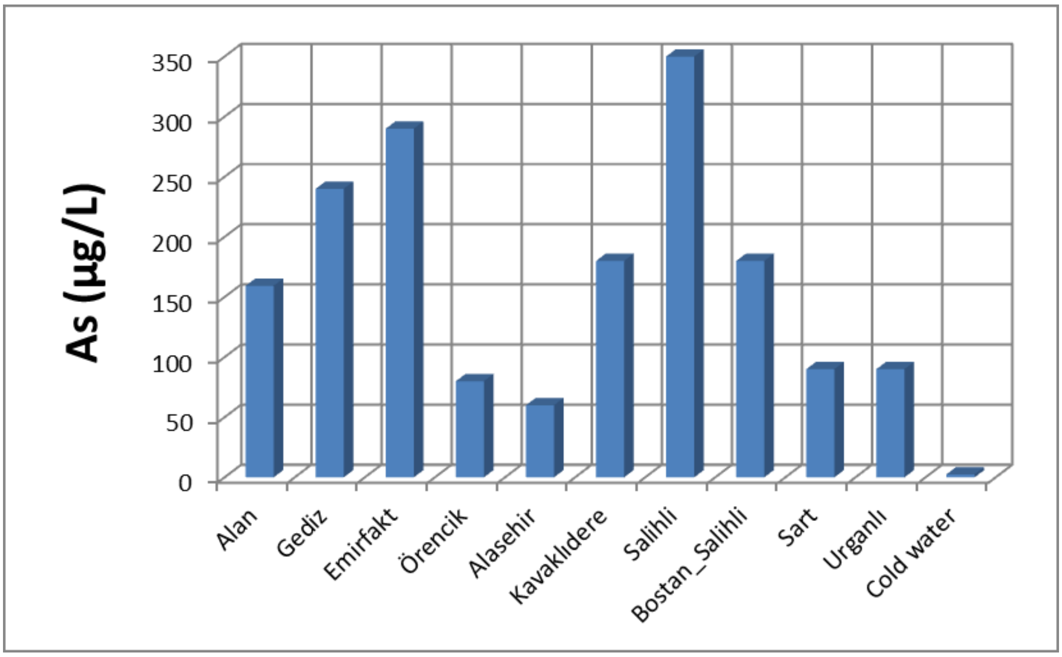

Figure 5: Concentration of arsenic in Gediz Graben

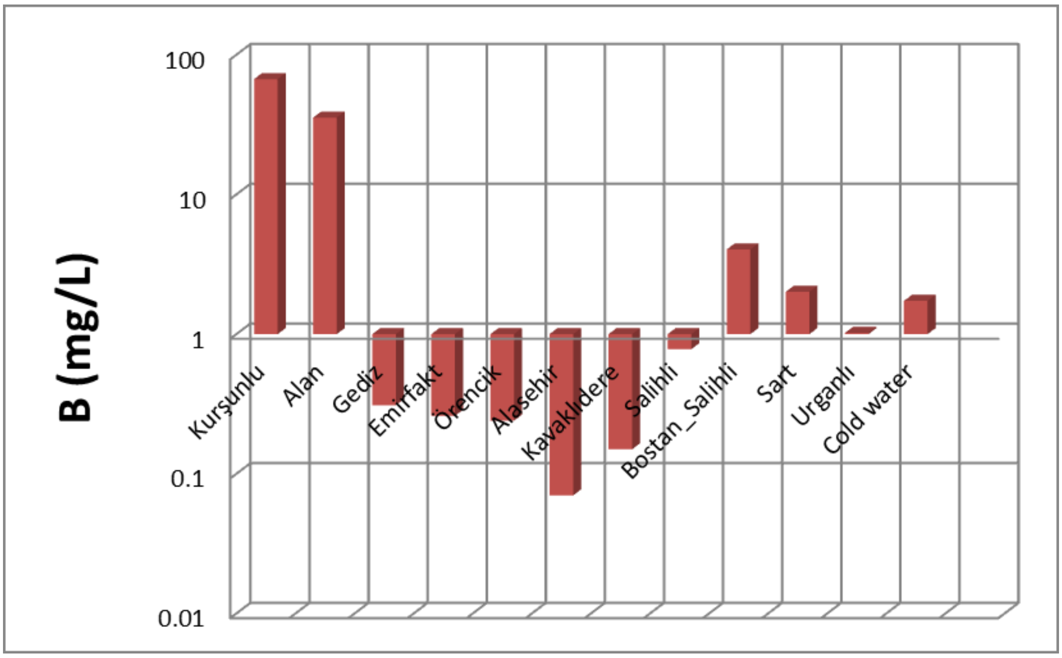

Figure 6: Concentration of boron in Gediz Graben

In parallel to developing geothermal energy applications in Turkey, many sites experience problems associated with not only waste geothermal fluid disposal but also uncontrolled surface eruptions during drilling operations. Alasehir Geothermal Area is one such area located in the southern part of the Gediz Graben System (Figure 7). The geothermal fluid erupted from Alan field during the drilling operation of a geothermal borehole, which collapsed and caused significant thermal and chemical contamination. Detailed analysis of this situation revealed the fact that unexpected geothermal fluid eruptions in this field influenced groundwater resources of the area where groundwater is commonly used for agricultural irrigation (Baba and Murathan, 2013). However, no significant effect of these eruptions were detected on the quality of regional groundwater resources until today Nevertheless, levels of some of heavy metals such as boron and arsenic were found to increase in regional groundwater resources (Baba and Murathan, 2013). Although boron is a constituent that is present in many natural waters, but its concentration are typically very low. Boron concentration limits recommended for irrigation waters vary with crop's tolerance to boron and is a strict function of the type of soil. Soils that adsorb boron to a higher degree are likely to protect the plants by reducing the availability of boron in the soil (Webster and Timperley, 1995). The approximate safe limit for sensitive crops (for example; grape, pear, orange, lemon) is 0.7 ppm B in the soil saturation extract; 0.7 to 1.5 ppm is marginal and more than 1.5 ppm appears to be unsafe (Camp, 1963).

Figure 7: Effects of geothermal eruption on environment

CONCLUSION

Discharge of waste geothermal fluid is a potential source of chemical pollution for cold groundwater. Gediz graben is very important for agriculture activity and the alluvium aquifer is extensively used for agricultural production. With its high boron and arsenic levels, the waste geothermal fluid of this area is a potential risk for agricultural production. Thus, dispersion of geothermal fluid into cold groundwater reserves should be minimized and the status of groundwater quality should be monitored on a regular basin to guarantee that geothermal fluid do not contaminate the cold groundwater reserves in the Gediz Graben. Therefore, strict re-injection practices need to be implemented in Gediz Graben in order to prevent contamination of the already scarce water resources of the region.

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