HYDROGEOCHEMICAL INVESTIGATION OF GROUNDWATER CHARACTERISTICS IN ALPU COAL FIELD, ESKISEHIR-TURKEY

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ABSTRACT

HYDROGEOCHEMICAL INVESTIGATION OF GROUNDWATER CHARACTERISTICS IN ALPU COAL FIELD, ESKISEHIR-TURKEY

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Master of Science, Geological Engineering
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Hydrogeochemical characteristics and quality of groundwater resources in Alpu Coal field to the north of Porsuk Creek are investigated. EC, pH, DO and ORP average value ranges are determined as 438-1227 μS/cm, 7.43-8.69, 3.29-6.05 mg/l and 106-180 mv, respectively in spring waters and as 452-30233 μS/cm, 7.46-8.48, 0.6-6.0 mg/l ve 198- -183 mv, respectively in well waters. All spring waters are in HCO_3 - Mg, Mix(Ca-Mg), Ca facies. Groundwater facies, stratigraphically downward: change in the order of HCO_3, SO_4 and Cl according to the anion content and in the order of Mg, Mix and Na according to the cation content. Ammonia concentrations in deep groundwaters filtered about greater than 300 m depths are much higher than the expected values. In general, chloride values of groundwater decrease from surface to approximately 100 m depth but afterwards increase stratigraphically from 100 m depth to basement rocks (Pliocene to Miocene to Basement aquifers). The chemical characteristics of Pliocene, MAC and MBC + Mélange deep groundwaters are related to the hydrogeochemical evolution processes of deep sedimentary basin groundwaters under water-rock reaction relationships accompanied by very low permeability related ion filtration and diffusive/dispersive transport enrichment. In terms of classification limits, groundwater is in low quality.

Keywords: Hydrochemistry, Groundwater, Water Quality, Alpu Coal Field, Eskisehir, Water Facies

ÖZ

ALPU KÖMÜR SAHASI YERALTI SUYU ÖZELLİKLERİNİN HİDROJEOKİMYASAL İNCELENMESİ, ESKİŞEHİR-TÜRKİYE

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Porsuk çayı kuzeyindeki Alpu Kömür sahasındaki yeraltı suyu kaynaklarının hidrojeokimyasal özellikleri ve kalitesi araştırılmıştır. Kaynak sularında EC, pH, DO ve ORP ortalama değer aralıkları sırasıyla 438-1227 µS/cm, 7.43-8.69, 3.29-6.05 mg/l ve 106-180 mv ve kuyu sularında değer aralıkları sırasıyla 452-30233 µS/cm, 7.46-8.48, 0.6-6.0 mg/l ve 198- -183 mv olarak belirlenmiştir. Tüm kaynak suları HCO_3 - Mg, Karışım(Ca-Mg), Ca fasiyesindedir. Yeraltı suyu fasiyesi, stratigrafik olarak aşağı doğru: anyon içeriğine göre HCO_3, SO_4 ve Cl düzeninde ve katyon içeriğine göre Mg, Karışım ve Na sırasındaki değişim göstermektedir. Yaklaşık 300 m'den daha derin lokasyonlarda filtrelenen derin yeraltı sularındaki amonyak konsantrasyonları, beklenen değerlerden çok daha yüksektir. Genelde yeraltı suyunun klorür değerleri yüzeyden yaklaşık 100 m derinliğe kadar düşmekte ancak daha sonra 100 m derinlikten temel kayalara (stratikrafik olarak sırasıyla Pliyosen, Miyosen ve Taban akiferleri) stratigrafik olarak artmaktadır. Pliyosen, MAC ve MBC + Mélange derin yeraltı sularının kimyasal özellikleri, su-kayaç reaksiyonu ilişkileri altında derin tortul havza yeraltı sularının hidrojeokimyasal evrim süreçleriyle, çok düşük geçirgenlikle ilişkili iyon filtrasyonu ve yerel difüzif/dispersif taşıma zenginleştirmesi ile ilgilidir. Sınıflandırma sınırları açısından yeraltı suyu düşük kalitededir.

Anahtar Kelimeler: Hidrokimya, Yeraltı Suyu, Su Kalitesi, Alpu Kömür Sahası, Eskişehir, Su Fasiyesi

TO MY BELOVED COMPANION IN LIFE AND FAMILY …

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CHAPTER 1

INTRODUCTION

One of the fundamental components of the environmental impact studies in a given project is the establishment of baseline conditions in the study area. Considering very susceptible and vital nature of mining sites, hydrochemical base line conditions of groundwater require special attention and detailed investigations. In this respect, preservation of the quality of groundwater resources in mining areas is especially important. The Alpu coal field, which is located within the Eskişehir graben in the northwest of Central Anatolia Region (Figure 1.1), is planned to be mined in near future. The area, located approximately 11 km east of Eskişehir city center, is in the flow route of Porsuk Creek which is the longest brach of Sakarya river.

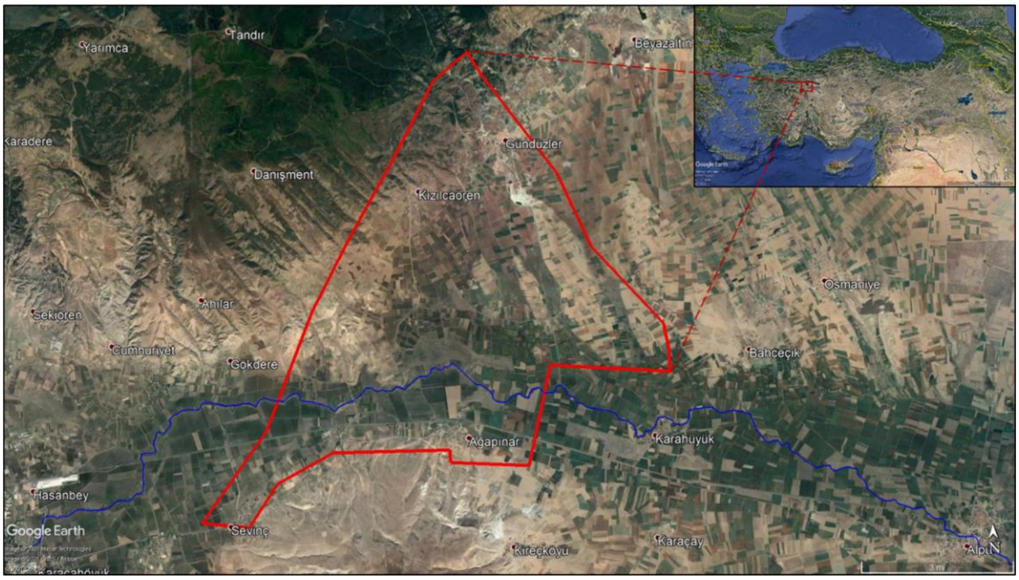


Figure 1.1. Google Earth image showing the location of the study area.

The Creek is extensively used for the irrigation purposes. Therefore, hydrochemical baseline studies of groundwater become even more important due to surface water-groundwater interactions.

1.1 Purpose and Scope

The purpose of the study is to investigate the hydrogeochemical characteristics and quality of groundwater resources in the Alpu Coal field to the north of Porsuk Creek.

The field and laboratory parameters covering chemical data collected from groundwaters of springs and aquifers (Alluvium, Pliocene, Miocene with and without coal levels) in the area by Yazıcıgil et al. (2018) are used for the investigation. In order to reach the purpose, hydrochemical properties of groundwaters are determined using both major and trace ion concentrations and possible groundwater mixing relationships among the aquifers are investigated based on water-rock interactions. The chemical data are further used to determine the quality of groundwater based on groundwater, human consumption and irrigation water related regulation limits/classifications.

1.2 Previous Studies

The initial detailed geological studies related to the study area and its surrounding were carried out by Siyako et al. (1991) on behalf of MTA. In this report, İ23, 24, 25, 26, 27 geological maps with 1/100000 scale were prepared to understand the distribution of Tertiary units in the field and the coal potential of the region was investigated.

Following this study, a report titled “Geology of Central and South Sakarya” was prepared by Gözler et al. (1997) on behalf of MTA. In this report, 1/100000 scale geology maps of the region covering numbered İ24, İ25, İ26 and İ27 were produced.

In the study conducted by Şengüler (2013), the geology and stratigraphy of the Alpu coal basin was investigated. The petrographic characteristics of the basin and the sedimentation environment were studied by Toprak et al. (2015). Then, in 2016, high-resolution two-dimensional seismic data were collected, and the faults were interpreted in the area covering TKI sectors of A, B, C, D, E and F by Turkey

Petroleum A. Ş. (TPAO, 2016). The scope reports for mining activities in the sectors of the coal field were prepared by Palaris (2016, 2017).

Hydrogeological studies for the study area and its surroundings are limited. In 1977, the Eskişehir-Alpu Plain Hydrogeological Survey Report was prepared by the General Directorate of State Hydraulic Works (DSI) in order to determine the groundwater potential, depth, quantity and quality of the plain and groundwater operation areas. Later, a revised report was prepared by DSI (2010) in order to recalculate the groundwater reserve in the plain. Preliminary hydrogeological investigation was carried out by MTA on Alpu Basin coal field by Bayram (2015) and hydrogeological survey was completed and reported in 2017 by Zeyrek et al., (2017). Within the license field of ESAN in the south of Porsuk Creek, Yazıcıgil et al. (2016) conducted a hydrogeological survey and characterization studies. The thesis entitled "Hydrogeological Characterization of the Alpu Coal Mine Exploration Site in Eskisehir-Turkey" by Catak (2016) was produced from the hydrogeoleogical section of this study in the ESAN field to the south of Porsuk. In addition, 3-dimensional groundwater flow model was developed and the amount of water that could reach to typical ground mining panels was estimated by Yazıcıgil et al. (2017a). The thesis of "Hydrogeological Investigation and Characterization of Alpu Sector-A Coal Field in Eskisehir, Turkey" by Duz (2018) was produced from the hydrogeoleogical part of the study conducted by Yazıcıgil et al. (2017b). The latest study was conducted within the boundaries of the basin covering the hydrogeological survey and characterization of A, B, C, D, E and F sectors of Alpu MTA coal field by Yazıcıgil et al. (2018). In this thesis research, as different from this study, the chemical data collected by Yazıcıgil et al. (2018) are further evaluated to establish hydrogeochemical conceptual model.

A recent paper by Taspinar et al. (2021) entitled "Soil contamination assessment and potential sources of heavy metals of Alpu plain, Eskisehir, Turkey" evaluates heavy metal concentrations in the agricultural lands in terms of the ecological and environmental risks of Alpu plain by using multiple pollution indices.

CHAPTER 2

GEOLOGY AND STRATIGRAPHY OF THE STUDY AREA

The geological map, a geological cross section and the stratigraphic section of the study area and near vicinity, prepared by Yazicigil et. al (2018) using well logs and generalized stratigraphic sections and maps of Siyako et. al (1991), Gözler et. al (1997), and Şengüler (2013) are given in Figure 2.1, Figure 2.1 and Figure 2.3, respectively.

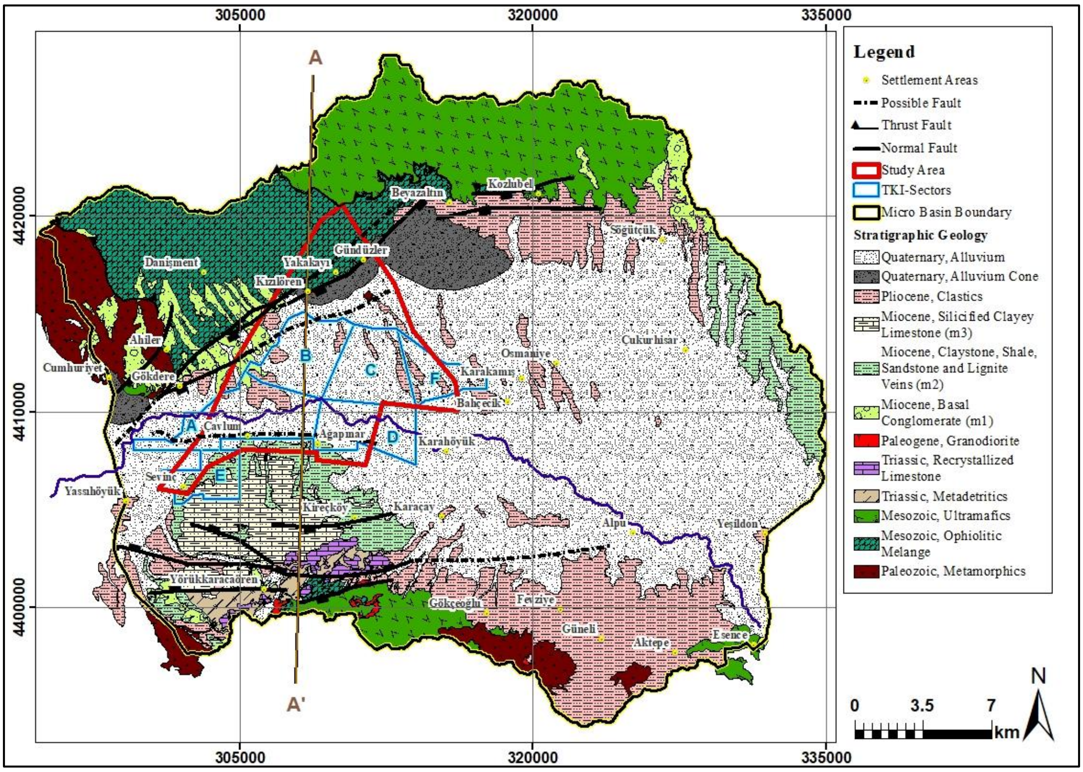


Figure 2.1. Geological map (scale: 1/185.000, UTM 36 Zone) of the study area and near vicinity (Yazıcıgil et. al, 2018).

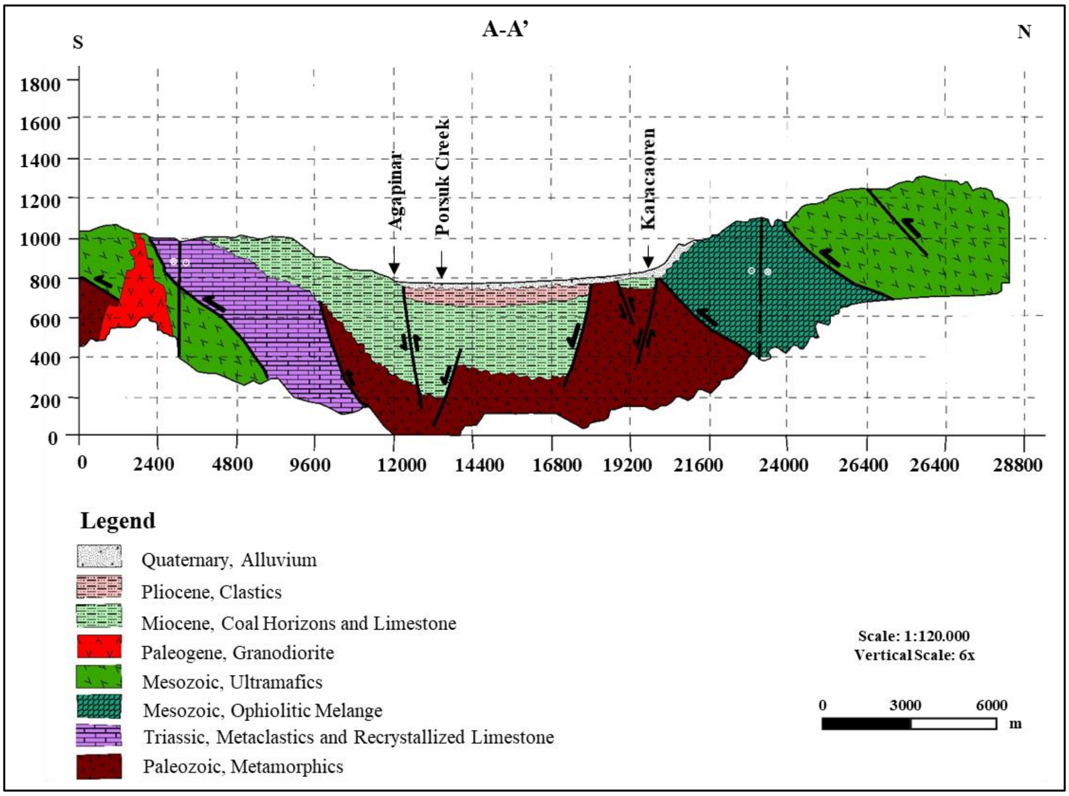
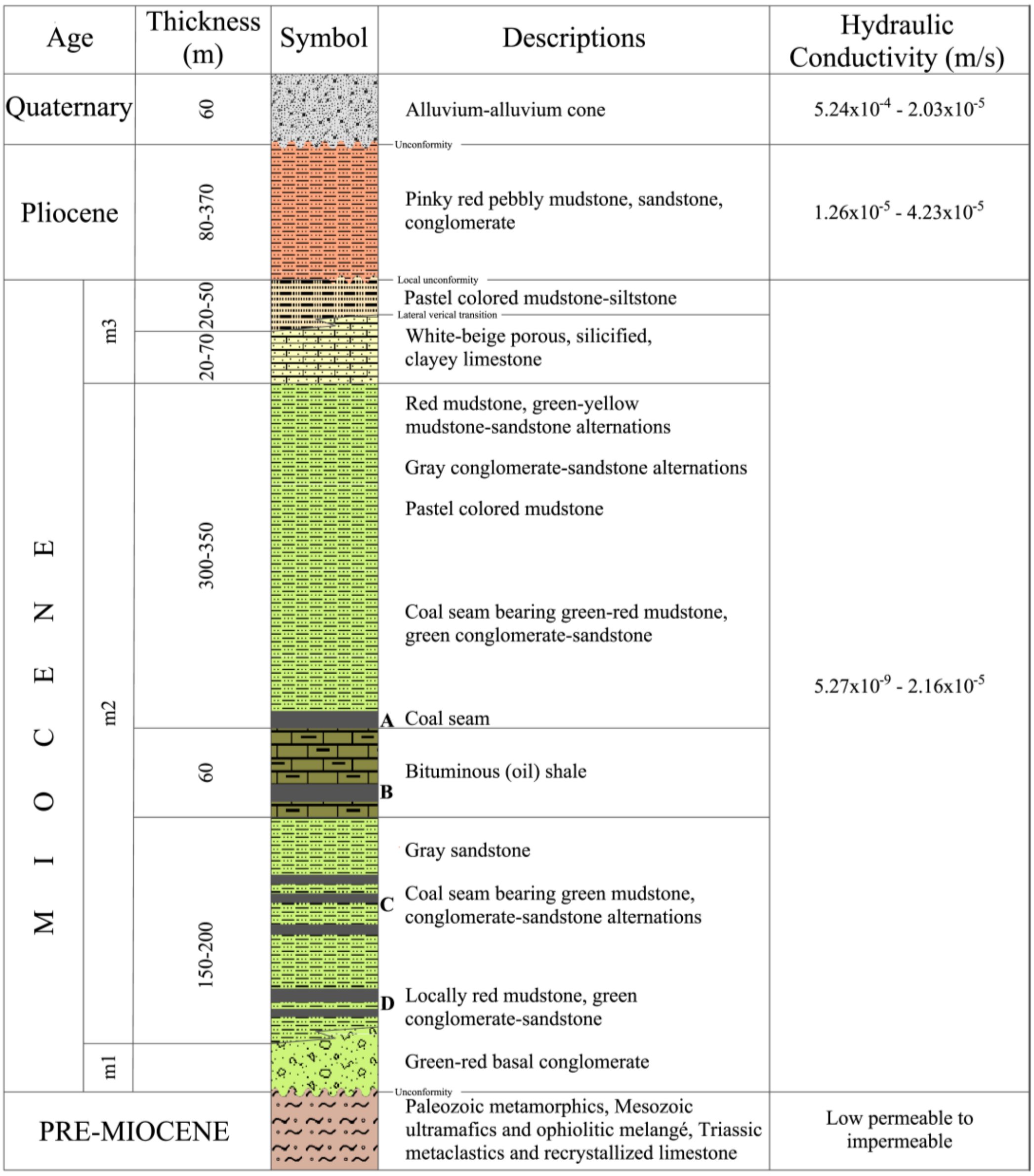


Figure 2.2. Geological cross section along A-A' line shown in Figure 2.1 (Yazıcıgil et. al, 2018).

The bedrock in the field outcropped at the north and northwestern sections consists of Paleozoic metamorphics, Mesozoic ultramafics and in between Mesozoic ophiolites. According to Gözler et. al (1997), the ophiolites based on tectonic activity include peridotite, serpentinite, pyroxenite, metapyroxenite, hornblendite, metahornblende, gabbro, metagabbro, diabase, metadiabase, listvenite units.

The Paleozoic-Mesozoic basement rocks are overlain unconformably by Paleocene conglomerates and Eocene conglomerates, sandstones and clayey limestones which do not outcrop in the study area but observed at the south of Porsuk Creek.

Miocene aged sediments, outcropped at the northwestern section in the study area containing lignite veins at lower levels, unconformably overlie the bedrock. Miocene sediments are grouped into three series as m1, m2, and m3 by Gözler et. al (1997).



Age		Thickness (m)	Symbol	Descriptions	Hydraulic Conductivity (m/s)
Quaternary		60		Alluvium-alluvium cone	$5.24x10^{-4}$ - $2.03x10^{-5}$
				Unconformity	
Pliocene		80-370		Pinky red pebbly mudstone, sandstone, conglomerate	$1.26x10^{-5}$ - $4.23x10^{-5}$
				Local unconformity	
M I O C E N E	m3	20-50		Pastel colored mudstone-siltstone	$5.27x10^{-9}$ - $2.16x10^{-5}$
				Lateral verical transition	
		20-70		White-beige porous, silicified, clayey limestone	
	m2	300-350		Red mudstone, green-yellow mudstone-sandstone alternations Gray conglomerate-sandstone alternations Pastel colored mudstone Coal seam bearing green-red mudstone, green conglomerate-sandstone	
			A	Coal seam	
		60	B	Bituminous (oil) shale	
		150-200		Gray sandstone	
			C	Coal seam bearing green mudstone, conglomerate-sandstone alternations	
			D	Locally red mudstone, green conglomerate-sandstone	
	m1			Green-red basal conglomerate	
				Unconformity	
PRE-MIOCENE				Paleozoic metamorphics, Mesozoic ultramafics and ophiolitic melangé, Triassic metaclastics and recrystallized limestone	Low permeable to impermeable

Figure 2.3. Stratigraphic section of the study area and near vicinity (modified from Yazıcıgil et. al, 2018).

The m1 series at the bottom consists of conglomerate, sandstone, and claystone units. Overlying this part in the middle Miocene m2 series (where coal levels are present), green colored claystone, coal level (D), green colored claystone, coal level (C), sandstone, bituminous shale, coal level (B), bituminous shale, coal level (A) and claystone-sandstone-conglomerate successions are present from bottom to top according to Gözler et. al (1997) who determined the varying thickness of this series between 150 m and 600 m. Tuffite and marl intercalations are common, especially in the eastern part of the study area and limestones are also observed between them. The m3 series consisting of silicified limestones do not outcrop in the study area but present at the far east and the southwest of Porsuk Creek.

Miocene units mainly outcrop at the northeastern part of the area (Figure 2.3). Pliocene sediments consist of mudstone and loose conglomerate-sandstone levels in general and the thickness of the unit reaches up to 370 m in the northeast of the basin according to Gözler et. al (1997). Siyako et al. (1991) reports locally high porosity including clayey limestones presence in the sequence.

Quaternary alluvium covering southern part of the area consists of clay levels including rarely loosely but generally compactly attached, gravel and sand grains. The thickness of the unit varies between 10-60 m.

In terms of structural properties, the basin is bounded by marginal faults. According to field observations by Gözler et. al (1997), the faults controlling the northern and southern margins of the Alpu coal basin operated over time as lateral strike-slip reverse component faults developed in the NE-SW compressional regime and, most recently, normal oblique faults developed in approximately NNW-SSE extensional regime. The northern margin faults are normal faults developed in the NW-SSE extensional regime, cutting the NE-SW trending Pliocene units located in the northwest and northern margin of Alpu (Gözler et. al (1997). These faults extend from Gökdere to Danişment and there are many parallel faults near the northern edge.

CHAPTER 3

HYDROGEOLOGY

3.1 Monthly Water Budget

The purpose of the hydrological water budget of the study area is to calculate the ratio of the water budget components consist of surface runoff, soil moisture, evapotranspiration and surplus water to total precipitation. Hydrological water budget components of the plain and mountainous sections of the study area have been calculated for each month using long-term average values of temperature and precipitation data reported by Yazıcıgil et. al, 2018 (Table 3.1). The average altitude of the mountainous area is about 982 m and an average altitude of the plain is the distributions of temperature and precipitation are shown in Figure 3.1. The monthly mean temperature in the study area changes between -2.1 ^{o}C and 21.7 ^{o}C. The monthly mean precipitation range is 13.64-45.63 mm in the plain and 15.44-51.65 mm in the mountainous sections. Higher precipitation values are observed between December and May. Annual precipitation is about 380 mm and 431 mm in the plain and mountainous sections, respectively.

Table 3.1 Monthly temperature and total precipitation data (Yazıcıgil et. al, 2018)

Temperature (°C)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Plain (780 m)	-0.1	1.4	5.0	10.4	15.2	19.0	21.7	21.6	17.3	12.0	6.6	2.1
Mountain (982 m)	-2.1	-0.7	2.9	8.3	13.1	16.9	19.6	19.5	15.2	9.9	4.5	0.0

Precipitation (mm/month)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Plain (780 m)	42.43	35.94	35.84	38.38	45.63	27.66	12.42	14.02	13.64	33.21	30.29	50.99
Mountain (982 m)	48.03	40.68	40.58	43.45	51.65	31.31	14.06	15.87	15.44	37.59	34.29	57.72

Figure 3.1. Monthly change of the precipitation (mm) and temperature (°C) (a) the plain and (b) the mountainous areas

In the calculations, potential evapotranspiration values are estimated using Thornthwaite method (Thornthwaite, 1948) and surface runoff values are estimated using the Curve Number (CN) method of the United States Soil Conservation Service (US-SCS, 1964). By using land use/vegetation cover, soil groups, slope and depth information for the plain and mountainous areas, the curve number was selected as 77 for the plain (soils having moderate rates of infiltration and water transmission and agricultural land use area) and 82 for mountainous section (soils having a very slow rates of infiltration and water transmission and woods land use area).

The general equation for CN method is given as follows:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where Q; runoff

P; rainfall

S; potential maximum retention after runoff begins

I_a; initial abstractions

The other input to the monthly water budget estimation is the soil-moisture storage capacity which is taken as 75.9 mm and 55.8 mm for the plain and mountainous areas, respectively. Snow and rain temperature threshold values of -10 and 3.3 ^{o}C are adapted from McCabe and Markstrom (2007). The calculated budget component values are listed in Table 3.2 and shown in Figure 3.2. Accordingly, 100% (380.5 mm) of the annual precipitation in the plain area is transformed into 81.2% (306.2 mm) evapotranspiration, 5.2% (19.7 mm) surface runoff, 17.8% (67.2 mm) surplus and 4.2% (28.5 mm) soil moisture. In the mountain area, 100% (421.7 mm) of the precipitation is transformed into 72.8% (291.9 mm) evapotranspiration, 12.7% (50.9 mm) surface runoff, 18.4% (73.9 mm) surplus and 3.9% (10.8 mm) soil moisture.

Table 3.2 Conceptual monthly water budget for (a) the plain and (b) the mountain areas

Plain	**Temperature (°C)**	**Precipitation (mm/month)**	**Surplus (mm/month)**	**Direct Runoff (mm/month)**	**Change in Soil Moisture Storage (mm/month)**	**Actual Evapotranspiration (mm/month)**
Jan	-0.1	42.4	12.5	7.2	0.0	0.0
Feb	1.4	35.9	29.6	3.4	0.0	2.9
Mar	5.0	35.8	25.0	0.1	0.0	17.5
Apr	10.4	38.4	0.0	0.0	-8.5	46.9
May	15.2	45.6	0.0	0.0	-33.4	79.0
June	19.0	27.7	0.0	0.0	-34.0	61.6
July	21.7	12.4	0.0	0.0	0.0	12.4
Aug	21.6	14.0	0.0	0.0	0.0	14.0
Sept	17.3	13.6	0.0	0.0	0.0	13.6
Oct	12.0	33.2	0.0	0.0	0.0	33.2
Nov	6.6	30.3	0.0	0.0	10.1	20.2
Dec	2.1	51.0	0.0	9.0	37.2	4.7
Total		**100.0%**	**17.8%**	**5.2%**	**4.2%**	**81.2%**

Mountainous Area	**Temperature (°C)**	**Precipitation (mm/month)**	**Surplus (mm/month)**	**Direct Runoff (mm/month)**	**Change in soil moisture storage (mm/month)**	**Actual Evapotranspiration (mm/month)**
Jan	-2.1	34.3	3.9	14.7	0.0	0.0
Feb	-0.7	37.5	27.3	10.2	0.0	0.0
Mar	2.9	48.1	31.8	4.1	0.0	12.2
Apr	8.3	52.8	10.9	0.0	0.0	41.9
May	13.1	51.7	0.0	0.0	-24.9	76.6
June	16.9	31.3	0.0	0.0	-30.8	62.1
July	19.6	14.1	0.0	0.0	0.0	14.1
Aug	19.5	15.9	0.0	0.0	0.0	15.9
Sept	15.2	15.4	0.0	0.0	0.0	15.4
Oct	9.9	37.6	0.0	0.0	0.0	37.6
Nov	4.5	34.3	0.0	0.8	17.3	16.2
Dec	0.0	48.8	0.0	21.2	27.6	0.0
Total		**100.0%**	**18.4%**	**12.7%**	**3.9%**	**72.8%**

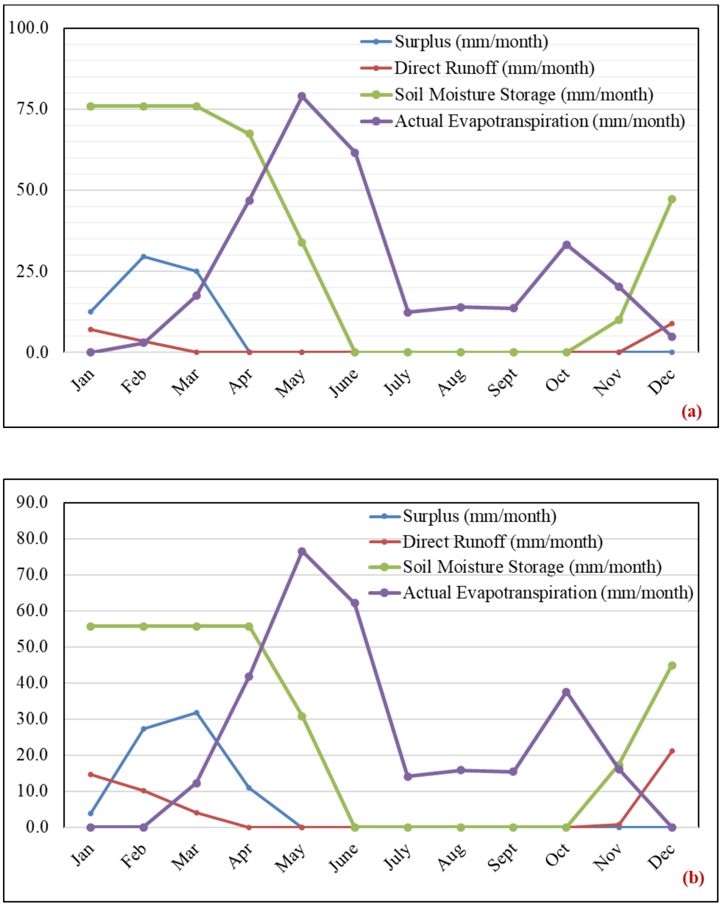


Figure 3.2. Distribution of water budget components for (a) the plain and (b) the mountain areas.

3.2 Springs and Fountains

A total of seven springs are present in near the NW boundary of the study area (Figure 3.3). Except F-17, the springs are piped as free flow, hence present as fountains in the area. The flow rates of the fountains as measured by Yazıcıgil et. al (2018) ranging from 0.16 L/s to 2.2 L/s are very low in general (Table 3.3).

Geological information suggests that the springs are discharged at the contacts along the NE-SW trending faults between Quaternary alluvium and Mesozoic ophiolites except F-11 which is located between Miocene m1 series and alluvium unit (Figure 2.2 and Figure 3.3).

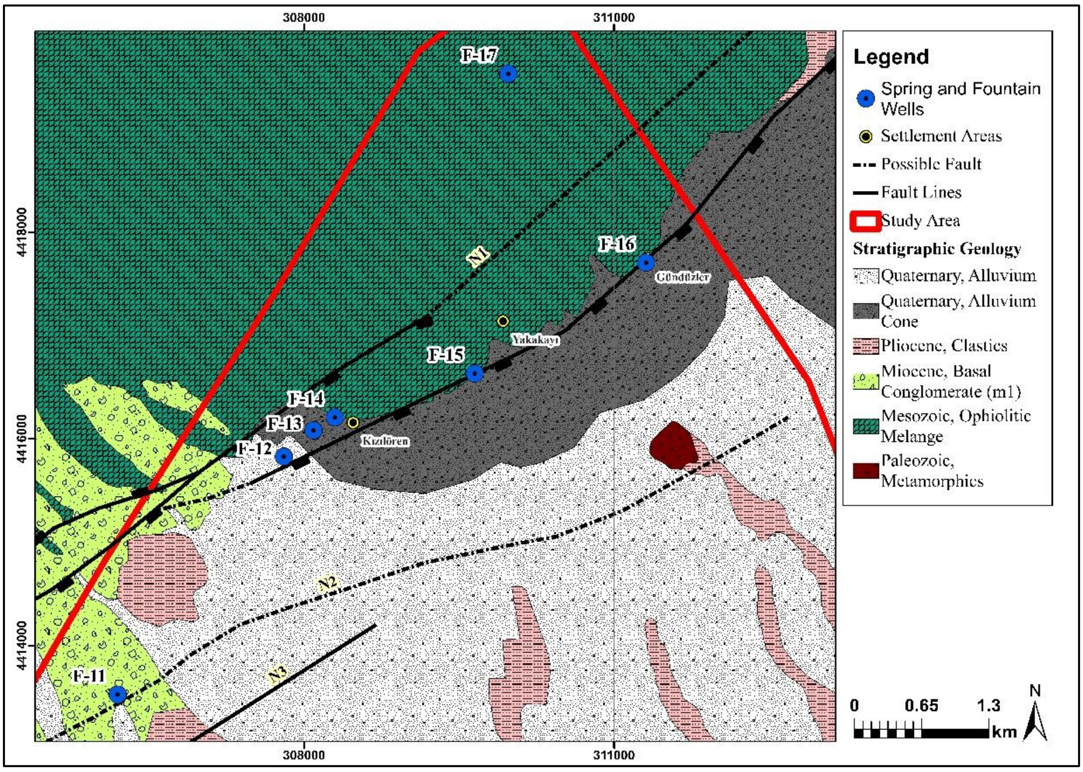


Figure 3.3. Spring and fountain locations.

Table 3.3 Spring and fountain discharge values

Spring ID	Settlement Area	Elevation (m)	Flow Rate (L/sec)		
			Minimum	Maximum	Average
F-11	Danişment	830	0.660	1.250	0.998
F-12	Kızılcaören	840	0.019	1.500	0.288
F-13		838	0.046	3.125	0.688
F-14		848	0.351	1.000	0.291
F-15	Yakakayı	842	0.018	0.560	0.164
F-16	Gündüzler	849	1.580	3.030	2.227
F-17		913	-	-	-

3.3 Aquifers

In the study area Yazıcıgil et. al (2018) delineated four hydrostratigraphic units from top to bottom: 1) Quaternary alluvium, 2) Pliocene limestones, sandstones and conglomerates, 3) lignite horizons including Miocene units and 4) basement rocks.

Basement rocks (Paleozoic metamorphics, Mesozoic ultramafics and ophiolites and Triassic metasediments and recrystallized limestones) generally are impermeable-low permeable but could bear some water in fault-controlled discontinuities according to Yazıcıgil et. al (2018).

Pumping test results of Yazıcıgil et. al (2018) indicate that hydraulic conductivity of lignite veins including Miocene units change between 5.27X10^{-9} m/s and 2.16X10^{-5} m/s with a geometric mean of 1.49X10^{-7} m/s.

Except in the D-sector, Pliocene units represented by conglomerate, sandstone, clayey limestone, tuffit including mudstone and claystone lithologies are determined to be the important water bearing units in the area. Although hydraulic conductivities range from 1.26X10^{-5} m/s to 4.23X10^{-5} m/s, representative wells in the Pliocene units indicate hydraulic conductivity of 2.98X10^{-5} m/s as a geometric mean value according to Yazıcıgil et. al (2018). This suggest that Pliocene units are about 100 times more conductive than those of Miocene.

Hydraulic conductivity of the alluvium consisting of silt and clay intercalated sand and gravel grains is determined to be in the range of 5.24X10^{-4} m/s to 2.03X10^{-5} m/s by Yazıcıgil et. al (2018). Representative wells in the Alluvium unit suggest hydraulic conductivity of 9.84X10^{-4} m/s. Basin wide DSI (1977) studies suggest about 5X10^{-4} m/s hydraulic conductivity for the alluvium as a geometric mean value.

3.4 Groundwater Table Map

Groundwater table map created by Yazıcıgil et. al (2018) is shown in Figure 3.4. The map was created by using the average of the static water levels measured in the wells mostly representing the Quaternary Alluvium. In addition, the areas where Pliocene unit outcrops are used in the preparation of the groundwater table elevation map. Groundwater flow in the study area is generally from North to South towards Porsuk Creek. Groundwater levels decrease from about 800 m in the north of the basin to about 770 m around the Porsuk Creek in the south. Porsuk Creek is the discharge area for the groundwater system. Hydraulic gradient is relatively steeper at east and at southern areas.

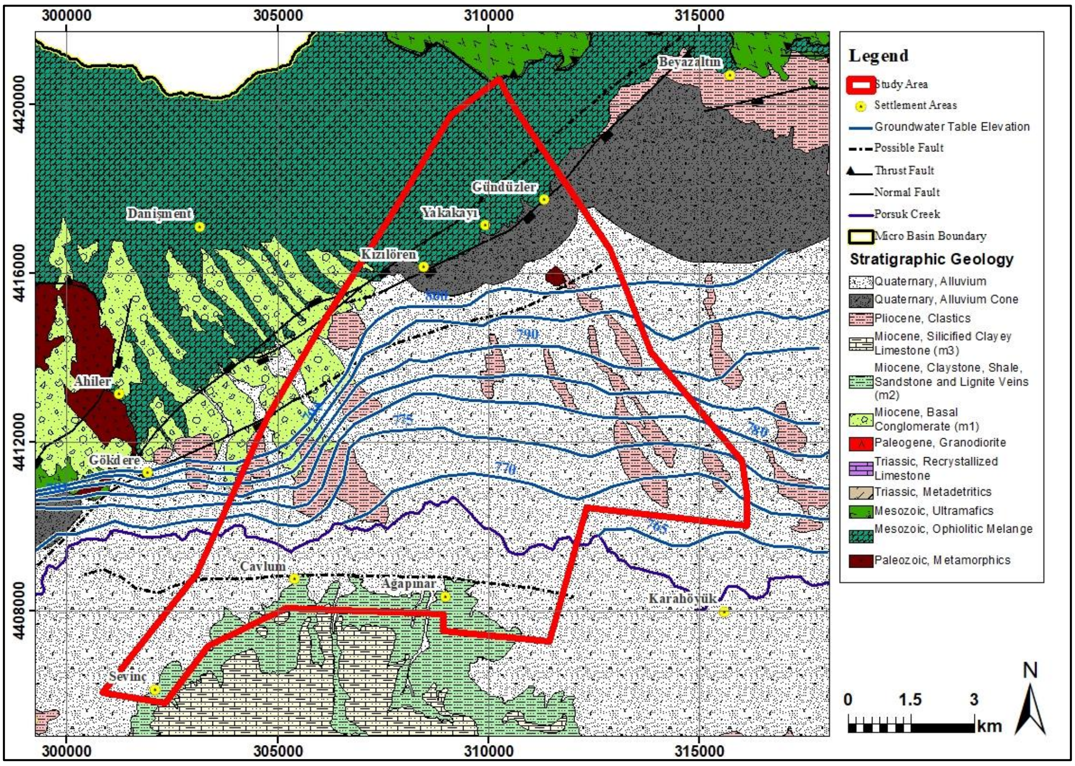


Figure 3.4. Groundwater elevation map of the study area (Yazıcıgil et. al, 2018).

While seasonal fluctuations are observed in the water levels of the wells drilled in the shallow and middle sections, the seasonal changes in the water levels of the deep wells drilled in the coal-bearing Miocene unit are insignificant. In the study area, an up-gradient from the deep system to the shallow system are determined from almost all deep wells. In the well BPK-2 (representing deep levels) however, reversal of the vertical gradient after the dry season was reported.

Pumping tests performed by Yazıcıgil et al. (2017b) at wells near Porsuk Creek revealed that the alluvium aquifer groundwater is in direct interaction with the Porsuk Creek as also indicated by the groundwater table map.

CHAPTER 4

HYDROCHEMISTRY

4.1 Data Collection

The measurements for the hydrochemical monitoring program were carried out between June 2016 and January 2018 by Yazıcıgil et. al (2018). The monitoring has been limited to the TKI-A sector area until May 2017 then expanded to include the TKI-B, C, D, E and F sectors (Figure 2.1). The monitoring locations of spring/fountain and wells are listed in Table 4.1 and the distribution of the locations is shown in Figure 4.1.

Table 4.1 Hydrochemical monitoring locations

(a) Spring and fountain waters

Station No	Latitude	Longitude	Definition
F-11	306194	4413525	The left side on the road of Danişment village
F-12	307805	4415827	The left side on the road of Kızılcaören village
F-13	308093	4416081	The right side on the road of Kızılcaören village
F-14	308298	4416207	Fountain is next to the Kızılcaören village mosque
F-15	309652	4416631	The left side on the road of Yakakayı village
F-16	311310	4417704	Across the road of Gündüzler mosque
F-17	309985	4419533	Değirmen stream

(b) Well waters [Al: Alluvium, Pl: Pliocene, MAC: Miocene Above Coal, CH: Coal Horizon, MBC: Miocene Below Coal]

Station No	Latitude	Longitude	Geological Units of Wells	Station No	Latitude	Longitude	Geological Units of Wells
APK-2	305430	4411188	MAC	E-7P	310270	4409683	Al + Pl
APK-3	304100	4409954	Al + MAC + CH	E-8-15P1	306793	4411830	Pl + MAC
APK-4	304119	4409925	Al	E-8-15P2	306722	4411792	MAC + CH
APK-5	308233	4408619	MAC +CH	E-9P1	309915	4414038	Pl + MAC
APK-6	308233	4408639	Al + MAC	E-10P1	304884	4409081	Al + MAC
APK-7	307819	4410704	Pl	E-11P1	315081	4411415	Pl + MAC
BPK-1	310135	4413567	Pl	E-11P2	315045	4411416	Pl
BPK-2	310154	4413546	MAC + CH	E-13P1	312499	4412445	Al + Pl + MAC
E-1P	306013	4409153	Al + MAC	E-13P2	312449	4412414	Al + Pl
E-2P	307791	4410718	Pl + MAC	E-14P1	306912	4413449	MAC
E-3P	308903	4412675	CH	E-14P2	306901	4413411	MAC
E-3P2	308924	4412725	Al + Pl	E-16P1	310261	4409649	Al + Pl + MAC + CH + MBC
E-3P3	308936	4412637	Pl + MAC	E-17P2	310996	4412835	Pl + MAC
E-4P	309530	4411227	Al + Pl + MAC + CH + MBC + Mélange	E-17P3	311036	4412837	Al + Pl
E-5P1	302033	4406657	Al + MAC	E-18P1	308271	4415038	Pl + MAC
E-6P1	310864	4407816	Al + MAC	E-20P1	310766	4410699	Al + Pl

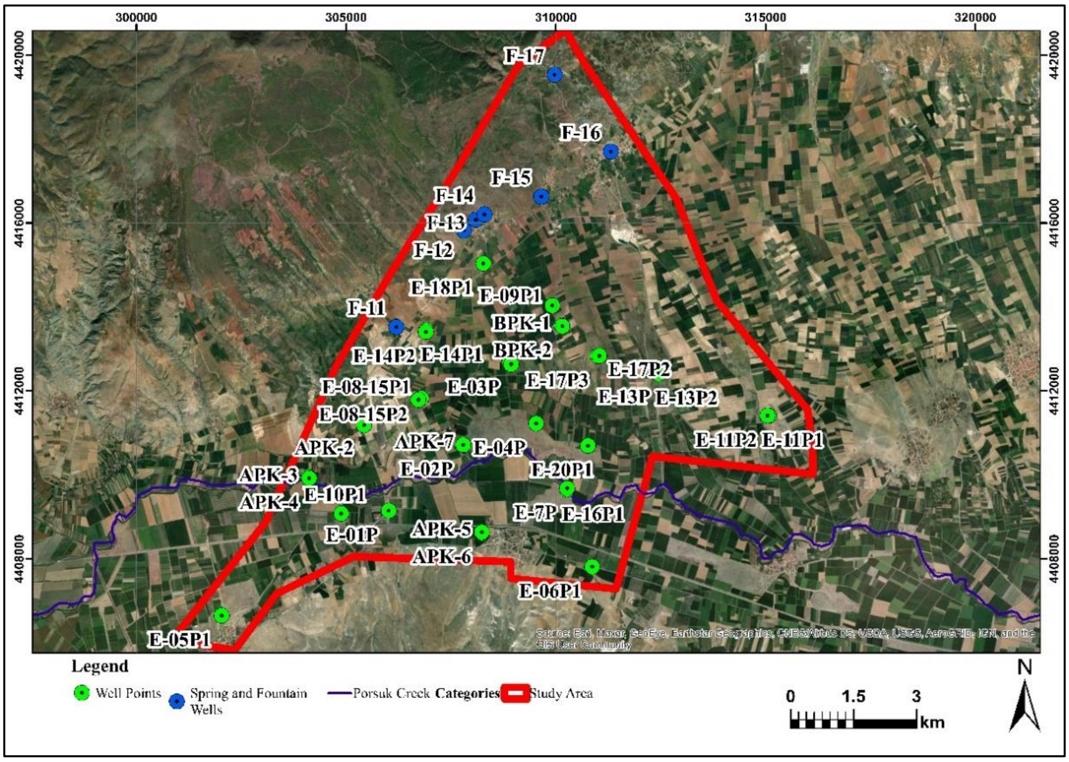


Figure 4.1. The distribution of hydrochemical monitoring locations

In monthly field studies, temperature (T), electrical conductivity (EC), total dissolved solids (TDS), salinity (S), pH, oxidation-reduction potential (ORP) and dissolved oxygen (DO) values of the waters were measured at the monitoring locations. Since pumping is necessary for wells to purge for the fresh formation water flow, the monthly monitoring program was not carried out for the non-flowing well waters.

Within the scope of field studies, in addition to the monthly field parameter measurements, water sampling studies were carried out between September 2016 and February 2017 (following the pump test; in wells of APK-2 and E-1P in September 2016, in wells of APK-7 and E-2P in November 2016, in well of APK-6 in January 2017, in the wells of APK-3, APK-4 and APK-5 in February 2017) and between May and September 2017 (spring waters in May, wells following pumping tests or purging in June, July, and August). The detailed chemical analyses of the samples were performed in ALKA (September 2016-February 2017 period) and in

ENCON (May 2017-September 2017) laboratories with TURKAK accreditation. Two sets of samples were collected for the metal analysis representing dissolved and total concentrations. The samples that have dissolved concentrations were acidified after filtration in the field with 0.45 μ filter. Chemical parameters analyzed are determined according to the water quality regulations of İTAS (2005), SKKY (2008), and YKBKK (2012). Detailed information about the collection of well water samples is given in Table 4.2.

Table 4.2 Well water sampling information

Well No	Sampling Date	Well Depth (m)	Depth of Pump (m)	Pump Operating Hours	Pump Flow Rate (L/sec)
APK-2	Sep-16	58.5	43	0.9	1.3-1.5
APK-3	Feb-17	460	374	72	1.3-1.6
APK-4	Feb-17	60	48	51.4	50-55
APK-5	Feb-17	400	380	31.3	1.3-1.5
APK-6	Jan-17	60	48	56.3	30-35
APK-7	Nov-16	72	60	72.2	19-20
E-1P	Sep-16	67	48	80	50-55
E-2P	Dec-16	350	250	51.9	1.3-1.5
APK-2	Jun-17	58.5	48	2	1.3-1.5
APK-3	Jun-17	460	444	4	1.3-1.5
APK-4	May-17	60	48	1	25-30
APK-5	Jun-17	400	384	25	1.3-1.5
APK-6	Jun-17	60	48	12	25-30
APK-7	Jun-17	72	60	5	25-30
BPK-1	Aug-17	102	72	72	25-30
BPK-2	Aug-17	460	444	72	1.3-1.5
E-1P	Jun-17	67	48	5	25-30
E-2P	Jun-17	350	336	16	1.3-1.5
E-3P	May-17	445	72	12	1.3-1.5
E-3P2	May-17	90	78	10	25-30
E-3P3	May-17	316	294	20	1.3-1.5
E-4P	Jun-17	507	-	-	Artesian
E-5P1	Jun-17	100	84	5	25-30
E-6P1	May-17	75	72	6	25-30
E-7P	Jul-17	75	24	72	50-55
E-8-15P1	Jul-17	90	72	72	25-30
E-8-15P2	Aug-17	350	90	72	25-30
E-9P1	Jun-17	110	84	17	1.3-1.5
E-10P1	Jun-17	350	282	17	1.3-1.5
E-11P1	Aug-17	350	276	21	1.3-1.5
E-11P2	Jul-17	90	72	2	25-30
E-13P1	Jun-17	280	216	13	1.3-1.5
E-13P2	May-17	75	66	7	25-30
E-14P1	May-17	250	156	20	1.3-1.5
E-14P2	May-17	90	66	4	25-30
E-16P1	Jul-17	500	72	72	25-30
E-17P2	May-17	350	270	18	1.3-1.5
E-17P3	May-17	75	60	6	25-30
E-18P1	May-17	200	108	6	1.3-1.5
E-20P1	Jun-17	200	150	12	1.3-1.5

In order to assure quality control, duplicate samples were collected at each sampling campaign. Furthermore, to check the groundwater representativeness of the sampling studies, additional samples were collected to examine the different cases described in the next section from APK-3 and BPK-2 well waters (APK-3/1, APK-3/2, APK-3total and BPK-2/1 BPK-2/2, BPK-2/3) and analyzed.

4.2 Quality Control

4.2.1 Control Measurements

Field Parameters

The accuracy and precision measurements for the field parameters were carried out using calibration solutions as unknowns and using multiple measurements from the same point, respectively at each monthly monitoring program. Overall average of these control measurements indicate that the errors associated with electrical conductivity, dissolved oxygen, pH and oxidation–reduction potential measurements are 2.68 %, 1.21 %, 0.50 % and 5.01 %, respectively.

Laboratory Parameters

In order to perform the quality control of the analyses, five duplicate samples were submitted to the laboratories in the sampling periods by assigning different names: F6 → W3, and F6 → Y2 in period of January-October 2016 to ALKA laboratory and E-3P2 → CPK-1, APK-4 → CPK-2 and E- 11P1 → CPK-3 in the period of May-September 2017 to ENCON laboratory. The laboratory results of these samples are given in Appendix-A.

Arithmetic means of the average deviations determined for each parameter using the duplicate results are listed in Table 4.3 percent errors.

According to the average percentage errors in duplicate samples, some parameters such as Ca^{2+}, COD, Mg^{2+}, Mn, TKN, N(org), $N\text{-}NH_4$, $N\text{-}NO_2$, $N\text{-}NO_3$, P(t), P and S^{-2} (11.4, 20.1, 12.8, 12.0, 14.6, 15.6, 16.1, 10.3, 20.6, 19.1 and 15.2 %, respectively) have relatively higher error values than the other parameters. Average value of all error percentages is about 4.8%. When higher error percentages including parameters are excluded, the average of the error percentages of duplicate samples decreases to 1.8%, approximately twice as much of the first value.

Table 4.3 Averages of the percentage errors determined from duplicate sample measurements

Parameter	**%Error**	**Parameter**	**%Error**	**Parameter**	**%Error**
Ag	0.00	F	6.27	P	19.08
Al	1.82	Fe	0.11	Sb	0.00
Alk.(t)	3.34	P,reac	4.74	Se	0.00
As	1.63	Hg	12.75	Si	1.36
B	2.66	K	3.46	Sn	0.00
Ba	1.79	Li	1.38	SO4	4.60
Be	0.00	Mg	12.00	Sr	0.43
Bi	0.00	Mn	14.57	S-2	15.15
BOD	4.14	Mo	0.00	TDS	1.87
Ca	11.38	Na	4.68	Ti	0.00
Cd	0.00	Ni	0.00	Tl	5.30
Cl	1.30	TKN	15.58	TOC	0.00
CN	0.00	N(Org)	16.34	TSS	0.65
Co	0.00	N-NH4	13.74	U	0.39
COD	20.10	N-NO2	16.13	V	0.45
Color	7.46	N-NO3	10.28	Trichloroethylene	0.00
Cr	0.02	P(t)	20.61	Tetrachloroethylene	0.00
Cu	0.00	Pb	0.11	Zn	3.78

Zero value in the list indicates below detection limit measurements.

Ion Charge Balance

Ion charge balance error (CBE) distributions of the measurements are shown in Figure 4.2. The analytical results are accepted using the threshold value of electrical neutrality having an error of ±10%.

The average ion charge balance error of all measurements determined from major ion concentrations (Ca^{+}, Na^{+}, Mg^{2+}, K^{+}, HCO_3^{-}, CO_3^{2-}, Cl^{-}, and SO_4^{2-}) is about 5.6%. The results of the analyses indicate that some measurements contain high ion charge balance errors. February 2017 results of the APK-3 and APK-5 samples receiving water from all units and containing high total dissolved solids (1726 mg/l and 2920 mg/l, respectively) and June 2017 results of the E-4P (TDS; 24312 mg/l) sample contain relatively high an ionic charge balance error (30-37%). When these examples are excluded, the average charge balance error drops to 4.9% (geometric mean 3.7%).

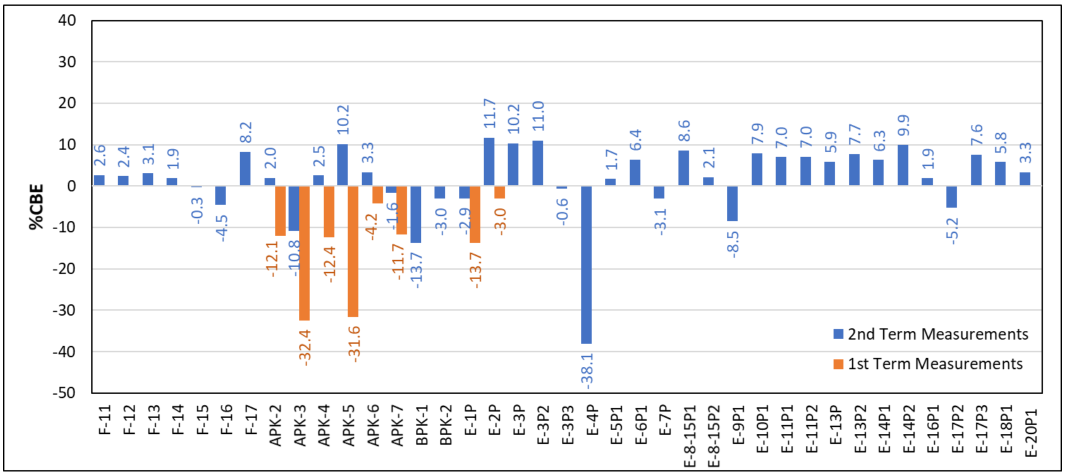


Figure 4.2. Ion charge balance error (CBE) of 1st term measurements and 2nd term measurements.

Control of Different Laboratory Results

Since two different laboratories are used in two different sampling periods for the chemical analyses of the project, in order to perform inter-laboratory quality control of measurements; average percentage deviations between the measurement results of each parameter of the same well waters analyzed in two different periods were calculated and evaluated after subtracting the analysis percentage errors determined by the duplicate samples. In these evaluations, it has been determined that the average deviation in sodium concentration is much higher than expected possible deviations in the groundwater compared to other ions' deviations. The determined percentage deviations are 63, 84, 83, 90, 81, 84, 59 and 86 in the APK-2, APK-3, APK-4, APK-5, APK-6, APK-7, E-1P and E-2P samples, respectively. Moreover, all the second period Na measurements of well waters are higher than those of the first period.

The main issues that can cause the differences in Na concentrations between these periods, excluding the nature of groundwater, are variations in the sampling methods and measurement errors due to different laboratory applications. The pump depth, pumping time and pump flow rates applied during both sampling periods are similar (Table 4.2).

When the deviations are evaluated in terms of laboratory analysis; except in sodium, high and only increasing or only decreasing deviation trends are not detected in the concentrations of the other parameters and the deviations of other major ion concentrations are less than 24% [excluding the highest values of Ca (51%), Cl (30%) concentrations in the first period of the E-2P sample and the highest value of Cl concentration (86%) in the APK-5 sample which includes high charge balance error (31%)]. In addition, high Na deviation percentage values are similar in different groundwater samples that indicate a systematic laboratory analysis error for Na.

On the other hand, Na measurement error percentages of four duplicate samples that were sent to the laboratory during the first sampling period are 0.3, 6.4, 2.2 and 0.2 and the error percentages of three duplicate samples that were sent to the laboratory during the second sampling period are 10, 10 and 2.4. These data suggest that there is no high error associated with the intra- laboratory measurements.

However, when the E-1P well water Na analyses (48, 39, 24 in mg/l) performed within the scope of the MTA project are compared with the first period (8.1 mg/l) and second period (39.6 mg/l) analyses of this work, it is observed that the first period Na measurements are low. Similarly, when the E-2P well water MTA Na analyzes (1364, 3260 in mg/l) are compared with the first period (58.2 mg/l) and second period (1915.4 mg/l) analyses of this study, it is observed that the first period Na measurement is very low. Therefore, it is concluded that the high Na deviation is related to the laboratory systematic measurement errors and does not reflect the groundwater properties. These evaluations indicate that care should be taken in the use of first period laboratory Na measurements.

4.2.2 Groundwater Representation of The Samples

In order to evaluate the groundwater representativeness of the sampling methods, well water samples were taken from APK-3 (APK-3/1, APK-3/2, APK-3total) and BPK-2 (BPK-2/1, BPK- 2/2, BPK-2/3) representing different cases explained below and were analyzed for their chemical characteristics.

1. *The filtration effect on concentration*

In order to eliminate the effect of possible total suspended solids (TSS) for the analysis of dissolved metal concentrations in the water, metal analysis samples were acidified after field filtration (0.45 μ) during sampling as mentioned earlier. While taking the APK-3 water sample (TSS<15 mg/l), in order to determine the possible metal concentration differences that could occur if the samples are taken in the field without filtering, both unfiltered (APK-3total) and filtered samples (APK-3) were subjected to acid protection. The aim is to determine the effect of filtering on metal concentrations. When the analysis results of the two samples are compared (Table 4.4) considering greater than 10% difference; the unfiltered APK-3 sample yielded higher Si, U, V concentrations (95.3%, 20.6%, 16.3%, respectively) than the filtered sample and yielded lower Li, Sr, B, Ca concentrations (31%, 13.7%, 11.7%, 11.2%, respectively) than the filtered sample.

Table 4.4 Metal parameter values (in mg/l) in filtered and unfiltered samples of APK-3

Parameter	APK-3	APK-3total	%Difference
Ag	<0.005	<0.005	0.0
Al	0.041	0.040	1.6
As	0.00202	0.00215	-6.5
B	15.9	14.0	11.7
Ba	<0.04	<0.04	0.0
Be	<0.001	<0.001	0.0
Bi	<0.1	<0.1	0.0
Ca	196	174	11.2
Cd	<0.002	<0.002	0.0
Co	<0.01	<0.01	0.0
Cr	<0.01	<0.01	0.0
Cu	<0.01	<0.01	0.0
Fe	3.6	3.9	-9.0
Hg	<0.0001	<0.0001	0.0
K	30.1	28.2	6.4
Li	1.31	0.90	31.0
Mg	165	157	5.1
Mn	0.39	0.36	6.4
Mo	<0.01	<0.01	0.0
Na	710	670	5.6
Ni	0.0171	0.0156	9.0
Pb	<0.01	<0.01	0.0
Sb	<0.0005	<0.0005	0.0
Se	<0.01	<0.01	0.0
Si	12.3	24.1	-95.3
Sr	4.1	3.5	13.7
Sn	<0.04	<0.04	0.0
Ti	<0.04	<0.04	0.0
Tl	<0.04	<0.04	0.0
U	0.0017	0.0021	-20.6
V	0.2011	0.2338	-16.3
Zn	<0.04	<0.04	0.0

Both sample waters are in low quality (Class III) according to the regulatory frameworks of water quality (SKKY, 2008). When only the analyzed parameters are taken into consideration, water facies are in Na type in terms of cation facies. This result suggests that although water facies and quality class may not be different, concentration differences will occur. The difference could be greater in waters with greater than 15 mg/l in TSS value and there exist a potential to create facies and quality classification differences.

2. *The effect of sampling the water pended in the well, filtering the same aquifer, on the concentrations*

In order to sample fresh formation water from the wells, unrepresentative pending waters were discharged by pumping before the sampling. To show the effects of the cases where such discharge is not performed, samples waited for about 2 months from 120 m (sample no: BPK-2/1), 250 m (sample no: BPK-2/2) and 444 m (sample no: BPK-2/3) of the BPK-2 well (closed from top to down 308 m, filter interval; 318-452 m, MAC between 308-318 m and CH between 318-452 m) were taken and concentrations of these samples are compared with the concentrations of the sample taken from 444 m (BPK-2) after 3 days of pumping (Table 4.5).

Table 4.5 BPK-2 well water concentrations from different level pre-purging samples and from the post-pumping sample (Unit: mg/l, Alkalinity as $CaCO_3$, EC: µs/cm)

Parameter	**BPK-2**	**(I) BPK-2/1**	**(II) BPK-2/2**	**(III) BPK-2/3**	**BPK-2/(III)**
pH	8.26	7.94	7.76	7.72	1.07
EC	4630	7370	7810	14600	0.32
DO	2.44	1.56	1.46	0.14	17.43
ORP	90	-95	-91	-123	0.73
Cl	1441	2689	2559	5168	0.28
SO4	301.2	770.3	627.8	42.9	7.02
Alk.(t)	172.2	96.2	97.6	200.4	0.86
Ag	<0.005	<0.005	<0.005	<0.005	1.00
Al	<0.04	<0.04	<0.04	<0.04	1.00
As	<0.001	<0.001	<0.001	<0.001	1.00
B	11.1	14.01	19.73	9.8	1.14
Ba	0.12	0.4044	0.2541	1.70	0.07
Be	<0.001	<0.001	<0.001	<0.001	1.00
Bi	<0.1	<0.1	<0.1	<0.1	1.00
Ca	114.9	192.2	203.1	251.1	0.46
Cd	<0.002	<0.002	<0.002	<0.002	1.00
Co	<0.01	<0.01	<0.01	<0.01	1.00
Cr	<0.01	<0.01	<0.01	<0.01	1.00
Cu	<0.01	<0.01	<0.01	<0.01	1.00
Fe	0.15	1.264	2.952	9.91	0.02
Hg	<0.0001	<0.0001	<0.0001	<0.0001	1.00
K	15.74	28.86	37.78	55.25	0.28
Li	1.41	2.226	2.256	1.83	0.77
Mg	84.95	152	105.3	183.6	0.46
Mn	0.22	0.3784	0.411	1.39	0.16
Mo	<0.01	<0.01	<0.01	<0.01	1.00
Na	754	1244	1403	2570	0.29
Ni	<0.01	<0.01	<0.01	<0.01	1.00
Pb	<0.01	<0.01	<0.01	<0.01	1.00
Sb	<0.0005	<0.0005	<0.0005	<0.0005	1.00
Se	<0.01	<0.01	<0.01	<0.01	1.00
Si	8.06	3.554	3.754	3.66	2.20
Sr	1.04	1.951	1.9	3.05	0.34
Sn	<0.04	<0.04	<0.04	<0.04	1.00
Ti	<0.04	<0.04	<0.04	<0.04	1.00
Tl	<0.04	<0.04	<0.04	<0.04	1.00
U	<0.001	<0.001	<0.001	<0.001	1.00
V	0.14	0.1812	0.181	0.27	0.51
Zn	<0.04	<0.04	<0.04	<0.04	1.00

According to the comparison results, the concentrations of EC, Cl^-, Ba, Ca^{2+}, Fe, K^+, Mg^{2+}, Mn, Na^+, Sr and V in the waited waters is much higher than those of the purged waters but concentrations of DO, ORP, SO_4^{2-} and Si were lower in the waited waters. These all-groundwater samples are classified as low-quality water due to B, Cl^-, EC, Na^+ and O_2 concentrations and all waters are in Na-Cl facies. However, in addition to these parameters, Fe parameter in the waited waters and SO_4 parameter in the purged water (BPK-2 comparing with the sample from the same depth BPK-2/(III)) are also among the low-quality parameters. On the other hand, sulfate concentrations in the samples taken from 120 m and 250 m depth are much higher than that of the water sample collected after pumping. These results indicate that the wells should be purged prior to samplings for collection of the representative formation water.

3. *The effect of sampling the water from different depths in the well that filters multiple aquifers*

In order to determine the concentration differences that could occur in the case of sampling of the waited water from different depths of a well that filters more than one aquifer, APK-3 well [filtering alluvium (56-60 m), Miocene units (60-312 m) and coal levels (312-452 m)] were sampled from both 150 m (APK-3/1) and 252 m (APK-3/2) depths.

According to the APK-3 waited (4 months) well water data, APK-3/2 groundwater has lower DO, ORP, As, U concentrations but higher SO_4, B, Fe, K, Li, Si and Sr concentrations than APK-3/1 groundwater (Table 4.6).

Table 4.6 APK-3 well water concentrations from different levels prior to purging and after purging (Unit: mg/l, Alkalinity as $CaCO_3$, EC: µs/cm)

Parameter	APK-3	(I) APK-3/1	(II) APK-3/2	(I)/(II)
pH	8.52	7.39	7.56	0.98
EC	4220	9260	10060	0.92
DO	2.47	2.5	1.3	1.92
ORP	-103	-123	-159	0.77
Cl	364	1019	1023	1.00
SO4	2579	5921	8569	0.69
Alk.(t)	238	262	290	0.90
Ag	<0.005	<0.005	<0.005	1.00
Al	0.041	0.096	0.085	1.14
As	0.0020	0.0144	0.0062	2.31
B	15.9	26.7	39.3	0.68
Ba	<0.04	<0.04	<0.04	1.00
Be	<0.001	<0.001	<0.001	1.00
Bi	<0.1	<0.1	<0.1	1.00
Ca	196.0	393.2	454.9	0.86
Cd	<0.002	<0.002	<0.002	1.00
Co	<0.01	<0.01	<0.01	1.00
Cr	<0.01	<0.01	<0.01	1.00
Cu	<0.01	<0.01	<0.01	1.00
Fe	3.6	8.2	11.9	0.68

Parameter	APK-3	(I) APK-3/1	(II) APK-3/2	(I)/(II)
Hg	<0.0001	<0.0001	<0.0001	1.00
K	30.1	70.2	86.1	0.82
Li	1.3	3.4	4.7	0.72
Mg	165	312	320	0.98
Mn	0.39	0.65	0.64	1.02
Mo	<0.01	<0.01	<0.01	1.00
Na	710	1820	2056	0.89
Ni	0.017	<0.01	<0.01	1.00
Pb	<0.01	<0.01	<0.01	1.00
Sb	<0.0005	<0.0005	<0.0005	1.00
Se	<0.01	<0.01	<0.01	1.00
Si	12.3	4.6	6.9	0.67
Sr	4.1	5.5	8.2	0.67
Sn	<0.04	<0.04	<0.04	1.00
Ti	<0.04	<0.04	<0.04	1.00
Tl	<0.04	<0.04	<0.04	1.00
U	0.0017	0.0013	0.0010	1.30
V	0.201	0.412	0.415	0.99
Zn	<0.04	<0.04	<0.04	1.00

Both waters are in Na-SO4 facies and have the low groundwater quality class depending on the same parameter concentrations. However, when quality of waters for human consumption is evaluated, APK-3/1 water is not suitable for the consumption due to high As (the limit is 0.01 mg/l) and B (the limit is 1 mg/l), yet APK-3/2 water is not suitable for consumption only due to high B content concentrations. In addition, the above detection limit concentrations of the waited water (excluding pH, ORP, silica and uranium) are much higher than those of the water that was taken from 444 m depth after purging.

4.3 Spring and Fountain Waters

4.3.1 Parameters Measured in The Field

The results of hydrochemical field parameter monthly measurements in spring and fountain waters are listed in Appendix-B. The Field measurements were taken from all spring and fountain locations between May, and December-2017 except for F-14 and F-17 waters. The flow was observed in F-14 location only in May, June, and December 2017, and in the F-17 monitoring point, only one measurement was taken in May-2017. The average and average deviation values of the parameters; temperature (T), pH, oxidation-reduction potential (ORP), electrical conductivity at 25ºC (EC), salinity (S), total dissolved oxygen (TDS) and dissolved oxygen (DO) are listed in Table 4.7. TDS and salinity values are reported by the EC meter using the empirical conversion method. The temperatures in the table include the ambient air temperature effects.

Average values of the field parameters (pH, ORP, EC and DO) are shown in Figure 4.3. Average electrical conductivity values at normalized to 25ºC change between 438 µS/cm (F-17) and 1227 µS/cm (F-11). Higher EC values are measured in F-11 and F-12 (888 µS/cm) monitoring locations. Average TDS values are in the interval of 285 - 797 mg/l and average salinity values range from 0.21 to 0.61 ppt.

Table 4.7 Field parameters measured at fountain and spring monitoring locations

av(avdev)	T(ºC)	pH	ORP (mV)	EC 25ºC (µS/cm)	S (ppt)	TDS (mg/l)	DO (mg/l)	DO%
F-11	15.4 (1.5)	7.72 (0.07)	108.8 (17.3)	1226.9 (9.1)	0.610 (0.005)	797.0 (5.9)	4.1 (0.2)	46.1 (2.2)
F-12	18.5 (6.9)	7.43 (0.07)	122.0 (13.8)	887.5 (57.1)	0.440 (0.029)	576.8 (37.1)	3.8 (1.1)	42.6 (10.0)
F-13	17.4 (5.6)	7.81 (0.16)	128.8 (15.8)	564.4 (50.1)	0.280 (0.025)	367.1 (32.5)	3.7 (1.2)	42.0 (10.0)
F-14	13.2 (1.3)	8.07 (0.06)	141.3 (13.8)	573.5 (7.3)	0.280 (0.004)	373.0 (4.7)	5.9 (0.8)	61.2 (7.3)
F-15	18.2 (6.0)	7.72 (0.25)	134.5 (6.5)	604.7 (72.3)	0.300 (0.036)	393.3 (46.9)	4.1 (0.9)	46.6 (9.7)
F-16	15.5 (5.5)	8.46 (0.19)	106.4 (15.5)	591.7 (130.9)	0.290 (0.065)	384.8 (84.9)	6.1 (1.3)	66.0 (10.0)
F-17	13.7 (sm)	8.69 (sm)	180.0 (sm)	438.0 (sm)	0.210 (sm)	285.1 (sm)	3.3 (sm)	35.6 (sm)

*av: Average; avdev: Average Deviation; sm: Single Measurements

Spring waters show weakly basic character. Average pH values vary in the range of 7.43-8.69. The pH values of F-14, F-16 and F-17 are relatively higher than those of the other observation points.

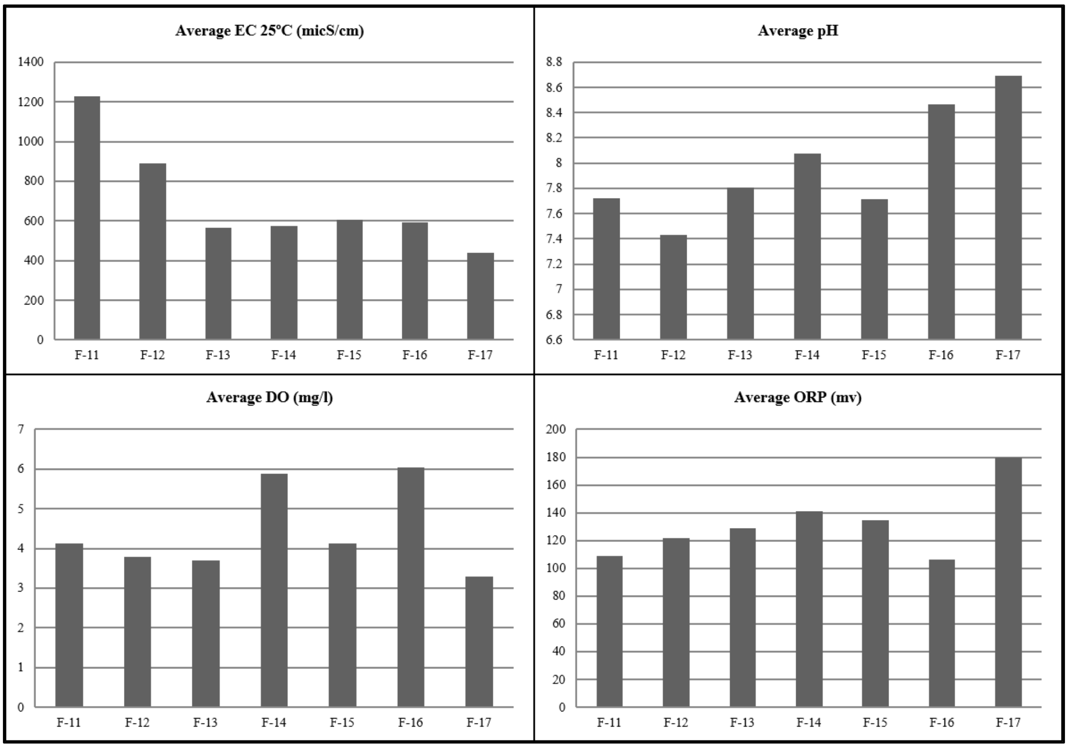


Figure 4.3. Comparison of average pH, ORP, EC and DO values in spring and fountain monitoring stations.

Average dissolved oxygen values of the waters are in the range of 3.29 (F-17)-6.05 (F-16) mg/l. The relatively higher values were measured in the waters of F-14 and F-16 locations.

Oxidation-reduction potential average values are in the range of 106.4 -180 mV and all spring waters show oxidizing character. The highest ORP values are determined in F-17 monitoring location (un-piped) compared to other locations.

The monthly change of field parameters is shown in Figure 4.4 and the relationship of the parameters with temperature, precipitation and flow rate is given in Figure 4.5. These drawings do not include F14 monitoring location parameter values due to mostly dry conditions and F-17 parameter values because of insufficient measurement.

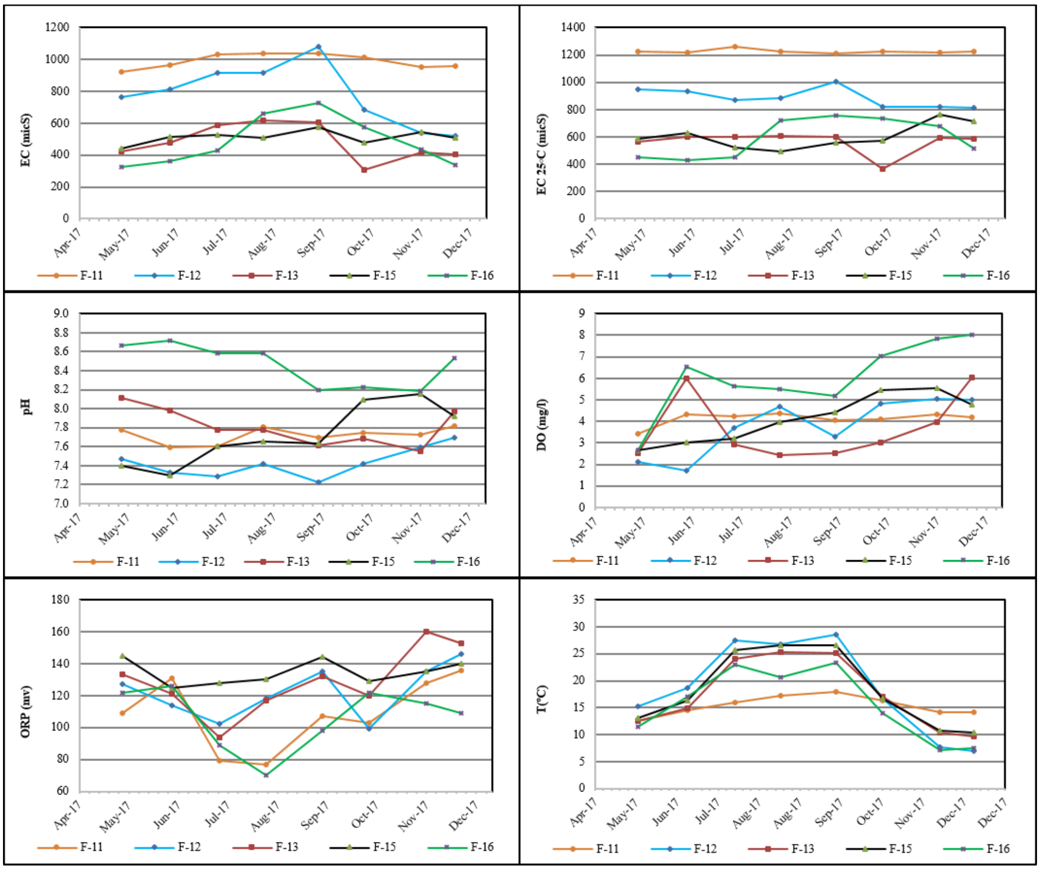


Figure 4.4. Monthly change of EC, pH, DO, ORP and T values in spring and fountain waters.

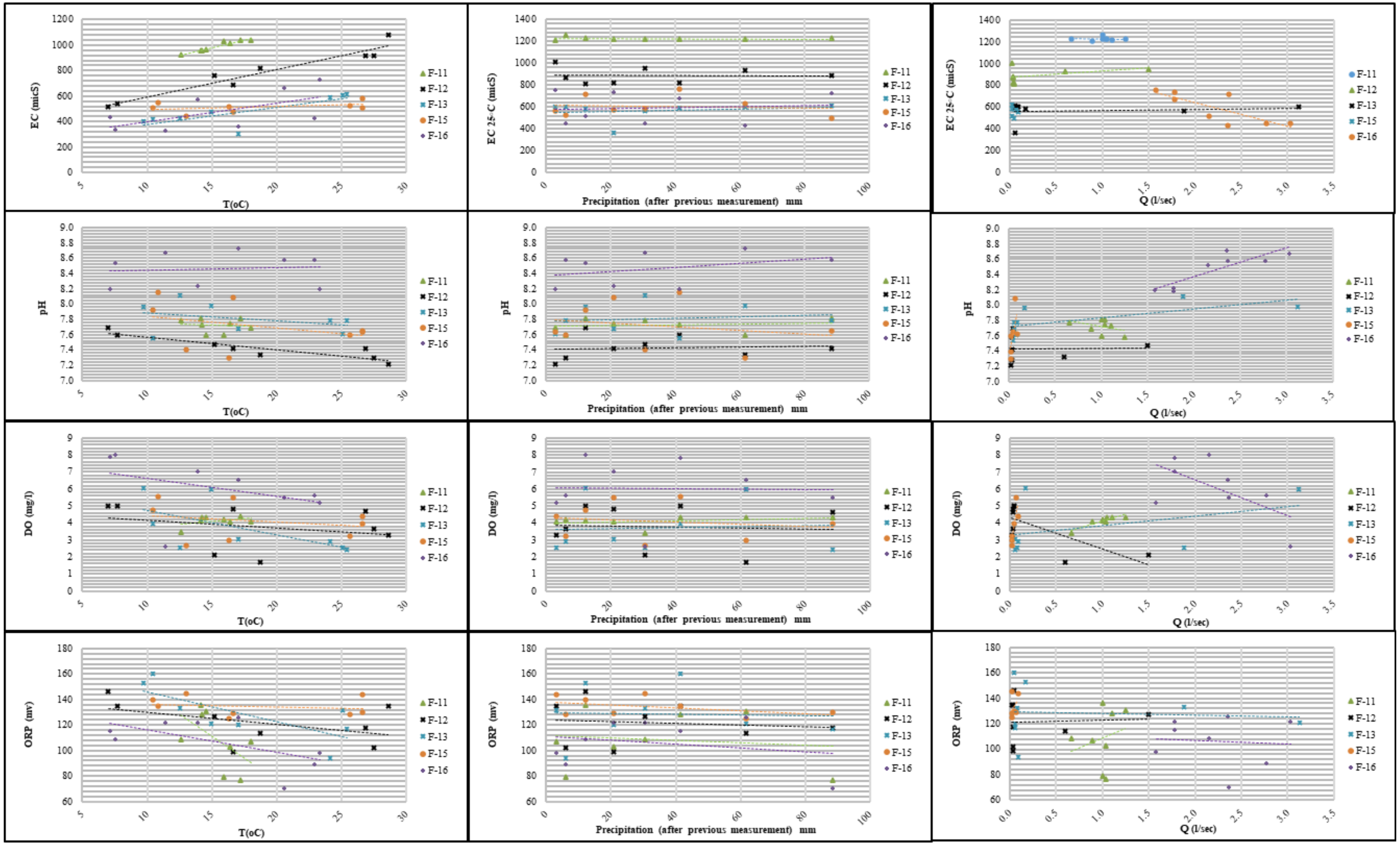


Figure 4.5. Change of EC, pH, DO and ORP values in spring and fountain waters with water temperature, precipitation and flow

The electrical conductivity values increase with the increasing water temperature but the change with the increasing precipitation is negligible. It generally increases slightly with increasing flow rate except for F-16 (Figure 4.5).

The variation in pH value is inversely proportional to the water temperature except for F-16 (Figure 4.5). The pH values measured at the F-16 location shows an increasing trend at first, and then a decreasing trend with the water temperature. The pH values increase slightly with the increasing precipitation. Except at F-11 and F-15 locations, pH values also increase with the increasing flow rate (Figure 4.5).

Dissolved oxygen values decrease in spring and fountain waters with the increasing temperature (Figure 4.5). However, there is a slight increase in DO values with the increasing precipitation amount (Figure 4.5). With the increasing flow rate, DO values increase in F-11 and F-13 waters but decrease in the others (Figure 4.5).

The oxidation-reduction potential values decrease with the increasing water temperature and precipitation (Figure 4.5). The decreasing trend with water temperature is higher than that of precipitation. With the increasing flow rate, ORP values increase in F-11 water and changes in the others are negligible (Figure 4.5).

4.3.2 Parameters Measured in the Laboratory

Detailed chemical analyses of spring and fountain waters are listed in Appendix-C. The water facies determined according to the major ion concentrations are shown on Piper diagram (Piper, 1944) in Figure 4.6 and the facies distribution in the study area is shown in Figure 4.7. All spring waters in the study area plot in HCO_3 facies in terms of anion content. In terms of cation content; F-11, F-12, F-16 and F-17 waters lie in Mg facies, F-13 water is in Mix(Ca-Mg) facies and F-14 and F-15 waters are in Ca^{2+} facies near Mg boundary.

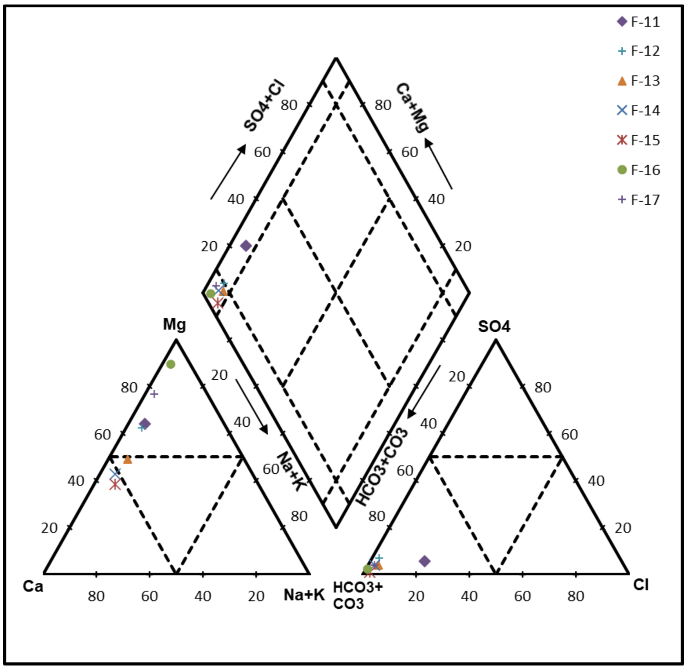


Figure 4.6. Major ion water facies of spring and fountain waters.

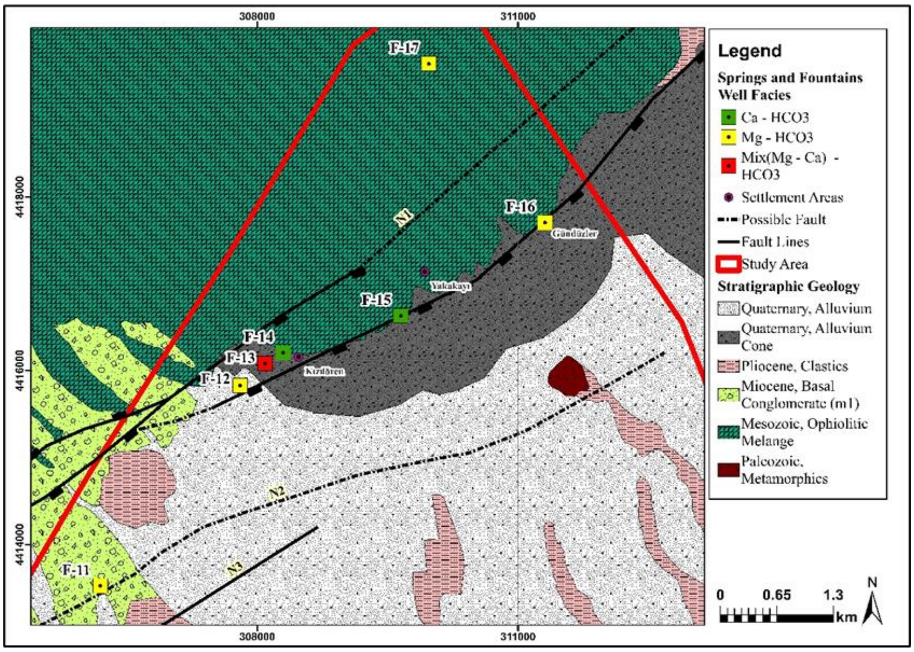


Figure 4.7. Water facies distribution of the spring and fountain waters.

The differences in the distribution of major ion concentrations are shown on the Schoeller diagram (Schoeller, 1962) in Figure 4.8. F-11 water and F-15 waters differ from the others in that they contain higher Cl^- concentrations than SO_4^{2-} concentrations. This is especially noticable in F-11 water which is discharged from the contact of Miocene m1 series and alluvium unit (Figure 4.7). Major ion concentrations of the others indicate that these spring waters were affected from the similar lithology but at different rates. Compared to waters from other locations, F-11 and F-12 waters include relatively higher and F-16 include relatively lower TDS values (Figure 4.8).

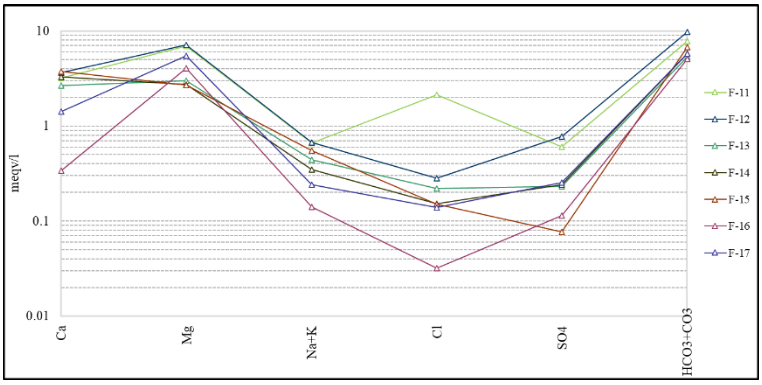


Figure 4.8. Major ion concentrations in the spring and fountain waters.

The distribution of non-major ion values with concentrations above the detection limits in the spring and fountain waters is shown in Figure 4.9. Ag, Al, B, Be, Bi, Cd, Co, CN, Cr, Cu, Hg, Li, Mn, Mo, Ni, N-NH4, P, Sb, Se, Sn, Ti, Tl, TOC, trichloroethylene, tetrahloroethylene, MBAS, and pesticide values are below the detection limits at all observation points. Concentrations in F-11 water are generally higher than those of the other waters (Figure 4.8). Concentration differences of Ba, Pb, Si, and V among the monitoring points are relatively low.

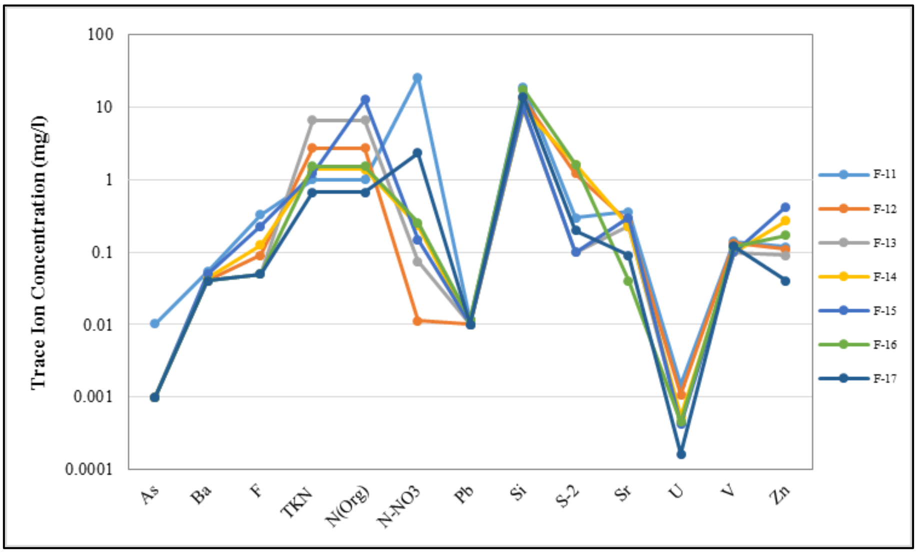


Figure 4.9. The distribution of the trace ion concentrations in spring and fountain waters (y-axis is logaritmic).

All spring stations in the study area are located on fault line or possible fault line (Figure 4.7). F-11 monitoring point is located on N2 coded fault line extending in NE-SW direction at the contact of alluvium-Miocene basal conglomerate (Figure 4.7). Other springs are located on N1 coded fault line at the contact of alluvium-alluvium cone in the case of F-12, at the contact of Mezosoic melange-alluvium cone in the case of the others except F-17, which is located on the melange discontinuities.

F, Ba, Si and Sr concentrations waters increase from F-13 to F-11 parallel to the increasing trend of Mg concentrations. F, Ba and Sr concentrations of F-16 and F-17 waters are lower, but Si concentrations are higher than those of the others. F-14 and F-15 waters having Ca-HCO_3 facies were possibly interacted with limestone. It should be also noted that As, F, N-NO3 and Sr concentrations in F-11 water are higher than those of the others.

4.4 Well Waters

Monitored wells related summary information is given in Table 4.8.

Table 4.8 Well summary information. For aquifer unit abbreviations see the caption of Table 4.1b

Well ID	**Aquifer Units**	**Well Depth (m)**	**Depth of Pump (m)**	**Filter Interval (m)**	**Saturated Alluvium Thickness (m)**	**Saturated Pliocene Thickness (m)**	**Saturated Miocene Above Coal Horizon Thickness (m)**	**Saturated Coal Horizon Thickness (m)**	**Saturated Miocene Below Coal Horizon Thickness (m)**	**Basement Thickness (m)**
APK-4	Al	60	48	16-56	54.1	0	0	0	0	0
E-17P3	Al+Pl	75	60	8-68	33.0	28.0	0	0	0	0
E-07P	Al+Pl	75	24	4-68	27.0	38.0	0	0	0	0
E-3P2	Al+Pl	90	78	4-86	22.9	57.0	0	0	0	0
E-13P2	Al+Pl	75	66	8-82	12.3	67.0	0	0	0	0
E-20P1	Al+Pl	200	150	8-192	36.0	153.0	0	0	0	0
E-01P	Al+MAC	67	48	6-54	29.3	0	21.0	0	0	0
APK-6	Al+MAC	60	48	16-56	30.0	0	21.8	0	0	0
E-05P1	Al+MAC	100	84	16-92	11.0	0	78.0	0	0	0
E-06P1	Al+MAC	75	72	8-80	8.0	0	70.0	0	0	0
E-10P1	Al+MAC	350	282	14-342	26.5	0	312.0	0	0	0
APK-7	Pl	72	60	16-68	0.0	68.0	0	0	0	0
E-11P2	Pl	90	72	8-82	0	71.3	0	0	0	0
BPK-1	Pl	102	72	20-96	0	78.8	0	0	0	0
APK-2	MAC	58.5	48	14.5-54.5	0	0	39.4	0	0	0
E-14P2	MAC	90	66	10-82	0	0	58.7	0	0	0
E-14P1	MAC	250	156	10-268	0	0	236.9	0	0	0
E-08-15P1	Pl+MAC	90	72	8-82	0	49.3	16.7	0	0	0
E-09P1	Pl+MAC	110	84	6-102	0	35.0	55.5	0	0	0
E-18P1	Pl+MAC	200	108	16-192	0	13.3	158.0	0	0	0
E-13P1	Al+Pl+MAC	280	216	12-268	11.5	175.0	78.0	0	0	0
E-17P2	Pl+MAC	350	270	75-342	0	105.0	162.0	0	0	0
E-11P1	Pl+MAC	350	276	10-338	0	306.3	28.0	0	0	0
E-3P3	Pl+MAC	316	294	90-298	0	37.0	171.0	0	0	0
E-02P	Pl+MAC	350	336	62-342	0	65.0	202.0	0	0	0
E-16P1	Al+Pl+MAC+CH+MBC	500	72	24-492	27.0	70.0	302.0	35.0	55	0
APK-3	Al+MAC+CH	460	444	56-452	55.6	0	270.0	130.0	0	0
E-08-15P2	MAC+CH	350	90	96-340	0	0	234.0	10.0	0	0
APK-5	MAC+CH	400	384	44-392	0	0	283.0	65.0	0	0
BPK-2	MAC+CH	460	444	308-452	0	0	10.0	140.0	0	0
E-03P	CH	445	72	321-441	0	0	0	120.0	0	0
E-04P	Al+Pl+MAC+CH+MBC+Melange	507	-	15-491	42.6	75	242.0	78.0	45.0	6.0

4.4.1 Parameters Measured in the Field

Hydrochemical field parameter values measured in well waters are listed in Appendix-B and the average values together with average deviations from these values are listed in Table 4.9. Average deviation is not indicated for single measurement including wells (Table 4.9). Since pumping is necessary for wells to purge for the fresh formation water flow, the monthly monitoring program was carried out only for artesian flowing wells (E-2P and E-4P).

Table 4.9 Field parameter values measured in well waters (av: Average, avdev: Average Deviation)

av(avdev)	**T(°C)**	**pH**	**ORP (mv)**	**EC 25°C (µS/cm)**	**S(ppt) 0%**	**TDS (mg/l)**	**DO (mg/l)**	**DO%**
APK-2	16.7 (0.0)	7.81 (0.14)	79 (74)	802 (37)	0.39 (0.02)	521 (24)	3.51 (0.58)	39.7 (5.7)
APK-3	20.2 (1.2)	7.70 (0.04)	-53 (51)	4035 (512)	2.01 (0.26)	2619 (333)	2.83 (0.36)	36.3 (1.8)
APK-4	15.2 (1.1)	7.69 (0.21)	198 (55)	730 (13)	0.36 (0.01)	475 (9)	4.25 (0.94)	45.8 (9.8)
APK-5	22.3 (1.6)	7.69 (0.06)	-131 (3)	5528 (845)	2.76 (0.42)	3588 (548)	3.19 (1.20)	39.6 (12.3)
APK-6	15.1 (2.4)	7.87 (0.005)	72 (49)	997 (89)	0.49 (0.04)	648 (58)	4.12 (0.38)	43.0 (1.4)
APK-7	15.7 (0.8)	7.74 (0.13)	114 (47)	715 (27)	0.35 (0.01)	465 (18)	5.93 (1.52)	67.5 (17.6)
BPK-1	17.1	8.12	107	508	0.25	331	6.21	73.2
BPK-2	21.3	8.26	90	5000	2.49	3245	2.44	32.5
E-1P	15.0 (0.1)	7.61 (0.04)	102 (65)	952 (83)	0.47 (0.04)	619 (54)	3.10 (0.61)	32.9 (5.4)
E-2P	16.7 (3.0)	8.48 (0.14)	-183 (26)	12,038 (277)	6.01 (0.14)	7812 (180)	1.82 (0.42)	20.2 (4.7)
E-3P	15.7	8	13	635	0.31	413	-	-
E-3P2	16	7.62	185	589	0.29	383	4.34	40.4
E-3P3	18.9	7.8	-108	4806	2.4	3120	1.62	17.1
E-4P	21.9 (1.9)	7.56 (0.22)	-182 (17)	30,233 (752)	15.11 (0.38)	19619 (488)	0.57 (0.23)	6.3 (1.9)
E-5P1	16.3	7.48	-8	793	0.39	516	3.03	33.3
E-6P1	17.9	7.94	154	599	0.29	390	-	-
E-7P	18.5	7.65	64	749	0.37	487	3.97	46.6
E-8-15P1	16.3	7.94	65	736	0.36	479	6.55	76.2
E-8-15P2	22.6	7.61	-68	10819	5.4	7022	3.26	43.4
E-9P1	16.2	7.88	25	529	0.26	344	5.97	66.8
E-10P1	20	7.59	-111	2767	1.38	1796	1.93	23.6
E-11P1	30.7	8.26	-143	2496	1.24	1620	0.95	17.6
E-11P2	16.6	8.05	82	614	0.3	399	5.79	66.1
E-13P1	24.5	8.33	-73	496	0.24	323	2.33	32.3
E-13P2	17.5	8.34	47	452	0.22	294	3.1	36.1
E-14P1	18.4	7.67	-24	1023	0.51	665	4.5	51.6
E-14P2	17.2	7.52	155	918	0.45	597	4.41	57.2
E-16P1	18.7	7.79	29	897	0.44	583	3.15	34.6
E-17P2	22.6	8.01	36	2805	1.4	1821	1.58	22.2
E-17P3	17.2	7.52	155	918	0.45	597	4.41	57.2
E-18P1	15.8	7.65	11	547	0.27	356	5.3	58.7
E-20P1	18.2	7.46	-32	705	0.35	458	4.2	43.1

In addition to the temperatures measured from the samples during field measurements, groundwater temperatures at wells were also measured by vibrating wire piezometers regularly. Information about these measurements is listed in Table 4.1, and the well locations are shown in Table 4.10.

Table 4.10 Average groundwater temperature with respect to depth

Well No	Piezometer Depth (m)	Date Interval (Day-Month)	Number of Measurement	Average Temperature (°C)
ML-3	16	21-2; 13-12	881	14.16
VW003A	21.35	6-7;12-12	2339	14.2
VW001A	29.4	27-7;12-12	3675	14.34
ML-3	30	21-2; 13-12	881	12.68
ML-1&2	32	21-2; 13-12	3409	14.586
VW003A	41.35	6-8;12-12	388	14.29
VW002A	48.5	13-8;12-12	1906	13.65
ML-1&2	53	21-2; 13-12	3409	15.33
VW001A	69.55	1-8;12-12	2234	15.72
ML-1&2	70	21-2; 13-12	3409	16.37
VW003B	108	17-7;12-12	450	16.8
ML-3	108	21-2; 13-12	881	18.49
VW001C	109.7	11-10;12-12	189	17.49
VW001B	150	21-8;12-12	342	19.27
ML-3	163	21-2; 13-12	881	20.2

Well No	Piezometer Depth (m)	Date Interval (Day-Month)	Number of Measurement	Average Temperature (°C)
VW001C	203.7	21-8;12-12	342	21.38
ML-4	224.95	21-2; 13-12	881	23.42
VW001B	283	5-9;12-12	297	23.88
VW003B	300	21-7;12-12	437	27.9
ML-4	307.95	21-2; 13-12	881	26.59
VW002B	330	8-8;12-12	3150	26.88
ML-4	332.2	21-2; 13-12	881	28.8
VW003B	368	15-7;12-12	456	31.09
ML-1&2	375.4	21-2; 13-12	3409	30.65
ML-4	390.2	21-2; 13-12	881	33.3
VW002B	393	8-8;12-12	3150	31.87
VW002C	418	25-8;12-12	330	33.9
VW003C	418.5	6-7;12-12	2339	33.89
ML-1&2	439.9	21-2; 13-12	3409	34.89
VW002C	450	24-8;12-12	333	36.97
VW003C	454	17-7;12-12	450	37.21

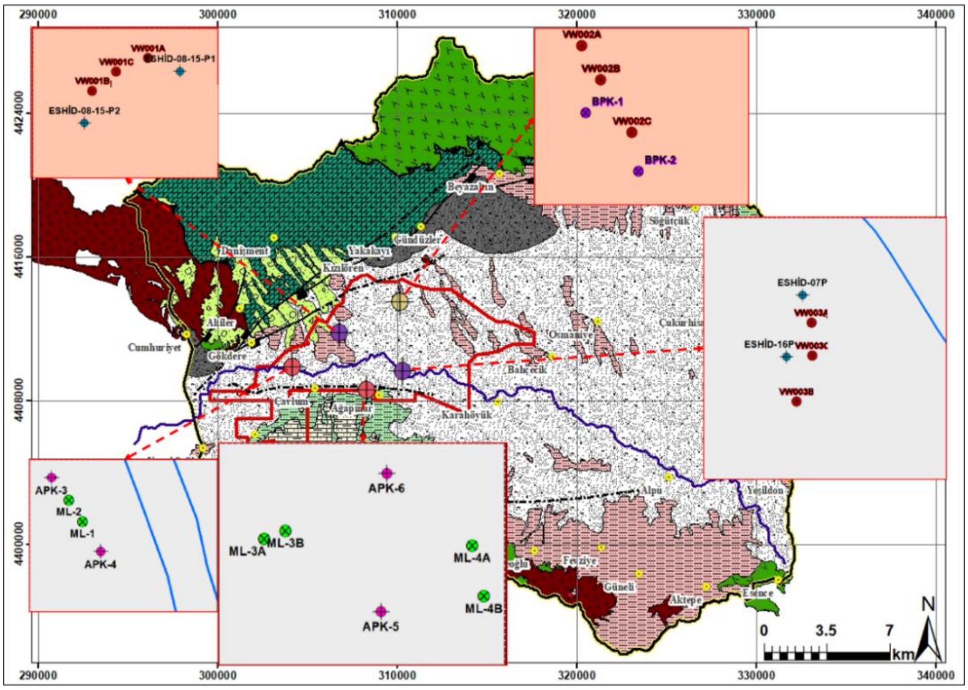


Figure 4.10. Distribution of wells mounted with vibrating wire piezometers.

The data indicate that the average groundwater temperature increases with increasing depth (at the intervals of alluvium-coal levels from 16 m to 454 m) between 14.2°C and 37.2°C (Table 4.10). The average water temperature gradient is calculated to be about 38 º C/km using 16 m depth and 14.16 º C temperature for the surface conditions. This gradient value is about 3.6 ºC/km higher than the gradient value determined using Turkey average temperature of 31 °C at the depth of 500 m (Başel et al., 2010) and surface water temperature of 13.7 °C (average surface water temperature determined using 3 years of spring and fountain measurements in the area). The increasing gradient trend to the depth of about 100 m becomes nearly constant between the depths of 100 m and 330 m, then increases again at a lower rate in coal-bearing levels. The trends of the temperature and the gradient are shown in Figure 4.11.

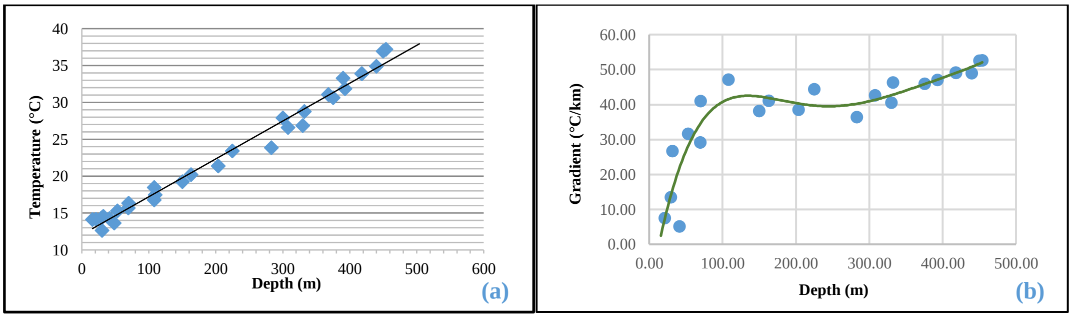


Figure 4.11. Depth-dependent groundwater (a) temperature and (b) gradient variations.

pH, ORP, EC and DO values (average for APK-2, APK-3, APK-4, APK-5, APK-6, APK-7, E-1P, E-2P and E-4P waters) are shown in Figure 4.12. The colors in the figures represent similar stratigraphic units which are filtered by the wells and the logarithmic scale is used for y-axis of EC figure. Due to the aquifer similarities in some wells, the average of the measured values was used to give general information about the aquifer units in Table 4.11. In the Al (Alluvium) + MAC (Miocene Above Coal) group, the MAC unit thickness varies between 21 m and 78 m in the wells except that of E-10P1 where the MAC thickness is 312 m.

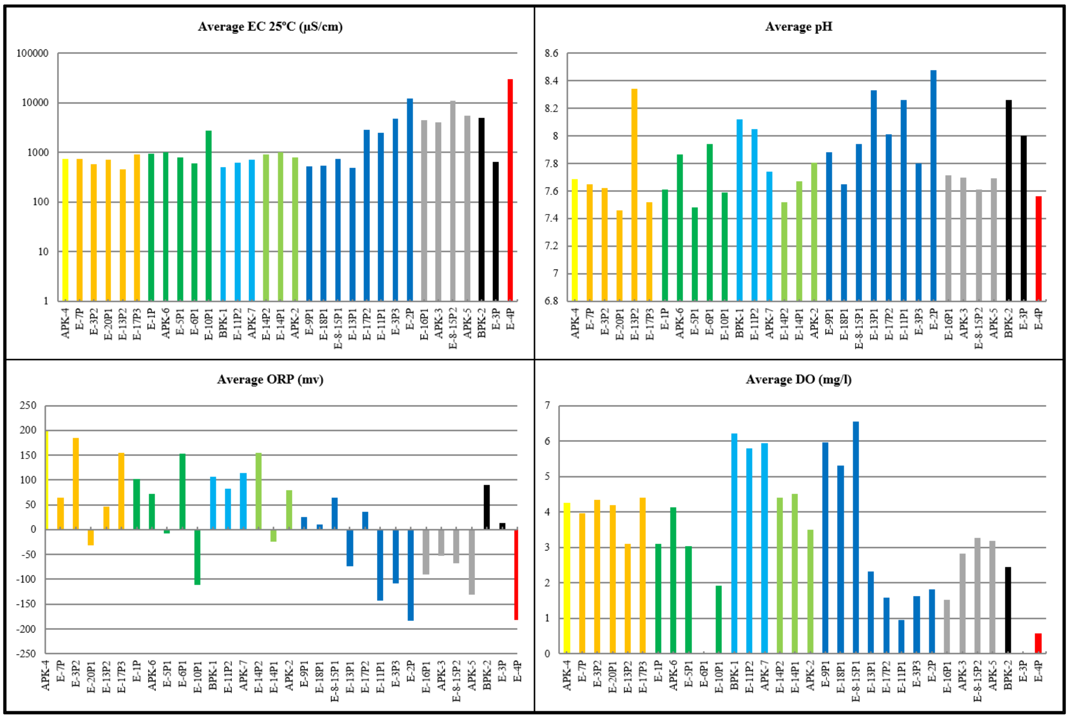


Figure 4.12. EC, pH, ORP and DO values of well waters (Stratigraphically sequencing in the wells; yellow: Al; orange: Al+Pl; green: Al+MAC; light blue: Pl; light green: MAC; blue: Pl+MAC; gray: MAC+CH+/-Al+/-Pl; black: CH+MAC; red: Al+Pl+MAC+CH+MBC+Melange. Abbreviations are expressed in Table 4.1b.

Table 4.11 General information about aquifer units in the study area

Aquifer Units	Well ID	T(°C)	pH	ORP (mV)	EC 25°C (µS/cm)	S (%)	TDS (mg/l)	DO (mg/l)	DO%
Al	APK-4	15.2	7.69	198	730	0.36	474	4.3	46
Al+Pl	E-7P, E-3P2, E-20P1, E-13P2, E-17P3	17.5	7.72	84	683	0.33	444	4.0	45
Al+MAC	E-1P, APK-6, E-5P1, E-6P1, E-10P1	16.9	7.7	42	1222	0.6	794	3.0	33
Pl	BPK-1, E-11P2, APK-7	16.5	7.97	101	613	0.30	398	6.0	69
MAC	E-14P2, E-14P1, APK-2	19.0	7.82	74	2314	1.15	1502	3.8	47
Pl+MAC	E-9P1, E-18P1, E-8-15P1, E-13P1, E-17P2, E-11P1, E-3P3, E-2P	20.2	8.0	-46	3057	1.5	1984	3.3	39
MAC+CH+/-Al	APK-3, E-8-15P2, APK-5	21.7	7.67	-84	6794	3.39	4410	3.1	40
Al+Pl+MAC+CH+MBC +Melange	E-4P	21.9	7.56	-182	30233	15.11	19619	0.6	6

Electrical conductivity values of well waters vary between 496-12038 µS/cm if the lowest (452 µS/cm; E-13P2) and the highest (30233 µS/cm; E-4P) values are excluded. EC values in the groundwaters are:

730 µS/cm in the Alluvium (measured in a single well, APK-4);

683 µS/cm in Al + Pl (Pliocene);

835 µS/cm in Al + MAC when upper MAC levels are considered otherwise 1222 µS/cm with lower levels (E-10P1);

613 µS/cm in the outcropped Pl (E-11P2 whose depth is less than 100 m);
918 µS/cm in the outcropped MAC (E-14P2 whose depth is less than 100 m) otherwise 2314 µS/cm when lower levels are considered;
3057 µS/cm in Pl + MAC (depth of 100-350 m, if E-2P, 12038 µS/cm, is excluded; 1773 µS/cm);
6794 µS/cm in the deep (350-500 m) MAC + CH (excluding E-16P1 receiving/mixing water from the upper units due to shallow sampling pump location if included 5320 µS/cm); 5000 µS/cm in MAC + CH (BPK-2, 10 m of MAC and 140 m of CH; receiving/mixing water from upper units); and 635 µS/cm in CH (E-3P, 120 m of CH; possible well installation problem exits).
On the other hand, EC of E-4P well [Alluvium (45 m) + Pliocene (75 m) + MAC (242 m) + CH (78 m) + MBC (45 m) + Melange (6 m)] water is 30233 µS/cm.

EC values of Al + Pl and Al + MAC groundwaters generally exhibit negative relationship with the filtered Pl and MAC unit thickness and positive relationship with the increasing Al thickness excluding E-20P1 and E-10P1 wells (whose filtered thickness are greater in Pl and MAC, respectively, and were sampled from the pump located at deeper levels). In the wells with less than 100 m thickness, decreasing EC values upon increasing Pl or MAC unit thickness or increasing EC values upon increasing Al unit thickness suggest that the alluvium groundwater contains greater TDS in comparison to the upper level groundwaters of Pliocene and Miocene. EC values of Al + MAC groundwaters are greater than those of Al + Pl groundwaters.

EC values of wells penetrating Pliocene and upper levels of MAC units from surface down to 60-102 m depths in general decrease with increasing filtered unit thicknesses. This suggests that groundwaters in Pliocene and upper levels of Miocene units have higher TDS values. When compared, in general EC values of MAC groundwater is higher than that of Pl groundwater. In addition, EC values of Pl and MAC groundwaters increase as the pump locations used for purging in the wells deepens.

Very high EC value (12038 µS/cm) of E-2P well water in comparison to the values from the wells having similar depths is probably related to the dissolution of gypsum horizons as suggested by very high sulphate concentration (3367 mg/l, which is about 13 times greater than those of the others).

EC values of MAC+CH deep groundwater increase with increasing filtered unit thickness.

Possibility of relatively low EC occurrence in BPK-2 (10 m of MAC and 140 m of CH) and E-3P (120 m of CH) groundwaters will be evaluated later using laboratory data.

EC measurements made by Zeyrek et al. (2017) during pumping tests in mostly coal unit (115 m, 130 m) and less MBC (Miocene Below Coal) unit (10 m, 30 m) filtering E-8-15P3 and E-17P1 MTA wells are 22725 µS/cm and 32147 µS/cm, respectively. Because the wells became dry in a very short period of time during the pumping tests, it is interpreted that the values measured in these well waters reflect stagnant (very low flow) conditions of MAC and CH groundwaters. As a result, these data indicate that coal level groundwater has local EC properties. Reasons behind such differences will be further evaluated later using laboratory data.

Laboratory data evaluations presented later indicate that high EC values of relatively high pressure driven free flow E-4P well water could be related to groundwaters in local MBC and/or mélange units.

Total dissolved solids and salinity values, respectively; 475 mg/l, 0.36 ppt in Al; 444 mg/l, 0.33 ppt in Al + Pl; 863 mg/l, 0.66 ppt in Al + MAC; 398 mg/l, 0.30 ppt in Pl; 575 mg/l, 0.44 ppt in MAC; 1984 mg/l, 1.52 ppt in Pl + MAC; 4410 mg/l, 2.7 ppt in MAC+CH; 413-3245 mg/l, 0.31-2.5 ppt in CH; and 19619 mg/l, 15.1 ppt in MBC groundwaters.

Well waters are slightly basic in character with pH values between 7.46 (E-20P1) and 8.48 (E-2P). pH value of the Al unit well water is 7.69 (APK-4). The average pH value of Pl unit (7.97) is greater than that (7.72) of Al + Pl units. pH value of MAC unit well water (7.67) is slightly less alkaline than that of Al + MAC (7.72). The pH average of well waters containing Pl + MAC units is slightly more alkaline (8.04). pH value of well waters associated with MAC+CH units is about 7.67, excluding E-16P1 receiving (mixing with) water from the upper units (7.80) water. The BPK-2 well water mostly filtered from CH (140 m) and less from MAC (10 m of CH) has a pH value of 8.26. On the other hand, pH value of well water (E-3P) filtered from only CH is 8.00. The deep well water of E-4P filtered from all units [Alluvium (45 m) + Pliocene (75 m) + MAC (242 m) + CH (78 m) + MBC (45 m) + Melange (6 m)] has a pH value of 7.56. When considered stratigraphically, groundwater pH values increase from Al to Pl, from Al + Pl to MAC and from MAC to CH. The values decrease in and after CH unit. Mostly coal unit and less MBC unit filtering E-8-15P3 and E-17P1 MTA wells include acidic water (6.99, 6.33, respectively) according to Zeyrek et al. (2017). Relatively acidic groundwater in coal units is probably related to the oxidation of pyrite (Toprak et al., 2015) in the coal levels.

Average dissolved oxygen concentrations in mg/l are 4.3, 4.0, 3.2, 6.0, 4.1, 3.3, 3.1 and 2.4 mg/l in groundwaters of Al, Al + Pl, Al + MAC, Pl, MAC, Pl + MAC, MAC + CH, and CH, respectively. The lowest concentration of 0.6 mg/l was measured in E-4P well water. Deep groundwaters include low DO but relatively shallow groundwaters include higher DO probably depending on the relatively faster recharge. On the other hand, Al + Pl groundwater (DO: 4.0 mg/l) contains relatively less DO in comparison to Pl groundwater (DO: 6.0 mg/l). Similar observation is also valid for Al + MAC groundwater (DO: 3.2 mg/l) compared to MAC groundwater (DO: 4.1 mg/l). These observations could be reasoned to the flow relationship between alluvium groundwater and Porsuk Creek and/or agricultural activities (irrigation, fertilizer applications, etc.). Dissolved oxygen values of 0.75 mg/l and 3.94 mg/l (measured in April and May 2017, respectively) were measured in the canal waters which is used for the irrigation in the plain.

Oxidation-reduction potential values are equal to 198, 84, 42 (including E-10P1; 80), 101, 70, -46, -56 (excluding E-16P1 -84), 90, and 13 mV in groundwaters of Al, Al + Pl, Al + MAC, Pl, MAC, Pl + MAC, MAC+CH, low MAC + high CH, and CH, respectively. The lowest value of -182 mV is measured in E-4P well water. While groundwaters of Al, P1 and the upper sections of MAC have the oxidizing character, groundwaters of the deep Pl + MAC have educing character. On the other hand, although located at deeper levels (350-460 m), BPK-2 and E-3P waters show oxidizing character probably due to dilute groundwater mixture from the upper levels. This process will be evaluated with laboratory parameters later.

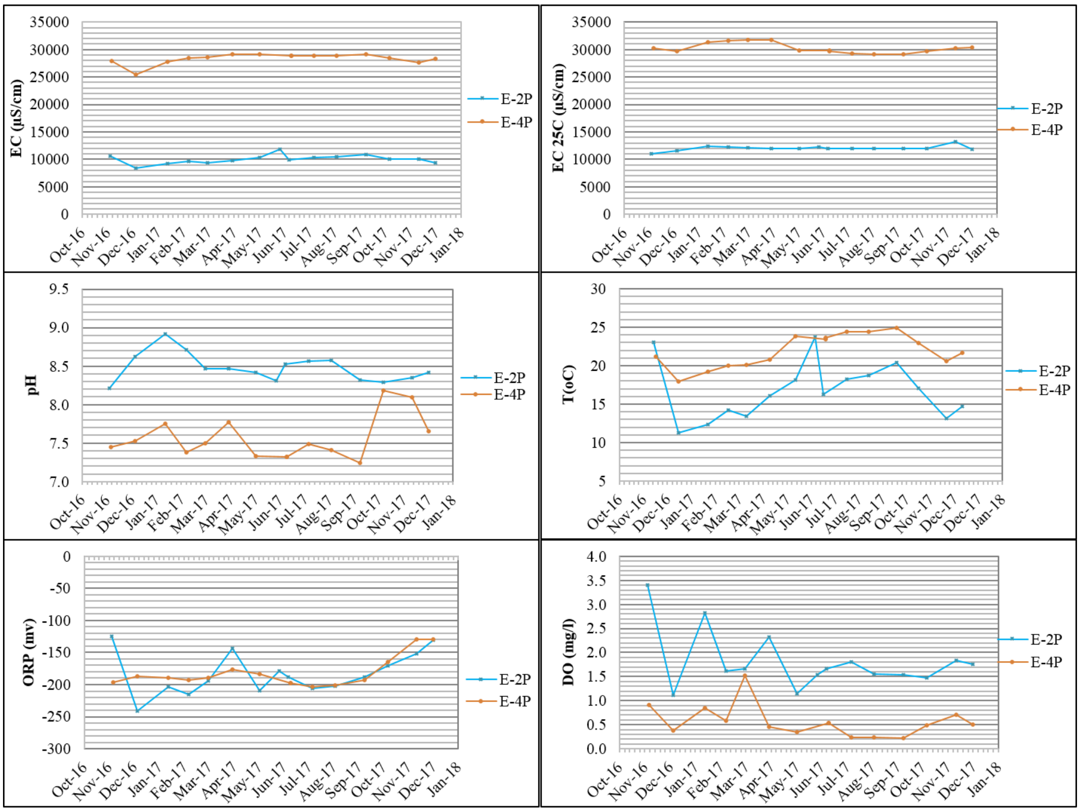


Figure 4.13. Monthly change of EC, pH, ORP and DO values in E-2P and E-4P well waters.

Monthly measurements made from free-flowing artesian well (E-2P and E-4P) waters are shown in Figure 4.13. The increasing and decreasing water temperatures in warm and cold months could be related to the atmospheric conditions during the monitoring rather than that of groundwater in the aquifer. While 25^{o}C normalized EC of E-2P groundwater increases in winter and spring, it decreases toward summer. The EC of E-4P waters do not exhibit any noticeable change (Figure 4.13). DO values in general show a reverse trend of EC values. ORP values increases from August to December 2017 (Figure 4.13).

4.4.2 Parameters Measured in The Laboratory

Detailed chemical analyses of well waters are listed in Appendix-C. When the laboratory results in the wells are examined, the disproportional change in Na concentration between two-term measurements (performed by two different laboratories) of APK-2, APK-3, APK-4, APK-5, APK-6, APK-7, E-1P and E-2P wells is determined. As discussed in the section 4.2, the percentage average deviations of sodium concentrations are much higher than the possible deviations that may arise from the properties of groundwater itself. Therefore, it is concluded that the differences are related to the measurement errors and the first-term Na parameter concentration data is ignored as justified in the quality control section. In addition, the comparison of single term E-4P concentrations with the concentrations from compatible (similar depth and filtered units) well waters indicate that ionic balance error (38%) determined in E-4P water is related to the Na concentration. The charge is balanced when measured 1034 mg/l concentration is increased to 4780 mg/l. As a result, this Na value is used in the evaluation of E-4P well water.

The distribution of water facies determined using major ion concentrations of the well waters is shown in Figure 4.14. The distribution depth-wise is shown in Figure 4.15.

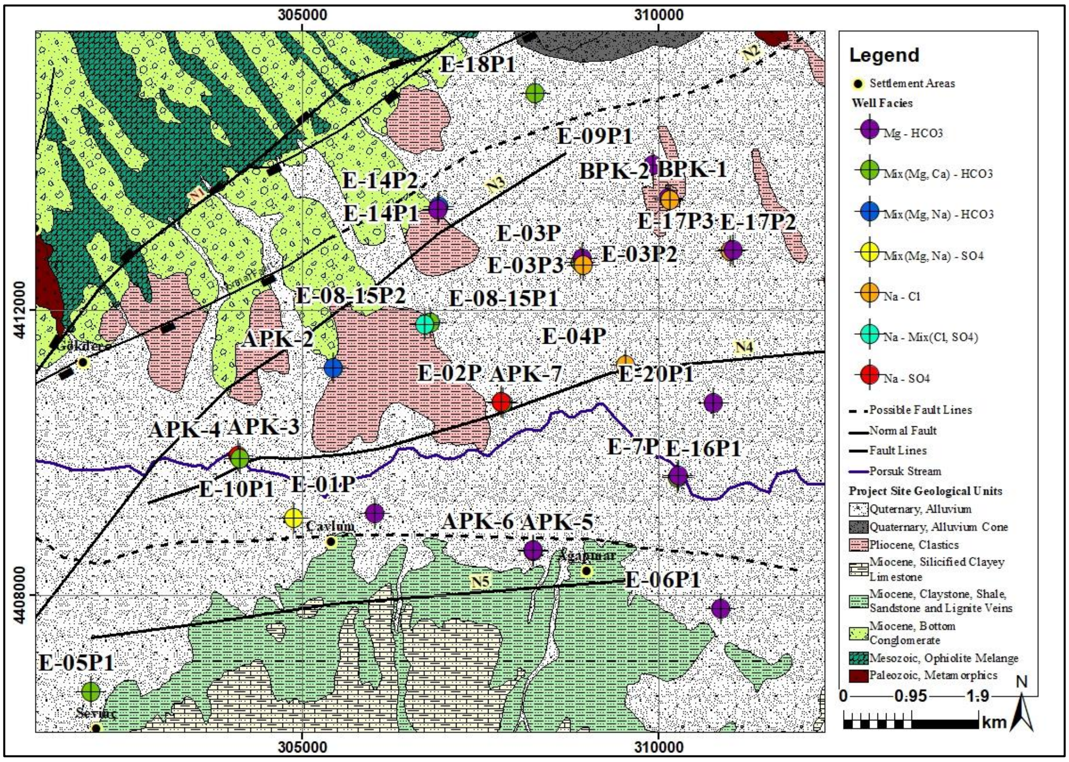
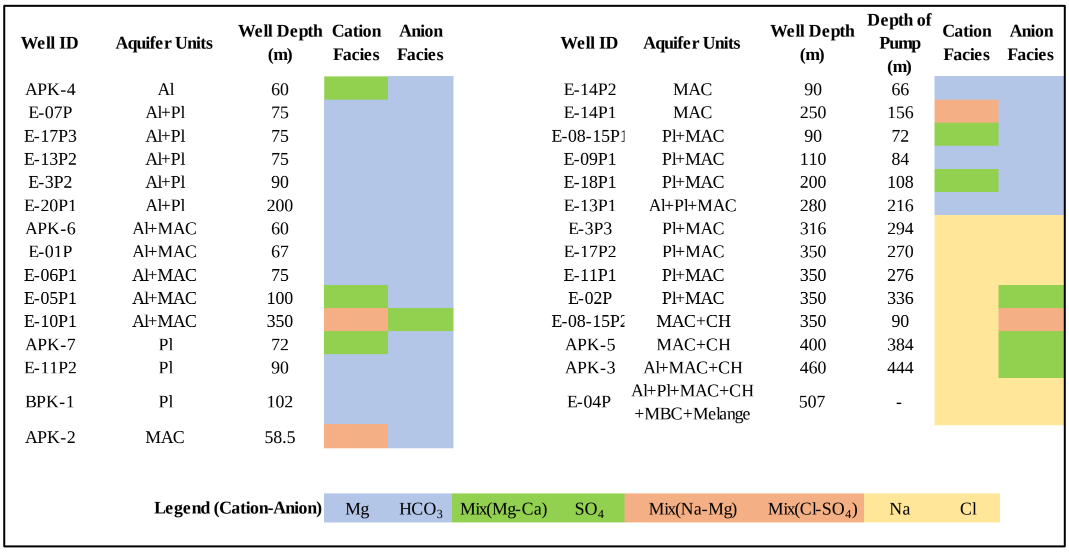


Figure 4.14. Water facies distribution in well waters.



Well ID	Aquifer Units	Well Depth (m)	Cation Facies	Anion Facies	Well ID	Aquifer Units	Well Depth (m)	Depth of Pump (m)	Cation Facies	Anion Facies
APK-4	Al	60	🟩	🟦	E-14P2	MAC	90	66	🟦	🟦
E-07P	Al+Pl	75	🟦	🟦	E-14P1	MAC	250	156	🟧	🟦
E-17P3	Al+Pl	75	🟦	🟦	E-08-15P1	Pl+MAC	90	72	🟩	🟦
E-13P2	Al+Pl	75	🟦	🟦	E-09P1	Pl+MAC	110	84	🟦	🟦
E-3P2	Al+Pl	90	🟦	🟦	E-18P1	Pl+MAC	200	108	🟩	🟦
E-20P1	Al+Pl	200	🟦	🟦	E-13P1	Al+Pl+MAC	280	216	🟦	🟦
APK-6	Al+MAC	60	🟦	🟦	E-3P3	Pl+MAC	316	294	🟨	🟨
E-01P	Al+MAC	67	🟦	🟦	E-17P2	Pl+MAC	350	270	🟨	🟨
E-06P1	Al+MAC	75	🟦	🟦	E-11P1	Pl+MAC	350	276	🟨	🟨
E-05P1	Al+MAC	100	🟩	🟦	E-02P	Pl+MAC	350	336	🟨	🟩
E-10P1	Al+MAC	350	🟧	🟩	E-08-15P2	MAC+CH	350	90	🟨	🟧
APK-7	Pl	72	🟩	🟦	APK-5	MAC+CH	400	384	🟨	🟩
E-11P2	Pl	90	🟦	🟦	APK-3	Al+MAC+CH	460	444	🟨	🟩
BPK-1	Pl	102	🟦	🟦	E-04P	Al+Pl+MAC+CH +MBC+Melange	507	-	🟨	🟨
APK-2	MAC	58.5	🟧	🟦						

Legend (Cation-Anion) 🟦 Mg 🟦 HCO$_3$ 🟩 Mix(Mg-Ca) 🟩 SO$_4$ 🟧 Mix(Na-Mg) 🟧 Mix(Cl-SO$_4$) 🟨 Na 🟨 Cl

Figure 4.15. Depth wise water facies distribution.

Al, Al + Pl, Al + MAC, Pl and MAC Well Waters

The facies of well waters of Al, Al + Pl, Al + MAC, Pl and MAC aquifers are shown Piper diagram in Figure 4.16. The Al aquifer water (APK-4) is in Mix(Mg, Ca)-HCO3 facies.

Groundwaters of Al + Pl units (E-3P2, E-7P, E-13P2, E-17P3 and E-20P1) and Al + MAC units (APK-6, E-1P, E-6P1), excluding Mix-HCO3 type nearby Mg border of E-5P1 water, are in Mg-HCO3 facies. Surface outcropped Pl unit waters (BPK-1, E-11P2, excluding Mix-HCO3 type nearby Mg border of APK-7) are in Mg-HCO3 facies. Surface outcropped MAC unit waters (APK-2, E-14P1, excluding Mg-HCO3 type of E-14P2) are in Mix(Mg, Na)-HCO3 facies. Mix(Mg, Na)-SO4 type of E-10P1 (Al + MAC filtering but having greater depth than the other similar wells) water (sampled from 280 m depth) facies reflect the characteristics of MAC deep groundwater.

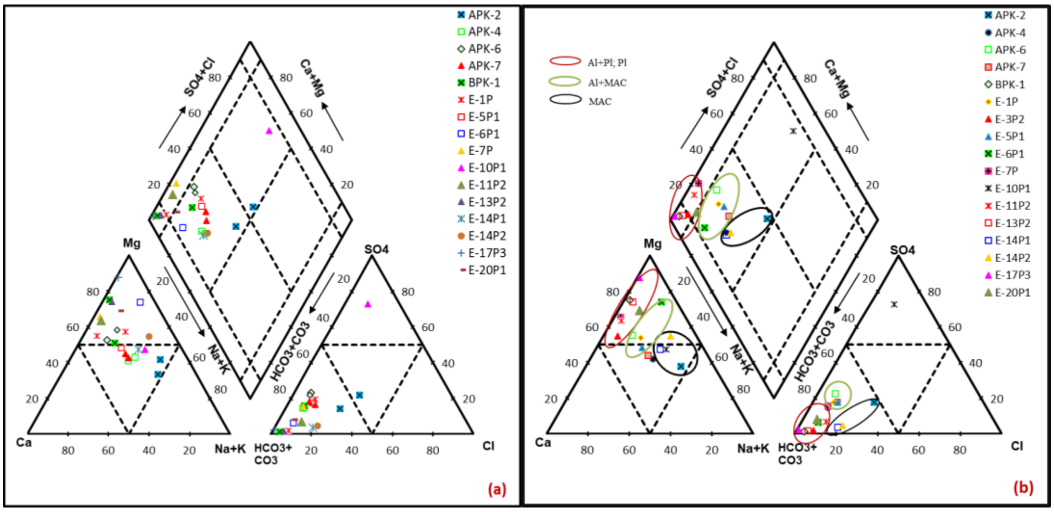


Figure 4.16. Water facies in Al, Al+Pl, Al+MAC, Pl and MAC well waters. (a) all data and (b) average data.

The differences in the distribution of major ion concentrations are also shown in the Schoeller graph (Figure 4.17). Concentrations of Na$^+$, Cl$^-$ and SO$_4^{2-}$ increases towards deep groundwater. The E-17P3 well water has the lowest Na$^+$ and Cl$^-$ concentrations.

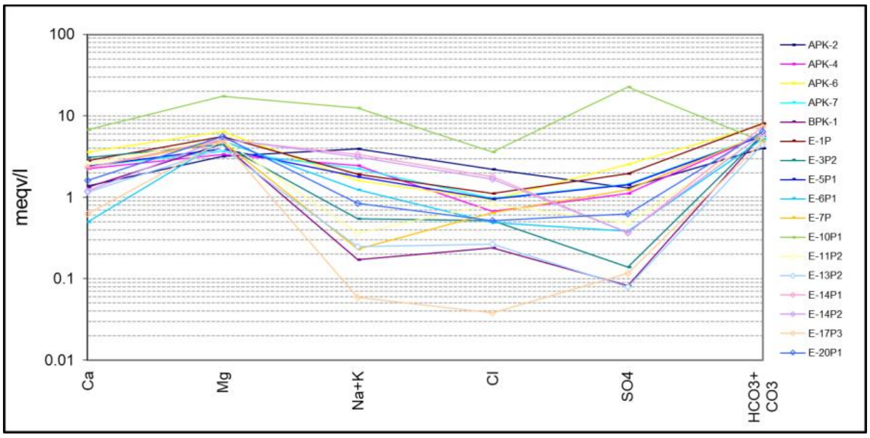


Figure 4.17. Major ion concentrations in Al, Al + Pl, Al + MAC, Pl and MAC well waters.

Pl + MAC Well Waters

Water facies of Pl + MAC units determined are shown in Figure 4.18. E-9P1 and E-13P1 well waters are in Mg-HCO3 type; E-8-15P1 and E-18P1 well waters are in Mix(Mg, Ca)-HCO_3 type; E-2P water is in Na-SO_4 type; and E-17P2, E-11P1 and E-3P3 waters are in Na-Cl type (Figure 4.18).

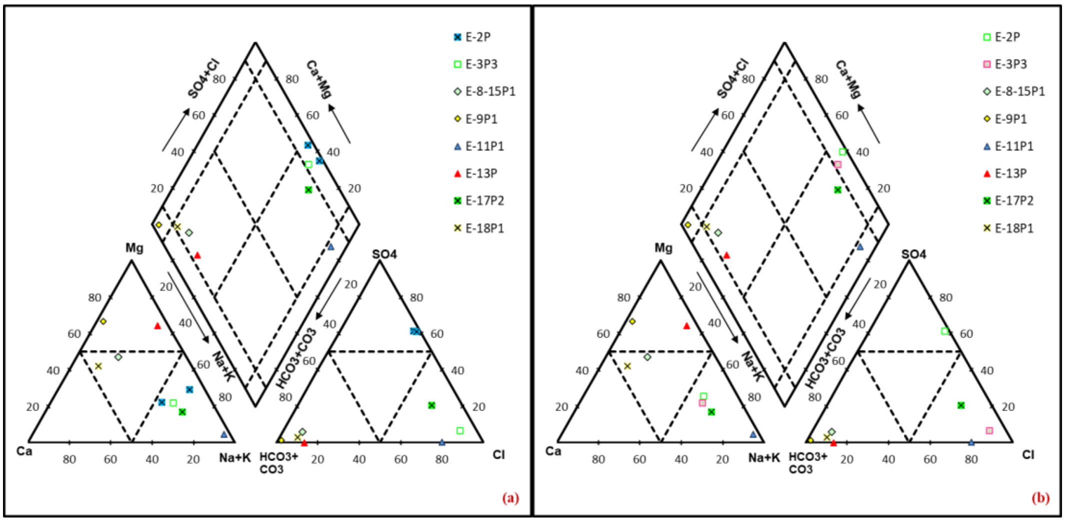


Figure 4.18. Water facies in Pl + MAC well waters. (a) all data and (b) average data.

In general, water facies change in the order of Mg, Mix → Na cations and in the order of HCO_3 → SO_4 → Cl anions.

The differences in the distribution of major ion concentrations in Pl + MAC well waters are shown in Scholler diagram (Figure 4.19). Na, SO_4 and Cl ions increase as the well gets deeper except for those of E-18P1.

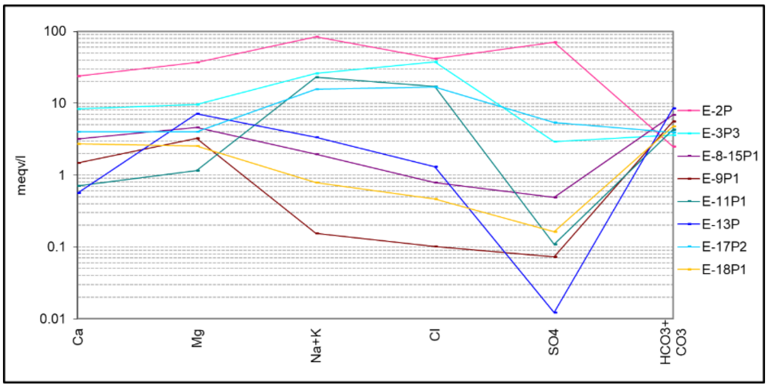


Figure 4.19. The distribution of the major ion concentrations in Pl + MAC well waters.

Well Waters Containing Coal Levels

Water facies of well waters that include coal horizons (MAC +/- Pl +/- Al) are shown in Figure 4.20. E-16P1 well water mixed with diluted shallow groundwater includes

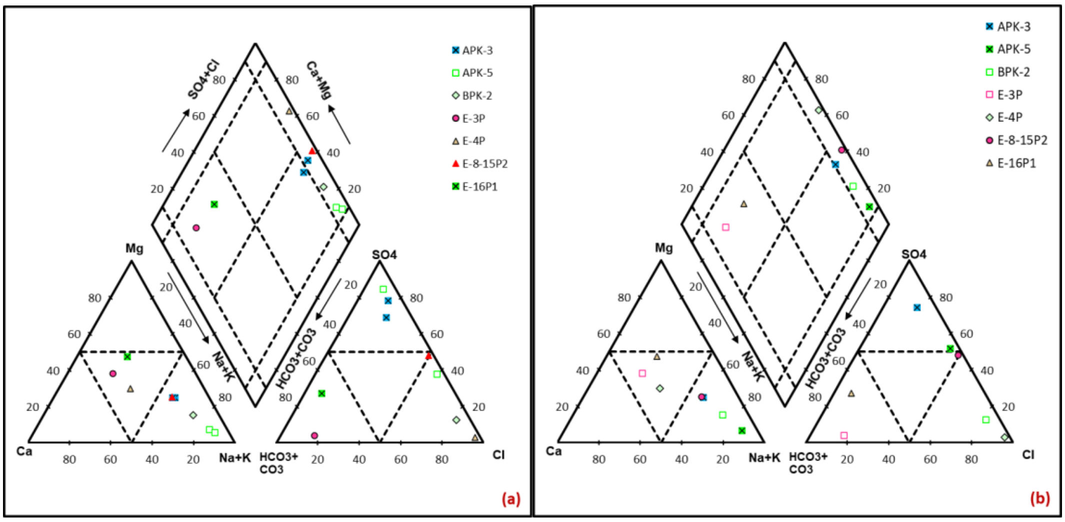


Figure 4.20. Water facies in coal bearing well waters. (a) all data and (b) average data.

Mix(Ca, Mg)-HCO_3 type of water facies. In the order of increasing Miocene unit thickness, the following water facies are determined in CH filtering wells: Na-Mix(Cl, SO_4) in E-8-15P2; Na-SO_4 in APK-3 and APK-5; Na-Cl in E-4P. Mostly CH including BPK-2 water is in Na-Cl facies. Only CH including E-3P (having possible well installation problem) water is in Mix(Ca, Mg)-HCO_3 facies.

Except in those of E-16P1 and E-3P, cation facies evolve to Na and anion facies evolve to SO_4 or Mix → Cl toward coal level groundwater.

The differences in the distribution of major ion concentrations are shown in the Schoeller graph (Figure 4.21). Concentrations of Na, SO_4 and Cl increase towards the deeper groundwaters.

Only coal unit (120 m) filtering E-3P well and MBC (55m) + coal unit (35 m) + MAC (302 m) + Pl (70 m) and Al (27 m) filtering E-16P1 well waters are in bicarbonate facies which is different from those of the other deep wells. The sampling pump location (72 m depth) of E-16P1 well is relatively shallow. EC of this well water is also relatively low (897 µS/cm). Therefore, concentrations of this well water are probably reflecting relatively upper levels groundwater influences. On the other hand, although the sampling pump location (72 m depth) of E-3P well is also relatively shallow, the influence of upper groundwaters is not expected because only the coal levels are filtered in this well, and the rest of the well is cemented. EC value of E-3P well water is also low (635 µS/cm).

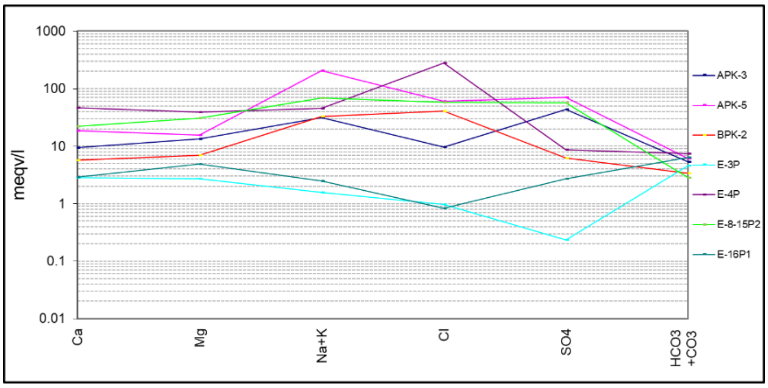


Figure 4.21. Major ion concentrations of well waters including coal-bearing levels.

Concentrations determined in this well water in the study of Zeyrek et al. (2017) are similar. As a result, it is interpreted those concentrations of E-3P well water either reflect the mixing influenced local CH groundwater characteristics and/or reflect well installation problem. The mixing possibility will be further evaluated later.

In summary, major ion chemistry of groundwaters in the study area stratigraphically downward: according to the anion content, change in the order of HCO_3 → SO_4 → Cl and according to the cation content while Ca remains nearly constant Na increases upon Mg decrease; change in the order of Mg → Mix → Na (Figure 4.22).

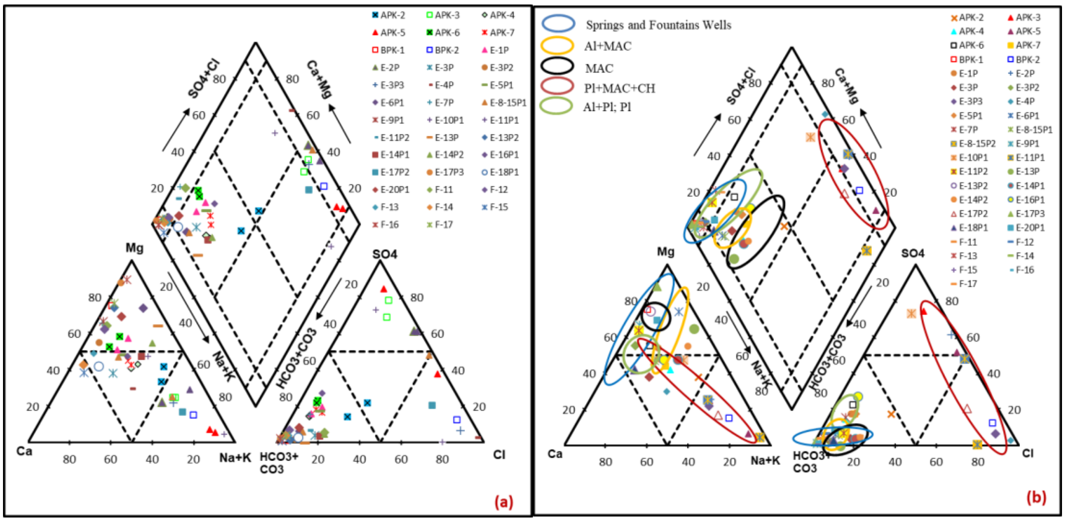


Figure 4.22. Water facies in spring and well waters. (a) all data and (b) average data.

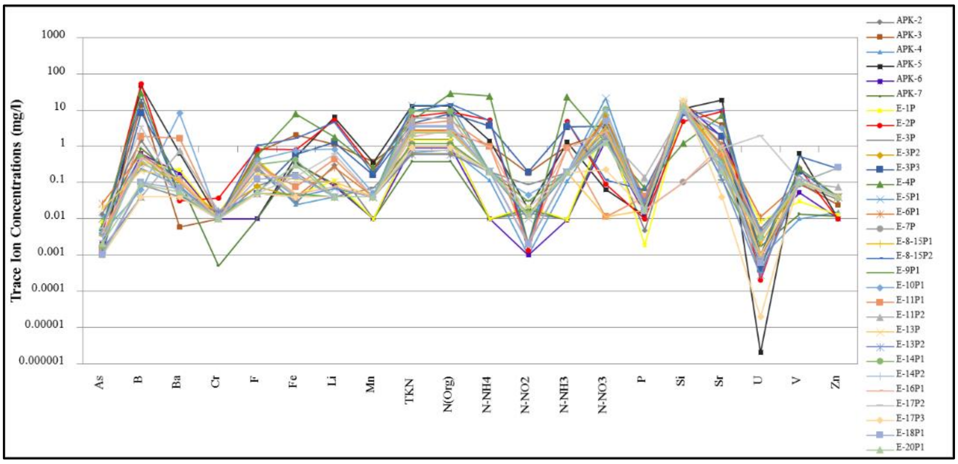


Figure 4.23. The distribution of the trace ion concentrations in well waters

Diagram showing minor ion values with above the limits of detection in well waters is shown in Figure 4.23. Be, Bi, Cd, CN, Co, Cu, Hg (excluding E-6P1 and E-11P1), Mo (excluding E-2P), Ni (excluding APK-3), Sb, Se, Sn (excluding APK-3), Ti, Tl, TOC (excluding APK-5, E-14P1) and organic parameters; trichloroethylene, tetrachloroethylene, pesticides (except endosulphane, 0.00128 μg/l of APK-6 in January 2017) and volatile organic parameters (except 0.014 mg/l E-2P in December 2016) are below the detection limits at all observation points. Only in some well waters (alluvium unit filtering APK-3, APK-4, APK-6, E-4P, E-7P, E-16P1 and un-filtering APK-5, E-2P) MBAS (in the interval of 0.054-0.142 mg/l) values are measured above the detection limits (MBAS: 0.05 mg/l).

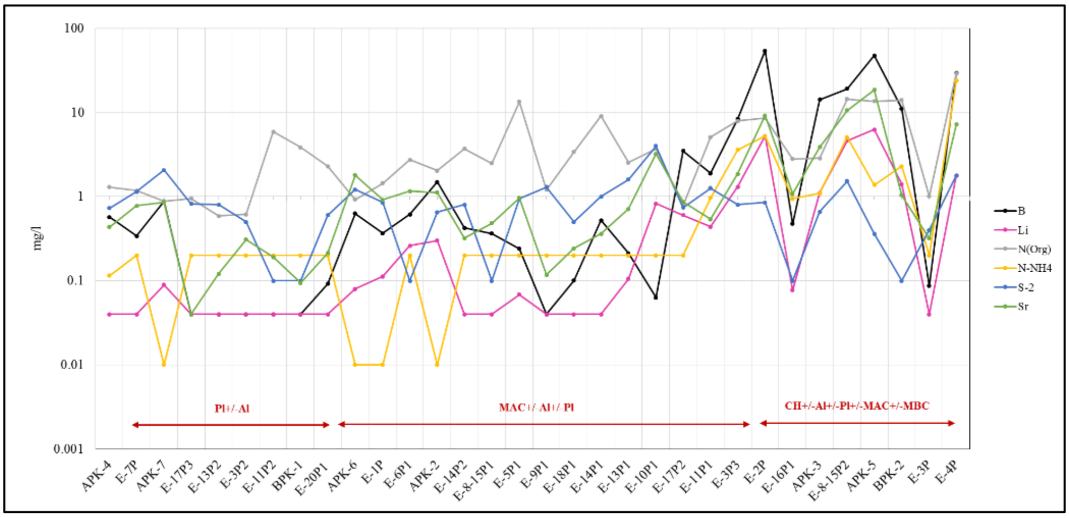


Figure 4.24. B, Li, N (org), N-NH_4, S^{-2} and Sr concentrations in well waters.

In general, B, Ca, K^+, Li, Mg^{2+}, Na^+, NH_4, N(org), S^{-2}, SO_4^{2-}, Sr and TKN concentrations increase upon increasing groundwater depth (Figure 4.24). Ammonia concentrations in Pl + MAC [E-11P1 (350 m): 0.96 mg/l, E-3P3 (316 m): 3.59 mg/l, E-2P (350 m): 5.23 mg/l] and MAC + CH [APK-3 (460 m): 1.09 mg/l, APK-5 (400 m): 1.38 mg/l, BPK-2 (460 m): 2.29 mg/l, E-8-15P2 (350 m): 5.07 mg/l, E-4P (507 m): 24.05 mg/l] deep groundwaters filtered about greater than 300 m depths (except E-3P and E-17P2) are much higher than the expected value (< 0.2 mg/l). These high ammonia values are most probably not anthropogenic but are caused by the decomposition of organic materials in the units as the depthwise increase suggests.

CHAPTER 5

HYDROGEOCHEMICAL CONCEPTUALIZATION

5.1 Non-reactive Chloride Evaluations

In order to determine hydrogeochemical processes creating observed groundwater chemistry in the study area, non-reactive (assuming no chloride-bearing mineral phases present in the aquifer and groundwater is not saturated with respect to any chloride mineral) chloride concentrations are used.

When the wells in the study area are evaluated in general, the chloride values of groundwater decrease from surface to approximately 100 m depth but increase stratigraphically from 100 m depth to basement rocks (Pliocene aquifer → Miocene aquifer → Basement aquifer) (Figure 5.1).

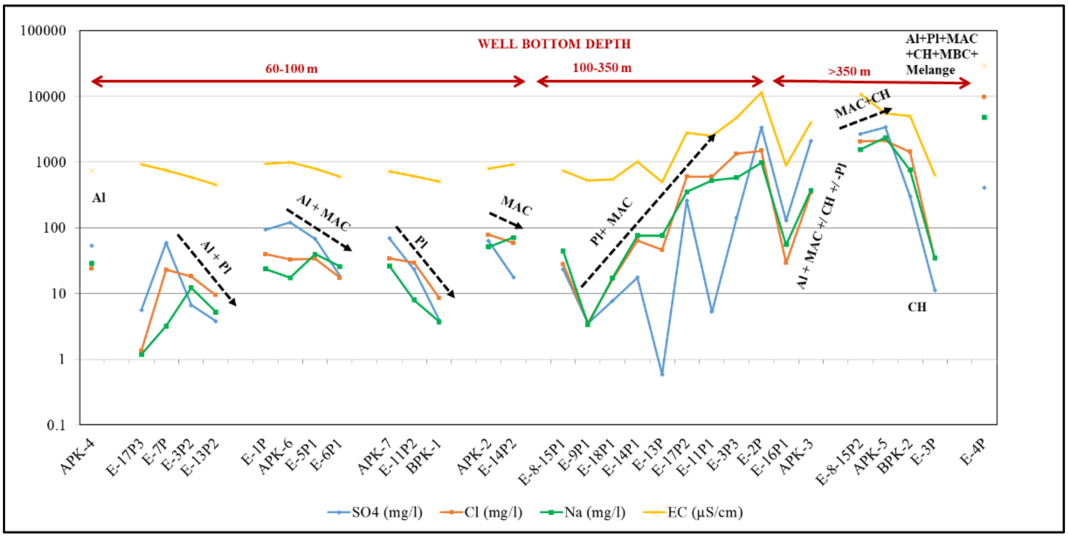


Figure 5.1. Average SO_4, Cl^-, Na^+ and EC concentrations in well waters.

Concentrations of E-20P1 well filtering Al + Pl units are not included into Figure 5.1 due to the deep sampling pumping depth (150 m). In addition, deep E-13P1 well water (the sampling pumpage depth of 280 m in Al + Pl + MAC units) and deep E-

14P1 well water (the sampling pumpage depth of 156 m in MAC unit) is included into the Pl + MAC group.

<u>0-100 m well bottom depth;</u>

Chloride concentrations are in the range of 9-23 mg/l and 17-40 mg/l in Al + Pl and Al + MAC-upper level (having well bottom depth interval of 67-100 m) groundwaters, respectively. The chloride concentrations of these groundwaters decrease (except in the water of E-17P3 but whose EC is compatible) with increasing saturated filtered thickness of Pliocene/MAC unit and decreasing saturated filtered thickness of alluvium unit. This indicates that chloride concentrations of groundwater in alluvium unit are higher than those of groundwaters in the underlying Pliocene and MAC-upper levels (Figure 5.1).

The chloride concentrations are in the range of 9-34 mg/l in Pliocene only unit (having well bottom depth interval of 72-102 m) and 59-79 mg/l in Miocene-upper levels only unit (having well bottom depth interval of 59-100 m) (Figure 5.1). The chloride concentrations of these groundwaters decrease with increasing saturated filtered thickness (and increasing unit depth) of the related aquifer.

The possibility of increase/decrease of groundwater chloride concentrations in the direction of groundwater horizontal flow in these units shown in Figure 5.1 is investigated on the basis of the assumption that each groundwater analysis represents similar flow level and are aligned along the same flow line.

- Increase between some Al + Pl groundwaters (E-3P2, E-13P2, E-17P3 → E-7P) is possible but increase/decrease is not possible for the others (E-3P2, E-13P2, E-17P3) because they have similar groundwater levels.
- Increase/decrease in chloride concentrations along horizontal flow direction does not seem to be possible for Al + MAC wells due to similar groundwater levels.

- Among the Pliocene groundwaters, an increase in chloride concentration seems to be possible along BPK-1 → E-11P2 → APK-7.
- The MAC observation points are located very close to each other and have similar groundwater levels, hence horizontal flow related chloride concentration increase/decrease is not possible.

These evaluations and absence of any chloride point source in the area suggest that relative decrease in chloride concentration has developed in a vertical direction. Decrease of chloride concentrations downward in the groundwaters of the outcropping units could be related to the evaporation and/or agricultural activities (irrigation, fertilizer applications, saltation, etc.) and/or Porsuk Creek (Cl: 21-86 mg/l) feedings in possible locations.

Low chloride concentrations (1-10 mg/l) of springs along the fault line (N1; Figure 4.7) could be reasoned to: a) springs represent relatively deeper and diluted groundwater flow to surface via the fault discontinuity, or b) springs are located in the areas where processes increasing chloride concentrations are not operative, or c) Spring chloride concentrations reflect rather shallower mélange lithology effects. On the other hand, F-11 spring, which is located on different fault system (N2; Figure 4.7), has high chloride concentration (76 mg/l). This could be related to groundwater in deeper levels. It should be noted that F-11 is located at the contact of alluvium-Miocene basal conglomerate units (Figure 4.7).

100-350 m well bottom depth;

Chloride concentrations of well waters filtered from Pl + MAC units (in the range of 90-350 m well bottom depth) increase with increasing sampling pump depth (Figure 5.1). Two exceptions are E-8-15P1 well water which is filtered in mostly Pliocene unit and sampled from relatively shallower depths (the pump depth, 82 m) and E-13P1 well water which is filtered in mostly Pliocene unit but also in Alluvium unit. Among these wells (having 100-350 m bottom depths), sulphate concentration (3367 mg/l) of E-2P well water is much higher (at least 13 times) than other well waters

(140-258 mg/l). This could be related to the dissolution of local gypsum horizons. On the contrary, sulphate concentrations are much lower in the waters of E-11P1 and E-13P1 (5 mg/l and 1 mg/l, respectively).

>350 m well bottom depth;

Chloride concentrations of groundwaters in MAC +/- Pl +/- Al units (having well bottom depth of 350-500 m) increase with increasing filtered Miocene unit thickness (Figure 5.1). Sulphate concentrations of these groundwaters are also very high (2085-3402 mg/l). Very low chloride concentration (29 mg/l) of E-16P1 well water is probably related to the dilute water mixing from Al and Pl units located at the upper levels during the sampling pumpage (the pump was located at the depth of 72 m). Relatively low concentration (342 mg/l) of APK-3 well (located nearby Porsuk Creek and filters thick, 56 m, alluvium unit) water, which is pumped out from 444 m depth, could be reasoned to the mixing dilute water from shallow levels during pumpage and/or natural flow related mixing dilution from water coming through structural discontinuities. Considering that the buried the dip-slip F1 fault located at the near vicinity starts from 200 m depth downward, the discontinuity dependent mixing does not seem to be sound reasoning (Figure 5.2).

Chloride and sulphate concentrations (1441 mg/l and 301 mg/l, respectively) of BPK-2 well (filtering 10 m MAC and 140 m CH) water is lower than those well waters (Cl about 2000 mg/l and SO4 about 3000 mg/l) which are also filtered from MAC + CH units. Chloride and sulphate concentrations (34 mg/l and 11 mg/l, respectively) of E-3P well (filtering only coal unit) is even much lower. Oxidation-reduction potential values of these groundwaters are much higher than those of compatible well waters from similar depths. The data suggest possible mixing of dilute groundwater from upper/lower unit levels to coal unit at these locations. In fact, the drawdown observation in Pliocene aquifer during BPK-2 well pump testing was reported by Yazıcıgil et. al (2018). In addition, this well is located on the dip-slip F4 fault (confirmed from 0 to 550 m depth with seismic data) after 250-300 m depth (Figure 5.2). But no drawdown was reported from the pumping test of E-3P well nearby which no major fault zone is present either. It is interpreted that well installation problem could exit for the well.

On the other hand, chloride concentrations of 8640 mg/l and 15800 mg/l reported by Zeyrek et al. (2017) were measured in E-8-15P3 well (115 m CH+30 m MAC) and E-17P1 well (130 m CH+10 m MAC) waters representing high chloride-high sulphate groundwater composition under very low flow conditions. The comparison of these values with those of BPK-2 (and E-3P3) indicate that coal level groundwater chemistry bears local differences probably depending on structural discontinuities.

MBC+Melange wells

Chloride concentration of the deepest (507 m) free-flowing well (E-4P) water (Cl: 9897 mg/l, SO_4: 411 mg/l) is much higher (about 4 times) than those of all sampled groundwaters filtering MAC+CH units. E-4P well filters (MAC: 242 m, CH: 78 m, MBC: 45 m, mélange 6 m) the thickest MAC + CH units among the wells. However, all of the other well waters (excluding mixing modified E-16P1, BPK-2, E-3P waters) filtering MAC + CH units also include very high sulphate concentrations (2000-3500 mg/l) in addition to the high chloride concentrations (about 2000 mg/l) contrary to the relatively low sulphate content of E-4P well water. On the other hand, MBC and mélange units are filtered only in E-4P well (excluding E-16P1 well, whose water is modified by mixing processes as mentioned earlier).

Although E-4P equivalent high chloride concentrations are also measured in E-8-15P3 and E-17P1 well waters (8640, 15800 mg/l) together with high sulphate concentrations (4870, 3200 mg/l), as mentioned earlier, these wells waters reflect concentrations of very low flow (stagnant) conditions. On the contrary, high free flow discharge rates are observed in E-4P well. In addition, as mentioned earlier, coal unit dependent high sulphate contents (due to presence of pyrite) of these wells is not present in E-4P well water.

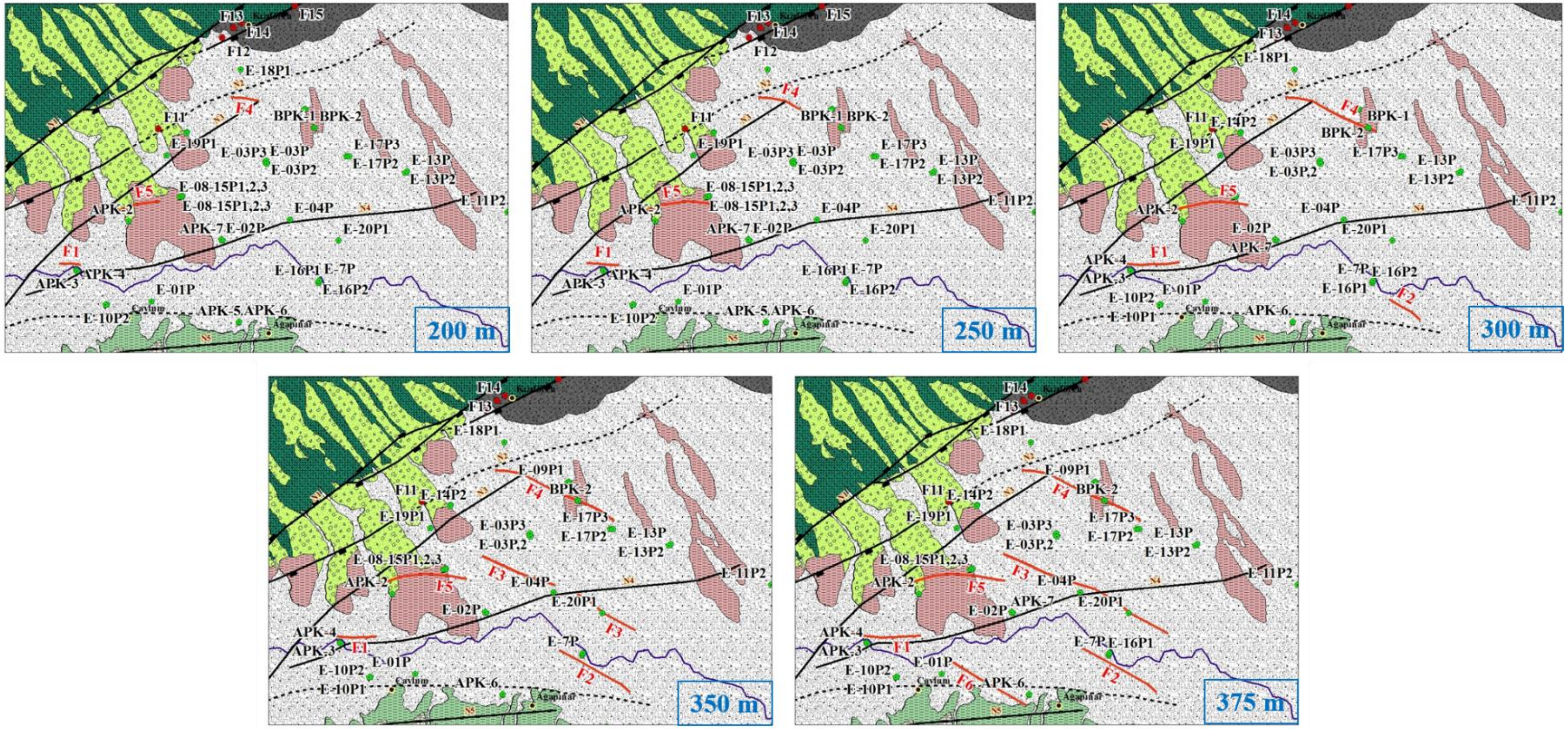


Figure 5.2. Distribution of buried major faults (red color) with depth. The fault lines are from Yılmaz et al. (2016).

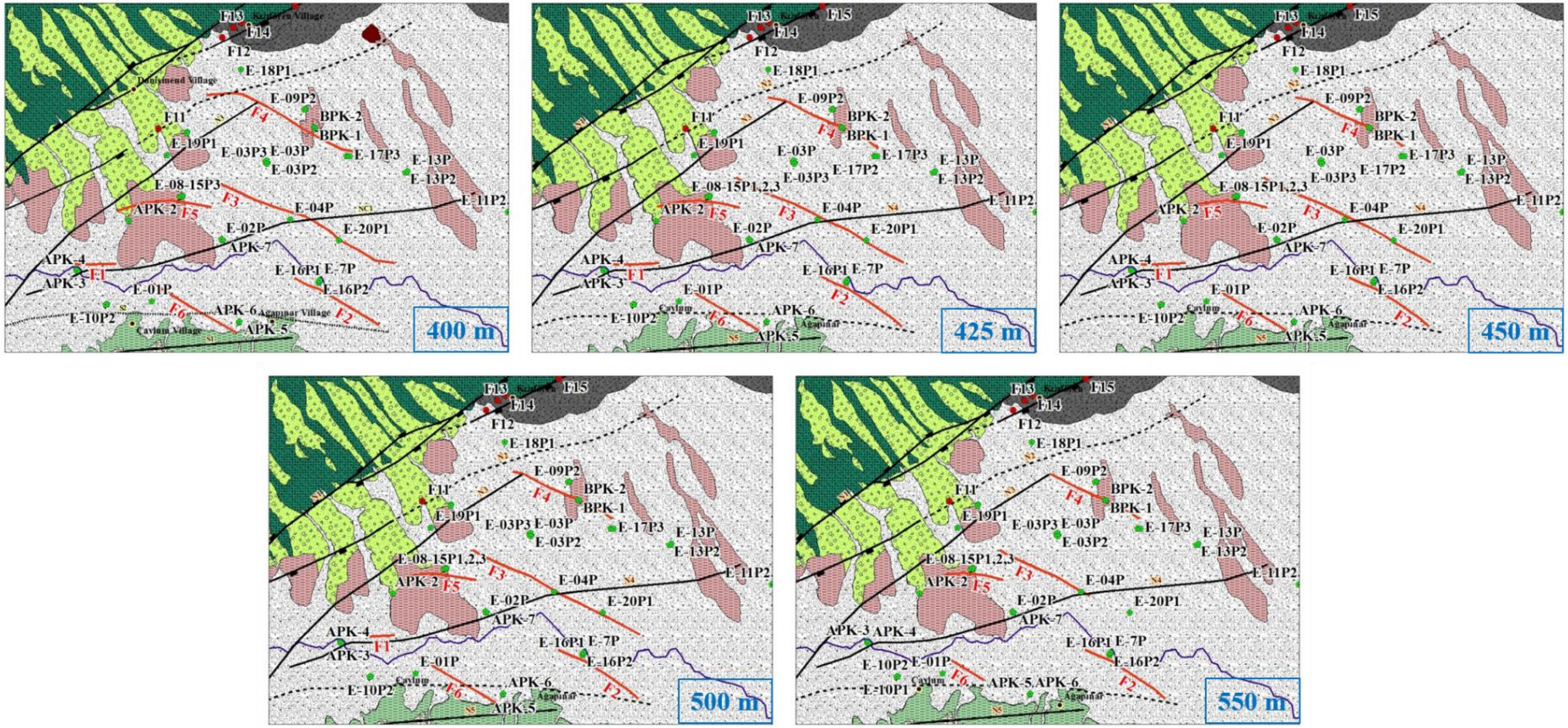


Figure 5.2. continued.

These evaluations indicate that high chloride-low sulphate characteristic of free-flowing E-4P well water is related to the characteristics of groundwaters in MBC and/or mélange units. These unit groundwaters could have been subjected to the mixing of even deeper groundwater possessing very high chloride concentration. There exists a dip-slip fault (F3), which can be traced from 350 m down to 550 m with seismic data (Yılmaz et al., 2016), in location of E-4P well (Figure 5.2). But linear projection of this fault shortens after 450 m downward.

The evaluations suggest three scenarios for the formation of MBC + basement groundwater (E-4P) characteristics:

(1a) The MBC + basement groundwater composition represents in situ natural steady evolution characteristics.

(2a) The MBC + basement groundwater composition is related to the advective mass transport mixing of the deep geothermal reservoir groundwater.

(3a) The MBC + basement groundwater composition is related to the diffusive mass transport mixing of the deep geothermal reservoir groundwater.

The evaluations further suggest three scenarios for the formation of deep MAC, CH and Pl groundwaters characteristics:

(1b) The above MBC groundwater compositions represent in situ natural steady evolution characteristics.

(2b) The above MBC groundwater composition is related to the advective mass transport mixing of the MBC + basement groundwater.

There is no observation suggesting such flux occurrences from the basement aquifer groundwater into those of the overlying units. In fact, field observations indicate that groundwater below the coal levels are under confined conditions. As a result, any discontinuity related advective flux mixing from the MBC + basement aquifers would result somehow irregular spatial distribution of chloride concentrations in the overlying aquifers. The data do not confirm such a distribution.

(3b) The above MBC groundwater composition is related to the diffusive mass transport mixing of the MBC + basement groundwater.

These scenarios are evaluated in the following sections.

5.2 Geothermal Reservoir Water Involvement

Studies conducted by MTA regarding the geothermal system in the region are not accessible. In relation to this study, only one chemical analysis of geothermal water is provided in Bayram (2015), who does not provide any detailed information about the geothermal research details (the well log, reservoir characteristics, sampling depth, temperature distribution, etc.). HT-TTM (2016) reports that the well is drilled to a depth of 1017 m in the vicinity of Ağapınar village and the bottom water temperature of the well is about 53°C.

According to the best fit equation obtained using well water temperature of vibrating wire piezometers (Table 4.10) and geothermal water temperature and the measured depths (Figure 5.3a), the temperature of E-4P well water at the bottom (507 m) is estimated to be 36°C under unmixing of deeper hot groundwater conditions.

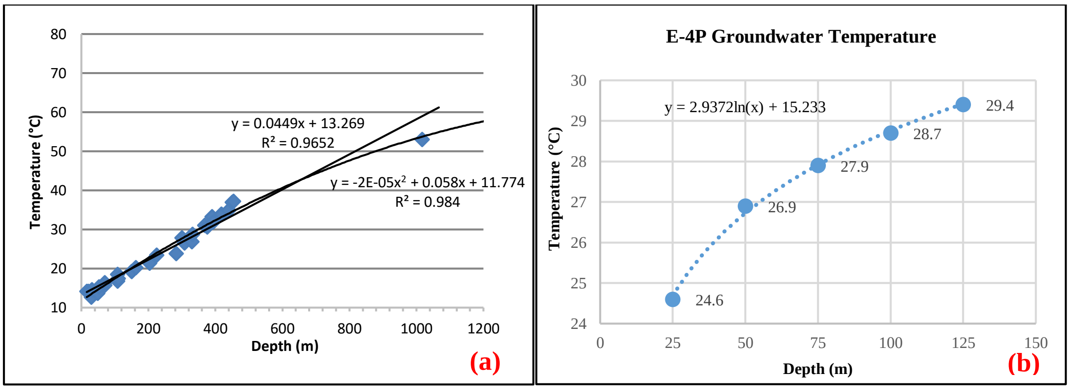


Figure 5.3. Change of groundwater temperature with depth (a) in the aquifers studied and (b) in the free-flowing E-4P well water

Intercept of the best fit line (where depth is zero) in Figure 5.3a indicates a surface water temperature of 13.3°C, which is similar to the average spring water temperature (Table 4.10) obtained from three years of measurements in the study area. Using previously determined the average water temperature gradient in the study area (38^{o}C/km, see section 4.4.1) and this surface temperature, the temperature of E-4P well water at the bottom is estimated to be 33^{o}C.

The probe was sent into E-4P well to measure well water bottom temperature, but the probe could not be lowered deeper than 125 m. The measurements taken down to 125 m along 25 m intervals are as follows: 0 m; 22.3^{o}C, 25 m; 24.6^{o}C; 50 m; 26.9^{o}C, 75 m; 27.9^{o}C, 100 m; 28.7^{o}C and 125 m; 29.5^{o}C. According to the best fit equation (Figure 5.3b) obtained using these values, E-4P bottom water temperature is estimated as about 34^{o}C. Because groundwater in the well flows upward (free flow) with relatively high velocity and the well is filtered in low hydraulic conductivity associated Miocene unit prior to 125 m depth from surface, it is thought that this estimated bottom water temperature does not include high error. The calculated bottom water temperature of 34^{o}C is very close to those calculated temperatures (33^{o}C and 36^{o}C), which were obtained using vibrating wire piezometers data. These temperature values and the linear trend of the temperature increase from top aquifers to the geothermal reservoir (in fact the slope of temperature trend from about 450 m to the reservoir slightly decreases) indicate that no hot groundwater flow (flux) mixing occurs from the geothermal reservoir upward to the bottom location of well E-4P.

The evaluations suggest that the advective mass transport from thermal water at deeper aquifer(s) to the bottom of E-4P well units (MBC + Mélange), *Scenario 2a*, is not operative.

5.3 Diffusive Mass Transport

The possible mixing amount from the geothermal reservoir to the location of E-4P well is calculated to be about 45% using geothermal reservoir chloride concentration of 21939 mg/l (Bayram, 2015) at a depth of 1017 m and average 9897 mg/l chloride concentration of E-4P well at a depth of 507 m.

The mixing estimates from the location of E-4P well to upward into the Miocene and Pliocene units using concentrations of the selected representative wells are also carried out (Table 5.1) and are shown in Figure 5.4.

Table 5.1 Mixing amounts of the basement groundwater into the overlying aquifers

Well No	Lithology	Cl (mg/l)	E-4P %
E-9P1	Pl + MAC	4	0.0
E-14P1	MAC	64	0.6
E-3P3	Pl + MAC	1343	13.5
E-2P	Pl + MAC	1487	15.0
E-8-15P2	MAC + CH	2065	20.8
APK-5	MAC + CH	2136	21.6
E-4P	Pl + MAC + CH + MBC + Mélange	9897	100.0

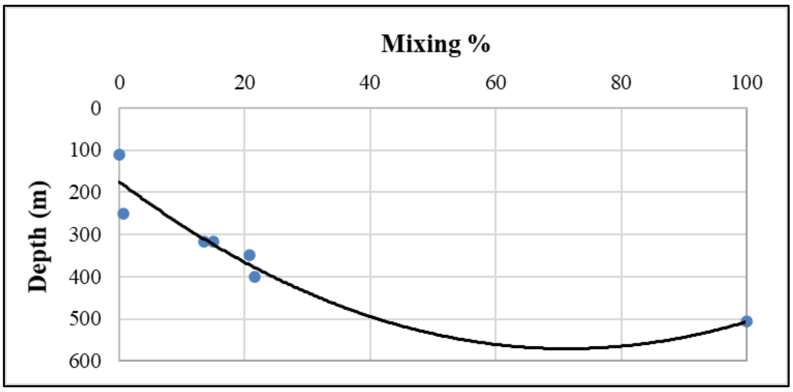


Figure 5.4. The mixing trends from the basement to the upward units

The feasibility of diffusive mass transport related mixing (the scenarios 3a and 3b) in terms of time constraint is investigated using Ogata-Banks equation (Ogata and Banks, 1961) based on a constant source boundary condition.

$$C(x,t) = \left({}^{C_0}/_{2}\right)\left(erfc\left[\frac{x - v_x t}{2(D_x t)^{1/2}}\right] + exp\left(\frac{v_x x}{D_x}\right) erfc\left[\frac{x + v_x t}{2(D_x t)^{1/2}}\right]\right)$$

Where C_o is the source concentration and C is the concentration at a distance of x at a given time t. The erfc is the complementary error function. D is the hydrodynamic dispersion coefficient [= α (dispersivity) * v (average linear groundwater velocity) + D_e (effective diffusion coefficient)]. Since only diffusive transport is assumed groundwater velocity and dispersivity are equal to zero.

The effective diffusion coefficient depends on several factors (e.g., pore size, density, cation exchange capacity, viscosity factor, tortuosity, volumetric water content, etc.) and there is a wide range of data in the literature for chloride (e.g., Patriarche et al., 2004, Camur and Yazicigil, 2005). According to Desaulniers et al. (1981), the threshold values of the chloride effective diffusion coefficient are generally between 6.3 x 10^{-11} m^2/s and 5.0 x 10^{-10} m^2/s representing materials with porosities ranging from 25% to 50%. Due to the lack of information on the rock properties between the geothermal reservoir and the basement aquifer, these effective diffusion coefficient range values are used in the calculations. The diffusion transport times of about 115 million years (m.y.) and 14.5 m.y. are estimated using the range values, respectively between the geothermal reservoir and the MBC + basement aquifer. Whether such time range is reasonable or not in terms of the existence of the geothermal reservoir is highly questionable. Hence, the diffusive inferred mixing (*Scenario 3a*) does not seem to be a viable process to explain the concentration at the location of E-4P. The evaluations suggest that the inferred possible mixing of 45% would require an advective mass flux contribution, but such flux with given very high mixing percentage is prohibited at the depth of E-4P well due to the normal geothermal gradient related water temperature. Although an advective flux at the deeper locations is possible, there is not enough data to investigate this possibility. Yet, it should be kept in mind that the MBC + basement groundwater characteristics could also be reflecting its unmixed natural in situ properties (*Scenario 1a*).

Due to lithological similarities, the effective diffusion coefficient range of 3×10^{-13} m^2/s to 3×10^{-12} m^2/s, obtained from argillites, shales and marls of Tournemire Massif involving interstitial water and laboratory diffusion experiments by Patriarche et al. (2004), are used for the Miocene unit upward calculations. The estimated times for the selected representative well locations are listed in Table 5.2.

Table 5.2 Chloride diffusion transport times required from the basement to the upward units

Well No	Lithology	Depth	Cl (mg/l)	Time (m.y.)	AverageTime (m.y.)
E-9P1	Pl + MAC	110	4	66.6-666	366
E-14P1	MAC	250	64	47.1-471	259
E-3P3	Pl + MAC	316	1343	93.2-932	513
E-2P	Pl + MAC	316	1487	86.6-866	476
E-8-15P2	MAC + CH	350	2065	82.5-825	454
APK-5	MAC + CH	400	2136	39.5-395	217
E-4P	Pl + MAC + CH + MBC + Mélange	507	9897	0	

The results suggest that, on average, about 69-693 m.y. diffusive transport time is required in order to obtain the chloride distribution observed in the Pl, MAC and CH units from the MBC + basement upward. These times are unreasonable and suggest that the diffusive mixing (*Scenario 3b*) is not a viable process. If mixing occurred, it would need an advective mass flux (*Scenario 2b*). However, as explained earlier, there is no observation suggesting such flux occurrences between the MBC + basement aquifer groundwater and those of overlying units. Hence, groundwater characteristics in the units above the MBC represent its mixing free natural in situ properties (*Scenario 1b*). If there is, the contribution of concentrations with upward diffusional flux seems very small and not enough solely to explain concentrations observed in the units.

5.4 Water-Rock Reaction Relationships

Groundwaters minerals from adjacent rocks with which they interact until the water-mineral equilibrium is reached. The increase in the concentrations of the ions causes groundwater to become supersaturated with respect to a mineral and then the mineral precipitates. The water-mineral reactions depend on not only the concentrations both in the water and the mineral but also temperature and pressure of the environment. The saturation conditions of groundwater could provide means for the evaluation of hydrogeochemical evolution of a system.

In order to evaluate possible water-mineral interactions in the study area based on saturation index concept, saturation calculations were performed using PHREEQC software (Parkhust and Appello, 2013) with LLNL database (Johnson et al., 1992). In the evaluations, instead of using solid solution properties of minerals, pure end member thermodynamic components are used due to lack of mineralogical data. Furthermore, exchange reactions are not incorporated into the calculations. All rock forming ion (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, alkalinity, Cl^{-}, SO_4^{2-}, Si, Al, Ti, Fe, Mn and P) concentrations are used as parameters. Distributions of the index related ion concentrations are shown in Figure 5.5.

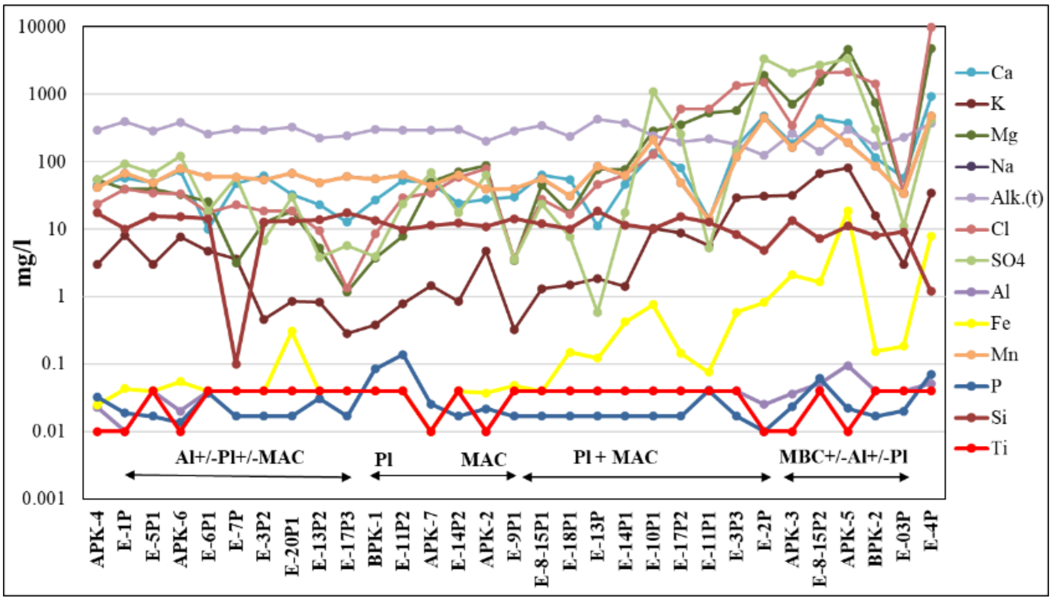


Figure 5.5. Distribution of the saturation index related ion concentrations

Considering the depth and stratigraphic sequence, wells representing varying aquifer types depth-wise are selected for the saturation index calculations; Al + Pl (E-7P, E-3P2, E-13P2), Pl (APK-7, E-11P2, BPK-1), MAC (APK-2, E-14P2), Pl + MAC (E-9P1, E-14P1, E-17P2, E-11P1, E-3P3, E-2P), MAC + CH (E-8-15P2, APK-5) and MAC + CH + MBC + mélange (E-4P well). The estimated saturation indices of the depth and aquifer unit wise selected groundwater compositions are tabulated in Appendix-D. An example output of the software is provided in Appendix-D. The supersaturated minerals are listed in Table 5.3 for each well water.

Table 5.3 Supersaturated minerals in representative well waters

Well ID	**Aquifer Units**	**Well Depth (m)**	**Pompage Depth (m)**	**Super-Saturated Minerals**
E-7P	Al+Pl	75	24	Aragonite, Calcite, Dolomite, Magnesite
E-3P2	Al+Pl	90	78	Aragonite, Calcite, Chalcedony, Dolomite, Quartz, Talc, Tridymite
E-13P2	Al+Pl	75	66	Antigorite, Aragonite, Calcite, Chalcedony, Chrysotile, Dolomite, Huntite, Magnesite, Quartz, Sepiolite, Talc, Tremolite, Tridymite
APK-7	Pl	72	60	Aragonite, Calcite, Chalcedony, Dolomite, Magnesite, Quartz, Talc, Tridymite
E-11P2	Pl	90	72	Antigorite, Aragonite, Calcite, Chalcedony, Chrysotile, Dolomite, Huntite, Hydroxylapatite, Quartz, Talc, Tridymite
BPK-1	Pl	102	72	Antigorite, Aragonite, Calcite, Chalcedony, Chrysotile, Dolomite, Huntite, Magnesite, Quartz, Sepiolite, Talc, Tremolite, Tridymite
APK-2	MAC	58.5	43	Andradite, Antigorite, Aragonite, Calcite, Chalcedony, Cronstedtite-7A, Dolomite, Fe(OH)3, Goethite, Hematite, Magnesite, Magnetite, Quartz, Talc, Tridymite
E-14P2	MAC	90	66	Chalcedony, Dolomite, Quartz, Talc, Tridymite
E-9P1	Pl+MAC	250	84	Andradite, Antigorite, Aragonite, Calcite, Chalcedony, Cristobalite(alpha), Cronstedtite-7A, Dolomite, Ferrite-Ca,Mg, Goethite, Hematite, Magnesite, Magnetite, Quartz, Talc, Tridymite
E-14P1	Pl+MAC	350	156	Andradite, Antigorite, Aragonite, Calcite, Chalcedony, Cronstedtite-7A, Dolomite, Fe(OH)3, Ferrite-Ca,Mg, Goethite, Hematite, Magnesite, Magnetite, Quartz, Talc, Tridymite
E-17P2	Pl+MAC	350	270	Andradite, Antigorite, Aragonite, Calcite, Chalcedony, Cronstedtite-7A, Dolomite, Fe(OH)3, Ferrite-Ca,Mg, Goethite, Hematite, Huntite, Magnesite, Magnetite, Quartz, Sepiolite, Talc, Tremolite, Tridymite
E-11P1	Pl+MAC	316	276	Antigorite, Antigorite, Aragonite, Calcite, Chrysotile, Cronstedtite-7A, Dolomite, Fe(OH)3, Ferrite-Ca,Mg, Goethite, Hematite, Magnesite, Magnetite, Quartz, Sepiolite, Talc, Tremolite, Tridymite
E-3P3	Pl+MAC	350	294	Antigorite, Antigorite, Aragonite, Calcite, Chrysotile, Cronstedtite-7A, Dolomite, Fe(OH)3, Ferrite-Ca,Mg, Goethite, Hematite, Huntite, Magnesite, Magnetite, Quartz, Talc
E-2P	Pl+MAC	350	250	Amesite-14A, Andradite, Anthophyllite, Antigorite, Aragonite, Beidellite-Ca,K,Mg,Na, Boehmite, Calcite, Celadonite, Chrysotile, Clinochlore, Cronstedtite-7A, Diaspore, Dolomite, Epidote, Fe(OH)3, Ferrite-Ca,Mg, Gibbsite, Gismondine, Goethite, Hematite, Huntite, Illite, Kaolinite, K-feldspar, Laumontite, Lawsonite, Magnesite, Magnetite, Microcline, Mesolite, Monohydrocalcite, Montmor-Ca,K,Na,Mg, Muscovite, Nontronite-Ca,H,Mg,K,Na, Paragonite, Phlogopite, Ripidolite-14A, Saponite-Ca,H,Mg,K,Na, Scolecite, Sepiolite, Smectite-Fe-Mg, Stilbite, Talc, Tremolite
E-8-15P2	MAC+CH	350	90	Albite, Amesite-14A, Analcime, Andradite, Antigorite, Aragonite, Beidellite-Ca,K,Mg,Na, Boehmite, Calcite, Celadonite, Chrysotile, Clinochlore, Clinoptilolite-Ca,K,Na, Corundum, Cronstedtite-7A, Dawsonite, Diaspore, Dolomite, Epidote, Fe(OH)3, Ferrite-Ca,Mg, Gibbsite, Gismondine, Goethite, Hematite, Hydroxylapatite, Illite, Jarosite, Kaolinite, K-feldspar, Laumontite, Lawsonite, Magnesite, Magnetite, Margarite, Microcline, Mesolite, MnHPO4, Montmor-Ca,K,Na,Mg, Muscovite, Natrolite, Nontronite-Ca,H,K,Mg,Na, Paragonite, Phlogopite, Pyrophyllite, Quartz, Ripidolite-14A, Sanidine_high, Saponite-Ca,H,Mg,K,Na, Scolecite, Smectite-Fe-Mg, Stilbite, Talc
APK-5	MAC+CH	400	380	Albite, Amesite-14A, Analcime, Andradite, Annite, Antigorite, Aragonite, Beidellite-Ca,K,Mg,Na, Boehmite, Calcite, Celadonite, Chamosite-7A, Chrysotile, Clinochlore, Clinoptilolite-Ca,K,Na, Corundum, Cronstedtite-7A, Daphnite, Dawsonite, Diaspore, Dolomite, Epidote, Fe(OH)3, Ferrite-Ca,Mg, Gibbsite, Gismondine, Goethite, Hematite, Hercynite, Huntite, Hydroxylapatite, Illite, Jarosite, Kaolinite, K-feldspar, Laumontite, Lawsonite, Magnesite, Magnetite, Margarite, Maximum_Microcline, Mesolite, Minnesotaite, MnHPO4, Monohydrocalcite, Montmor-Ca,K,Na,Mg, Mordenite, Muscovite, Natrolite, Nontronite-Ca,H,K,Mg,Na, Paragonite, Phlogopite, Prehnite, Pyrophyllite, Quartz, Ripidolite, Sanidine_high, Saponite-Ca,H,Mg,K,Na, Scolecite, Smectite-Fe-Mg, Stilbite, Talc
E-4P	Al+Pl+MAC +CH+MBC+ Melange	507		Amesite-14A, Andradite, Aragonite, Beidellite-Ca,Mg, Boehmite, Calcite, Chamosite-7A, Clinochlore, Corundum, Cronstedtite-7A, Daphnite-14A, Dawsonite, Diaspore, Dolomite, Epidote, Fe(OH)3, Ferrite-Ca,Mg, Gibbsite, Goethite, Hematite, Huntite, Hydroxylapatite, Illite, Jarosite, Kaolinite, Magnesite, Magnetite, Mesolite, MnHPO4, Monohydrocalcite, Muscovite, Nontronite-Ca,H,K,Mg,Na, Paragonite, Phlogopite, Ripidolite-14A, Saponite-Ca,Mg, Scolecite, Siderite, Smectite-Fe-Mg

Al + Pl filtering (E-7P, E-3P2 and E-13P2) and only Pliocene filtering (APK-7, E-11P2 and BPK-1) well waters are supersaturated with respect to Ca-Mg-carbonates (aragonite, calcite, dolomite, magnesite, huntite) and silica (quartz, calcedony, tridymite) minerals. Additionally, hydroxide group minerals of sepiolite, talc, antigorite, chrysotile and tremolite (amphibole end member) components are also supersaturated. Only shallow level (< 100 m) Miocene unit filtering (APK-2 and E-14P2) well waters in addition to the above components, are supersaturated with respect to Fe-hydroxide and oxide mineral components (cronstedtite-7A, Fe(OH)3, ferrite-Ca, Mg, goethite, hematite and magnetite) as well.

Supersaturation of Pl + Miocene filtering deep (> 100 m) groundwaters (E-9P1, E-14P1, E-17P2, E-11P1 and E-3P3) are similar to the shallow Miocene groundwaters. On the other hand, MAC + CH filtering deeper groundwaters (including Pl + MAC filtering E-2P) are additionally supersaturated with respect to feldspar components and a greater number of hydroxide minerals (phyllosilicates in general) including different clay group minerals (illite, kaolinite, montmorillonite, nontronite, sepiolites, zeolites) suggesting greater influence of exchange reactions (e.g. Mg, Ca ⇔ Na) as also indicated by the water facies changes. It should be kept in mind that these supersaturation conditions are for pure thermodynamic components of those minerals that include solid solutions. In other words, saturation indices do not include the solid solution and possible kinetic control effects on the reactions. Therefore, they should be viewed rather as components reflecting reaction relationships with the actual related minerals in the aquifer units.

5.5 Discussion

Major ion chemistry of groundwaters in the study area stratigraphically downward changes; in the order of HCO_3 → SO_4 → Cl according to the anion content and in the order of Mg → Mix → Na according to the cation content, while Ca remains nearly constant Na increases upon Mg decrease. Groundwaters in Al + Pl and Al + MAC-upper-level units representing shallow aquifers are in Mg-HCO_3 facies.

Surface outcropped only Pliocene and only MAC unit groundwaters, representing also shallow aquifers are in Mg- (Mix-) HCO_3 and Mix- (Mg-) HCO_3, respectively. The facies of Miocene unit (representing relatively deep to deep aquifer) groundwater change in the order of Mix-HCO_3; Mix-SO_4; Na-SO_4 and Na-Cl with increasing unit thickness downward. Such facies (ion concentration) changes are typically observed in groundwaters of deep sedimentary rock units including basements and reasoned to decreasing hydraulic conductivity (downward to very small values) associated longer residence time of groundwater. Longer the residence time of groundwater in the aquifer, more the concentrations would be transferred to groundwater from aquifer media via reactions meantime less flow/delayed recharge related accumulations and ionic radius filtration effect related accumulations would also be occurring. However, if highly concentrated groundwater source is present at deeper levels, then it is probable to interpret that the observed facies (ion concentrations) changes have been developed upward due to either advective in the presence of vertical upward gradient and/or diffusive mass transport. There exists a geothermal system in the area representing such a source.

As to the hydraulic gradients, the groundwater level measurements indicate that the water levels measured in the shallow system show seasonal changes while the water levels measured in the deep system do not significantly change seasonally. Furthermore, it has been determined that there is a vertical gradient from the deep (about >250 m depth) system to the shallow system [E-13P1 (Al + Pl + MAC, 280 m) → E-13P2 (Pl + MAC, 75 m), E-02P (Pl + MAC, 350 m) → APK-7 (Pl, 72 m), E-17P2 (Pl + MAC, 350 m) → E-17P3 (Al + Pl, 75 m), E-11P1 (Pl + MAC, 350 m) → E-11P2 (Pl, 90 m), E-8-15P2 (MAC + CH, 350 m) → E-8-15P1 (Pl +MAC, 90 m), APK-5 (MAC + CH, 400 m) → APK-6 (Al + MAC, 60 m), APK-3 (Al + MAC + CH, 460 m) → APK-4 (Al, 60 m)]. Considering groundwater levels (gradients) and ion concentration trends approximate shallow-deep groundwater system boundary, although changes from one location to another present, could be set grossly to about 150-250 m depth.

Nonreactive chloride concentration distributions indicate that the concentrations decrease downward in the shallow aquifer. This requires surface input source because the expected trend is reverse. The decrease of chloride concentrations downward in the groundwaters of the outcropping units could be related to the possible following sources: evaporation and/or agricultural activities (irrigation, fertilizer applications, saltation, etc.) and/or Porsuk Creek feedings in possible locations. The other important implication of this chloride trend is that there is no advective flow vertically upward from the deep to shallow aquifers although the vertical gradient exists. Otherwise, one would expect increasing chloride concentration surface downward. As a result, it is concluded that in general there is no mass transport flux from deep aquifers to shallow aquifers excluding possible local existences.

The possibly of upward mass transport within the deep aquifer from MBC + basement aquifer upward also needs to be evaluated. The investigations preclude upward advective flux related mass transport in general. But some data suggest that advective mixing of different aquifer groundwaters in local scale could take place in the units above the MBC. The estimated time constraints preclude the only upward diffusive transport mass enrichment mechanism as the controlling mechanism for the concentration distributions observed from MBC + basement aquifer upward. As a result, it is concluded that upward mass transport in deep aquifers could only be possible under very low upward flow and/or dispersive conditions.

The assumption of geothermal system as a source of observed concentration trend in the deep aquifer also requires discussion. The earlier presented evaluations based on temperature distribution suggest that the advective mass transport from thermal water to the bottom of E-4P well units (MBC + Mélange) is not operative. In addition, the diffusion transport times estimated between the geothermal reservoir and the MBC + basement aquifer using nonreactive chloride concentrations is found to be highly questionable. As a result, it is concluded that the inferred possible mixing would require an advective mass flux contribution, but such flux with given very high mixing percentage is prohibited at the depth of E-4P well due to the normal geothermal gradient related water temperature. Yet an advective flux at the even deeper locations (between bottom of E-4P and geothermal reservoir) is possible but there is not enough data to investigate this possibility. It should be kept in mind that the MBC + basement groundwater characteristics could also be reflecting its unmixed natural in situ properties.

The evaluations suggest that the facies and concentration changes with depth after about 100 m probably reflects hydrogeochemical evolution processes of deep sedimentary basin groundwaters under water-rock reaction relationships accompanied by very low permeability related ion filtration and local diffusive/dispersion transport enrichment. There is not enough data to investigate the processes creating the chemical characteristics of MBC + Mélange groundwater.

Finally, the following limitations should be noted:

- There is not enough data for the hydrogeochemical evaluation of the bedrock aquifer(s) between geothermal reservoir and bottom of Miocene unit.
- There is not enough data for the geothermal system to investigate the relationships between geothermal reservoir and bedrock units.
- Detailed investigation is required for the flow and mass flux relationship between surface waters (Porsuk creek and irrigation canals) and groundwater.

CHAPTER 6

WATER QUALITY

Inland water resources groundwater classification (SKKY, 2008; YKBKK, 2012), irrigation water classification (AATTUT, 2010) and human consumption water limits (ITAS, 2005) are used for the evaluation of water quality using arithmetic means of quality data. These regulatory frameworks are listed in Appendix-E.

After the regulation of groundwater protection against contamination and degradation (YKBKK, 2012), previously used groundwater quality classification limits (SKKY, 2008) are abolished. Because groundwater quality standards and threshold values have not been established yet by Water Management Directorate of Turkey as required by the aforementioned regulation, groundwater quality based on old limits in addition to YKBKK (2012).

As indicated in Hydrogeology section, the alluvium aquifer groundwater is in direct interaction with Porsuk Creek. Therefore, it should be kept in mind that quality of alluvium groundwater presented here could be reflecting the creek effects. Due to lack of chemical data and temporal/spatial flow relations between the alluvium aquifer and the creek, no specific chemical interaction is discussed in the following text.

6.1 Spring and Fountain Waters

The quality summary of spring and fountain waters based on the inland water resources groundwater classification, irrigation water classification and human consumption limits, is given in Table 6.1.

When the concentration values are evaluated according to the inland groundwater criteria; all spring and fountain waters contain low quality (Class III) groundwater due to their high B/TKN/S^{2-}/NO_3/N-NH_4/EC/pH and low O_2 content (Table 6.2). According to the human consumption limits, waters are suitable only at F-15 and F-17 locations. When bacterial limits are omitted, all spring and fountain waters are suitable except F-11 due to high As/B/NO_3/Pb, F-12 due to high Alpha-activity and F-16 due to Pb parameter values. Among these parameters As, Pb and NO_3 are the minimum groundwater monitoring parameters listed in YKBKK (2012). The As and B values at F-11 water are 0.0103 mg/l and 1.02 mg/l, respectively, and the Pb values of F-11 and F-16 water are 0.0117 mg/l and 0.0115 mg/l, respectively. These values are very close to the limit values.

Table 6.1 Quality classification of spring and fountain waters

	INLAND WATER CLASSIFICATION	HUMAN CONSUMPTION	HUMAN CONSUMPTION INDICATOR PARAMETERS	IRRIGATION WATER CLASSIFICATION	APPLICATION QUALITY
F-11	Class III - Ba, N-NO3, S-2, EC, O2	As, B, N-NO3, Pb, Coli-t	O2	Class III - Na(I), Coli-f(A), V	Coli-f(A), V
F-12	Class III - TKN, S-2, O2	Alpha ac.	O2	Class III - Na(I)	V
F-13	Class III - TKN, O2	Coli-t	O2	Class III - Na(I)	Coli-f(A)
F-14	Class III - S-2, O2	Coli-t	O2	Class II - Na(I)	Coli-f(A)
F-15	Class III, N-NH4, O2		Mn, N-NH4, O2	Class III - Na(I)	
F-16	Class III - TKN, S-2, O2	Pb, Coli-t	O2	Class II - Na(I)	Coli-f(A), V
F-17	Class III - S-2, O2		O2	Class II - Na(I)	TSS(A), TSS(B)

Note for irrigation water classification:

(A): CLASS A; Good quality irrigation water required for irrigation of non-commercially processed food products and urban areas such as parks and gardens, as there may be water contact with people's plants, both with the edible product and in areas such as parks and gardens.

(B) CLASS B; Lower quality irrigation water that can be used in areas where public access is restricted, such as commercially processed food products (orchards and vineyards), grass production and cultivation, and pasture and hay farming for grazing animals.

→Post parameters are non-classification parameters. Metals are for continuous irrigation on all kinds of grounds.
(I): Surface irrigation, (II): Drip irrigation

In terms of irrigation water, F-11, F-12, F-13 and F-15 spring and fountain waters are classified as hazardous (Class III) and F14, F16 and F-17 waters are low-intermediate hazardous (Class-II) for surface irrigation due to high Na (I) concentration, but they are suitable for drip irrigation (Table 6.3). Other than classification limits, all spring and fountain waters, except F-15 water contains elements that cause low quality due to TSS(A)/TSS(B)/Coli-f(A)/V parameters. Coli-f(A) values in F-11and F-13 waters and V values in all waters are very close to the limit values. Hence when these parameters are excluded, F-14 are F-16 waters are suitable for drip irrigation due to Coli-f(A), but F-17 water is not suitable for irrigation due to TSS(A)/TSS(B) waters.

Table 6.2 Inland water classification and human consumption quality of spring and fountain waters

Groundwater	**Inland Water Classification**			**Human Consumption**	**F-11**	**F-12**	**F-13**	**F-14**	**F-15**	**F-16**	**F-17**
Parameter	**Class I**	**Class II**	**Class III**	ITAS 2005; EU 1998; WHO 2011	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**
As	0.02	0.05	>0.05	0.01	● 0.010	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
B	1	1	>1	1	● 1.02	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Ba	1	2	>2	1.3	0.05	-0.04	-0.04	0.04	0.05	-0.04	-0.04
BOD	4	8	>8		-3	-3	-3	-3	3	-3	3
Cd	0.003	0.005	>0.005	0.005	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
CN	0.01	0.05	>0.005	0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Co	0.01	0.02	>0.02		-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
COD	25	50	>50		3	-3	8	-3	10	-3	13
Cr	0.02	0.05	>0.05	0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cu	0.02	0.05	>0.05	2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1	1.5	>1.5	1.5	0.32	0.09	-0.05	0.12	0.23	-0.05	-0.05
Hg	0.0001	0.0005	>0.0005	0.001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
TKN	0.5	1.5	>1.5		1.0	2.7	6.6	1.4	1.2	1.5	0.7
NO2				0.5	0.007	-0.007	-0.007	-0.007	-0.007	-0.007	0.007
NO3				50	● 113.7	-0.1	0.3	1.0	0.7	1.1	10.2
N-NO2	0.002	0.01	>0.01	0.15	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
N-NO3	5	10	>10	11.5	● 25.66	0.01	0.07	0.23	0.15	0.25	2.31
Ni	0.02	0.05	>0.05	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
P,t	0.02	0.16	>0.16		-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	0.04
Pb	0.01	0.02	>0.02	0.01	● 0.01	-0.01	-0.01	-0.01	-0.01	● 0.01	-0.01
S-2	0.002	0.002	>0.002		0.3	1.2	-0.1	1.6	-0.1	1.6	0.2
Sb				0.005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005
Se	0.01	0.01	>0.01	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Temperature	25	25	>25		13	15	13	13	13	11	14
TDS	500	1500	>1500		497	521	305	304	331	240	371
TOC	5	8	>8		-2	-2	-2	-2	-2	-2	-2
Zn	0.2	0.5	>0.5		0.12	0.11	0.09	0.27	0.42	0.17	0.04
Pesticides,t	0.001	0.01	>0.01	0.0005	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
Tri-tetraCE				0.01	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
MBAS	0.05	0.2	>1		0.05	0.05	0.05	0.05	0.05	0.05	0.05
Coli-f	10	200	>200		1	0	2	20	0	25	0
Coli-t	100	20000	>20000	0	● 3	0	● 30	● 20	0	● 60	0
Alpha ac.	0.5	5	>5	0.1	0.094	● 0.374	0.074	0.091	0.067	0.085	0.074
Beta ac.	1	10	>10	1	0.073	0.137	0.065	0.07	0.069	0.068	0.069
				Indicator Parameters							
Al	0.3	0.3	>0.3	0.2	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Cl	25	200	>200	250	76	10	8	5	5	1	5
EC	400	1000	>1000	2500	1226	950	564	565	584	448	438
Fe	0.3	1	>1	0.2	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Mn	0.1	0.5	>0.5	0.05	-0.04	-0.04	-0.04	-0.04	● 0.09	-0.04	-0.04
Na	125	125	>125	200	15	15	10	8	12	3	5
NH4				0.5	-0.26	-0.26	-0.26	-0.26	● 14.68	-0.26	-0.26
N-NH4	0.2	1	>1	0.39	-0.2	-0.2	-0.2	-0.2	● 11.4	-0.2	-0.2
O2	8	6	<6	5	● 3.4	● 2.1	● 2.5	● 4.8	● 2.7	● 2.6	● 3.3
O2%	90	70	<70		37.2	22.6	27.0	50.3	28.3	25.9	35.6
pH	6.5-8.5	6.5-8.5	≤6.5-≥8.5	6.5-8.5	7.78	7.47	8.11	8.10	7.40	8.67	8.69
Color	5	50	>50		-5	-5	-5	-5	-5	-5	-5
SO4	200	200	>200	250	29	37	11	12	4	5	12

(Unit; EC: uS/cm, Coliform: cfu/100 mL, color: pt/co, temperature: °C, Alpha and Beta act. Bq/L and the other parameters are in mg/l. Detection limits are shown as minus. Yellow circle represents the human consumption limits exceeding values)

Irrigation water quality distribution and infiltration effects defined according to sodium adsorption ratio (SAR) and electrical conductivity (EC) values are shown in Figure 6.1. Spring and fountain waters have low sodium-medium salinity (F-11 and F-12 high salinity) hazard and waters do not have any effect in rate of infiltration reduction.

Table 6.3 Irrigation water classification of spring and fountain waters

AATTUT, 2010	Irrigation Water Classification			F-11	F-12	F-13	F-14	F-15	F-16	F-17
Parameter	**Class I**	**Class II**	**Class III**	**Class III**	**Class III**	**Class III**	**Class II**	**Class III**	**Class II**	**Class II**
B	0.7	3	>3	1.02	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Cl(I)	140	350	>350	76.0	10.0	7.8	5.4	5.3	1.1	4.9
Cl(II)	100		>100	76.0	10.0	7.8	5.4	5.3	1.1	4.9
EC	700	3000	>3000	1226	950	564	565	584	448	438
Na(I)	3	9	>9	15	15	10	8	12	3	5
Na(II)	70		>70	15	15	10	8	12	3	5
SAR-EC (Infiltration)				I	I	I	I	I	I	I
TDS	500	2000	>2000	497	521	305	304	331	240	371
	Application Quality									
Parameter	**HIGH**		**LOW**							
BOD (A)	20		>20	-3	-3	-3	-3	3	-3	3
BOD (B)	30		>30	-3	-3	-3	-3	3	-3	3
TSS (A)	5		>5	-15	-15	-15	-15	-15	-15	88
TSS (B)	30		>30	-15	-15	-15	-15	-15	-15	88
Coli-f (A)	0		>0	1	0	2	20	0	25	0
Coli-f (B)	200		>200	1	0	2	20	0	25	0
pH	6.0-9.0		<6->9	7.78	7.47	8.11	8.10	7.40	8.67	8.69
Al	5		>5	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
As	0.1		>0.1	0.010	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Be	0.1		>0.1	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Cd	0.01		>0.01	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
Co	0.05		>0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cr	0.1		>0.1	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cu	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1		>1	0.32	0.09	-0.05	0.12	0.23	-0.05	-0.05
Fe	5		>5	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Li	2.5		>2.5	0.05	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Mn	0.2		>0.2	-0.04	-0.04	-0.04	-0.04	0.09	-0.04	-0.04
Mo	0.01		>0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Ni	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Pb	5		>5	0.01	-0.01	-0.01	-0.01	-0.01	0.01	-0.01
Se	0.02		>0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
V	0.1		>0.1	0.14	0.13	-0.10	-0.10	-0.10	0.12	0.12
Zn	2		>2	0.12	0.11	0.09	0.27	0.42	0.17	0.04

(Unit; EC: uS/cm, Coliform: cfu/100 mL, the other parameters are in mg/l. Detection limits are shown as minus)

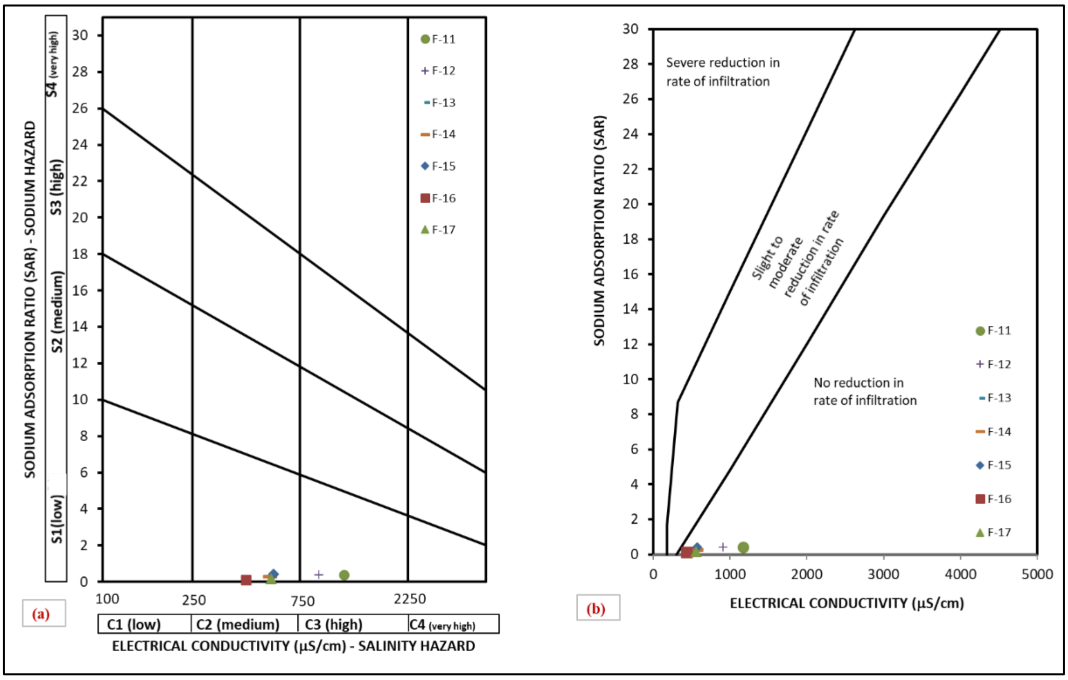


Figure 6.1. (a) Quality Distribution and (b) Irrigation infiltration effects of spring and fountain waters according to SAR, % Na and EC values.

6.2 Well Waters

The quality summary of well waters based on the inland water resources groundwater classification, irrigation water classification and human consumption limits, is given in Table 6.4. For the reasons explained in the quality control section (section 4.4.2.), the second term Na concentration values are used for the wells of E-1P, E-2P, APK-2, APK-3, APK-4, APK-5, APK-6, and APK-7.

All well waters contain low quality (Class III) groundwater due to high concentrations of B/Ba/TKN/N-NO_2/N-NO_3/S^{-2}/TDS parameters. The parameters causing the low quality in each well water are given in Table 6.5 for both inland water and human consumption classifications. According to the concentrations in the wells, only E-8-15P1 and E-14P1 waters are suitable for human consumption. Other wells have higher concentration values of As/B/NO_2/NO_3/Ni/Pb/Coli-t/Alpha ac/

Table 6.4 Summary of well water quality classification

Well ID	INLAND WATER CLASSIFICATION	HUMAN CONSUMPTION	HUMAN CONSUMPTION INDICATOR PARAMETERS	IRRIGATION WATER CLASSIFICATION	APPLICATION QUALITY
APK-2	Class III - B, TKN, N-NO2, S-2, O2	As, B, Pb, Coli-t, Alpha ac.	Fe, O2	Class III - Na(I), Na(II)	TSS(A), TSS(B)
APK-3	Class III - B, TKN, N-NO2, S-2, TDS, Cl, Na, N-NH4, O2, SO4	B, NO2, N-NO2, Ni, Pb, Coli-t, E-Coli	Cl, EC, Fe, Mn, Na, NH4, N-NH4, O2, SO4	Class III - B, EC, Na(I), Na(II), TDS	Mn, V
APK-4	Class III - O2	Pb, Coli-t, E-Coli	Fe, Mn, O2	Class III - Na(I), Na(II)	
APK-5	Class III - B, TKN, N-NO2, S-2, TDS, Cl, EC, Na, N-NH4, O2, SO4	B, Pb, Coli-t, E-Coli-Alpha ac.	Cl, EC, Fe, Mn, Na, NH4, N-NH4, O2, SO4	Class III - B, Cl(I), Cl(II), EC, Na(I), Na(II), TDS	TSS(A), Li, Mn, V
APK-6	Class III - S-2, O2	As, Coli-t, E-Coli, Alpha ac.	Fe, O2	Class III - Na(I), Na(II)	V
APK-7	Class III - N-NO2, S-2, Grease&Oil	Coli-t, Alpha ac.	Fe	Class III- Na(I), Na(II)	TSS(A), TSS(B)
BPK-1	Class III - TKN	Coli-t	Fe	Class II - Na(I), Na(II)	
BPK-2	Class III - B, TKN, TKN, N-NO2, TDS, Cl, EC, Na, N-NH4, O2, SO4	B	Cl, EC, Mn, Na, NH4, N-NH4, O2, SO4	Class III - B, Cl(I), Cl(II), EC, Na(I), Na(II), TDS	Mn, V
E-1P	Class III - N-NO2, S-2, O2	Coli-t, Alpha ac.	Fe, O2	Class III - Na(I), Na(II)	V
E-2P	Class III - B, TKN, S-2, TDS, Cl, EC, Na, N-NH4, O2, SO4	B, Coli-t, Alpha ac., Beta ac.	Cl, EC, Fe, Mn, Na, NH4, N-NH4, O2, SO4	Class III - B, Cl(I), Cl(II), EC, Na(I), Na(II), TDS	TDS, TSS(A), Li, Mn, Mo, V
E-3P	Class III - N-NO2, S-2	Coli-t	Mn	Class III - Na(I), Na(II),	TSS(A), Coli-f(A)
E-3P2	Class III - S-2, O2	Coli-t, Alpha ac.	O2	Class III - Na(I), Na(II), TSS(A), Coli-f(A)	Class III - Na(I), Na(II), TSS(A), Coli-f(A)
E-3P3	Class III - B, TKN, N-NO2, S-2, TDS, Cl, EC, Na, N-NH4, O2, SO4	B, NO2, N-NO2, Coli-t, Alpha ac.	Cl, EC, Mn, Na, NH4, N-NH4, O2	Class III - B, Cl(I), Cl(II), EC, Na(I), Na(II), TDS, TSS(A), V	Class III - B, Cl(I), Cl(II), EC, Na(I), Na(II), TDS, TSS(A), V
E-4P	Class III - B, TKN, S-2, TDS, Cl, EC, Na, N-NH4, O2, Color, SO4	B	Cl, EC, Fe, Mn, Na, NH4, N-NH4, O2, Color, SO4	Class III - B, Cl(I), Cl(II), EC, Na(I), Na(II), TDS	Mn, V
E-5P1	Class III - TKN, N-NO2, S-2, O2	NO3, N-NO3, Coli-t, Alpha ac.	Fe, O2	Class III - Na(I), Na(II)	
E-6P1	Class III - TKN, N-NO2	NO3, N-NO3, Coli-t, Alpha ac., Beta ac.	Fe	Class III - Na(I), Na(II)	
E-7P	Class III - S-2, O2	Alpha ac.	Fe, O2	Class II - EC, Na(I), Na(II)	
E-8-15P1	Class III - TKN		Fe	Class III - Na(I), Na(II)	TSS(A), TSS(B)
E-8-15P2	Class III - B, TKN, S-2, TDS, Cl, EC, Fe, Na, N-NH4, O2, SO4	B, Coli-t, Alpha ac., Beta ac.	Cl, EC, Fe, Mn, Na, NH4, N-NH4, O2, SO4	Class III - B, Cl(I), Cl(II), EC, Na(I), Na(II), TDS	TSS(A), F, Fe, Li
E-9P1	Class III - N-NO2, S-2, O2	Coli-t		Class II - Na(I), Na(II)	
E-10P1	Class III - Ba, TKN, N-NO2, S-2, TDS, EC, Na, O2, SO4	Ba, Coli-t, Alpha ac.	EC, Fe, Mn, Na, O2, SO4	Class III - Na(I), Na(II)	TDS, V
E-11P1	Class III - B, TKN, S-2, Temperature, Cl, EC, Na, O2	B, Ba, Pb, Alpha ac.	Cl, Fe, Na, NH4, N-NH4, O2	Class III - Cl(I), Cl(II), Na(I), Na(II)	
E-11P2	Class III - TKN, O2	Coli-t, Alpha ac.		Class II - Na(I), Na(II)	TSS(A), TSS(B)
E-13P	Class III - TKN, S-2, O2	As, Pb, Coli-t	O2	Class III - Na(I), Na(II)	
E-13P2	Class III - S-2, O2	Coli-t, Alpha ac.	O2	Class II - Na(I), Na(II)	
E-14P1	Class III - TKN, N-NO2, N-NO3, S-2, EC, O2		Fe, O2	Class III - Na(I), Na(II)	V
E-14P2	Class III - TKN, N-NO3, S-2, O2	Coli-t	Fe, O2	Class III - Na(I), Na(II)	TSS(A), TSS(B), Coli-f(A)
E-16P1	Class III - TKN, O2	Alpha ac.	Fe, NH4, N-NH4, O2	Class III - Na(I), Na(II)	
E-17P2	Class III - B, N-NO2, S-2, TDS, Cl, EC, Na, O2, SO4	B, Alpha ac.	Cl, EC, Na, O2, SO4	Class III - B, Cl(I), Cl(II)	V
E-17P3	Class III - S-2, O2	Pb, Coli-t	O2	Class II - EC	V
E-18P1	Class III - TKN, S-2, O2	Coli-t		Class III - Na(I), Na(II)	
E-20P1	Class III - TKN, N-NO2, S-2, O2	Coli-t	O2	Class III - Na(I), Na(II)	

(Explanation for the irrigation water classification is given in Table 6.4.)

Beta activity than the limit values. When bacterial and radioactive parameters are excluded, APK-7, BPK-1, E-1P, E-3P, E-3P2, E-7P, E-9P1, E-11P2, E-13P2, E-14P2, E-16P1, E-18P1, and E-20P1waters are also suitable for human consumption.

Table 6.5 Inland water classification and human consumption quality of well waters

Groundwater	**Inland Water Classification**			**Human Consumption**	**APK-2**	**APK-3**	**APK-4**	**APK-5**	**APK-6**	**APK-7**	**BPK-1**	**BPK-2**
Parameter	**Class I**	**Class II**	**Class III**	ITAS 2005; EU 1998; WHO 2011	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**
As	0.02	0.05	>0.05	0.01	● 0.013	0.002	0.006	-0.001	● 0.012	0.008	-0.001	-0.001
B	1	1	>1	1	● 1.49	● 14.19	0.57	● 47.39	0.63	0.88	-0.04	● 11.13
Ba	1	2	>2	1.3	0.04	0.05	0.12	0.64	0.18	0.11	-0.04	0.12
BOD	4	8	>8		3	5	3	4	2	3	-3	-3
Cd	0.003	0.005	>0.005	0.005	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
CN	0.01	0.05	>0.005	0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Co	0.01	0.02	>0.02		-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
COD	25	50	>50		11	14	9	15	7	8	-3	4
Cr	0.02	0.05	>0.05	0.05	-0.01	-0.01	0.01	-0.01	-0.01	0.01	0.02	-0.01
Cu	0.02	0.05	>0.05	2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1	1.5	>1.5	1.5	0.23	0.67	0.27	0.53	0.36	0.33	0.39	0.05
Hg	0.0001	0.0005	>0.0005	0.001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
TKN	0.5	1.5	>1.5		2.0	2.4	1.2	12.8	0.9	0.9	3.8	11.7
NO2				0.5	0.054	● 0.600	-0.003	0.069	0.005	0.059	-0.007	0.056
NO3				50	9.2	10.7	17.0	0.4	6.6	9.9	7.0	10.3
N-NO2	0.002	0.01	>0.01	0.15	0.017	● 0.183	-0.001	0.021	0.002	0.018	-0.002	0.017
N-NO3	5	10	>10	11.5	2.07	2.42	3.84	0.08	1.49	2.24	1.59	2.32
Ni	0.02	0.05	>0.05	0.02	-0.01	● 0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
P,t	0.02	0.16	>0.16		nm	0.05	0.05	0.05	0.05	0.05	nm	nm
Pb	0.01	0.02	>0.02	0.01	● 0.01	● 0.01	● 0.01	● 0.02	-0.01	-0.01	-0.01	-0.01
S-2	0.002	0.002	>0.002		0.7	0.7	0.7	0.4	1.2	2.1	-0.1	-0.1
Sb				0.005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005
Se	0.01	0.01	>0.01	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Temperature	25	25	>25		17	20	15	22	15	16	17	21
TDS	500	1500	>1500		467	2579	347	4080	489	377	271	3067
TOC	5	8	>8		-2	-1	-1	1	-1	-2	-2	-2
Zn	0.2	0.5	>0.5		0.03	0.02	0.02	0.01	0.05	0.01	-0.04	-0.04
Pesticides,t	0.001	0.01	>0.01	0.0005	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Tri-tetraCE				0.01	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
MBAS	0.05	0.2	>1		-0.01	0.06	0.03	0.06	0.08	-0.01	-0.05	-0.05
Coli-f	10	200	>200		20	0	0	0	0	0	0	0
Coli-t	100	20000	>20000	0	● 345	● 10	● 15	● 34	● 36	● 80	● 30	0
Alpha ac.	0.5	5	>5	0.1	● 0.1515	-0.18	0.05	● 1.236	● 0.1615	● 0.1325	-0.034	0.032
Beta ac.	1	10	>10	1	0.3295	-0.6	0.1105	0.9305	0.384	0.1505	-0.036	-0.02
				Indicator Parameters								
Al	0.3	0.3	>0.3	0.2	-0.01	0.04	0.02	0.09	0.02	-0.01	-0.04	-0.04
Cl	25	200	>200	250	79	● 342	24	● 2136	33	34	9	● 1441
EC	400	1000	>1000	2500	802	● 4035	730	● 5528	997	723	508	● 5000
Fe	0.3	1	>1	0.2	● 0.23	● 0.67	● 0.27	● 0.53	● 0.36	● 0.33	● 0.39	-0.05
Mn	0.1	0.5	>0.5	0.05	-0.01	● 0.38	● 0.08	● 0.36	-0.01	-0.01	-0.04	● 0.22
Na	125	125	>125	200	88	● 710	55	● 4673	33	51	4	● 754
NH4				0.5	-0.01	● 1.41	0.15	● 1.78	-0.01	-0.01	-0.26	● 2.95
N-NH4	0.2	1	>1	0.39	0.0	● 1.1	0.1	● 1.4	0.0	0.0	-0.2	● 2.3
O2	8	6	<6	5	● 3.5	● 2.8	● 4.3	● 3.2	● 4.1	6.6	6.2	● 2.4
O2%	90	70	<70		39.7	36.3	45.8	39.6	43.0	75.9	73.2	32.5
pH	6.5-8.5	6.5-8.5	≤6.5-≥8.5	6.5-8.5	7.81	7.70	7.68	7.69	7.87	7.84	8.12	8.26
Color	5	50	>50		10	7	6	7	6	5	-5	-5
SO4	200	200	>200	250	63	● 2085	54	● 3402	121	69	4	● 301

(Unit; EC: uS/cm, Coliform: cfu/100 mL, color: pt/co, temperature: ˚C, Alpha and Beta act. Bq/L and the other parameters are in mg/l. Detection limits are shown as minus. Yellow circle represents the human consumption limits exceeding values. nm refers to no measurement.)

Table 6.5 continued

Groundwater	**Inland Water Classification**			**Human Consumption**	**E-1P**	**E-2P**	**E-3P**	**E-3P2**	**E-3P3**	**E-4P**	**E-5P1**	**E-6P1**
Parameter	**Class I**	**Class II**	**Class III**	ITAS 2005; EU 1998; WHO 2011	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**
As	0.02	0.05	>0.05	0.01	0.008	0.004	-0.001	-0.001	-0.001	0.006	0.010	● 0.026
B	1	1	>1	1	0.37	● 54.04	0.09	-0.04	● 8.34	● 29.46	0.24	0.61
Ba	1	2	>2	1.3	0.22	0.03	-0.04	-0.04	0.11	0.05	0.08	0.10
BOD	4	8	>8		6	3	4	4	-3	4	5	-3
Cd	0.003	0.005	>0.005	0.005	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
CN	0.01	0.05	>0.005	0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.01
Co	0.01	0.02	>0.02		-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
COD	25	50	>50		20	7	11	14	8	13	19	-3
Cr	0.02	0.05	>0.05	0.05	-0.01	0.05	-0.01	0.02	-0.01	-0.01	-0.01	-0.01
Cu	0.02	0.05	>0.05	2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1	1.5	>1.5	1.5	0.45	0.86	0.08	0.08	0.05	0.54	0.39	0.35
Hg	0.0001	0.0005	>0.0005	0.001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	0.0003
TKN	0.5	1.5	>1.5		1.4	6.6	1.0	0.6	4.3	5.0	13.4	2.7
NO2				0.5	0.070	0.004	0.290	-0.007	● 0.642	-0.007	0.033	0.043
NO3				50	20.8	0.4	26.8	31.7	15.7	5.8	● 93.9	26.1
N-NO2	0.002	0.01	>0.01	0.15	0.021	0.001	0.088	-0.002	● 0.195	-0.002	0.010	0.013
N-NO3	5	10	>10	11.5	4.69	0.09	6.04	7.16	3.56	1.31	● 21.20	5.88
Ni	0.02	0.05	>0.05	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
P,t	0.02	0.16	>0.16		nm	0.05	nm	nm	nm	nm	nm	nm
Pb	0.01	0.02	>0.02	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	● 0.02
S-2	0.002	0.002	>0.002		0.9	0.9	0.4	0.5	0.8	1.8	0.9	-0.1
Sb				0.005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005
Se	0.01	0.01	>0.01	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Temperature	25	25	>25		15	23	16	16	19	23	16	18
TDS	500	1500	>1500		544	7613	383	380	3045	24312	488	382
TOC	5	8	>8		-2	-2	-2	-2	-2	-2	-2	-2
Zn	0.2	0.5	>0.5		0.01	-0.01	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Pesticides,t	0.001	0.01	>0.01	0.0005	-0.0001	-0.0001	-0.0003	-0.0003	-0.0003	-0.0001	-0.0001	-0.0003
Tri-tetraCE				0.01	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
MBAS	0.05	0.2	>1		-0.01	0.05	-0.05	-0.05	-0.05	0.14	-0.05	-0.05
Coli-f	10	200	>200		0	0	1	4	0	0	0	0
Coli-t	100	20000	>20000	0	● 13.5	● 150	● 30	● 40	● 70	0	● 160	● 120
Alpha ac.	0.5	5	>5	0.1	● 0.314	● 1.0675	0.044	● 0.209	● 0.288	-2.595	● 0.121	● 3.113
Beta ac.	1	10	>10	1	0.6185	● 1.63	0.058	0.129	0.447	-3.417	0.11	● 1.379
				Indicator Parameters								
Al	0.3	0.3	>0.3	0.2	-0.01	0.03	-0.04	-0.04	-0.04	0.05	-0.04	-0.04
Cl	25	200	>200	250	40	● 1487	34	18	● 1343	● 9897	34	17
EC	400	1000	>1000	2500	952	● 11621	635	589	● 4806	● 29733	793	599
Fe	0.3	1	>1	0.2	● 0.45	● 0.86	0.08	0.08	-0.05	● 0.54	● 0.39	● 0.35
Mn	0.1	0.5	>0.5	0.05	-0.01	● 0.22	● 0.07	-0.04	● 0.16	● 0.25	-0.04	-0.04
Na	125	125	>125	200	40	● 1915	35	12	● 580	● 4780	40	26
NH4				0.5	-0.01	● 6.75	-0.26	-0.26	● 4.64	● 31.02	-0.26	-0.26
N-NH4	0.2	1	>1	0.39	0.0	● 5.2	-0.2	-0.2	● 3.6	● 24.1	-0.2	-0.2
O2	8	6	<6	5	● 3.1	● 2.5	8.2	● 4.3	● 1.6	● 0.5	● 3.0	7.6
O2%	90	70	<70		32.9	31.3	nm	40.4	17.1	5.6	33.3	nm
pH	6.5-8.5	6.5-8.5	≤6.5-≥8.5	6.5-8.5	7.61	8.26	8.00	7.60	7.80	7.32	7.48	7.94
Color	5	50	>50		10	6	-5	-5	10	624	-5	5
SO4	200	200	>200	250	93	● 3367	11	7	141	● 411	68	18

Table 6.5 continued

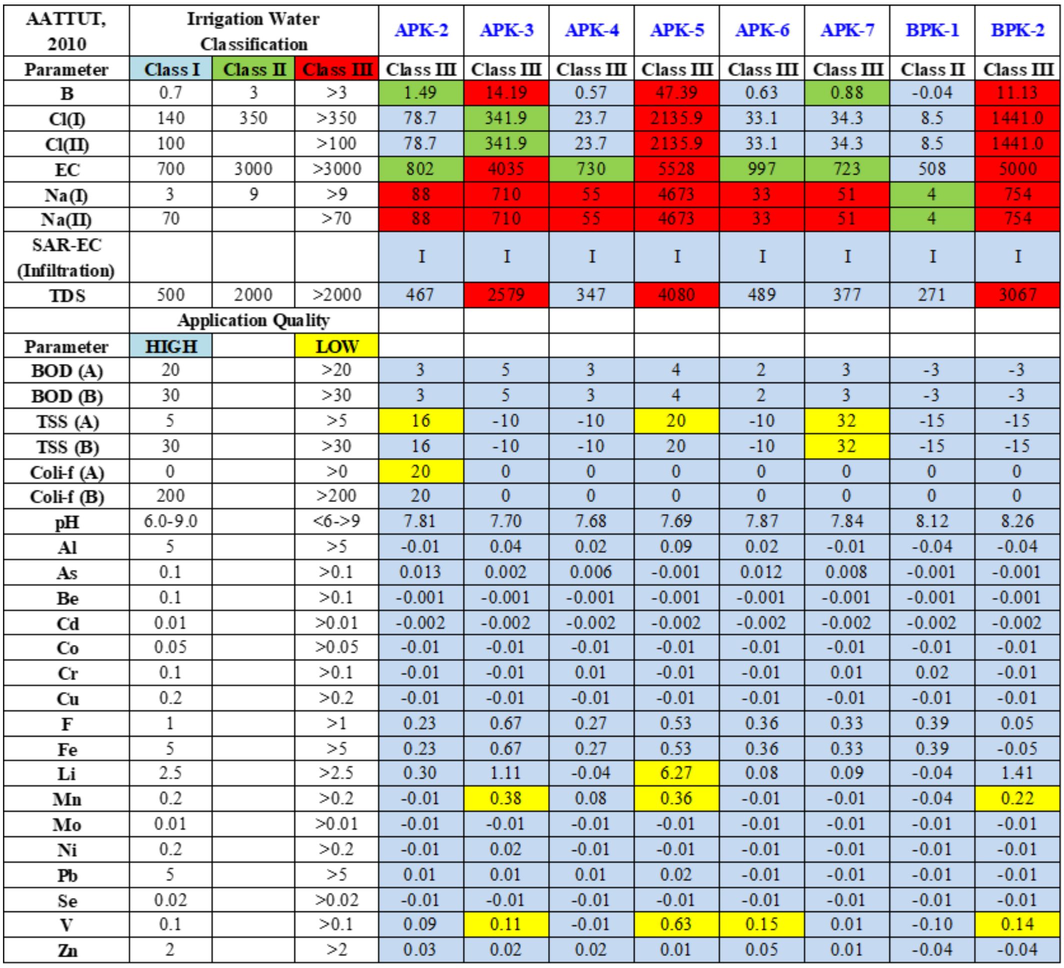
Groundwater	Inland Water Classification			Human Consumption	E-7P	E-8-15P1	E-8-15P2	E-9P1	E-10P1	E-11P1	E-11P2	E-13P
Parameter	**Class I**	**Class II**	**Class III**	ITAS 2005; EU 1998; WHO 2011	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**
As	0.02	0.05	>0.05	0.01	0.004	0.003	0.005	-0.001	0.004	0.002	0.001	● 0.019
B	1	1	>1	1	0.34	0.36	● 19.04	-0.04	0.06	● 1.88	-0.04	0.21
Ba	1	2	>2	1.3	0.11	0.10	-0.04	-0.04	● 8.16	● 1.66	0.75	0.13
BOD	4	8	>8		-3	-3	-3	-3	6	-3	4	5
Cd	0.003	0.005	>0.005	0.005	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
CN	0.01	0.05	>0.005	0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Co	0.01	0.02	>0.02		-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
COD	25	50	>50		-3	6	7	3	22	5	11	17
Cr	0.02	0.05	>0.05	0.05	-0.01	0.01	-0.01	0.01	-0.01	-0.01	0.02	-0.01
Cu	0.02	0.05	>0.05	2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1	1.5	>1.5	1.5	0.23	0.42	1.05	0.05	0.42	0.30	0.05	0.17
Hg	0.0001	0.0005	>0.0005	0.001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	0.0005	-0.0001	-0.0001
TKN	0.5	1.5	>1.5		1.2	2.5	9.4	1.2	3.7	4.1	5.9	2.5
NO2				0.5	0.007	-0.007	-0.007	0.099	0.148	-0.007	-0.007	-0.007
NO3				50	11.7	15.4	0.5	8.3	6.3	-0.1	9.0	-0.1
N-NO2	0.002	0.01	>0.01	0.15	0.002	-0.002	-0.002	0.030	0.045	-0.002	-0.002	-0.002
N-NO3	5	10	>10	11.5	2.63	3.48	0.12	1.87	1.42	-0.01	2.03	-0.01
Ni	0.02	0.05	>0.05	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
P,t	0.02	0.16	>0.16		nm	nm	nm	nm	nm	nm	nm	nm
Pb	0.01	0.02	>0.02	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	● 0.01	-0.01	● 0.01
S-2	0.002	0.002	>0.002		1.1	-0.1	1.5	1.3	4.0	1.3	-0.1	1.6
Sb				0.005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005
Se	0.01	0.01	>0.01	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Temperature	25	25	>25		19	16	23	16	20	31	17	25
TDS	500	1500	>1500		452	777	8239	288	2093	1286	365	293
TOC	5	8	>8		-2	-2	-2	-2	-2	-2	-2	-2
Zn	0.2	0.5	>0.5		-0.04	0.26	0.24	-0.04	-0.04	-0.04	0.07	-0.04
Pesticides,t	0.001	0.01	>0.01	0.0005	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Tri-tetraCE				0.01	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
MBAS	0.05	0.2	>1		0.12	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
Coli-f	10	200	>200		0	0	0	0	0	0	0	0
Coli-t	100	20000	>20000	0	0	0	● 10	● 180	● 200	0	● 70	● 120
Alpha ac.	0.5	5	>5	0.1	● 0.107	0.075	● 1.723	-0.066	● 0.387	● 0.134	● 0.173	-0.06
Beta ac.	1	10	>10	1	0.139	0.065	0.75	-0.072	0.487	-0.119	0.125	-0.069
				Indicator Parameters								
Al	0.3	0.3	>0.3	0.2	-0.04	-0.04	0.05	-0.04	-0.04	-0.04	-0.04	-0.04
Cl	25	200	>200	250	23	28	● 2065	4	128	● 607	29	46
EC	400	1000	>1000	2500	749	736	● 10819	529	● 2767	2496	614	496
Fe	0.3	1	>1	0.2	● 0.23	● 0.42	● 1.05	-0.05	● 0.42	● 0.30	-0.05	0.17
Mn	0.1	0.5	>0.5	0.05	-0.04	-0.04	● 0.17	-0.04	● 0.05	-0.04	-0.04	-0.04
Na	125	125	>125	200	3	44	● 1564	3	● 282	● 523	8	76
NH4				0.5	-0.26	-0.26	● 6.55	-0.26	-0.26	● 1.24	-0.26	-0.26
N-NH4	0.2	1	>1	0.39	-0.2	-0.2	● 5.1	-0.2	-0.2	● 1.0	-0.2	-0.2
O2	8	6	<6	5	● 4.0	6.6	● 3.3	6.0	● 1.9	● 1.0	5.8	● 2.3
O2%	90	70	<70		46.6	76.2	43.4	66.8	23.6	17.6	66.1	32.3
pH	6.5-8.5	6.5-8.5	≤6.5-≥8.5	6.5-8.5	7.65	7.94	7.61	7.88	7.59	8.26	8.05	8.33
Color	5	50	>50		-5	-5	-5	-5	-5	-5	-5	-5
SO4	200	200	>200	250	59	23	● 2706	4	● 1093	5	23	1

Table 6.5 continued

Groundwater	Inland Water Classification			Human Consumption	E-13P2	E-14P1	E-14P2	E-16P1	E-17P2	E-17P3	E-18P1	E-20P1
Parameter	**Class I**	**Class II**	**Class III**	ITAS 2005; EU 1998; WHO 2011	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**	**Class III**
As	0.02	0.05	>0.05	0.01	0.001	0.002	0.003	0.004	0.005	-0.001	-0.001	0.002
B	1	1	>1	1	-0.04	0.52	0.43	0.47	● 3.48	-0.04	0.10	0.09
Ba	1	2	>2	1.3	0.04	0.07	0.05	0.11	-0.04	-0.04	0.07	0.06
BOD	4	8	>8		4	5	5	-3	-3	-3	5	5
Cd	0.003	0.005	>0.005	0.005	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
CN	0.01	0.05	>0.005	0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Co	0.01	0.02	>0.02		-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
COD	25	50	>50		12	12	11	10	-3	9	15	17
Cr	0.02	0.05	>0.05	0.05	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cu	0.02	0.05	>0.05	2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1	1.5	>1.5	1.5	0.05	0.31	0.34	0.31	0.05	0.05	0.12	0.06
Hg	0.0001	0.0005	>0.0005	0.001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
TKN	0.5	1.5	>1.5		0.6	9.0	3.7	1.8	0.8	1.0	3.4	2.3
NO2				0.5	-0.007	0.046	0.007	0.033	0.066	-0.007	0.007	0.043
NO3				50	6.9	45.0	47.4	11.5	6.2	1.0	21.5	5.6
N-NO2	0.002	0.01	>0.01	0.15	-0.002	0.014	0.002	0.010	0.020	-0.002	0.002	0.013
N-NO3	5	10	>10	11.5	1.56	10.15	10.69	2.59	1.39	0.23	4.85	1.27
Ni	0.02	0.05	>0.05	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
P,t	0.02	0.16	>0.16		nm	nm	nm	nm	nm	nm	nm	nm
Pb	0.01	0.02	>0.02	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	● 0.01	-0.01	-0.01
S-2	0.002	0.002	>0.002		0.8	1.0	0.8	-0.1	0.7	0.8	0.5	0.6
Sb				0.005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005
Se	0.01	0.01	>0.01	0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Temperature	25	25	>25		18	18	17	19	23	17	15	18
TDS	500	1500	>1500		278	600	576	634	1807	291	343	472
TOC	5	8	>8		-2	2	-2	-2	-2	-2	-2	-2
Zn	0.2	0.5	>0.5		-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	0.26	-0.04
Pesticides,t	0.001	0.01	>0.01	0.0005	-0.0003	-0.0003	-0.0003	-0.0001	-0.0003	-0.0003	-0.0003	-0.0001
Tri-tetraCE				0.01	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
MBAS	0.05	0.2	>1		-0.05	-0.05	-0.05	0.05	-0.05	-0.05	-0.05	-0.05
Coli-f	10	200	>200		0	0	1	0	0	0	0	0
Coli-t	100	20000	>20000	0	● 60	0	● 1	0	0	● 70	● 60	● 30
Alpha ac.	0.5	5	>5	0.1	● 0.116	0.054	-0.114	● 0.189	● 0.516	0.062	0.099	0.06
Beta ac.	1	10	>10	1	-0.137	-0.069	-0.128	0.081	0.204	-0.067	-0.063	-0.072
				Indicator Parameters								
Al	0.3	0.3	>0.3	0.2	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Cl	25	200	>200	250	9	64	59	29	● 602	1	17	18
EC	400	1000	>1000	2500	452	1023	918	897	● 2805	918	547	705
Fe	0.3	1	>1	0.2	-0.05	● 0.31	● 0.34	● 0.31	-0.05	-0.05	0.12	0.06
Mn	0.1	0.5	>0.5	0.05	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Na	125	125	>125	200	5	76	71	55	● 353	1	17	19
NH4				0.5	-0.26	-0.26	-0.26	● 1.21	-0.26	-0.26	-0.26	-0.26
N-NH4	0.2	1	>1	0.39	-0.2	-0.2	-0.2	● 0.9	-0.2	-0.2	-0.2	-0.2
O2	8	6	<6	5	● 3.1	● 4.5	● 4.4	● 3.2	● 1.6	● 4.4	5.3	● 4.2
O2%	90	70	<70		36.1	51.6	57.2	34.6	22.2	57.2	58.7	43.1
pH	6.5-8.5	6.5-8.5	≤6.5-≥8.5	6.5-8.5	8.34	7.67	7.52	7.79	8.01	7.52	7.65	7.46
Color	5	50	>50		14	8	10	-5	-5	8	8	-5
SO4	200	200	>200	250	4	18	18	130	● 258	6	8	30

BPK-1, E-7P, E-9P1, E-11P2, E-13P2 and E-17P3 well waters are suitable for surface irrigation of low-intermediate hazardous (Class II) quality Table 6.4. All other well waters contain hazardous quality (Class III) water in terms of surface irrigation, but APK-3, APK-4, APK-6, BPK-1, BPK-2, E-1P, E-3P, E-3P2, E-5P1, E-6P1, E-10P1, E-11P1, E-13P, E-13P2, E-14P1, E-16P1, E-17P2, E-17P3, E-18P1, and E-20P1 waters are in Class-A category and suitable for drip irrigation. The parameters defining low irrigation water quality are listed in Table 6.4.

Table 6.6 Irrigation water classification of well waters



AATTUT, 2010	Irrigation Water Classification			APK-2	APK-3	APK-4	APK-5	APK-6	APK-7	BPK-1	BPK-2
Parameter	**Class I**	**Class II**	**Class III**	Class III	Class III	Class III	Class III	Class III	Class III	Class II	Class III
B	0.7	3	>3	1.49	14.19	0.57	47.39	0.63	0.88	-0.04	11.13
Cl(I)	140	350	>350	78.7	341.9	23.7	2135.9	33.1	34.3	8.5	1441.0
Cl(II)	100		>100	78.7	341.9	23.7	2135.9	33.1	34.3	8.5	1441.0
EC	700	3000	>3000	802	4035	730	5528	997	723	508	5000
Na(I)	3	9	>9	88	710	55	4673	33	51	4	754
Na(II)	70		>70	88	710	55	4673	33	51	4	754
SAR-EC (Infiltration)				I	I	I	I	I	I	I	I
TDS	500	2000	>2000	467	2579	347	4080	489	377	271	3067
	Application Quality										
Parameter	**HIGH**		**LOW**								
BOD (A)	20		>20	3	5	3	4	2	3	-3	-3
BOD (B)	30		>30	3	5	3	4	2	3	-3	-3
TSS (A)	5		>5	16	-10	-10	20	-10	32	-15	-15
TSS (B)	30		>30	16	-10	-10	20	-10	32	-15	-15
Coli-f (A)	0		>0	20	0	0	0	0	0	0	0
Coli-f (B)	200		>200	20	0	0	0	0	0	0	0
pH	6.0-9.0		<6->9	7.81	7.70	7.68	7.69	7.87	7.84	8.12	8.26
Al	5		>5	-0.01	0.04	0.02	0.09	0.02	-0.01	-0.04	-0.04
As	0.1		>0.1	0.013	0.002	0.006	-0.001	0.012	0.008	-0.001	-0.001
Be	0.1		>0.1	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Cd	0.01		>0.01	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
Co	0.05		>0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cr	0.1		>0.1	-0.01	-0.01	0.01	-0.01	-0.01	0.01	0.02	-0.01
Cu	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1		>1	0.23	0.67	0.27	0.53	0.36	0.33	0.39	0.05
Fe	5		>5	0.23	0.67	0.27	0.53	0.36	0.33	0.39	-0.05
Li	2.5		>2.5	0.30	1.11	-0.04	6.27	0.08	0.09	-0.04	1.41
Mn	0.2		>0.2	-0.01	0.38	0.08	0.36	-0.01	-0.01	-0.04	0.22
Mo	0.01		>0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Ni	0.2		>0.2	-0.01	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Pb	5		>5	0.01	0.01	0.01	0.02	-0.01	-0.01	-0.01	-0.01
Se	0.02		>0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
V	0.1		>0.1	0.09	0.11	-0.01	0.63	0.15	0.01	-0.10	0.14
Zn	2		>2	0.03	0.02	0.02	0.01	0.05	0.01	-0.04	-0.04

(Unit; EC: µS/cm, Coliform: cfu/100 mL, are units of the other parameters are mg/l. Detection limits are shown as minus.)

Table 6.6 continued

AATTUT, 2010	Irrigation Water Classification			E-1P	E-2P	E-3P	E-3P2	E-3P3	E-4P	E-5P1	E-6P1
Parameter	Class I	Class II	Class III	Class III	Class III	Class III	Class III	Class III	Class III	Class III	Class III
B	0.7	3	>3	0.37	54.04	0.09	-0.04	8.34	29.46	0.24	0.61
Cl(I)	140	350	>350	39.7	1487.2	34.1	18.3	1343.0	9897.0	33.9	17.4
Cl(II)	100		>100	39.7	1487.2	34.1	18.3	1343.0	9897.0	33.9	17.4
EC	700	3000	>3000	952	11621	635	589	4806	29733	793	599
Na(I)	3	9	>9	40	1915	35	12	580	4780	40	26
Na(II)	70		>70	40	1915	35	12	580	4780	40	26
SAR-EC (Infiltration)				I	I	I	I	I	I	I	I
TDS	500	2000	>2000	544	7613	383	380	3045	24312	488	382
	Application Quality										
Parameter	HIGH		LOW								
BOD (A)	20		>20	6	3	4	4	-3	4	5	-3
BOD (B)	30		>30	6	3	4	4	-3	4	5	-3
TSS (A)	5		>5	-10	19	16	15	28	88	-15	-15
TSS (B)	30		>30	-10	19	16	15	28	88	-15	-15
Coli-f (A)	0		>0	0	0	1	4	0	0	0	0
Coli-f (B)	200		>200	0	0	1	4	0	0	0	0
pH	6.0-9.0		<6->9	7.61	8.26	8.00	7.60	7.80	7.32	7.48	7.94
Al	5		>5	-0.01	0.03	-0.04	-0.04	-0.04	0.05	-0.04	-0.04
As	0.1		>0.1	0.008	0.004	-0.001	-0.001	-0.001	0.006	0.010	0.026
Be	0.1		>0.1	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Cd	0.01		>0.01	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
Co	0.05		>0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cr	0.1		>0.1	-0.01	0.05	-0.01	0.02	-0.01	-0.01	-0.01	-0.01
Cu	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1		>1	0.45	0.86	0.08	0.08	0.05	0.54	0.39	0.35
Fe	5		>5	0.45	0.86	0.08	0.08	-0.05	0.54	0.39	0.35
Li	2.5		>2.5	0.11	5.24	-0.04	-0.04	1.31	1.79	0.07	0.26
Mn	0.2		>0.2	-0.01	0.22	0.07	-0.04	0.16	0.25	-0.04	-0.04
Mo	0.01		>0.01	-0.01	0.35	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Ni	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Pb	5		>5	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.02
Se	0.02		>0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
V	0.1		>0.1	0.13	0.24	-0.10	-0.10	0.20	0.25	-0.10	-0.10
Zn	2		>2	0.01	-0.01	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04

Table 6.6 continued

AATTUT, 2010	Irrigation Water Classification			E-7P	E-8-15P1	E-8-15P2	E-9P1	E-10P1	E-11P1	E-11P2	E-13P
Parameter	**Class I**	**Class II**	**Class III**	**Class II**	**Class III**	**Class III**	**Class II**	**Class III**	**Class III**	**Class II**	**Class III**
B	0.7	3	>3	0.34	0.36	19.04	-0.04	0.06	1.88	-0.04	0.21
Cl(I)	140	350	>350	23.1	27.7	2065.0	3.6	128.2	606.7	29.3	46.3
Cl(II)	100		>100	23.1	27.7	2065.0	3.6	128.2	606.7	29.3	46.3
EC	700	3000	>3000	749	736	10819	529	2767	2496	614	496
Na(I)	3	9	>9	3	44	1564	3	282	523	8	76
Na(II)	70		>70	3	44	1564	3	282	523	8	76
SAR-EC (Infiltration)				I	I	I	I	I	I	I	II
TDS	500	2000	>2000	452	777	8239	288	2093	1286	365	293
	Application Quality										
Parameter	**HIGH**		**LOW**								
BOD (A)	20		>20	-3	-3	-3	-3	6	-3	4	5
BOD (B)	30		>30	-3	-3	-3	-3	6	-3	4	5
TSS (A)	5		>5	-15	106	16	-15	-15	-15	207	-15
TSS (B)	30		>30	-15	106	16	-15	-15	-15	207	-15
Coli-f (A)	0		>0	0	0	0	0	0	0	0	0
Coli-f (B)	200		>200	0	0	0	0	0	0	0	0
pH	6.0-9.0		<6->9	7.65	7.94	7.61	7.88	7.59	8.26	8.05	8.33
Al	5		>5	-0.04	-0.04	0.05	-0.04	-0.04	-0.04	-0.04	-0.04
As	0.1		>0.1	0.004	0.003	0.005	-0.001	0.004	0.002	0.001	0.019
Be	0.1		>0.1	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Cd	0.01		>0.01	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
Co	0.05		>0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cr	0.1		>0.1	-0.01	0.01	-0.01	0.01	-0.01	-0.01	0.02	-0.01
Cu	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1		>1	0.23	0.42	1.05	0.05	0.42	0.30	0.05	0.17
Fe	5		>5	0.23	0.42	1.05	-0.05	0.42	0.30	-0.05	0.17
Li	2.5		>2.5	-0.04	-0.04	4.62	-0.04	0.82	0.44	-0.04	0.11
Mn	0.2		>0.2	-0.04	-0.04	0.17	-0.04	0.05	-0.04	-0.04	-0.04
Mo	0.01		>0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Ni	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Pb	5		>5	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	-0.01	0.01
Se	0.02		>0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
V	0.1		>0.1	-0.10	-0.10	0.52	-0.10	0.14	-0.10	-0.10	-0.10
Zn	2		>2	-0.04	0.26	0.24	-0.04	-0.04	-0.04	0.07	-0.04

Table 6.6 continued

AATTUT, 2010	Irrigation Water Classification			E-13P2	E-14P1	E-14P2	E-16P1	E-17P2	E-17P3	E-18P1	E-20P1
Parameter	**Class I**	**Class II**	**Class III**	**Class II**	**Class III**	**Class III**	**Class III**	**Class III**	**Class II**	**Class III**	**Class III**
B	0.7	3	>3	-0.04	0.52	0.43	0.47	3.48	-0.04	0.10	0.09
Cl(I)	140	350	>350	9.5	63.9	58.9	29.2	601.6	1.4	16.5	18.4
Cl(II)	100		>100	9.5	63.9	58.9	29.2	601.6	1.4	16.5	18.4
EC	700	3000	>3000	452	1023	918	897	2805	918	547	705
Na(I)	3	9	>9	5	76	71	55	353	1	17	19
Na(II)	70		>70	5	76	71	55	353	1	17	19
SAR-EC (Infiltration)				I	I	I	I	I	I	I	I
TDS	500	2000	>2000	278	600	576	634	1807	291	343	472
	Application Quality										
Parameter	**HIGH**		**LOW**								
BOD (A)	20		>20	4	5	5	-3	-3	-3	5	5
BOD (B)	30		>30	4	5	5	-3	-3	-3	5	5
TSS (A)	5		>5	-15	-15	42	-15	-15	-15	-15	-15
TSS (B)	30		>30	-15	-15	42	-15	-15	-15	-15	-15
Coli-f (A)	0		>0	0	0	1	0	0	0	0	0
Coli-f (B)	200		>200	0	0	1	0	0	0	0	0
pH	6.0-9.0		<6->9	8.34	7.67	7.52	7.79	8.01	7.52	7.65	7.46
Al	5		>5	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
As	0.1		>0.1	0.001	0.002	0.003	0.004	0.005	-0.001	-0.001	0.002
Be	0.1		>0.1	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Cd	0.01		>0.01	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
Co	0.05		>0.05	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cr	0.1		>0.1	0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Cu	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
F	1		>1	0.05	0.31	0.34	0.31	0.05	0.05	0.12	0.06
Fe	5		>5	-0.05	0.31	0.34	0.31	-0.05	-0.05	0.12	0.06
Li	2.5		>2.5	-0.04	-0.04	-0.04	0.08	0.60	-0.04	-0.04	-0.04
Mn	0.2		>0.2	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
Mo	0.01		>0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Ni	0.2		>0.2	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
Pb	5		>5	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	-0.01	-0.01
Se	0.02		>0.02	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
V	0.1		>0.1	-0.10	0.10	0.10	-0.10	0.11	0.12	-0.10	-0.10
Zn	2		>2	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	0.26	-0.04

Irrigation water quality distribution and infiltration effects according to SAR and EC values are shown in Figure 6.2. In terms of SAR and EC values: very high sodium – very high salinity hazard in BPK-2, E-2P and E-8-15P2 waters; high sodium - very high salinity hazard in APK-3, E-3P3 and E-17P2 waters; medium sodium – very high salinity hazard in only E-10P1 water; low sodium - medium salinity hazard in APK-6, E-1P, E-14P1, E-14P2 and E-16P1 waters; and low sodium - medium salinity hazard in the rest of well waters. APK-2 and E-13P well waters have slightly to moderate reduction effect in the rate of infiltration while the others have properties that will not cause a reduction in the rate of infiltration.

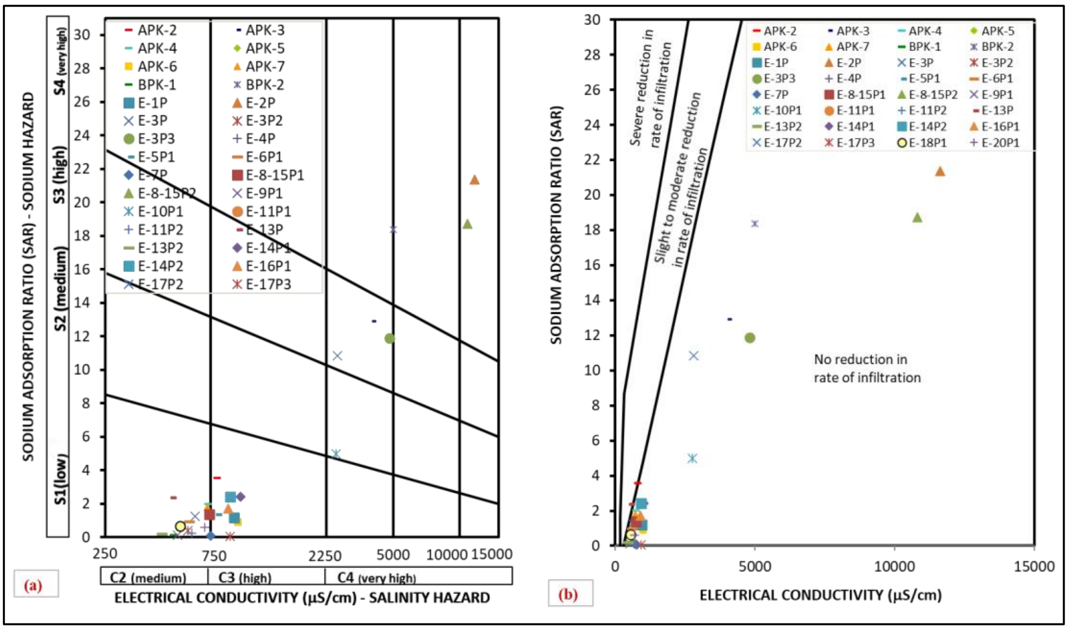


Figure 6.2. (a) Quality distribution and (b) Irrigation infiltration effects of well waters according to SAR, % Na and EC values.

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary and Conclusions

The bedrock includes Paleozoic metamorphics, Mesozoic ultramafics and in between Mesozoic ophiolites. Miocene sediments unconformably overlie the bedrock and consist of conglomerate, sandstone and claystone units at the bottom. Overlying this part in the middle levels (where coal levels are present), from bottom to top; claystone, sandstone, bituminous shale and claystone-sandstone-conglomerate successions are present. Miocene units are unconformably overlaid by Pliocene aged mudstone and loose conglomerate-sandstone levels. Quaternary alluvium consists of clay levels including compactly attached, gravel and sand grains.

According to the monthly conceptual water budget for the plain area, annual precipitation of 380.5 mm is transformed into 306.2 mm of evapotranspiration, 19.7 mm of surface runoff, 67.2 mm of surplus and -28.5 mm of soil moisture.

Geological information suggests that the springs are discharged at the contacts along the NE-SW trending faults between Quaternary alluvium and Mesozoic ophiolites or between Miocene m1 series and alluvium unit.

Hydraulic conductivity values of the aquifers decrease in a sequence of Quaternary alluvium, Pliocene, Miocene and basement rocks. The most water bearing formations are Quaternary alluvium and Pliocene limestones, sandstones and conglomerates. Groundwater flow in the study area is generally from North to South towards Porsuk Creek.

Quality control measurements indicate that the errors associated with EC, DO, pH and ORP measurements are 2.68 %, 1.21 %, 0.50 % and 5.01 %, respectively. The average value of ion concentration errors is about 5.2 %. The average ion charge balance error of all measurements is about 5.6 %. The sampling method evaluations in terms of groundwater representativeness covering the effects of filtration and the effects of pended well water suggest that the sampling can be done in waters with less than 15 mg/l in TSS value without filtering in subsequent studies and the wells should be purged prior to the sampling for the representative formation water.

EC, pH, DO and ORP average value ranges of the spring and fountain waters are determined as 438-1227 µS/cm 7.43-8.69, 3.29-6.05 mg/l and 106-180 mv, respectively. All spring waters in the study area are in HCO3 facies in terms of anion content. In terms of cation content Mg, Mix(Ca-Mg) and Ca facies at nearby Mg boundary are observed.

Average groundwater temperature increases with increasing depth between 14.2°C and 37.2°C. EC, pH, DO and ORP average values of the well waters vary within the intervals of 452-30233 µS/cm, 7.46-8.48, 0.6-6.0 mg/l and 198- -183 mv, respectively. Decreasing EC values upon increasing Pl or MAC unit thickness or increasing EC values upon increasing Al unit thickness in Al+Pl and Al+MAC well waters suggest that the alluvium groundwater contains greater TDS in comparison to the upper level groundwaters of Pliocene and Miocene units. In general EC values of MAC groundwater is higher than that of Pl groundwater. In addition, EC values of Pl and MAC groundwaters increase as the wells deepens. Very high EC values of E-4P well water is related to groundwater of MBC and/or Melange units.

Major ion chemistry of groundwaters in the study area stratigraphically downward: according to the anion content, change in the order of HCO3 → SO4 → Cl and according to the cation content, change in the order of Mg → Mix → Na while Ca remains nearly constant Na increases upon Mg decrease. Ammonia concentrations (5-24 mg/l) in deep groundwaters filtered about greater than 300 m depths are much higher than the expected value (< 0.2 mg/l).

In general, the chloride values of groundwater decrease from surface to approximately 100 m depth but increase stratigraphically from 100 m depth to the basement rocks (Pliocene aquifer → Miocene aquifer → Basement aquifer). Chloride concentrations of groundwater in alluvium unit are higher than those of groundwaters in the underlying Pliocene and MAC-upper levels. Chloride concentrations of groundwaters in MAC +/- Pl units (having well bottom depth of 350-500 m) increase with increasing filtered Miocene unit thickness. Sulphate concentrations of these groundwaters are also very high. Coal level groundwater chemistry bears local differences. Chloride concentration of the deepest free flow well (E-4P) water is much higher than those of all sampled groundwaters filtering MAC+CH units. However, all other well waters filtering MAC + CH units also include very high sulphate concentrations in addition to the high chloride concentrations contrary to the relatively low sulphate content of E-4P well water.

The temperature evaluations indicate that the *advective mass transport* from *thermal water* at deeper aquifer(s) to the bottom of E-4P well units (MBC + Mélange) is not operative. On the other hand, only diffusive transport related mixing-time requirement investigations indicate that the possible mixing of 45% cannot be explained by diffusive transport only. Hence, the inferred mixing processes, if occurred must have been taken place at much deeper locations in the form of flux flow. But there is not enough data to investigate such processes. Yet the basement groundwater characteristics could also be reflecting its unmixed natural in situ properties.

Mixing and only diffusive transport related time requirement investigations carried out to obtain the chloride distribution observed in the Miocene and Pliocene units from the MBC + basement upward suggest that the inferred possible mixing if occurred, needs an advective mass flux. But there is no observation suggesting such flux occurrences between the basement aquifer groundwater and those of the overlying units. Upward mass transport in deep aquifers could only be possible under very low upward flow and dispersion conditions. Groundwater characteristics in the units above the MBC + basement represent mixing free natural in situ properties.

The chemical characteristics of Pliocene, MAC and MBC + Mélange deep groundwaters are related to the hydrogeochemical evolution processes of deep sedimentary basin groundwaters under water-rock reaction relationships accompanied by very low permeability related ion filtration effect and local diffusive/dispersive transport enrichment.

Saturation index calculations indicate that Al + Pl filtering and only Pliocene filtering well waters are supersaturated with respect to Ca, Mg carbonate and silica minerals. Additionally, hydroxide group mineral components are also supersaturated. Only shallow level (< 100 m) Miocene unit filtering well waters in addition to the above components are supersaturated with respect to Fe-hydroxide and oxide mineral components as well. Supersaturation of Pl + Miocene filtrating deep (> 100 m) groundwaters are similar to the shallow Miocene groundwaters. On the other hand, MAC + CH filtering deeper groundwaters are additionally supersaturated with respect to the greater number of hydroxide mineral components including different clay group minerals suggesting greater influence of exchange reactions.

When the concentration values are evaluated according to the inland groundwater criteria; all spring and fountain waters contain low quality groundwater due to their high B/TKN/S^{-2}/NO_3/N-NH_4/EC/pH and low O_2 content. According to the human consumption limits, all spring and fountain waters are suitable except those of F-11, F-12 and F-16. In terms of irrigation water, F-11, F-12, F-13 and F-15 spring and fountain waters are hazardous and F14, F16 and F-17 waters are low-intermediate hazardous for surface irrigation due to high Na concentrations, but they can be used for the drip irrigation.

All well waters contain low quality groundwater due to high concentrations of B/Ba/TKN/N-NO_2/N-NO_3/S^{-2}/TDS parameters. According to the concentrations in the wells, E-8-15P1, E-14P1, APK-7, BPK-1, E-1P, E-3P, E-3P2, E-7P, E-9P1, E-11P2, E-13P2, E-14P2, E-16P1, E-18P1 and E-20P1waters are suitable for human consumption if bacterial and radioactive parameters are excluded. BPK-1, E-7P, E-9P1, E-11P2, E-13P2 and E-17P3 well waters are suitable for surface irrigation of low-intermediate hazardous quality. All the other well waters contain hazardous quality water in terms of surface irrigation, but APK-3, APK-4, APK-6, BPK-1, BPK-2, E-1P, E-3P, E-3P2, E-5P1, E-6P1, E-10P1, E-11P1, E-13P, E-13P2, E-14P1, E-16P1, E-17P2, E-17P3, E-18P1 and E-20P1 waters are in Class-A category and suitable for the drip irrigation.

7.2 Recommendations

- To clarify the assessment on the interaction of above-coal aquifers (Miocene unit aquifer and Pliocene unit aquifer) with geothermal reservoir and in order to determine characteristics of below coal level Miocene units and basement aquifer, further investigations should be carried out.
- Flow relationships between Porsuk Creek and aquifers should be investigated in order to delineate the chemical interactions.
- Anomalous ammonia concentrations at deeper aquifers require special investigation in terms of source and possible consequences of nitrogen gas presence in the coal horizons for the mine operation.
- Acid rock drainage characteristics of the coal horizons and potential waste rocks should be investigated to avoid possible environmental effects in future.
- Chemical characteristics of the water bearing units depth wise should be determined from those wells which are closely located to each other in order to further clarify ionic interaction relationships.

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APPENDICES

APPENDIX -A Duplicate data

Table A1. Laboratory results of duplicate samples. Unit: mg/l

SAMPLE	F6	W3	F6	Y2	E-3P2	CPK-1	APK-4	CPK-2	E-11P1	CPK-3
DATE	Jun-16	Jun-16	Oct-16	Oct-16	May-17	May-17	Jun-17	Jun-17	Aug-17	Aug-17
Ag	<0.010	<0.010	<0.010	<0.010	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Al	0.015	0.018	<0.010	<0.010	<0.040	<0.040	<0.040	<0.040	<0.040	<0.040
Alk.(t)	230	220	200	225	297	254	279	276	216	217
As	<0.010	<0.010	<0.010	<0.010	<0.001	<0.001	0.006	0.006	0.002	0.002
B	0.08	0.09	0.08	0.07	<0.04	<0.04	0.52	0.54	1.88	1.83
Ba	0.05	0.05	0.06	0.06	<0.04	<0.04	0.12	0.12	1.66	1.73
Be	<0.010	<0.010	<0.010	<0.010	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BOD	2.2	2.5	2.2	2.8	4.0	3.8	<3.0	<3.0	<3.0	<3.0
Ca	39	36	21	20	62	57	39	49	14	28
Cd	<0.003	<0.003	<0.003	<0.003	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cl	4	4	4	4	18	18	24	25	607	611
CN (Weak Acid)	<0.02	<0.02	<0.02	<0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD	10	13	12	9	14	10	6	<3	5	<3
Color	4	7	20	18	<5	<5	<5	<5	<5	<5
Cr	<0.01	<0.01	<0.01	<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
F	0.29	0.27	0.29	0.29	0.08	0.08	0.28	0.25	0.30	0.46
Fe	0.02	0.02	<0.01	<0.01	<0.04	<0.04	<0.04	<0.04	0.08	0.08
P,reac	<0.01	<0.01	<0.06	<0.06	<0.02	<0.02	0.05	0.05	0.03	0.04
Hg	<0.0010	<0.0010	<0.0010	<0.0010	<0.0001	<0.0001	<0.0001	<0.0001	0.0005	<0.0001
K	0.5	0.5	0.4	0.5	0.5	0.6	2.5	2.5	5.8	5.7
Li	<0.05	<0.05	<0.05	0.05	<0.04	<0.04	<0.04	<0.04	0.44	0.46
Mg	28	27	31	29	54	41	40	45	14	31
Mn	<0.01	<0.01	<0.01	<0.01	<0.04	<0.04	<0.04	0.25	<0.04	<0.04
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TKN	<0.5	<0.5	<0.5	<0.5	1	1	2	3	4	2
N(Org)	<0.5	<0.5	<0.5	<0.5	1	1	2	3	5	2
Na	3.5	3.5	1.6	1.6	12.3	15.1	54.6	67.3	522.5	548.5
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH4	<0.01	<0.01	<0.01	<0.01	<0.26	<0.26	0.27	<0.26	1.24	<0.26
NO2	<0.003	<0.003	0.145	0.125	<0.007	0.043	<0.007	<0.007	<0.007	<0.007
NH3	<0.01	<0.01	<0.01	<0.01	<0.23	<0.23	0.24	<0.23	1.10	<0.23
NO3	17.2	17.3	11.9	11.3	31.7	30.4	17.5	17.8	<0.1	0.1
P(t)	0.02	0.02	0.04	0.04	<0.02	<0.02	0.03	0.11	0.04	0.07
Pb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	0.01
P	0.02	0.02	<0.05	<0.05	<0.02	<0.02	0.03	0.11	0.04	0.07
Sb	<0.005	<0.005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Se	<0.005	<0.005	<0.005	<0.005	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Si	7	7	7	7	13	13	19	19	13	13
Sn	<0.05	<0.05	<0.05	<0.05	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
SO4	11	11	9	9	7	7	52	58	5	7
S-2	<0.1	<0.1	<0.1	<0.1	0.5	0.9	1.4	1.6	1.3	0.6
Sr	0.4	0.4	0.5	0.5	0.3	0.3	0.4	0.4	0.5	0.6
TDS	178	180	156	168	380	363	408	429	1286	1278
Ti	<0.01	<0.01	<0.01	<0.01	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Tl	<0.05	<0.05	0.06	0.11	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
TSS	<10	<10	<10	<10	15	16	<15	<15	<15	<15
U	-	-	0.001	0.001	0.001	0.001	0.002	0.002	<0.001	<0.001
V	<0.01	<0.01	0.08	0.08	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Trichlorethylene	<0.0050	<0.0050	<0.0050	<0.0050	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Tetrachlorethylene	<0.0050	<0.0050	<0.0050	<0.0050	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zn	0.02	0.02	<0.01	<0.01	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

APPENDIX -B Field parameters

Table B1. Field parameter measurements of spring and fountain waters

ID	DATE	T(°C)	pH	ORP (mv)	EC (µS/cm)	EC 25°C(µS/cm)	S(%0)	TDS (mg/l)	DO (mg/l)	DO%	Q (l/sec)
F-11	May-17	12.6	7.78	109	922	1226	0.61	796	3.4	37.2	0.66
	Jun-17	14.5	7.59	131	965	1222	0.60	794	4.3	46.7	1.25
	Jul-17	15.9	7.60	79	1033	1263	0.63	820	4.2	48.3	1.00
	Aug-17	17.2	7.81	77	1036	1227	0.61	797	4.4	49.0	1.04
	Sep-17	18.0	7.69	107	1040	1209	0.60	786	4.1	46.9	0.89
	Oct-17	16.4	7.75	103	1014	1225	0.61	796	4.1	46.5	1.03
	Nov-17	14.2	7.73	128	954	1217	0.60	790	4.3	48.1	1.10
	Dec-17	14.1	7.82	136	959	1226	0.61	797	4.2	46.4	1.00
F-12	May-17	15.2	7.47	127	764	950	0.47	617	2.1	22.6	1.50
	Jun-17	18.7	7.33	114	815	932	0.46	606	1.7	22.4	0.60
	Jul-17	27.5	7.29	102	914	870	0.43	566	3.7	50.5	0.03
	Aug-17	26.8	7.42	118	915	883	0.44	574	4.7	54.0	0.03
	Sep-17	28.6	7.22	135	1081	1008	0.50	655	3.3	46.4	0.02
	Oct-17	16.6	7.42	99	685	823	0.41	535	4.8	52.1	0.03
	Nov-17	7.7	7.59	135	537	821	0.40	534	5.0	47.1	0.04
	Dec-17	7.0	7.69	146	519	811	0.40	527	5.0	45.3	0.05
F-13	May-17	12.5	8.11	133	423	564	0.28	367	2.5	27.0	1.88
	Jun-17	14.9	7.98	121	479	600	0.29	390	6.0	66.0	3.13
	Jul-17	24.1	7.78	94	590	601	0.29	391	2.9	38.8	0.09
	Aug-17	25.4	7.78	117	615	610	0.30	397	2.5	34.7	0.06
	Sep-17	25.1	7.61	132	603	602	0.29	391	2.5	35.0	0.08
	Oct-17	17.0	7.68	120	306	364	0.18	237	3.0	36.5	0.06
	Nov-17	10.4	7.55	160	418	590	0.29	384	4.0	39.3	0.05
	Dec-17	9.7	7.97	153	405	584	0.29	380	6.0	57.9	0.17
F-14	May-17	12.7	8.10	125	426	565	0.28	368	4.8	50.3	1.00
	Jun-17	15.1	7.99	137	458	571	0.28	371	5.8	62.9	0.97
	Jul-17	-	-	-	-	-	-	-	-	-	-
	Aug-17	-	-	-	-	-	-	-	-	-	-
	Sep-17	-	-	-	-	-	-	-	-	-	-
	Oct-17	-	-	-	-	-	-	-	-	-	-
	Nov-17	-	-	-	-	-	-	-	-	-	-
	Dec-17	11.7	8.13	162	429	584	0.29	380	7.0	70.5	0.35
F-15	May-17	13.0	7.40	145	444	584	0.29	380	2.7	28.3	0.56
	Jun-17	16.3	7.30	125	517	626	0.31	407	3.0	36.8	0.48
	Jul-17	25.6	7.60	128	528	522	0.25	339	3.2	36.6	0.03
	Aug-17	26.6	7.65	130	511	495	0.24	322	4.0	48.1	0.02
	Sep-17	26.6	7.63	144	578	560	0.27	364	4.4	64.4	0.02
	Oct-17	16.6	8.09	129	477	573	0.28	373	5.5	59.4	0.05
	Nov-17	10.8	8.15	135	546	763	0.37	496	5.5	52.9	0.09
	Dec-17	10.4	7.92	140	506	715	0.35	465	4.8	45.9	0.07
F-16	May-17	11.4	8.67	122	326	448	0.22	291	2.6	25.9	3.03
	Jun-17	17.0	8.72	126	363	432	0.21	281	6.5	74.0	2.36
	Jul-17	22.9	8.58	89	429	448	0.22	291	5.6	70.4	2.77
	Aug-17	20.6	8.58	70	660	724	0.36	470	5.5	68.5	2.36
	Sep-17	23.3	8.20	98	730	756	0.37	491	5.2	67.3	1.58
	Oct-17	13.9	8.23	122	573	737	0.36	479	7.0	76.3	1.78
	Nov-17	7.1	8.19	115	433	674	0.33	439	7.9	71.4	1.78
	Dec-17	7.5	8.53	109	335	515	0.25	335	8.0	73.9	2.15
F-17	May-17	13.7	8.69	180	339	438	0.21	285	3.3	35.6	-

Table B2. Field parameter measurements of well waters

ID	DATE	T(°C)	pH	ORP (mv)	EC (µS/cm)	EC 25°C(µS/cm)	S(%0)	TDS (mg/l)	DO (mg/l)	DO%
APK-2	Sep-16	16.7	7.67	153	638	765	0.38	497	2.9	34.0
	Jun-17	16.7	7.94	5	699	838	0.41	545	4.1	45.3
APK-3	Feb-17	19.0	7.74	-2	3100	3523	1.75	2287	3.2	38.0
	Jun-17	21.4	7.66	-103	4220	4547	2.27	2952	2.5	34.5
APK-4	Feb-17	14.1	7.48	143	581	743	0.37	483	3.3	36.0
	Jun-17	16.3	7.89	253	592	717	0.35	466	5.2	55.5
APK-5	Feb-17	20.7	7.75	-134	4280	4683	2.33	3039	4.4	51.8
	Jun-17	23.8	7.63	-128	6220	6373	3.18	4136	2.0	27.3
APK-6	Jan-17	12.7	7.87	121	819	1086	0.54	706	4.5	44.4
	Jun-17	17.5	7.86	23	772	908	0.45	590	3.7	41.6
APK-7	Oct-16	16.2	7.56	120	577	700	0.34	455	4.6	51.1
	Nov-16	14.6	7.94	179	546	690	0.34	449	5.0	57.6
	Jun-17	16.4	7.73	43	626	756	0.37	491	8.2	93.9
BPK-1	Aug-17	17.1	8.12	107	428	508	0.25	331	6.2	73.2
BPK-2	Aug-17	21.3	8.26	90	4630	5000	2.49	3245	2.4	32.5
E-1P	Sep-16	15.1	7.57	166	697	869	0.43	565	2.5	27.5
	Jun-17	14.9	7.65	37	826	1035	0.51	673	3.7	38.3
E-2P	Nov-16	23.0	8.21	-125	10584	11025	5.51	7155	3.4	43.4
	Dec-16	11.3	8.62	-241	8366	11523	5.76	7478	1.1	11.8
	Jan-17	12.4	8.92	-204	9250	12366	6.18	8025	2.8	26.7
	Feb-17	14.2	8.71	-215	9620	12270	6.13	7963	1.6	16.7
	Mar-17	13.4	8.47	-194	9340	12161	6.07	7892	1.7	20.9
	Apr-17	16.1	8.47	-143	9860	11995	5.99	7785	2.3	24.7
	May-17	18.1	8.42	-209	10320	11972	5.98	7770	1.1	12.4
	Jun-17	23.7	8.31	-179	11900	12218	6.10	7929	1.5	19.2
	Jun-17	16.3	8.53	-188	9930	12022	6.00	7802	1.7	17.5
	Jul-17	18.2	8.56	-206	10350	11979	5.98	7774	1.8	20.1
	Aug-17	18.7	8.57	-202	10480	11991	5.99	7782	1.6	18.8
	Sep-17	20.4	8.32	-188	10850	11949	5.97	7755	1.5	17.3
	Oct-17	17.1	8.29	-171	10130	12031	6.01	7808	1.5	17.9
	Nov-17	13.1	8.35	-152	10100	13255	6.62	8602	1.8	17.9
	Dec-17	14.7	8.42	-131	9380	11814	5.90	7667	1.8	17.4
E-3P	May-17	15.7	8.00	13	517	635	0.31	413	-	-
E-3P2	May-17	16.0	7.62	185	483	589	0.29	383	4.3	40.4
E-3P3	May-17	18.9	7.80	-108	4220	4806	2.40	3120	1.6	17.1
E-4P	Nov-16	21.2	7.45	-197	27933	30230	15.11	19617	0.9	10.6
	Dec-16	17.9	7.53	-187	25413	29619	14.80	19221	0.4	3.4
	Jan-17	19.2	7.75	-189	27700	31335	15.66	20334	0.8	7.0
	Feb-17	20.0	7.38	-193	28500	31667	15.83	20549	0.6	7.2
	Mar-17	20.1	7.50	-190	28600	31707	15.85	20576	1.5	10.9
	Apr-17	20.8	7.77	-177	29100	31769	15.88	20615	0.5	5.2
	May-17	23.8	7.33	-183	29100	29816	14.90	19348	0.4	6.6
	Jun-17	23.4	7.32	-198	28900	29855	14.92	19374	0.5	5.6
	Jun-17	23.6	7.32	-198	28900	29733	14.86	19294	0.5	5.6
	Jul-17	24.4	7.49	-203	28900	29251	14.62	18982	0.2	3.4
	Aug-17	24.4	7.41	-201	28800	29150	14.57	18916	0.2	2.7
	Sep-17	24.9	7.24	-193	29100	29158	14.57	18922	0.2	4.5
	Oct-17	22.9	8.18	-165	28400	29645	14.82	19238	0.5	6.0
	Nov-17	20.6	8.09	-130	27600	30263	15.13	19639	0.7	9.6
	Dec-17	21.7	7.65	-130	28300	30300	15.14	19662	0.5	6.3

Table B2. continued

ID	DATE	T(°C)	pH	ORP (mv)	EC (µS/cm)	EC 25°C(µS/cm)	S(%0)	TDS (mg/l)	DO (mg/l)	DO%
E-5P1	Jun-17	16.3	7.48	-8	655	793	0.39	515	3.0	33.3
E-6P1	May-17	17.9	7.94	154	514	599	0.29	390	-	-
E-7P	Jul-17	18.5	7.65	64	652	749	0.37	487	4.0	46.6
E-8-15P1	Jul-17	16.3	7.94	65	608	736	0.36	479	6.6	76.2
E-8-15P2	Aug-17	22.6	7.61	-68	10300	10819	5.40	7022	3.3	43.4
E-9P1	Jun-17	16.2	7.88	25	436	529	0.26	344	6.0	66.8
E-10P1	Jun-17	20.0	7.59	-111	2490	2767	1.38	1796	1.9	23.6
E-11P1	Aug-17	30.7	8.26	-143	2780	2496	1.24	1620	1.0	17.6
E-11P2	Jul-17	16.6	8.05	82	511	614	0.30	399	5.8	66.1
E-13P	Jun-17	24.5	8.33	-73	491	496	0.24	323	2.3	32.3
E-13P2	May-17	17.5	8.34	47	384	452	0.22	294	3.1	36.1
E-14P1	May-17	18.4	7.67	-24	888	1023	0.51	665	4.5	51.6
E-14P2	May-17	17.2	7.52	155	775	918	0.45	597	4.4	57.2
E-16P1	Jul-17	18.7	7.79	29	784	897	0.44	583	3.2	34.6
E-17P2	May-17	22.6	8.01	36	2670	2805	1.40	1821	1.6	22.2
E-17P3	May-17	17.2	7.52	155	775	918	0.45	597	4.4	57.2
E-18P1	May-17	15.8	7.65	11	446	547	0.27	356	5.3	58.7
E-20P1	Jun-17	18.2	7.46	-32	609	705	0.35	458	4.2	43.1

APPENDIX -C Laboratory parameters

Table C1. Laboratory parameter measurements of spring and fountain waters. Unit: mg/l

SAMPLE	F-11	F-12	F-13	F-14	F-15	F-16	F-17
DATE	May-17	May-17	May-17	May-17	May-17	May-17	May-17
Ag	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Al	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Alk.(t)	390	492	268	289	342	253	288
As	0.010	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	1.02	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Ba	0.05	<0.04	<0.04	0.04	0.05	<0.04	<0.04
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BOD	<3	<3	<3	<3	3.20	<3	3.36
Ca	64	73	54	66	76	7	28
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cl	75.96	9.98	7.79	5.39	5.31	1.13	4.94
CN	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD	3	<3	8	<3	10	<3	13
Color	<5	<5	<5	<5	<5	<5	<5
Cr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
F	0.32	0.09	<0.05	0.12	0.23	<0.05	<0.05
Fe	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
P,reac	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.06
Hg	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
K	1.10	0.38	0.60	0.56	0.30	0.36	0.46
Li	0.05	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Mg	84.46	86.80	36.45	33.15	32.76	49.20	66.48
Mn	<0.04	<0.04	<0.04	<0.04	0.09	<0.04	<0.04
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TKN	1.0	2.7	6.6	1.4	1.2	1.5	0.7
N(Org)	1.0	2.7	6.6	1.4	12.6	1.5	0.7
Na	14.67	15.25	9.78	7.68	12.43	3.01	5.28
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH4	-0.26	-0.26	-0.26	-0.26	14.68	-0.26	-0.26
NO2	0.007	-0.007	-0.007	-0.007	-0.007	-0.007	0.007
NH3	-0.23	-0.23	-0.23	-0.23	13.00	-0.23	-0.23
NO3	113.67	-0.05	0.33	1.02	0.66	1.12	10.24
P(t)	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	0.04
Pb	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
P	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	0.037
Sb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Se	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Si	18.7	13.1	9.4	9.7	9.9	17.6	13.8
Sn	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
SO4	29.07	37.08	11.13	11.52	3.71	5.50	12.23
S-2	0.30	1.20	<0.1	1.60	<0.1	1.60	0.20
Sr	0.36	0.25	0.23	0.23	0.30	<0.04	0.09
TDS	497	521	305	304	331	240	371
Ti	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Tl	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
TOC	<2	<2	<2	<2	<2	<2	<2
TSS	<15	<15	<15	<15	<15	<15	88
U	0.00151	0.00108	0.00046	0.00054	0.00043	0.00046	0.00016
V	0.14	0.13	<0.1	<0.1	<0.1	0.12	0.12
Trichlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Tetrachlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zn	0.12	0.11	0.09	0.27	0.42	0.17	<0.04
Coli-f	1	0	2	20	0	25	0
Coli-t	3	0	30	20	0	60	0
Pesticides, t	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003
MBAS	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Alpha-ac	0.09	0.37	0.07	0.09	<0.067	0.09	0.07
Beta-ac	<0.07	<0.14	<0.07	<0.07	<0.07	<0.07	<0.07
Tri-tetraCE	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table C2. Laboratory parameter measurements of well waters. Unit: mg/l

SAMPLE	**APK-2**		**APK-3**		**APK-4**		**APK-5**		**APK-6**	
DATE	Sep-16	Jun-17	Feb-17	Jun-17	Feb-17	Jun-17	Feb-17	Jun-17	Jan-17	Jun-17
Ag	<0.01	<0.005	<0.01	<0.005	<0.01	<0.005	<0.01	<0.005	<0.01	<0.005
Al	<0.01	<0.01	0.03	0.04	0.02	0.02	0.03	0.16	0.02	0.02
Alk.(t)	145	253	295	238	305	279	255	350	430	345
As	0.018	0.009	0.002	0.002	0.006	0.006	<0.001	<0.001	<0.01	0.014
B	1.19	1.79	12.53	15.85	0.62	0.52	48.31	46.47	0.83	0.43
Ba	0.05	0.04	0.05	<0.04	0.13	0.12	0.03	1.25	0.19	0.17
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BOD	3.60	<3	6.07	<3	3.42	<3	2.74	5.20	2.39	2.39
Ca	31	24	179	196	50	39	422	317	89	56
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cl	75.08	82.28	319.90	363.90	23.61	23.72	272.90	3998.80	36.90	29.34
CN	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD	19	<3	22	6	13	6	11	19	10	<3
Color	14.86	<5	8.41	<5	6.51	<5	9.67	<5	7.77	<5
Cr	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
F	0.26	0.21	0.29	1.05	0.27	0.28	0.12	0.95	0.38	0.35
Fe	<0.01	0.06	0.63	3.57	0.02	0.02	4.63	32.52	0.01	0.10
P,reac	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	<0.01	0.04	<0.01	0.04
Hg	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
K	3.60	5.89	33.51	30.08	3.48	2.48	42.11	118.00	8.81	6.46
Li	0.36	0.23	0.92	1.31	<0.04	<0.04	1.67	10.88	0.06	0.10
Mg	33.42	44.80	163.10	165.28	41.99	40.40	215.20	163.30	82.55	74.84
Mn	<0.01	<0.01	0.37	0.39	0.12	<0.04	0.24	0.48	<0.01	<0.01
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TKN	<0.5	3.6	0.6	4.2	<0.5	1.9	1.0	24.7	0.7	1.1
N(Org)	<0.5	3.6	<0.5	5.2	<0.5	2.1	<0.5	26.6	0.7	1.1
Na	15	88	30	710	3	55	65	4673	2	33
Ni	<0.01	<0.01	0.02	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH4	<0.013	<0.013	1.53	1.29	0.02	0.27	1.07	2.48	<0.013	<0.013
NO2	0.102	<0.007	0.997	0.204	<0.003	<0.003	0.130	<0.007	<0.003	<0.003
NH3	<0.01	<0.01	1.35	1.14	0.02	0.24	0.95	2.20	<0.01	<0.01
NO3	10.30	8.08	11.40	10.02	16.60	17.46	<0.089	0.66	5.86	7.31
P(t)	0.03	<0.017	0.02	0.03	0.04	0.03	<0.01	0.03	0.01	0.01
Pb	<0.01	0.01	0.01	<0.01	<0.01	0.01	0.03	<0.01	<0.01	<0.01
P	0.027	<0.017	0.016	0.031	0.038	0.027	<0.01	0.034	0.014	0.014
Sb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Se	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Si	3.9	17.9	14.6	12.3	16.4	18.8	8.5	13.6	15.9	14.7
Sn	<0.04	<0.04	0.13	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
SO4	68	58	1590	2579	55	52	3327	3477	139	104
S-2	<0.1	1.20	<0.1	1.22	<0.1	1.36	<0.1	0.62	<0.1	2.32
Sr	1.00	1.23	3.64	4.09	0.46	0.41	6.22	31.02	1.70	1.88
TDS	382	551	1726	3431	286	408	2920	5240	518	459
Ti	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Tl	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
TOC	<2	<2	<1	<1	<1	<1	1.43	1.43	<1	<1
TSS	16	<15	<10	<10	<10	<10	13	27	<10	<10
U	0.005720	0.004493	0.000002	0.001743	0.000002	0.00165	<0.000002	<0.000002	0.00001	0.00804
V	0.09	0.09	<0.01	0.20	<0.01	<0.01	0.49	0.78	0.20	<0.1
Trichlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Tetrachlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zn	0.03	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.06	<0.04
Coli-f	40	0	0	0	0	0	0	0	0	0
Coli-t	660	30	0	20	10	20	68	0	42	30
Pesticides, t	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
MBAS	<0.01	<0.01	<0.01	0.11	<0.01	0.06	<0.01	0.11	<0.01	0.14
Alpha-ac	0.08	0.22	<0.18	<0.18	0.05	0.05	0.82	1.65	0.18	0.14
Beta-ac	0.39	0.27	<0.60	<0.60	0.15	0.07	0.75	1.11	0.54	0.23
Tri-tetraCE	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table C2. continued

SAMPLE	APK-7		BPK-1	BPK-2	E-1P		E-2P		E-3P	E-3P2
DATE	Nov-16	Jun-17	Aug-17	Aug-17	Sep-16	Jun-17	Nov-16	Jun-17	May-17	May-17
Ag	<0.01	<0.005	<0.005	<0.005	<0.01	<0.005	<0.01	<0.005	<0.005	<0.005
Al	<0.01	<0.01	<0.04	<0.04	<0.01	<0.01	0.03	0.03	<0.04	<0.04
Alk.(t)	290	293	299	172	455	337	120	129	233	297
As	0.010	0.005	<0.001	<0.001	0.008	0.008	0.004	0.004	<0.001	<0.001
B	0.84	0.91	<0.04	11.13	0.34	0.39	60.02	48.06	0.09	<0.04
Ba	0.13	0.09	<0.04	0.12	0.21	0.23	0.03	0.03	<0.04	<0.04
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	<0.01	<0.01	<0.1	<0.1	<0.01	<0.01	<0.01	<0.01	<0.1	<0.1
BOD	3.01	<3	<3	<3	8.55	<3	3.21	<3	3.88	3.96
Ca	51	46	27	115	67	46	764	194	57	62
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cl	40.41	28.28	8.52	1441.00	37.28	42.20	1015.00	1959.40	34.06	18.32
CN	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD	11	5	<3	4	37	<3	10	<3	11	14
Color	4.63	4.63	<5	<5	14.33	5.00	7.89	<5	<5	<5
Cr	0.01	<0.01	0.02	<0.01	<0.01	<0.01	0.08	<0.01	<0.01	0.02
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
F	0.34	0.32	0.39	<0.05	0.45	0.45	<0.02	1.70	0.08	0.08
Fe	<0.01	<0.01	<0.04	0.15	0.02	0.06	0.59	1.04	0.18	<0.04
P,reac	<0.06	0.03	0.05	<0.02	<0.01	<0.01	<0.01	<0.01	<0.02	<0.02
Hg	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
K	1.64	1.25	0.38	15.74	6.68	9.60	14.40	47.98	2.99	0.46
Li	0.13	0.05	<0.04	1.41	0.14	0.08	4.46	6.03	<0.04	<0.04
Mg	47.58	41.02	55.51	84.95	65.90	69.90	420.90	475.20	33.15	54.04
Mn	<0.01	<0.01	<0.04	0.22	<0.01	<0.01	0.17	0.28	0.07	<0.04
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.69	<0.01	<0.01	<0.01
TKN	<0.5	1.3	3.8	11.7	1.3	1.5	5.8	7.4	1.0	0.6
N(Org)	<0.5	1.3	3.8	14.0	1.3	1.5	2.6	14.7	1.0	0.6
Na	2	51	4	754	8	40	58	1915	35	12
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH4	<0.013	<0.013	<0.26	2.95	<0.013	<0.013	4.14	9.36	<0.26	<0.26
NO2	0.100	0.016	<0.007	0.056	0.131	0.010	0.004	0.004	0.290	<0.007
NH3	<0.01	<0.01	<0.23	2.61	<0.01	<0.01	3.66	8.29	<0.23	<0.23
NO3	8.92	10.93	7.03	10.28	18.86	22.73	0.24	0.57	26.76	31.73
P(t)	<0.01	0.04	0.08	<0.017	0.02	<0.017	<0.01	<0.01	0.02	<0.017
Pb	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
P	<0.01	0.041	0.084	<0.017	0.021	<0.017	<0.01	<0.01	0.020	<0.017
Sb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Se	<0.005	<0.005	<0.01	<0.01	<0.005	<0.005	<0.005	<0.005	<0.01	<0.01
Si	11.8	11.1	13.5	8.1	3.7	16.6	4.7	5.0	9.0	12.9
Sn	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
SO4	67	72	4	301	95	92	2373	4361	11	7
S-2	<0.1	4.02	<0.1	<0.1	<0.1	1.60	<0.1	1.60	0.40	0.50
Sr	0.69	1.03	0.09	1.04	0.82	1.02	9.69	8.68	0.32	0.31
TDS	308	446	271	3067	456	631	5526	9699	383	380
Ti	<0.01	<0.01	<0.04	<0.04	<0.01	<0.01	<0.01	<0.01	<0.04	<0.04
Tl	<0.01	<0.01	<0.04	<0.04	<0.04	<0.04	<0.01	<0.01	<0.04	<0.04
TOC	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
TSS	<10	53	<15	<15	<10	<10	<10	28	16	15
U	0.00140	0.00205	<0.001	<0.001	0.00814	0.00856	0.00059	<0.001	0.00033	0.00057
V	0.01	0.01	<0.1	0.14	0.16	<0.1	0.04	0.44	<0.1	<0.1
Trichlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Tetrachlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zn	0.01	0.01	<0.04	<0.04	0.01	0.01	<0.01	<0.01	<0.04	<0.04
Coli-f	-	0	0	0	0	0	-	0	1	4
Coli-t	-	80	30	0	7	20	-	150	30	40
Pesticides, t	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	<0.0001	<0.0003	<0.0003
MBAS	<0.01	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01	0.08	<0.05	<0.05
Alpha-ac	<0.04	0.23	<0.034	0.03	0.11	0.52	<0.25	1.89	0.04	0.21
Beta-ac	<0.10	0.20	<0.04	<0.02	0.41	0.83	1.63	1.63	0.06	0.13
Tri-tetraCE	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table C2. continued

SAMPLE	**E-3P3**	**E-4P**	**E-5P1**	**E-6P1**	**E-7P**	**E-8-15P1**	**E-8-15P2**	**E-9P1**	**E-10P1**	**E-11P1**
DATE	May-17	Jun-17	Jun-17	May-17	Jul-17	Jul-17	Aug-17	Jun-17	Jun-17	Aug-17
Ag	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Al	<0.04	0.05	<0.04	<0.04	<0.04	<0.04	0.05	<0.04	<0.04	<0.04
Alk.(t)	183	376	282	259	304	348	143	284	246	216
As	<0.001	0.006	0.010	0.026	0.004	0.003	0.005	<0.001	0.004	0.002
B	8.34	29.46	0.24	0.61	0.34	0.36	19.04	<0.04	0.06	1.88
Ba	0.11	0.05	0.08	0.10	0.11	0.10	<0.04	<0.04	8.16	1.66
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BOD	<3	3.50	5.28	<3	<3	<3	<3	<3	6.20	<3
Ca	166	939	49	10	47	64	440	30	136	14
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cl	1343.00	9897.00	33.93	17.43	23.12	27.73	2065.00	3.59	128.20	606.70
CN	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD	8	13	19	<3	<3	6	7	3	22	5
Color	10.42	623.72	<5	5.00	<5	<5	<5	<5	<5	<5
Cr	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01	<0.01
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
F	<0.05	0.54	0.39	0.35	0.23	0.42	1.05	<0.05	0.42	0.30
Fe	0.59	7.79	<0.04	<0.04	<0.04	<0.04	1.66	0.05	0.76	0.08
P,reac	<0.02	0.11	<0.02	0.03	0.04	<0.02	0.04	0.03	<0.02	0.03
Hg	<0.0001	<0.0001	<0.0001	0.00	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.00
K	29.00	34.10	3.03	4.68	3.59	1.31	66.90	0.32	10.23	5.76
Li	1.31	1.79	0.07	0.26	<0.04	<0.04	4.62	<0.04	0.82	0.44
Mg	117.10	478.20	48.11	59.97	59.40	55.70	373.70	39.68	210.60	14.12
Mn	0.16	0.25	<0.04	<0.04	<0.04	<0.04	0.17	<0.04	0.05	<0.04
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TKN	4.3	5.0	13.4	2.7	1.2	2.5	9.4	1.2	3.7	4.1
N(Org)	7.9	29.0	13.4	2.7	1.2	2.5	14.5	1.2	3.7	5.1
Na	580	1034	40	26	3	44	1564	3	282	523
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH4	4.64	31.02	<0.26	<0.26	<0.26	<0.26	6.55	<0.26	<0.26	1.24
NO2	0.640	<0.007	0.033	0.043	0.007	<0.007	<0.007	0.099	0.148	<0.007
NH3	4.11	27.47	<0.23	<0.23	<0.23	<0.23	5.80	<0.23	<0.23	1.10
NO3	15.75	5.79	93.92	26.07	11.66	15.43	0.53	8.28	6.31	<0.050059
P(t)	<0.017	0.07	<0.017	0.04	<0.017	<0.017	0.06	<0.017	<0.017	0.04
Pb	<0.01	<0.01	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
P	<0.017	0.071	<0.017	0.037	<0.017	<0.017	0.061	<0.017	<0.017	0.041
Sb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Se	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Si	8.4	1.2	15.4	14.4	<0.1	12.0	7.2	14.2	10.2	12.7
Sn	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
SO4	141	411	68	18	59	23	2706	4	1093	5
S-2	0.80	1.78	0.94	<0.1	1.14	<0.1	1.52	1.30	4.00	1.26
Sr	1.87	7.22	0.96	1.16	0.78	0.48	10.55	0.12	3.22	0.54
TDS	3045	24312	488	382	452	777	8239	288	2093	1286
Ti	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Tl	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
TOC	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
TSS	28	88	<15	<15	<15	106	16	<15	<15	<15
U	0.00041	<0.001	0.00401	0.01118	0.00321	0.00203	<0.001	<0.001	0.00395	<0.001
V	0.20	0.25	<0.1	<0.1	<0.1	<0.1	0.52	<0.1	0.14	<0.1
Trichlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Tetrachlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zn	<0.04	<0.04	<0.04	<0.04	<0.04	0.26	0.24	<0.04	<0.04	<0.04
Coli-f	0	0	0	0	0	0	0	0	0	0
Coli-t	70	0	160	120	0	0	10	180	200	0
Pesticides, t	<0.0003	<0.0001	<0.0001	<0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
MBAS	<0.05	0.14	<0.05	<0.05	0.12	<0.05	<0.05	<0.05	<0.05	<0.05
Alpha-ac	0.29	<2.595	0.12	3.11	0.11	0.08	1.72	<0.066	0.39	0.13
Beta-ac	0.45	<3.417	0.11	1.38	0.14	0.07	0.75	<0.07	0.49	<0.12
Tri-tetraCE	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table C2. continued

SAMPLE	**E-11P2**	**E-13P**	**E-13P2**	**E-14P1**	**E-14P2**	**E-16P1**	**E-17P2**	**E-17P3**	**E-18P1**	**E-20P1**
DATE	Jul-17	Jun-17	May-17	May-17	May-17	Jul-17	May-17	May-17	May-17	Jun-17
Ag	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Al	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Alk.(t)	289	426	222	371	298	320	196	244	239	324
As	0.001	0.019	0.001	0.002	0.003	0.004	0.005	<0.001	<0.001	0.002
B	<0.04	0.21	<0.04	0.52	0.43	0.47	3.48	<0.04	0.10	0.09
Ba	0.75	0.13	0.04	0.07	0.05	0.11	<0.04	<0.04	0.07	0.06
Be	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bi	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
BOD	3.80	5.24	3.92	4.56	4.56	<3	<3	<3	4.72	5.24
Ca	52	11	23	46	24	58	80	13	54	33
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cl	29.34	46.29	9.46	63.85	58.93	29.24	601.60	1.35	16.53	18.41
CN	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
COD	11	17	12	12	11	10	<3	9	15	17
Color	<5	<5	14.27	8.50	10.42	<5	<5	8.50	8.50	<5
Cr	0.02	<0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
F	<0.05	0.17	<0.05	0.31	0.34	0.31	<0.05	<0.05	0.12	0.06
Fe	<0.04	0.12	<0.04	0.42	<0.04	0.05	0.14	<0.04	0.15	0.30
P,reac	<0.02	<0.02	<0.02	0.04	0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Hg	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
K	0.79	1.85	0.83	1.43	0.84	4.01	8.79	0.29	1.51	0.84
Li	<0.04	0.11	<0.04	<0.04	<0.04	0.08	0.60	<0.04	<0.04	<0.04
Mg	62.99	86.41	49.09	62.30	63.70	59.40	48.79	59.97	30.90	67.75
Mn	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Mo	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TKN	5.9	2.5	0.6	9.0	3.7	1.8	0.8	1.0	3.4	2.3
N(Org)	5.9	2.5	0.6	9.0	3.7	2.8	0.8	1.0	3.4	2.3
Na	8	76	5	76	71	55	353	1	17	19
Ni	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
NH4	<0.26	<0.26	<0.26	<0.26	<0.26	1.21	<0.26	<0.26	<0.26	<0.26
NO2	<0.007	<0.007	<0.007	0.046	0.007	0.033	0.066	<0.007	0.007	0.043
NH3	<0.23	<0.23	<0.23	<0.23	<0.23	1.07	<0.23	<0.23	<0.23	<0.23
NO3	8.98	<0.050059	6.92	44.96	47.36	11.45	6.17	1.01	21.46	5.63
P(t)	0.14	<0.017	0.03	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
Pb	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
P	0.138	<0.017	0.031	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
Sb	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Se	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Si	9.8	18.4	13.7	11.6	12.4	<0.1	15.2	17.6	10.1	13.2
Sn	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
SO4	23	1	4	18	18	130	258	6	8	30
S-2	<0.1	1.60	0.80	1.00	0.80	<0.1	0.74	0.82	0.50	0.60
Sr	0.19	0.71	0.12	0.36	0.32	1.08	0.87	<0.04	0.24	0.21
TDS	365	293	278	600	576	634	1807	291	343	472
Ti	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Tl	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
TOC	<2	<2	<2	2.00	<2	<2	<2	<2	<2	<2
TSS	207	<15	<15	<15	42	<15	<15	<15	<15	<15
U	<0.001	<0.001	0.00028	0.00311	0.00296	0.00351	1.94800	0.00002	0.00061	0.00311
V	<0.1	<0.1	<0.1	0.10	0.10	<0.1	0.11	0.12	<0.1	<0.1
Trichlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Tetrachlorethylene	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Zn	0.07	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	0.26	<0.04
Coli-f	0	0	0	0	1	0	0	0	0	0
Coli-t	70	120	60	0	1	0	0	70	60	30
Pesticides, t	<0.0001	<0.0001	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0003	<0.0001
MBAS	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	<0.05	<0.05	<0.05
Alpha-ac	0.17	<0.06	0.12	0.05	<0.114	0.19	0.52	0.06	0.10	0.06
Beta-ac	0.13	<0.07	<0.14	<0.07	<0.13	0.08	0.20	<0.07	<0.06	<0.07
Tri-tetraCE	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

APPENDIX -D Saturation index estimations

Table D1. Saturation index input data

SOLUTION 1	E-7P		SOLUTION 2	E-3P2		SOLUTION 3	E-13P2	
units	mg/l		units	mg/l		units	mg/l	
pe	4		pe	4		pe	4	
redox	pe		redox	pe		redox	pe	
temp	16.04		temp	16.04		temp	16.04	
pH	7.65		pH	7.62		pH	8.34	
Al	0		Al	0		Al	0	
Alkalinity	303.6	as Ca.5(CO3).5	Alkalinity	297.2	as Ca.5(CO3).5	Alkalinity	222.2	as Ca.5(CO3).5
Ca	46.97		Ca	61.72		Ca	23.25	
Cl	23.12		Cl	18.32		Cl	9.461	
Fe	0		Fe	0		Fe	0	
K	3.586		K	0.4559		K	0.8308	
Mg	59.4		Mg	54.04		Mg	49.09	
Mn	0		Mn	0		Mn	0	
Na	3.196		Na	12.345		Na	5.226	
P	0		P	0		P	0.031	
pH	7.65		pH	7.62		pH	8.34	
Si	0		Si	12.86		Si	13.71	
S (6)	59.23		S (6)	6.647		S (6)	3.801	
Ti	0		Ti	0		Ti	0	

SOLUTION 4	APK-7		SOLUTION 5	E-11P2		SOLUTION 6	BPK-1	
units	mg/l		units	mg/l		units	mg/l	
pe	4		pe	4		pe	4	
redox	pe		redox	pe		redox	pe	
temp	17.41		temp	16.8		temp	15.89	
pH	7.84		pH	8.05		pH	8.12	
Al	0		Al	0		Al	0	
Alkalinity	291.5	as Ca.5(CO3).5	Alkalinity	289.4	as Ca.5(CO3).5	Alkalinity	299	as Ca.5(CO3).5
Ca	48.165		Ca	52.1		Ca	26.75	
Cl	34.345		Cl	29.34		Cl	8.519	
Fe	0		Fe	0		Fe	0	
K	1.446		K	0.7932		K	0.3848	
Mg	44.3		Mg	62.99		Mg	55.51	
Mn	0		Mn	0		Mn	0	
Na	26.42		Na	7.942		Na	3.728	
P	0.0255		P	0.138		P	0.084	
pH	7.835		pH	8.05		pH	8.12	
Si	11.435		Si	9.774		Si	13.51	
S (6)	69.385		S (6)	23.3		S (6)	3.945	
Ti	0		Ti	0		Ti	0	

Table D1. continued

SOLUTION 7	APK-2		SOLUTION 8	E-14P2		SOLUTION 9	E-9P1	
units	mg/l		units	mg/l		units	mg/l	
pe	4		pe	4		pe	4	
redox	pe		redox	pe		redox	pe	
temp	24.94		temp	15.22		temp	16.8	
pH	7.81		pH	7.52		pH	7.88	
Al	0		Al	0		Al	0	
Alkalinity	199	as Ca.5(CO3).5	Alkalinity	297.6	as Ca.5(CO3).5	Alkalinity	283.8	as Ca.5(CO3).5
Ca	27.51		Ca	24.05		Ca	29.86	
Cl	78.68		Cl	58.93		Cl	3.59	
Fe	0.03743		Fe	0		Fe	0.04818	
K	4.7425		K	0.8448		K	0.3205	
Mg	39.11		Mg	63.7		Mg	39.68	
Mn	0		Mn	0		Mn	0	
Na	51.385		Na	71.07		Na	3.391	
P	0.0218		P	0		P	0	
pH	7.805		pH	7.52		pH	7.88	
Si	10.893		Si	12.35		Si	14.24	
S (6)	63.33		S (6)	17.69		S (6)	3.52	
Ti	0		Ti	0		Ti	0	

SOLUTION 10	E-14P1		SOLUTION 11	E-17P2		SOLUTION 12	E-11P1	
units	mg/l		units	mg/l		units	mg/l	
pe	4		pe	4		pe	4	
redox	pe		redox	pe		redox	pe	
temp	16.8		temp	30.03		temp	30.03	
pH	7.67		pH	8.01		pH	8.26	
Al	0		Al	0		Al	0	
Alkalinity	370.8	as Ca.5(CO3).5	Alkalinity	196.2	as Ca.5(CO3).5	Alkalinity	216.2	as Ca.5(CO3).5
Ca	46.33		Ca	80.16		Ca	14.232	
Cl	63.85		Cl	601.6		Cl	606.7	
Fe	0.4236		Fe	0.1437		Fe	0.07616	
K	1.431		K	8.79		K	5.758	
Mg	62.3		Mg	48.79		Mg	14.124	
Mn	0		Mn	0		Mn	0	
Na	76.47		Na	353.3		Na	522.5	
P	0		P	0		P	0.041	
pH	7.67		pH	8.01		pH	8.26	
Si	11.56		Si	15.21		Si	12.73	
S (6)	17.58		S (6)	258.1		S (6)	5.257	
Ti	0		Ti	0		Ti	0	

Table D1. continued

SOLUTION 13	E-3P3		SOLUTION 14	E-2P		SOLUTION 15	E-8-15P2	
units	mg/l		units	mg/l		units	mg/l	
pe	4		pe	4		pe	4	
redox	pe		redox	pe		redox	pe	
temp	28.3		temp	30.03		temp	30.03	
pH	7.8		pH	8.37		pH	7.61	
Al	0		Al	0.0253		Al	0.05117	
Alkalinity	182.6	as Ca.5(CO3).5	Alkalinity	124.5	as Ca.5(CO3).5	Alkalinity	142.8	as Ca.5(CO3).5
Ca	166.41		Ca	478.8		Ca	440.1	
Cl	1343		Cl	1487.2		Cl	2065	
Fe	0.5876		Fe	0.8183		Fe	1.655	
K	29		K	31.19		K	66.9	
Mg	117.1		Mg	448.05		Mg	373.7	
Mn	0.1591		Mn	0.2232		Mn	0.1701	
Na	579.5		Na	986.81		Na	1563.6	
P	0		P	0		P	0.061	
pH	7.8		pH	8.37		pH	7.61	
Si	8.356		Si	4.8475		Si	7.241	
S (6)	141.2		S (6)	3366.875		S (6)	2706	
Ti	0		Ti	0		Ti	0	

SOLUTION 16	APK-5		SOLUTION 17	E-4P	
units	mg/l		units	mg/l	
pe	4		pe	4	
redox	pe		redox	pe	
temp	32.58		temp	38.03	
pH	7.69		pH	7.32	
Al	0.0945		Al	0.05104	
Alkalinity	302.3	as Ca.5(CO3).5	Alkalinity	376.4	as Ca.5(CO3).5
Ca	369.065		Ca	938.7	
Cl	2135.85		Cl	9897	
Fe	18.575		Fe	7.79	
K	80.055		K	34.1	
Mg	189.25		Mg	478.2	
Mn	0.35685		Mn	0.2544	
Na	2369.23		Na	1034	
P	0.022		P	0.071	
pH	7.69		pH	7.32	
Si	11.0495		Si	1.193	
S (6)	3402		S (6)	411	
Ti	0		Ti	0	

Table D2. Saturation index output data

Well ID	E-7P	E-3P2	E-13P2	APK-7	E-11P2	BPK-1	APK-2	E-14P2	E-9P1	E-14P1	E-17P2	E-11P1	E-3P3	E-2P	E-8-15P2	APK-5	E-4P
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Talc	-	0.7	5.1	1.6	3.1	3.9	1.9	0.2	2.2	1.0	4.0	3.8	2.7	6.0	2.1	2.4	-1.4
Sylvite	-8.1	-9.0	-9.1	-8.3	-8.6	-9.4	-7.5	-8.3	-9.9	-8.0	-6.4	-6.6	-5.6	-5.6	-5.2	-5.1	-4.9
Siderite	-	-	-	-	-	-	-3.0	-	-3.0	-1.5	-2.9	-3.6	-1.9	-3.2	-1.3	-0.1	0.2
Sepiolite	-	-3.5	2.3	-2.4	-0.5	0.7	-2.2	-4.2	-1.5	-3.1	0.6	0.2	-1.3	2.9	-2.1	-1.7	-7.6
Rhodochrosite	-	-	-	-	-	-	-	-	-	-	-	-	-0.5	-0.3	-1.0	-0.3	-0.6
Pyrolusite	-	-	-	-	-	-	-	-	-	-	-	-	-7.9	-5.5	-8.6	-7.7	-8.6
Albite	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.2	0.9	1.7	-2.2
Alunite	-	-	-	-	-	-	-	-	-	-	-	-	-	-8.0	-2.5	-2.3	-4.4
Anhydrite	-2.4	-3.2	-3.8	-2.3	-2.8	-3.8	-2.5	-3.2	-3.7	-3.0	-1.6	-3.9	-1.7	-0.2	-0.4	-0.3	-0.9
Anorthite	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.9	-3.0	-2.3	-4.5
Aragonite	0.1	0.2	0.4	0.3	0.5	0.3	0.0	-0.3	0.2	0.2	0.6	0.2	0.6	1.1	0.5	0.8	1.0
Calcite	0.3	0.4	0.5	0.5	0.7	0.5	0.2	-0.2	0.3	0.4	0.7	0.3	0.7	1.3	0.6	0.9	1.2
Chalcedony	-	0.3	0.3	0.2	0.1	0.3	0.0	0.3	0.3	0.2	0.1	0.0	-0.2	-0.5	-0.3	-0.1	-1.2
Chrysotile	-	-2.3	2.0	-1.3	0.3	0.7	-0.7	-2.9	-0.9	-1.9	1.4	1.3	0.5	4.4	0.1	0.2	-1.6
CO2(g)	-2.2	-2.1	-3.0	-2.4	-2.6	-2.6	-2.4	-2.0	-2.4	-2.1	-2.7	-2.9	-2.5	-3.4	-2.5	-2.2	-1.8
Dolomite	2.0	2.0	2.8	2.2	2.8	2.7	1.9	1.4	2.1	2.2	2.7	2.1	2.7	3.8	2.5	2.9	3.5
Gibbsite	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	1.4	1.5	1.4
Goethite	-	-	-	-	-	-	5.3	-	5.1	6.0	6.0	5.8	6.6	6.8	7.1	8.2	7.8
Gypsum	-2.1	-2.9	-3.6	-2.0	-2.5	-3.5	-2.3	-2.9	-3.5	-2.7	-1.4	-3.8	-1.6	-0.1	-0.2	-0.2	-0.9
H2(g)	-23.5	-23.5	-24.9	-23.8	-24.3	-24.5	-23.6	-23.3	-24.0	-23.5	-23.9	-24.4	-23.5	-24.6	-23.1	-23.2	-22.4
H2O(g)	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.6	-1.8	-1.8	-1.8	-1.5	-1.5	-1.5	-1.5	-1.5	-1.4	-1.3
Halite	-8.7	-8.2	-8.8	-7.6	-8.2	-9.0	-7.0	-6.9	-9.5	-6.9	-5.3	-5.1	-4.8	-4.6	-4.2	-4.1	-3.8
Hausmannite	-	-	-	-	-	-	-	-	-	-	-	-	-8.0	-3.5	-9.8	-7.9	-9.9
Hematite	-	-	-	-	-	-	11.5	-	11.1	12.9	13.1	12.5	14.2	14.6	15.1	17.4	16.7
Illite	-	-	-	-	-	-	-	-	-	-	-	-	-	1.9	4.3	5.1	0.7
Kaolinite	-	-	-	-	-	-	-	-	-	-	-	-	-	1.2	3.7	4.1	1.7
K-feldspar	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	2.3	2.9	-1.1
Manganite	-	-	-	-	-	-	-	-	-	-	-	-	-3.9	-2.2	-4.6	-4.0	-5.0
Melanterite	-	-	-	-	-	-	-9.6	-	-10.8	-8.7	-9.3	-11.9	-8.4	-8.8	-6.4	-5.5	-6.1
O2(g)	-39.2	-39.3	-36.4	-38.0	-37.4	-37.4	-35.9	-40.0	-38.0	-38.9	-33.6	-32.6	-35.0	-32.2	-35.2	-34.2	-34.2

Table D2. continued

Well ID	**E-7P**	**E-3P2**	**E-13P2**	**APK-7**	**E-11P2**	**BPK-1**	**APK-2**	**E-14P2**	**E-9P1**	**E-14P1**	**E-17P2**	**E-11P1**	**E-3P3**	**E-2P**	**E-8-15P2**	**APK-5**	**E-4P**
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Afwillite	-	-32.3	-29.2	-31.2	-30.1	-30.4	-30.7	-34.4	-31.4	-32.4	-27.2	-28.0	-28.5	-24.6	-28.8	-27.9	-29.7
Akermanite	-	-17.3	-13.7	-16.2	-14.9	-15.0	-15.6	-18.8	-16.2	-17.2	-12.6	-13.2	-13.7	-9.8	-14.0	-13.4	-15.2
Al	-	-	-	-	-	-	-	-	-	-	-	-	-	-112.9	-109.6	-109.1	-106.6
Al(g)	-	-	-	-	-	-	-	-	-	-	-	-	-	-162.7	-159.4	-158.3	-154.9
Al2(SO4)3	-	-	-	-	-	-	-	-	-	-	-	-	-	-58.8	-52.5	-52.2	-53.1
Alum-K	-	-	-	-	-	-	-	-	-	-	-	-	-	-19.9	-16.5	-16.5	-18.5
Albite_low	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.2	0.9	1.7	-2.2
Albite_high	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.5	-0.4	0.4	-3.4
Al2(SO4)3:6H2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-42.0	-35.6	-35.6	-37.0
Andalusite	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.6	-1.3	-1.0	-2.1
Amesite-14A	-	-	-	-	-	-	-	-	-	-	-	-	-	7.6	5.9	6.3	4.3
Analcime	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.1	0.7	1.4	-1.5
Analcime-dehy	-	-	-	-	-	-	-	-	-	-	-	-	-	-6.4	-5.5	-4.8	-7.5
Andradite	-	-	-	-	-	-	3.9	-	3.6	4.4	8.7	7.2	8.4	12.3	8.9	12.1	8.2
Annite	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.8	-0.5	3.3	-0.7
Antarcticite	-13.7	-13.8	-14.7	-13.3	-13.4	-14.8	-12.9	-13.2	-15.5	-12.8	-10.8	-11.5	-9.9	-9.6	-9.4	-9.5	-7.7
Anthophyllite	-	-11.6	-1.5	-9.4	-6.0	-4.4	-8.2	-13.0	-8.2	-10.8	-3.0	-3.4	-5.8	2.4	-6.9	-6.3	-13.5
Antigorite	-	-23.4	45.5	-6.9	18.0	25.9	2.4	-32.2	-0.8	-16.7	35.0	34.1	21.0	82.7	14.8	15.4	-14.5
Aphthitalite	-19.3	-23.3	-23.2	-19.4	-21.7	-24.4	-17.6	-20.9	-24.7	-20.2	-15.1	-18.7	-14.2	-11.7	-10.7	-10.1	-13.8
Arcanite	-9.7	-12.4	-12.1	-10.4	-11.4	-12.8	-9.5	-11.5	-13.0	-11.1	-8.6	-10.6	-8.0	-6.9	-6.3	-6.1	-8.0
Artinite	-5.3	-5.5	-3.5	-4.9	-4.0	-3.9	-4.7	-5.7	-4.8	-5.1	-3.8	-3.9	-3.9	-1.8	-4.0	-4.0	-3.5
Bassanite	-3.0	-3.9	-4.5	-2.9	-3.4	-4.4	-3.1	-3.9	-4.4	-3.6	-2.2	-4.5	-2.3	-0.9	-1.0	-1.0	-1.6
Beidellite-Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	3.4	4.2	0.0
Beidellite-H	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.9	2.3	3.0	-1.1
Beidellite-K	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	3.1	3.9	-0.5
Beidellite-Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	3.5	4.2	0.1
Beidellite-Na	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4	3.3	4.1	-0.2
Berlinite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-5.5	-5.9	-5.1
Birnessite	-	-	-	-	-	-	-	-	-	-	-	-	-47.4	-30.7	-52.5	-45.6	-50.9
Bischofite	-13.7	-13.9	-14.5	-13.5	-13.4	-14.5	-12.8	-12.8	-15.4	-12.8	-11.1	-11.6	-10.1	-9.8	-9.6	-9.9	-8.1

Table D2. continued

Well ID	E-7P	E-3P2	E-13P2	APK-7	E-11P2	BPK-1	APK-2	E-14P2	E-9P1	E-14P1	E-17P2	E-11P1	E-3P3	E-2P	E-8-15P2	APK-5	E-4P
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Bixbyite	-	-	-	-	-	-	-	-	-	-	-	-	-6.7	-3.3	-8.0	-6.6	-8.0
Bloedite	-15.2	-15.9	-17.1	-13.3	-15.2	-17.3	-12.8	-13.5	-17.6	-13.5	-10.3	-13.6	-10.3	-7.2	-7.1	-6.9	-9.3
Boehmite	-	-	-	-	-	-	-	-	-	-	-	-	-	0.6	1.7	1.8	1.6
Brucite	-4.4	-4.5	-3.1	-4.1	-3.5	-3.5	-3.7	-4.7	-4.0	-4.3	-3.0	-2.9	-3.1	-1.6	-3.2	-3.2	-3.0
Brushite	-	-	-16.5	-16.3	-15.6	-16.0	-16.6	-	-	-	-	-16.6	-	-	-15.8	-16.2	-15.5
Burkeite	-34.6	-33.0	-35.0	-28.7	-32.6	-36.0	-27.2	-27.7	-36.5	-27.3	-21.2	-23.1	-21.1	-17.3	-17.0	-15.3	-20.1
C	-34.2	-34.1	-37.8	-35.2	-36.3	-36.5	-35.6	-33.5	-35.4	-34.3	-37.0	-38.2	-35.9	-39.1	-35.2	-35.4	-33.8
C(g)	-155.7	-155.6	-159.3	-156.1	-157.4	-158.1	-153.3	-155.4	-156.6	-155.4	-152.5	-153.7	-152.1	-154.7	-150.7	-149.9	-146.1
Ca(g)	-137.3	-137.2	-137.6	-136.7	-136.9	-137.6	-133.5	-138.0	-137.1	-137.0	-130.9	-131.6	-131.3	-130.4	-130.4	-129.4	-126.7
Ca	-111.1	-111.0	-111.4	-110.6	-110.8	-111.4	-108.2	-111.7	-111.0	-110.9	-106.2	-106.9	-106.4	-105.6	-105.7	-104.9	-102.7
Ca2Al2O5:8H2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-15.4	-16.4	-16.5	-18.0
Ca2Cl2(OH)2:H2O	-23.7	-23.7	-23.7	-23.0	-22.6	-24.1	-22.8	-23.8	-25.2	-22.9	-20.0	-20.9	-19.2	-17.6	-18.8	-18.9	-17.4
Ca3Al2O6	-	-	-	-	-	-	-	-	-	-	-	-	-	-52.2	-54.7	-53.6	-52.8
Ca4Al2Fe2O10	-	-	-	-	-	-	-	-	-	-	-	-	-	-50.2	-53.7	-50.0	-49.7
Ca4Al2O7:13H2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-34.6	-38.7	-38.7	-40.7
Ca4Cl2(OH)6:13H2O	-41.5	-41.3	-39.2	-40.0	-38.7	-40.4	-40.4	-42.6	-42.3	-40.5	-36.0	-37.3	-35.5	-31.1	-35.5	-35.5	-34.6
Ca4Al2O7:19H2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-31.0	-35.1	-35.1	-37.2
Ca-Al_Pyroxene	-	-	-	-	-	-	-	-	-	-	-	-	-	-9.0	-8.3	-7.7	-8.8
CaAl2O4	-	-	-	-	-	-	-	-	-	-	-	-	-	-15.7	-15.1	-14.6	-14.5
CaAl2O4:10H2O	-	-	-	-	-	-	-	-	-	-	-	-	-	-8.1	-7.5	-7.6	-8.8
CaAl4O7	-	-	-	-	-	-	-	-	-	-	-	-	-	-20.9	-18.2	-17.5	-17.4
Carnallite	-20.9	-22.1	-22.7	-20.9	-21.2	-23.1	-19.3	-20.3	-24.5	-20.0	-16.6	-17.2	-14.7	-14.4	-13.7	-14.0	-11.9
CaSO4:0.5H2O(beta)	-3.2	-4.0	-4.6	-3.1	-3.6	-4.6	-3.3	-4.0	-4.6	-3.8	-2.4	-4.7	-2.5	-1.1	-1.2	-1.1	-1.7
Celadonite	-	-	-	-	-	-	-	-	-	-	-	-	-	3.7	3.6	4.3	-0.7
Chamosite-7A	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.7	-0.3	2.1	0.8
Chloromagnesite	-32.0	-32.2	-32.8	-31.6	-31.6	-32.8	-30.2	-31.2	-33.6	-31.0	-28.1	-28.5	-27.2	-26.8	-26.5	-26.6	-24.3
Cl2(g)	-46.1	-46.3	-46.8	-45.5	-45.7	-46.9	-43.4	-45.4	-47.5	-45.0	-40.8	-40.8	-40.5	-40.1	-39.9	-39.4	-37.3
Clinochlore-14A	-	-	-	-	-	-	-	-	-	-	-	-	-	9.8	4.7	4.9	2.2
Clinochlore-7A	-	-	-	-	-	-	-	-	-	-	-	-	-	6.5	1.4	1.6	-1.1
Clinoptilolite-Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.4	3.5	6.1	-9.6

Table D2. continued

Well ID	E-7P	E-3P2	E-13P2	APK-7	E-11P2	BPK-1	APK-2	E-14P2	E-9P1	E-14P1	E-17P2	E-11P1	E-3P3	E-2P	E-8-15P2	APK-5	E-4P
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Clinoptilolite-dehy-Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	-35.3	-31.4	-28.5	-43.4
Clinoptilolite-dehy-K	-	-	-	-	-	-	-	-	-	-	-	-	-	-38.7	-33.6	-30.4	-47.9
Clinoptilolite-dehy-Na	-	-	-	-	-	-	-	-	-	-	-	-	-	-36.2	-31.6	-28.0	-45.3
Clinoptilolite-hy-Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.4	3.5	6.0	-9.7
Clinoptilolite-hy-K	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.7	1.4	4.2	-13.9
Clinoptilolite-hy-Na	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.3	3.3	6.5	-11.5
Clinoptilolite-K	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.8	1.3	4.1	-14.1
Clinoptilolite-Na	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.3	3.3	6.5	-11.5
Clinozoisite	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.1	-1.5	-0.4	-3.8
Coesite	-	-0.3	-0.3	-0.4	-0.4	-0.3	-0.5	-0.3	-0.3	-0.4	-0.5	-0.6	-0.7	-1.0	-0.8	-0.6	-1.7
Cordierite_anhyd	-	-	-	-	-	-	-	-	-	-	-	-	-	-10.8	-8.7	-7.7	-12.7
Cordierite_hydr	-	-	-	-	-	-	-	-	-	-	-	-	-	-8.4	-6.3	-5.2	-10.3
Corundum	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.8	0.2	0.5	0.3
Cristobalite(alpha)	-	0.0	0.0	-0.1	-0.2	0.0	-0.3	0.0	0.0	-0.1	-0.2	-0.3	-0.4	-0.7	-0.5	-0.4	-1.4
Cristobalite(beta)	-	-0.5	-0.5	-0.6	-0.6	-0.5	-0.7	-0.5	-0.5	-0.6	-0.6	-0.7	-0.9	-1.2	-1.0	-0.8	-1.8
Cronstedtite-7A	-	-	-	-	-	-	5.7	-	5.1	9.1	8.4	6.7	10.7	10.1	13.0	17.5	15.7
Daphnite-14A	-	-	-	-	-	-	-	-	-	-	-	-	-	-8.7	-0.8	5.1	1.6
Daphnite-7A	-	-	-	-	-	-	-	-	-	-	-	-	-	-12.0	-4.1	1.8	-1.7
Dawsonite	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.7	0.7	1.2	0.7
Delafossite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diaspore	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	2.1	2.1	2.0
Dicalcium_silicate	-	-17.5	-15.4	-16.8	-16.0	-16.2	-16.4	-18.9	-16.9	-17.6	-14.1	-14.6	-14.8	-12.1	-15.0	-14.4	-15.3
Diopside	-	-4.3	-1.8	-3.7	-2.8	-2.6	-3.5	-5.2	-3.5	-4.3	-1.7	-2.1	-2.5	-0.2	-2.8	-2.5	-4.4
Dioptase	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dolomite-dis	0.4	0.4	1.2	0.6	1.2	1.1	0.3	-0.2	0.5	0.6	1.1	0.6	1.2	2.3	1.0	1.4	2.1
Dolomite-ord	2.0	2.0	2.8	2.3	2.8	2.7	1.9	1.4	2.1	2.2	2.7	2.1	2.7	3.8	2.5	2.9	3.5
Enstatite	-	-3.0	-1.6	-2.7	-2.2	-2.0	-2.4	-3.2	-2.5	-2.9	-1.7	-1.7	-2.0	-0.8	-2.2	-2.1	-3.0
Epidote	-	-	-	-	-	-	-	-	-	-	-	-	-	7.3	7.2	9.3	5.5
Epidote-ord	-	-	-	-	-	-	-	-	-	-	-	-	-	7.3	7.2	9.3	5.5
Epsomite	-4.4	-5.3	-5.6	-4.4	-4.7	-5.5	-4.5	-4.8	-5.7	-4.9	-4.0	-6.1	-4.1	-2.6	-2.7	-3.0	-3.5

Table D2. continued

Well ID	**E-7P**	**E-3P2**	**E-13P2**	**APK-7**	**E-11P2**	**BPK-1**	**APK-2**	**E-14P2**	**E-9P1**	**E-14P1**	**E-17P2**	**E-11P1**	**E-3P3**	**E-2P**	**E-8-15P2**	**APK-5**	**E-4P**
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Ettringite	-	-	-	-	-	-	-	-	-	-	-	-	-	-17.0	-19.8	-19.4	-22.0
Fayalite	-	-	-	-	-	-	-8.8	-	-9.1	-7.0	-7.6	-8.7	-6.3	-7.3	-5.0	-2.7	-3.7
Fe	-	-	-	-	-	-	-32.6	-	-33.3	-31.7	-32.3	-33.4	-31.2	-32.7	-30.1	-29.1	-28.2
Fe(OH)3	-	-	-	-	-	-	0.2	-	-0.2	0.8	1.0	0.7	1.5	1.7	2.0	3.2	2.9
Fe(OH)2	-	-	-	-	-	-	-6.9	-	-7.2	-6.1	-6.3	-6.8	-5.5	-5.9	-4.9	-3.8	-3.7
Fe2(SO4)3	-	-	-	-	-	-	-48.6	-	-53.8	-48.8	-46.5	-53.4	-45.5	-44.7	-39.9	-37.5	-39.0
FeO	-	-	-	-	-	-	-6.5	-	-6.9	-5.8	-5.9	-6.4	-5.2	-5.5	-4.5	-3.4	-3.3
Ferrite-Ca	-	-	-	-	-	-	2.3	-	1.5	3.0	5.1	4.3	5.9	7.8	6.8	9.3	8.8
Ferrite-Dicalcium	-	-	-	-	-	-	-20.7	-	-22.4	-21.2	-16.6	-17.6	-16.2	-12.7	-15.2	-12.3	-12.5
Ferrite-Mg	-	-	-	-	-	-	3.2	-	2.2	3.8	5.6	5.0	6.5	8.4	7.4	9.7	9.3
Ferrosilite	-	-	-	-	-	-	-4.1	-	-4.2	-3.1	-3.5	-4.1	-3.0	-3.6	-2.4	-1.2	-2.2
FeSO4	-	-	-	-	-	-	-14.7	-	-16.2	-14.1	-14.0	-16.7	-13.3	-13.6	-11.1	-10.1	-10.5
Forsterite	-	-7.8	-4.9	-7.0	-6.0	-5.8	-6.3	-8.2	-6.8	-7.5	-4.8	-4.8	-5.4	-2.6	-5.5	-5.5	-6.2
Foshagite	-	-29.8	-25.6	-28.5	-26.9	-27.2	-28.1	-32.5	-28.6	-30.0	-23.6	-24.7	-25.2	-20.2	-25.7	-24.5	-27.4
Gaylussite	-11.4	-10.2	-10.1	-9.2	-9.8	-10.5	-9.2	-9.2	-11.1	-8.4	-7.0	-6.7	-6.8	-5.7	-6.6	-5.6	-6.4
Gehlenite	-	-	-	-	-	-	-	-	-	-	-	-	-	-14.7	-15.5	-14.7	-15.7
Gismondine	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	3.6	4.0	-2.2
Glauberite	-12.5	-13.1	-14.6	-10.5	-12.5	-14.9	-10.2	-11.1	-14.9	-10.9	-7.3	-10.9	-7.4	-4.4	-4.2	-3.7	-6.2
Greenalite	-	-	-	-	-	-	-9.0	-	-9.2	-6.0	-7.3	-9.1	-5.5	-7.2	-3.7	-0.2	-2.4
Grossular	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.5	-6.4	-5.3	-8.6
Gyrolite	-	-9.8	-7.7	-9.3	-8.6	-8.5	-9.6	-11.1	-9.2	-10.0	-7.4	-8.1	-8.5	-6.5	-8.9	-8.2	-11.4
Hatrurite	-	-42.7	-39.6	-41.5	-40.3	-40.8	-40.4	-44.8	-41.8	-42.7	-36.7	-37.4	-37.8	-33.5	-37.9	-37.0	-37.5
HCl(g)	-17.6	-17.7	-18.7	-17.5	-17.8	-18.5	-16.8	-17.1	-18.6	-17.1	-15.9	-16.2	-15.5	-16.0	-15.1	-15.0	-13.8
Hedenbergite	-	-	-	-	-	-	-7.8	-	-7.8	-7.1	-6.0	-7.0	-6.0	-5.5	-5.5	-4.0	-6.1
Hercynite	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.4	-1.3	0.0	-0.1
Hexahydrite	-4.6	-5.6	-5.8	-4.6	-5.0	-5.7	-4.7	-5.1	-5.9	-5.1	-4.3	-6.3	-4.3	-2.8	-3.0	-3.2	-3.8
Hillebrandite	-	-17.1	-15.0	-16.3	-15.6	-15.8	-16.0	-18.4	-16.5	-17.1	-13.8	-14.3	-14.5	-11.8	-14.7	-14.2	-15.1
Huntite	-1.3	-1.4	0.5	-0.8	0.4	0.3	-1.2	-2.1	-0.9	-0.8	0.2	-0.7	0.3	2.6	0.0	0.5	2.1
Hydromagnesite	-9.7	-10.0	-6.3	-9.1	-7.1	-7.0	-8.7	-10.5	-8.9	-9.0	-7.0	-7.6	-6.9	-3.1	-7.3	-7.0	-5.1
Hydrophilite	-21.8	-21.9	-22.8	-21.4	-21.5	-22.9	-20.5	-21.3	-23.5	-20.9	-18.2	-18.9	-17.3	-17.0	-16.8	-16.7	-14.7

Table D2. continued

Well ID	**E-7P**	**E-3P2**	**E-13P2**	**APK-7**	**E-11P2**	**BPK-1**	**APK-2**	**E-14P2**	**E-9P1**	**E-14P1**	**E-17P2**	**E-11P1**	**E-3P3**	**E-2P**	**E-8-15P2**	**APK-5**	**E-4P**
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Hydroxylapatite	-	-	-1.2	-1.8	1.1	-0.6	-2.3	-	-	-	-	-0.7	-	-	1.6	0.5	2.7
Ice	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Jadeite	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.6	-0.7	-0.1	-2.9
Jarosite	-	-	-	-	-	-	-7.5	-	-11.9	-6.7	-4.6	-9.6	-2.6	-1.3	1.9	5.5	2.9
Jarosite-Na	-	-	-	-	-	-	-10.2	-	-13.7	-7.7	-7.2	-11.9	-5.4	-4.1	-1.0	2.4	-0.8
K	-59.0	-59.9	-59.7	-59.2	-59.6	-60.0	-57.4	-59.8	-60.0	-59.3	-56.4	-56.6	-56.2	-55.9	-55.6	-55.1	-54.7
K(g)	-70.1	-71.0	-70.7	-70.2	-70.6	-71.1	-68.1	-70.9	-71.0	-70.4	-66.8	-66.9	-66.6	-66.3	-65.9	-65.4	-64.7
K2CO3:1.5H2O	-16.2	-18.0	-16.9	-16.8	-17.1	-17.6	-16.0	-17.6	-18.1	-16.9	-15.3	-15.4	-14.6	-14.4	-14.3	-13.8	-14.9
K2O	-79.2	-81.1	-79.1	-79.3	-79.5	-80.3	-76.4	-81.0	-80.6	-79.8	-74.2	-74.1	-74.1	-72.6	-73.4	-72.5	-72.7
K3H(SO4)2	-23.3	-27.8	-28.2	-24.5	-26.5	-29.0	-23.0	-26.1	-29.0	-25.6	-21.5	-25.5	-20.6	-18.8	-17.3	-16.9	-19.9
K8H4(CO3)6:3H2O	-58.8	-66.0	-63.3	-61.7	-63.4	-65.6	-58.6	-64.1	-66.8	-61.5	-56.6	-57.2	-53.4	-54.2	-52.3	-49.7	-53.0
Kainite	-13.3	-15.3	-15.5	-13.6	-14.3	-15.9	-12.8	-14.0	-16.5	-13.8	-11.3	-13.5	-10.4	-9.0	-8.7	-8.8	-9.1
KAl(SO4)2	-	-	-	-	-	-	-	-	-	-	-	-	-	-27.7	-24.2	-24.0	-25.6
Kalicinite	-6.6	-7.6	-7.4	-7.1	-7.3	-7.6	-6.7	-7.3	-7.7	-7.0	-6.5	-6.6	-6.1	-6.4	-5.9	-5.6	-5.9
Kalsilite	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.7	-0.9	-0.5	-2.3
Katoite	-	-	-	-	-	-	-	-	-	-	-	-	-	-20.5	-23.0	-23.1	-24.9
KBr	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
K-Feldspar	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	2.3	2.9	-1.1
Kieserite	-6.1	-7.0	-7.2	-6.1	-6.4	-7.2	-6.2	-6.5	-7.4	-6.6	-5.7	-7.8	-5.7	-4.3	-4.4	-4.7	-5.2
KMgCl3	-38.6	-39.8	-40.4	-38.5	-38.8	-40.8	-36.3	-38.0	-42.1	-37.6	-33.2	-33.8	-31.4	-31.0	-30.3	-30.4	-27.9
KMgCl3:2H2O	-31.0	-32.2	-32.8	-30.9	-31.3	-33.2	-29.0	-30.4	-34.5	-30.0	-26.0	-26.6	-24.2	-23.9	-23.2	-23.4	-21.0
KNaCO3:6H2O	-12.9	-13.2	-12.7	-12.2	-12.8	-13.3	-11.6	-12.3	-13.7	-11.8	-10.4	-10.1	-10.0	-9.5	-9.6	-9.0	-10.0
Kyanite	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.4	-1.1	-0.7	-1.9
Lansfordite	-2.3	-2.4	-1.8	-2.3	-1.9	-1.8	-2.5	-2.4	-2.2	-2.2	-2.4	-2.5	-2.3	-1.7	-2.4	-2.4	-2.1
Larnite	-	-18.9	-16.8	-18.1	-17.3	-17.6	-17.7	-20.2	-18.3	-18.9	-15.4	-15.9	-16.1	-13.4	-16.3	-15.7	-16.5
Laumontite	-	-	-	-	-	-	-	-	-	-	-	-	-	0.5	1.8	2.7	-1.8
Lawrencite	-	-	-	-	-	-	-23.1	-	-26.1	-22.1	-21.2	-22.2	-19.4	-20.8	-18.0	-17.1	-15.0
Lawsonite	-	-	-	-	-	-	-	-	-	-	-	-	-	0.3	1.2	1.8	-0.5
Leonite	-13.9	-17.6	-17.5	-14.6	-16.0	-18.1	-13.7	-16.2	-18.4	-15.8	-12.3	-16.3	-11.7	-9.1	-8.7	-8.7	-11.1
Lime	-21.5	-21.4	-20.4	-20.9	-20.5	-20.8	-20.3	-22.1	-21.1	-21.3	-19.0	-19.2	-19.3	-17.8	-19.3	-19.0	-18.7

Table D2. continued

Well ID	E-7P	E-3P2	E-13P2	APK-7	E-11P2	BPK-1	APK-2	E-14P2	E-9P1	E-14P1	E-17P2	E-11P1	E-3P3	E-2P	E-8-15P2	APK-5	E-4P
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Magnesite	0.0	0.0	0.5	0.1	0.5	0.5	0.1	-0.1	0.1	0.2	0.3	0.2	0.4	1.0	0.3	0.4	0.8
Magnetite	-	-	-	-	-	-	8.2	-	7.5	10.4	10.3	9.2	12.1	12.2	13.8	17.2	16.5
Manganosite	-	-	-	-	-	-	-	-	-	-	-	-	-8.0	-6.9	-8.5	-7.9	-8.4
Margarite	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.0	1.0	1.9	-0.6
Maximum_Microcline	-	-	-	-	-	-	-	-	-	-	-	-	-	1.0	2.3	2.9	-1.1
Mayenite	-	-	-	-	-	-	-	-	-	-	-	-	-	-201.6	-205.4	-200.3	-197.9
Mercallite	-13.8	-15.6	-16.3	-14.3	-15.3	-16.4	-13.8	-14.8	-16.2	-14.8	-13.3	-15.3	-12.9	-12.3	-11.4	-11.2	-12.4
Merwinite	-	-29.0	-24.4	-27.5	-25.8	-26.0	-26.6	-31.2	-27.6	-28.9	-22.4	-23.1	-23.8	-18.3	-24.1	-23.2	-24.8
Mesolite	-	-	-	-	-	-	-	-	-	-	-	-	-	4.2	5.5	6.4	2.4
Mg	-93.1	-93.1	-93.1	-92.8	-92.8	-93.1	-90.5	-93.3	-93.0	-92.8	-89.1	-89.5	-89.2	-88.4	-88.5	-88.1	-86.0
Mg(g)	-113.6	-113.6	-113.6	-113.2	-113.3	-113.7	-110.3	-113.9	-113.4	-113.3	-108.4	-108.8	-108.6	-107.7	-107.8	-107.2	-104.7
Mg1.5SO4(OH)	-10.0	-11.0	-10.5	-9.8	-9.9	-10.7	-9.3	-10.6	-11.1	-10.4	-8.3	-10.4	-8.5	-6.2	-7.1	-7.3	-7.5
Mg1.25SO4(OH)0.5:0.5H2O	-8.9	-9.9	-9.8	-8.8	-9.1	-9.9	-8.5	-9.5	-10.1	-9.4	-7.7	-9.7	-7.8	-5.9	-6.4	-6.6	-6.8
MgCl2:2H2O	-22.5	-22.7	-23.3	-22.2	-22.2	-23.4	-21.1	-21.7	-24.2	-21.6	-19.2	-19.6	-18.2	-17.9	-17.6	-17.9	-15.7
MgCl2:4H2O	-16.8	-17.1	-17.6	-16.6	-16.6	-17.7	-15.7	-16.0	-18.6	-15.9	-13.9	-14.3	-12.9	-12.6	-12.3	-12.6	-10.6
MgCl2:H2O	-26.0	-26.2	-26.8	-25.7	-25.7	-26.9	-24.5	-25.2	-27.7	-25.1	-22.4	-22.9	-21.5	-21.1	-20.9	-21.1	-18.8
MgOHCl	-14.9	-15.1	-14.7	-14.6	-14.3	-14.9	-13.8	-14.7	-15.6	-14.4	-12.4	-12.6	-12.0	-11.1	-11.7	-11.8	-10.6
MgSO4	-11.6	-12.6	-12.8	-11.6	-12.0	-12.8	-11.3	-12.2	-12.9	-12.1	-10.6	-12.6	-10.7	-9.1	-9.3	-9.4	-9.6
Minnesotaite	-	-	-	-	-	-	-7.8	-	-7.4	-4.3	-6.0	-7.9	-4.6	-6.9	-2.9	0.8	-3.5
Mirabilite	-9.7	-9.5	-10.5	-7.9	-9.4	-10.7	-7.7	-7.5	-10.9	-7.6	-5.8	-7.1	-5.7	-4.3	-4.0	-3.6	-5.8
Misenite	-92.0	-105.7	-109.2	-95.7	-102.6	-110.6	-91.6	-100.0	-110.0	-99.2	-87.5	-101.8	-85.1	-80.3	-73.8	-72.9	-81.4
Mn	-	-	-	-	-	-	-	-	-	-	-	-	-53.4	-53.3	-53.3	-52.7	-52.0
Mn(OH)2(am)	-	-	-	-	-	-	-	-	-	-	-	-	-5.5	-4.4	-6.0	-5.4	-5.9
Mn(OH)3	-	-	-	-	-	-	-	-	-	-	-	-	-10.4	-8.7	-11.1	-10.5	-11.5
Mn3(PO4)2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-17.4	-17.2	-17.7
MnCl2:2H2O	-	-	-	-	-	-	-	-	-	-	-	-	-12.9	-13.0	-12.8	-12.5	-11.2
MnCl2:H2O	-	-	-	-	-	-	-	-	-	-	-	-	-14.4	-14.5	-14.3	-14.0	-12.6
MnCl2:4H2O	-	-	-	-	-	-	-	-	-	-	-	-	-11.7	-11.8	-11.6	-11.3	-10.1
MnHPO4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.0	0.2
MnO2(gamma)	-	-	-	-	-	-	-	-	-	-	-	-	-9.2	-6.8	-9.9	-8.9	-9.5

Table D2. continued

Well ID	**E-7P**	**E-3P2**	**E-13P2**	**APK-7**	**E-11P2**	**BPK-1**	**APK-2**	**E-14P2**	**E-9P1**	**E-14P1**	**E-17P2**	**E-11P1**	**E-3P3**	**E-2P**	**E-8-15P2**	**APK-5**	**E-4P**
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
MnSO4	-	-	-	-	-	-	-	-	-	-	-	-	-11.8	-10.7	-10.8	-10.4	-11.4
Molysite	-	-	-	-	-	-	-39.2	-	-44.1	-38.8	-36.2	-37.2	-34.1	-35.5	-32.5	-31.5	-28.5
Monohydrocalcite	-0.6	-0.5	-0.3	-0.4	-0.1	-0.3	-0.7	-1.0	-0.5	-0.5	-0.1	-0.5	-0.1	0.4	-0.3	0.0	0.3
Monticellite	-	-9.6	-7.2	-8.9	-8.0	-8.0	-8.4	-10.5	-8.9	-9.5	-6.6	-6.8	-7.2	-4.5	-7.4	-7.1	-7.9
Montmor-Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	1.6	3.4	4.1	-0.3
Montmor-K	-	-	-	-	-	-	-	-	-	-	-	-	-	1.3	3.2	3.9	-0.7
Montmor-Na	-	-	-	-	-	-	-	-	-	-	-	-	-	1.5	3.4	4.1	-0.5
Montmor-Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8	3.5	4.2	-0.2
Mordenite	-	-	-	-	-	-	-	-	-	-	-	-	-	-1.6	-0.2	0.7	-5.0
Mordenite-dehy	-	-	-	-	-	-	-	-	-	-	-	-	-	-16.4	-15.1	-14.0	-19.3
Muscovite	-	-	-	-	-	-	-	-	-	-	-	-	-	3.5	6.9	7.7	3.4
Na	-55.2	-54.6	-55.0	-54.1	-54.7	-55.1	-52.6	-54.0	-55.0	-53.7	-51.0	-50.8	-51.1	-50.6	-50.4	-49.9	-49.5
Na(g)	-69.3	-68.7	-69.0	-68.0	-68.7	-69.2	-66.1	-68.1	-69.1	-67.7	-64.2	-64.0	-64.3	-63.8	-63.6	-62.9	-62.2
Na2CO3	-13.8	-12.7	-12.8	-11.8	-12.6	-13.2	-11.2	-11.3	-13.5	-11.0	-9.3	-8.7	-9.2	-8.6	-8.8	-8.0	-8.9
Na2CO3:7H2O	-12.2	-11.1	-11.3	-10.3	-11.1	-11.6	-10.0	-9.7	-12.0	-9.4	-8.3	-7.6	-8.2	-7.5	-7.8	-7.1	-8.2
Na2O	-61.8	-60.7	-60.0	-59.3	-60.1	-60.8	-57.2	-59.6	-61.1	-58.9	-54.2	-53.3	-54.5	-52.7	-53.8	-52.8	-53.2
Na2SiO3	-	-17.7	-17.0	-16.6	-17.3	-17.7	-15.7	-16.5	-18.2	-16.1	-13.3	-12.6	-13.7	-12.4	-13.3	-12.5	-14.7
Na3H(SO4)2	-25.5	-25.6	-27.8	-22.7	-25.5	-28.0	-21.9	-22.4	-28.0	-22.5	-18.7	-21.7	-18.7	-16.3	-15.2	-14.5	-17.5
Na4Ca(SO4)3:2H2O	-23.4	-23.8	-26.2	-19.4	-23.0	-26.8	-18.6	-19.9	-26.9	-19.5	-13.6	-18.4	-13.7	-9.1	-8.6	-7.7	-12.1
Na4SiO4	-	-58.8	-57.4	-56.4	-57.9	-58.9	-53.9	-56.4	-59.8	-55.4	-48.8	-47.1	-49.4	-46.3	-48.4	-46.7	-49.6
Na6Si2O7	-	-85.6	-83.5	-82.1	-84.2	-85.7	-78.4	-81.9	-87.1	-80.5	-70.6	-68.3	-71.7	-67.2	-70.2	-67.6	-72.6
NaFeO2	-	-	-	-	-	-	-9.0	-	-10.8	-8.7	-6.9	-6.8	-6.5	-5.4	-5.7	-4.1	-5.0
Nahcolite	-6.0	-5.4	-5.9	-5.1	-5.6	-5.9	-5.0	-4.6	-6.0	-4.5	-4.3	-4.1	-4.2	-4.3	-4.0	-3.5	-3.8
Natrolite	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.8	0.8	1.9	-2.8
Natron	-11.8	-10.6	-10.8	-9.8	-10.6	-11.2	-9.6	-9.2	-11.5	-8.9	-8.0	-7.4	-7.8	-7.3	-7.5	-6.8	-8.0
Natrosilite	-	-17.1	-16.3	-16.0	-16.8	-17.1	-15.3	-15.8	-17.6	-15.5	-12.9	-12.2	-13.5	-12.4	-13.2	-12.2	-15.4
Nepheline	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.8	-2.1	-1.5	-3.3
Nesquehonite	-3.0	-3.1	-2.5	-2.9	-2.6	-2.6	-2.9	-3.1	-2.9	-2.9	-2.7	-2.9	-2.6	-2.1	-2.7	-2.7	-2.3
Nontronite-Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	15.9	17.3	20.1	15.4
Nontronite-H	-	-	-	-	-	-	-	-	-	-	-	-	-	14.5	16.1	18.9	14.3

Table D2. continued

Well ID	**E-7P**	**E-3P2**	**E-13P2**	**APK-7**	**E-11P2**	**BPK-1**	**APK-2**	**E-14P2**	**E-9P1**	**E-14P1**	**E-17P2**	**E-11P1**	**E-3P3**	**E-2P**	**E-8-15P2**	**APK-5**	**E-4P**
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Nontronite-K	-	-	-	-	-	-	-	-	-	-	-	-	-	15.5	17.0	19.8	14.9
Nontronite-Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	16.0	17.4	20.1	15.5
Nontronite-Na	-	-	-	-	-	-	-	-	-	-	-	-	-	15.7	17.2	20.1	15.2
Okenite	-	-5.5	-4.4	-5.3	-5.0	-4.8	-5.6	-6.2	-5.2	-5.7	-4.5	-4.9	-5.1	-4.3	-5.4	-5.0	-7.1
Oxychloride-Mg	-11.8	-12.0	-10.1	-11.3	-10.4	-10.8	-11.1	-11.7	-12.1	-11.2	-9.7	-9.9	-9.3	-7.0	-9.2	-9.7	-9.0
P	-	-	-110.8	-107.1	-108.1	-108.9	-105.8	-	-	-	-	-108.0	-	-	-103.8	-104.3	-100.8
Paragonite	-	-	-	-	-	-	-	-	-	-	-	-	-	1.4	4.6	5.6	1.4
Pargasite	-	-	-	-	-	-	-	-	-	-	-	-	-	-7.6	-13.1	-11.6	-17.9
Pentahydrite	-4.9	-5.9	-6.1	-5.0	-5.3	-6.1	-5.1	-5.4	-6.2	-5.5	-4.6	-6.7	-4.6	-3.2	-3.3	-3.6	-4.1
Periclase	-9.7	-9.7	-8.3	-9.3	-8.8	-8.7	-8.7	-10.0	-9.3	-9.5	-7.9	-7.9	-8.1	-6.5	-8.1	-8.1	-7.8
Phlogopite	-	-	-	-	-	-	-	-	-	-	-	-	-	7.2	3.8	4.2	0.6
Picromerite	-13.6	-17.3	-17.2	-14.3	-15.7	-17.8	-13.4	-15.8	-18.1	-15.4	-12.0	-16.0	-11.4	-8.8	-8.4	-8.4	-10.8
Pirssonite	-11.5	-10.3	-10.3	-9.4	-10.0	-10.7	-9.4	-9.4	-11.2	-8.6	-7.1	-6.9	-7.0	-5.8	-6.7	-5.7	-6.6
Polyhalite	-17.0	-22.3	-23.4	-17.5	-19.8	-24.0	-17.1	-20.9	-24.2	-20.0	-14.1	-22.8	-13.7	-8.2	-8.0	-8.0	-11.7
Portlandite	-11.1	-11.0	-10.0	-10.6	-10.2	-10.4	-10.3	-11.7	-10.7	-11.0	-9.2	-9.4	-9.4	-7.9	-9.5	-9.3	-9.1
Prehnite	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.1	-0.5	0.4	-3.0
Pseudowollastonite	-	-5.8	-4.8	-5.5	-5.1	-5.2	-5.5	-6.5	-5.5	-5.9	-4.3	-4.6	-4.8	-3.6	-4.9	-4.6	-5.6
Pyrophyllite	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.8	2.1	2.8	-1.6
Quartz	-	0.5	0.6	0.5	0.4	0.6	0.3	0.5	0.6	0.5	0.3	0.2	0.1	-0.2	0.0	0.1	-0.9
Rankinite	-	-24.1	-21.0	-23.0	-21.9	-22.2	-22.6	-26.1	-23.2	-24.2	-19.1	-19.9	-20.4	-16.5	-20.7	-19.8	-21.6
Rhodonite	-	-	-	-	-	-	-	-	-	-	-	-	-3.8	-3.0	-4.4	-3.7	-5.3
Ripidolite-14A	-	-	-	-	-	-	-	-	-	-	-	-	-	2.7	2.8	5.3	2.2
Ripidolite-7A	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.7	-0.5	1.9	-1.1
Sanidine_high	-	-	-	-	-	-	-	-	-	-	-	-	-	-0.1	1.1	1.8	-2.2
Saponite-Ca	-	-	-	-	-	-	-	-	-	-	-	-	-	7.3	3.5	3.8	0.2
Saponite-H	-	-	-	-	-	-	-	-	-	-	-	-	-	5.9	2.3	2.6	-0.9
Saponite-Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	7.4	3.5	3.8	0.3
Saponite-K	-	-	-	-	-	-	-	-	-	-	-	-	-	6.9	3.2	3.5	-0.3
Saponite-Na	-	-	-	-	-	-	-	-	-	-	-	-	-	7.2	3.4	3.7	0.0
Scacchite	-	-	-	-	-	-	-	-	-	-	-	-	-17.6	-17.6	-17.4	-17.0	-15.6

Table D2. continued

Well ID	E-7P	E-3P2	E-13P2	APK-7	E-11P2	BPK-1	APK-2	E-14P2	E-9P1	E-14P1	E-17P2	E-11P1	E-3P3	E-2P	E-8-15P2	APK-5	E-4P
Aquifer Units	Al+Pl	Al+Pl	Al+Pl	Pl	Pl	Pl	MAC	MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	Pl+MAC	MAC+CH	MAC+CH	Al+Pl+MAC+CH+ MBC+Melange
Scolecite	-	-	-	-	-	-	-	-	-	-	-	-	-	2.4	3.6	4.3	0.8
Si	-	-115.1	-118.0	-115.7	-116.8	-117.1	-113.8	-114.9	-115.9	-115.2	-113.4	-114.5	-113.2	-115.3	-112.1	-111.7	-110.0
Si(g)	-	-188.6	-191.5	-188.8	-190.1	-190.7	-184.9	-188.6	-189.2	-188.5	-183.2	-184.3	-183.4	-185.1	-181.9	-180.8	-177.8
Sillimanite	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.0	-1.7	-1.3	-2.5
SiO2(am)	-	-0.8	-0.8	-0.9	-0.9	-0.8	-1.0	-0.8	-0.8	-0.9	-0.9	-1.0	-1.2	-1.4	-1.2	-1.1	-2.1
Smectite-high-Fe-Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5	3.1	4.5	0.5
Smectite-low-Fe-Mg	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5	3.3	4.4	0.1
Spinel	-	-	-	-	-	-	-	-	-	-	-	-	-	-6.4	-5.9	-5.7	-5.6
Starkeyite	-5.3	-6.3	-6.5	-5.4	-5.7	-6.5	-5.4	-5.8	-6.6	-5.9	-5.0	-7.1	-5.0	-3.6	-3.7	-3.9	-4.5
Stilbite	-	-	-	-	-	-	-	-	-	-	-	-	-	3.9	5.9	7.1	-0.5
Stilleite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strengite	-	-	-	-	-	-	-5.1	-	-	-	-	-5.2	-	-	-3.0	-2.4	-1.8
Syngenite	-10.7	-14.3	-14.5	-11.3	-12.8	-15.2	-10.6	-13.3	-15.3	-12.6	-8.8	-13.1	-8.3	-5.7	-5.3	-5.0	-7.5
Tachyhydrite	-45.3	-45.8	-48.0	-44.5	-44.6	-48.1	-42.7	-43.1	-50.6	-42.7	-37.3	-38.9	-34.3	-33.5	-32.7	-33.6	-28.1
Tephroite	-	-	-	-	-	-	-	-	-	-	-	-	-7.3	-5.4	-8.3	-7.1	-9.2
Thenardite	-11.0	-10.8	-11.7	-9.1	-10.6	-12.0	-8.5	-8.8	-12.1	-8.8	-6.4	-7.6	-6.4	-4.8	-4.5	-4.0	-5.9
Thermonatrite	-13.5	-12.4	-12.5	-11.5	-12.4	-12.9	-11.0	-11.0	-13.2	-10.7	-9.1	-8.5	-9.0	-8.4	-8.6	-7.8	-8.8
Tobermorite-11A	-	-27.8	-22.5	-26.3	-24.5	-24.5	-26.6	-31.1	-26.3	-28.2	-21.2	-22.8	-23.7	-18.1	-24.6	-22.9	-29.2
Tobermorite-14A	-	-25.7	-20.4	-24.3	-22.5	-22.4	-24.9	-29.0	-24.2	-26.1	-19.6	-21.1	-22.0	-16.5	-23.0	-21.4	-27.8
Tobermorite-9A	-	-31.5	-26.2	-30.0	-28.2	-28.2	-30.1	-34.8	-29.9	-31.9	-24.5	-26.1	-27.1	-21.4	-27.9	-26.2	-32.3
Todorokite	-	-	-	-	-	-	-	-	-	-	-	-	-38.7	-25.1	-43.7	-38.7	-45.2
Torbernite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tremolite	-	-6.0	3.3	-3.8	-0.6	0.5	-3.3	-8.2	-3.0	-5.6	2.4	1.4	-0.6	7.5	-1.8	-0.8	-8.5
Tridymite	-1000.0	0.4	0.4	0.3	0.2	0.4	0.1	0.4	0.4	0.3	0.1	0.1	-0.1	-0.4	-0.2	0.0	-1.1
Trona-K	-20.6	-21.8	-21.2	-20.3	-21.2	-22.0	-19.3	-20.6	-22.4	-19.8	-17.9	-17.8	-17.1	-17.0	-16.6	-15.6	-17.0
Wairakite	-	-	-	-	-	-	-	-	-	-	-	-	-	-3.8	-2.4	-1.5	-5.8
Whitlockite	-	-	-3.0	-3.2	-1.4	-2.4	-3.4	-	-	-	-	-2.6	-	-	-1.0	-1.8	-0.3
Wollastonite	-	-5.6	-4.5	-5.3	-4.9	-4.9	-5.2	-6.2	-5.3	-5.6	-4.1	-4.4	-4.6	-3.4	-4.7	-4.4	-5.4
Wustite	-	-	-	-	-	-	-5.9	-	-6.3	-5.2	-5.3	-5.7	-4.6	-4.9	-4.0	-2.9	-2.9
Xonotlite	-	-43.0	-36.7	-41.1	-38.9	-39.1	-40.8	-47.1	-41.2	-43.4	-33.9	-35.7	-36.8	-29.6	-37.6	-35.7	-41.5
Zoisite	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.2	-1.5	-0.5	-3.9

Table D3. Example output from saturation calculations

```
Initial solution 17.  E-4P

-----------------------------Solution composition------------------------------

       Elements           Molality       Moles

       Al                1.917e-06   1.917e-06
       Alkalinity        7.623e-03   7.623e-03
       Ca                2.373e-02   2.373e-02
       Cl                2.829e-01   2.829e-01
       Fe                1.414e-04   1.414e-04
       K                 8.838e-04   8.838e-04
       Mg                1.994e-02   1.994e-02
       Mn                4.693e-06   4.693e-06
       Na                4.558e-02   4.558e-02
       P                 2.323e-06   2.323e-06
       S(6)              4.337e-03   4.337e-03
       Si                2.012e-05   2.012e-05

----------------------------Description of solution----------------------------

                                       pH  =   7.320
                                       pe  =   4.000
                        Activity of water  =   0.994
                 Ionic strength (mol/kgw)  =   2.494e-01
                       Mass of water (kg)  =   1.000e+00
                    Total carbon (mol/kg)  =   7.761e-03
                       Total CO2 (mol/kg)  =   7.761e-03
                         Temperature (°C)  =  38.03
                  Electrical balance (eq)  =  -1.652e-01
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  = -39.68
                               Iterations  =   9
                                  Total H  = 1.110581e+02
                                  Total O  = 5.556588e+01

----------------------------Distribution of species----------------------------

                                               Log       Log       Log    mole V
   Species          Molality    Activity  Molality  Activity     Gamma   cm³/mol

   OH-             7.199e-07   5.033e-07    -6.143    -6.298    -0.155     (0)
   H+              5.954e-08   4.786e-08    -7.225    -7.320    -0.095      0.00
   H2O             5.553e+01   9.936e-01     1.744    -0.003     0.000     18.14
Al            1.917e-06
   AlO2-           1.806e-06   1.287e-06    -5.743    -5.890    -0.147     (0)
   HAlO2           9.958e-08   9.958e-08    -7.002    -7.002     0.000     (0)
   NaAlO2          9.180e-09   9.180e-09    -8.037    -8.037     0.000     (0)
   Al(OH)2+        2.100e-09   1.496e-09    -8.678    -8.825    -0.147     (0)
   AlOH+2          5.325e-11   1.368e-11   -10.274   -10.864    -0.590     (0)
   Al+3            2.170e-13   2.508e-14   -12.664   -13.601    -0.937     (0)
   AlHPO4+         1.375e-13   9.800e-14   -12.862   -13.009    -0.147     (0)
   AlSO4+          1.984e-14   1.413e-14   -13.703   -13.850    -0.147     (0)
   Al(SO4)2-       8.482e-16   6.044e-16   -15.072   -15.219    -0.147     (0)
   Al2(OH)2+4      8.461e-19   5.530e-21   -18.073   -20.257    -2.185     (0)
   Al3(OH)4+5      7.303e-23   3.857e-26   -22.137   -25.414    -3.277     (0)
   AlH2PO4+2       9.153e-25   2.351e-25   -24.038   -24.629    -0.590     (0)
   Al13O4(OH)24+7  1.136e-35   0.000e+00   -34.945   -41.378    -6.433     (0)
C(4)          7.761e-03
   HCO3-           6.056e-03   4.315e-03    -2.218    -2.365    -0.147     (0)
   CaHCO3+         5.089e-04   3.626e-04    -3.293    -3.441    -0.147     (0)
   MgHCO3+         4.582e-04   3.265e-04    -3.339    -3.486    -0.147     (0)
   CO2             3.997e-04   4.237e-04    -3.398    -3.373     0.025     (0)
   NaHCO3          1.529e-04   1.529e-04    -3.816    -3.816     0.000     (0)
   CaCO3           1.044e-04   1.044e-04    -3.981    -3.981     0.000     (0)
   MgCO3           3.854e-05   3.854e-05    -4.414    -4.414     0.000     (0)
   FeHCO3+         2.094e-05   1.492e-05    -4.679    -4.826    -0.147     (0)
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   CO3-2          1.949e-05   5.006e-06    -4.710    -5.301    -0.590     (0)
   FeCO3          1.496e-06   1.496e-06    -5.825    -5.825     0.000     (0)
   NaCO3-         5.276e-07   3.760e-07    -6.278    -6.425    -0.147     (0)
   MnCO3          1.483e-07   1.483e-07    -6.829    -6.829     0.000     (0)
   MnHCO3+        4.883e-08   3.479e-08    -7.311    -7.459    -0.147     (0)
   FeCO3+         1.343e-10   9.568e-11    -9.872   -10.019    -0.147     (0)
Ca             2.373e-02
   Ca+2           2.205e-02   6.728e-03    -1.657    -2.172    -0.516     (0)
   CaSO4          6.054e-04   6.054e-04    -3.218    -3.218     0.000     (0)
   CaHCO3+        5.089e-04   3.626e-04    -3.293    -3.441    -0.147     (0)
   CaCl+          4.064e-04   2.896e-04    -3.391    -3.538    -0.147     (0)
   CaCO3          1.044e-04   1.044e-04    -3.981    -3.981     0.000     (0)
   CaCl2          5.821e-05   5.821e-05    -4.235    -4.235     0.000     (0)
   CaHPO4         5.752e-07   5.752e-07    -6.240    -6.240     0.000     (0)
   CaPO4-         4.219e-08   3.006e-08    -7.375    -7.522    -0.147     (0)
   CaOH+          2.769e-08   1.973e-08    -7.558    -7.705    -0.147     (0)
   CaP2O7-2       7.736e-13   1.855e-13   -12.111   -12.732    -0.620     (0)
   CaH2PO4+       1.766e-15   1.258e-15   -14.753   -14.900    -0.147     (0)
Cl(-1)         2.829e-01
   Cl-            2.799e-01   1.916e-01    -0.553    -0.718    -0.165     (0)
   MgCl+          1.309e-03   9.326e-04    -2.883    -3.030    -0.147     (0)
   NaCl           1.166e-03   1.166e-03    -2.933    -2.933     0.000     (0)
   CaCl+          4.064e-04   2.896e-04    -3.391    -3.538    -0.147     (0)
   CaCl2          5.821e-05   5.821e-05    -4.235    -4.235     0.000     (0)
   KCl            4.937e-06   4.937e-06    -5.307    -5.307     0.000     (0)
   FeCl+          1.390e-06   9.901e-07    -5.857    -6.004    -0.147     (0)
   MnCl+          8.470e-07   6.035e-07    -6.072    -6.219    -0.147     (0)
   MnCl3-         4.862e-09   3.464e-09    -8.313    -8.460    -0.147     (0)
   HCl            2.060e-09   2.060e-09    -8.686    -8.686     0.000     (0)
   FeCl2          1.098e-09   1.098e-09    -8.959    -8.959     0.000     (0)
   FeCl4-2        5.358e-10   1.285e-10    -9.271    -9.891    -0.620     (0)
   FeCl2+         6.426e-14   4.579e-14   -13.192   -13.339    -0.147     (0)
   FeCl+2         2.192e-15   5.629e-16   -14.659   -15.250    -0.590     (0)
   FeCl4-         2.836e-18   2.021e-18   -17.547   -17.695    -0.147     (0)
Cl(1)          3.580e-34
   HClO           1.999e-34   1.999e-34   -33.699   -33.699     0.000     (0)
   ClO-           1.581e-34   1.126e-34   -33.801   -33.948    -0.147     (0)
Cl(3)          0.000e+00
   ClO2-          0.000e+00   0.000e+00   -60.056   -60.203    -0.147     (0)
   HClO2          0.000e+00   0.000e+00   -64.353   -64.353     0.000     (0)
Cl(5)          0.000e+00
   ClO3-          0.000e+00   0.000e+00   -73.026   -73.181    -0.155     (0)
Cl(7)          0.000e+00
   ClO4-          0.000e+00   0.000e+00   -90.217   -90.372    -0.155     (0)
Fe(2)          4.606e-05
   Fe+2           2.159e-05   6.589e-06    -4.666    -5.181    -0.516     (0)
   FeHCO3+        2.094e-05   1.492e-05    -4.679    -4.826    -0.147     (0)
   FeCO3          1.496e-06   1.496e-06    -5.825    -5.825     0.000     (0)
   FeCl+          1.390e-06   9.901e-07    -5.857    -6.004    -0.147     (0)
   FeSO4          5.752e-07   5.752e-07    -6.240    -6.240     0.000     (0)
   FeOH+          6.070e-08   4.325e-08    -7.217    -7.364    -0.147     (0)
   FeHPO4         4.081e-09   4.081e-09    -8.389    -8.389     0.000     (0)
   FePO4-         1.219e-09   8.688e-10    -8.914    -9.061    -0.147     (0)
   FeCl2          1.098e-09   1.098e-09    -8.959    -8.959     0.000     (0)
   FeCl4-2        5.358e-10   1.285e-10    -9.271    -9.891    -0.620     (0)
   Fe(OH)2        7.132e-12   7.132e-12   -11.147   -11.147     0.000     (0)
   Fe(OH)3-       8.271e-15   5.894e-15   -14.082   -14.230    -0.147     (0)
   FeH2PO4+       3.451e-17   2.459e-17   -16.462   -16.609    -0.147     (0)
   Fe(OH)4-2      5.103e-22   1.223e-22   -21.292   -21.912    -0.620     (0)
Fe(3)          9.529e-05
   Fe(OH)3        8.272e-05   8.272e-05    -4.082    -4.082     0.000     (0)
   Fe(OH)2+       1.196e-05   8.520e-06    -4.922    -5.070    -0.147     (0)
   Fe(OH)4-       6.053e-07   4.313e-07    -6.218    -6.365    -0.147     (0)
   FeOH+2         4.826e-09   1.239e-09    -8.316    -8.907    -0.590     (0)
   FeCO3+         1.343e-10   9.568e-11    -9.872   -10.019    -0.147     (0)
   FeHPO4+        3.056e-11   2.178e-11   -10.515   -10.662    -0.147     (0)
   Fe+3           8.002e-14   9.248e-15   -13.097   -14.034    -0.937     (0)
   FeCl2+         6.426e-14   4.579e-14   -13.192   -13.339    -0.147     (0)
   Fe2(OH)2+4     6.327e-15   4.135e-17   -14.199   -16.384    -2.185     (0)
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   FeCl+2          2.192e-15   5.629e-16   -14.659   -15.250    -0.590     (0)
   FeSO4+          1.154e-15   8.226e-16   -14.938   -15.085    -0.147     (0)
   Fe3(OH)4+5      1.393e-16   7.360e-20   -15.856   -19.133    -3.277     (0)
   Fe(SO4)2-       6.441e-18   4.590e-18   -17.191   -17.338    -0.147     (0)
   FeCl4-          2.836e-18   2.021e-18   -17.547   -17.695    -0.147     (0)
   FeH2PO4+2       3.966e-24   1.019e-24   -23.402   -23.992    -0.590     (0)
H(0)          6.302e-26
   H2              3.151e-26   3.340e-26   -25.502   -25.476     0.025     (0)
K             8.838e-04
   K+              8.749e-04   5.989e-04    -3.058    -3.223    -0.165     (0)
   KCl             4.937e-06   4.937e-06    -5.307    -5.307     0.000     (0)
   KSO4-           3.998e-06   2.849e-06    -5.398    -5.545    -0.147     (0)
   KHPO4-          7.879e-10   5.614e-10    -9.104    -9.251    -0.147     (0)
   KOH             4.310e-11   4.310e-11   -10.365   -10.365     0.000     (0)
   KHSO4           1.934e-13   1.934e-13   -12.714   -12.714     0.000     (0)
   KP2O7-3         3.006e-17   1.173e-18   -16.522   -17.931    -1.409     (0)
Mg            1.994e-02
   Mg+2            1.686e-02   6.113e-03    -1.773    -2.214    -0.441     (0)
   MgCl+           1.309e-03   9.326e-04    -2.883    -3.030    -0.147     (0)
   MgSO4           1.268e-03   1.268e-03    -2.897    -2.897     0.000     (0)
   MgHCO3+         4.582e-04   3.265e-04    -3.339    -3.486    -0.147     (0)
   MgCO3           3.854e-05   3.854e-05    -4.414    -4.414     0.000     (0)
   MgHPO4          7.731e-07   7.731e-07    -6.112    -6.112     0.000     (0)
   MgPO4-          5.159e-08   3.676e-08    -7.287    -7.435    -0.147     (0)
   MgP2O7-2        4.019e-12   9.636e-13   -11.396   -12.016    -0.620     (0)
   MgH2PO4+        2.920e-15   2.081e-15   -14.535   -14.682    -0.147     (0)
   Mg4(OH)4+4      7.056e-18   4.612e-20   -17.151   -19.336    -2.185     (0)
Mn(2)         4.693e-06
   Mn+2            3.471e-06   1.059e-06    -5.460    -5.975    -0.516     (0)
   MnCl+           8.470e-07   6.035e-07    -6.072    -6.219    -0.147     (0)
   MnSO4           1.712e-07   1.712e-07    -6.767    -6.767     0.000     (0)
   MnCO3           1.483e-07   1.483e-07    -6.829    -6.829     0.000     (0)
   MnHCO3+         4.883e-08   3.479e-08    -7.311    -7.459    -0.147     (0)
   MnCl3-          4.862e-09   3.464e-09    -8.313    -8.460    -0.147     (0)
   MnOH+           7.930e-10   5.651e-10    -9.101    -9.248    -0.147     (0)
   MnHPO4          6.264e-10   6.264e-10    -9.203    -9.203     0.000     (0)
   MnPO4-          3.566e-11   2.541e-11   -10.448   -10.595    -0.147     (0)
   MnH2PO4+        3.976e-12   2.833e-12   -11.401   -11.548    -0.147     (0)
   Mn(OH)2         2.879e-14   2.879e-14   -13.541   -13.541     0.000     (0)
   Mn2(OH)3+       1.772e-14   1.263e-14   -13.751   -13.899    -0.147     (0)
   Mn2OH+3         1.222e-14   6.412e-16   -13.913   -15.193    -1.280     (0)
   Mn(OH)3-        7.868e-19   5.606e-19   -18.104   -18.251    -0.147     (0)
   Mn(OH)4-2       4.111e-25   9.855e-26   -24.386   -25.006    -0.620     (0)
Mn(3)         1.371e-26
   Mn+3            1.371e-26   7.189e-28   -25.863   -27.143    -1.280     (0)
Mn(6)         0.000e+00
   MnO4-2          0.000e+00   0.000e+00   -44.644   -45.264    -0.620     (0)
Mn(7)         0.000e+00
   MnO4-           0.000e+00   0.000e+00   -49.772   -49.927    -0.155     (0)
Na            4.558e-02
   Na+             4.410e-02   3.142e-02    -1.356    -1.503    -0.147     (0)
   NaCl            1.166e-03   1.166e-03    -2.933    -2.933     0.000     (0)
   NaSO4-          1.605e-04   1.143e-04    -3.795    -3.942    -0.147     (0)
   NaHCO3          1.529e-04   1.529e-04    -3.816    -3.816     0.000     (0)
   NaCO3-          5.276e-07   3.760e-07    -6.278    -6.425    -0.147     (0)
   NaHSiO3         8.506e-08   8.506e-08    -7.070    -7.070     0.000     (0)
   NaHPO4-         5.706e-08   4.066e-08    -7.244    -7.391    -0.147     (0)
   NaAlO2          9.180e-09   9.180e-09    -8.037    -8.037     0.000     (0)
   NaOH            2.691e-09   2.691e-09    -8.570    -8.570     0.000     (0)
   NaHP2O7-2       1.081e-15   2.592e-16   -14.966   -15.586    -0.620     (0)
   NaP2O7-3        6.859e-16   2.677e-17   -15.164   -16.572    -1.409     (0)
   Na2P2O7-2       2.786e-16   6.681e-17   -15.555   -16.175    -0.620     (0)
O(0)          1.228e-37
   O2              6.141e-38   6.510e-38   -37.212   -37.186     0.025     (0)
P(-3)         0.000e+00
   PH4+            0.000e+00   0.000e+00  -166.989  -167.136    -0.147     (0)
P(5)          2.323e-06
   MgHPO4          7.731e-07   7.731e-07    -6.112    -6.112     0.000     (0)
   HPO4-2          6.489e-07   1.556e-07    -6.188    -6.808    -0.620     (0)
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   CaHPO4          5.752e-07   5.752e-07    -6.240    -6.240     0.000     (0)
   H2PO4-          1.680e-07   1.197e-07    -6.775    -6.922    -0.147     (0)
   NaHPO4-         5.706e-08   4.066e-08    -7.244    -7.391    -0.147     (0)
   MgPO4-          5.159e-08   3.676e-08    -7.287    -7.435    -0.147     (0)
   CaPO4-          4.219e-08   3.006e-08    -7.375    -7.522    -0.147     (0)
   FeHPO4          4.081e-09   4.081e-09    -8.389    -8.389     0.000     (0)
   FePO4-          1.219e-09   8.688e-10    -8.914    -9.061    -0.147     (0)
   KHPO4-          7.879e-10   5.614e-10    -9.104    -9.251    -0.147     (0)
   MnHPO4          6.264e-10   6.264e-10    -9.203    -9.203     0.000     (0)
   PO4-3           4.694e-11   1.832e-12   -10.328   -11.737    -1.409     (0)
   MnPO4-          3.566e-11   2.541e-11   -10.448   -10.595    -0.147     (0)
   FeHPO4+         3.056e-11   2.178e-11   -10.515   -10.662    -0.147     (0)
   MgP2O7-2        4.019e-12   9.636e-13   -11.396   -12.016    -0.620     (0)
   MnH2PO4+        3.976e-12   2.833e-12   -11.401   -11.548    -0.147     (0)
   H3PO4           1.026e-12   1.026e-12   -11.989   -11.989     0.000     (0)
   CaP2O7-2        7.736e-13   1.855e-13   -12.111   -12.732    -0.620     (0)
   AlHPO4+         1.375e-13   9.800e-14   -12.862   -13.009    -0.147     (0)
   HP2O7-3         1.534e-14   5.988e-16   -13.814   -15.223    -1.409     (0)
   MgH2PO4+        2.920e-15   2.081e-15   -14.535   -14.682    -0.147     (0)
   P2O7-4          2.528e-15   7.769e-18   -14.597   -17.110    -2.512     (0)
   CaH2PO4+        1.766e-15   1.258e-15   -14.753   -14.900    -0.147     (0)
   NaHP2O7-2       1.081e-15   2.592e-16   -14.966   -15.586    -0.620     (0)
   NaP2O7-3        6.859e-16   2.677e-17   -15.164   -16.572    -1.409     (0)
   H2P2O7-2        4.517e-16   1.083e-16   -15.345   -15.965    -0.620     (0)
   Na2P2O7-2       2.786e-16   6.681e-17   -15.555   -16.175    -0.620     (0)
   FeH2PO4+        3.451e-17   2.459e-17   -16.462   -16.609    -0.147     (0)
   KP2O7-3         3.006e-17   1.173e-18   -16.522   -17.931    -1.409     (0)
   H3P2O7-         1.753e-21   1.249e-21   -20.756   -20.903    -0.147     (0)
   FeH2PO4+2       3.966e-24   1.019e-24   -23.402   -23.992    -0.590     (0)
   AlH2PO4+2       9.153e-25   2.351e-25   -24.038   -24.629    -0.590     (0)
   H4P2O7          1.959e-27   1.959e-27   -26.708   -26.708     0.000     (0)
S(6)          4.337e-03
   SO4-2           2.297e-03   5.508e-04    -2.639    -3.259    -0.620     (0)
   MgSO4           1.268e-03   1.268e-03    -2.897    -2.897     0.000     (0)
   CaSO4           6.054e-04   6.054e-04    -3.218    -3.218     0.000     (0)
   NaSO4-          1.605e-04   1.143e-04    -3.795    -3.942    -0.147     (0)
   KSO4-           3.998e-06   2.849e-06    -5.398    -5.545    -0.147     (0)
   FeSO4           5.752e-07   5.752e-07    -6.240    -6.240     0.000     (0)
   MnSO4           1.712e-07   1.712e-07    -6.767    -6.767     0.000     (0)
   HSO4-           5.424e-09   3.864e-09    -8.266    -8.413    -0.147     (0)
   KHSO4           1.934e-13   1.934e-13   -12.714   -12.714     0.000     (0)
   AlSO4+          1.984e-14   1.413e-14   -13.703   -13.850    -0.147     (0)
   FeSO4+          1.154e-15   8.226e-16   -14.938   -15.085    -0.147     (0)
   Al(SO4)2-       8.482e-16   6.044e-16   -15.072   -15.219    -0.147     (0)
   Fe(SO4)2-       6.441e-18   4.590e-18   -17.191   -17.338    -0.147     (0)
   H2SO4           1.203e-19   1.203e-19   -18.920   -18.920     0.000     (0)
Si            2.012e-05
   SiO2            1.994e-05   1.994e-05    -4.700    -4.700     0.000     (0)
   HSiO3-          1.020e-07   7.267e-08    -6.991    -7.139    -0.147     (0)
   NaHSiO3         8.506e-08   8.506e-08    -7.070    -7.070     0.000     (0)
   H2SiO4-2        3.929e-13   9.420e-14   -12.406   -13.026    -0.620     (0)
   H6(H2SiO4)4-2   6.258e-18   1.500e-18   -17.204   -17.824    -0.620     (0)
   H4(H2SiO4)4-4   1.068e-23   3.282e-26   -22.971   -25.484    -2.512     (0)

------------------------------Saturation indices-------------------------------

  Phase               SI** log IAP   log K(311 K,   1 atm)

  Afwillite       -29.65     27.99   57.64  Ca3Si2O4(OH)6
  Akermanite      -15.15     27.95   43.11  Ca2MgSi2O7
  Al             -106.63     36.24  142.88  Al
  Al(g)          -154.92     36.24  191.17  Al
  Al2(SO4)3       -53.14    -36.98   16.17  Al2(SO4)3
  Al2(SO4)3:6H2O  -36.97    -37.00   -0.02  Al2(SO4)3:6H2O
  Albite           -2.19      0.07    2.26  NaAlSi3O8
  Albite_high      -3.43      0.07    3.50  NaAlSi3O8
  Albite_low       -2.19      0.07    2.26  NaAlSi3O8
  Alum-K          -18.49    -23.38   -4.88  KAl(SO4)2:12H2O
  Alunite          -4.44     -6.64   -2.20  KAl3(OH)6(SO4)2
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  Amesite-14A       4.28     73.70   69.42  Mg4Al4Si2O10(OH)8
  Analcime         -1.48      4.01    5.49  Na.96Al.96Si2.04O6:H2O
  Analcime-dehy    -7.54      4.02   11.56  Na.96Al.96Si2.04O6
  Andalusite       -2.14     12.01   14.15  Al2SiO5
  Andradite         8.18     39.14   30.96  Ca3Fe2(SiO4)3
  Anhydrite        -0.93     -5.43   -4.50  CaSO4
  Annite           -0.70     26.72   27.41  KFe3AlSi3O10(OH)2
  Anorthite        -4.47     19.77   24.24  CaAl2(SiO4)2
  Antarcticite     -7.72     -3.62    4.09  CaCl2:6H2O
  Anthophyllite   -13.55     49.36   62.90  Mg7Si8O22(OH)2
  Antigorite      -14.51    436.43  450.93  Mg48Si34O85(OH)62
  Aphthitalite    -13.80    -17.69   -3.89  NaK3(SO4)2
  Aragonite         1.01      2.78    1.77  CaCO3
  Arcanite         -8.02     -9.70   -1.68  K2SO4
  Artinite         -3.52     15.15   18.67  Mg2CO3(OH)2:3H2O
  Bassanite        -1.57     -5.43   -3.86  CaSO4:0.5H2O
  Beidellite-Ca     0.04      4.27    4.23  Ca.165Al2.33Si3.67O10(OH)2
  Beidellite-H     -1.12      2.21    3.33  H.33Al2.33Si3.67O10(OH)2
  Beidellite-K     -0.47      3.57    4.04  K.33Al2.33Si3.67O10(OH)2
  Beidellite-Mg     0.09      4.26    4.17  Mg.165Al2.33Si3.67O10(OH)2
  Beidellite-Na    -0.20      4.13    4.34  Na.33Al2.33Si3.67O10(OH)2
  Berlinite        -5.09    -13.09   -8.00  AlPO4
  Birnessite      -50.86   -136.41  -85.55  Mn8O14:5H2O
  Bischofite       -8.06     -3.67    4.39  MgCl2:6H2O
  Bixbyite         -8.02    -10.38   -2.35  Mn2O3
  Bloedite         -9.27    -11.75   -2.48  Na2Mg(SO4)2:4H2O
  Boehmite          1.64      8.35    6.72  AlO2H
  Brucite          -3.05     12.42   15.47  Mg(OH)2
  Brushite        -15.54     -8.99    6.55  CaHPO4:2H2O
  Burkeite        -20.07    -10.58    9.49  Na6CO3(SO4)2
  C               -33.75     27.50   61.26  C
  C(g)           -146.12     27.50  173.62  C
  Ca             -102.73     31.06  133.79  Ca
  Ca(g)          -126.67     31.06  157.73  Ca
  Ca-Al_Pyroxene   -8.77     24.47   33.24  CaAl2SiO6
  Ca2Al2O5:8H2O   -17.95     41.62   59.57  Ca2Al2O5:8H2O
  Ca2Cl2(OH)2:H2O -17.44      8.85   26.29  Ca2Cl2(OH)2:H2O
  Ca3Al2O6        -52.83     54.11  106.93  Ca3Al2O6
  Ca4Al2Fe2O10    -49.73     82.41  132.14  Ca4Al2Fe2O10
  Ca4Al2O7:13H2O  -40.72     66.53  107.25  Ca4Al2O7:13H2O
  Ca4Al2O7:19H2O  -37.16     66.52  103.68  Ca4Al2O7:19H2O
  Ca4Cl2(OH)6:13H2O -34.59     33.74   68.33  Ca4Cl2(OH)6:13H2O
  CaAl2O4         -14.52     29.18   43.70  CaAl2O4
  CaAl2O4:10H2O    -8.85     29.15   37.99  CaAl2O4:10H2O
  CaAl4O7         -17.45     45.89   63.33  CaAl4O7
  Calcite           1.15      2.78    1.63  CaCO3
  Carnallite      -11.88     -7.61    4.27  KMgCl3:6H2O
  CaSO4:0.5H2O(beta)  -1.73     -5.43   -3.70  CaSO4:0.5H2O
  Celadonite       -0.68      6.07    6.75  KMgAlSi4O10(OH)2
  Chalcedony       -1.17     -4.70   -3.53  SiO2
  Chamosite-7A      0.84     30.92   30.08  Fe2Al2SiO5(OH)4
  Chloromagnesite -24.28     -3.65   20.64  MgCl2
  Chrysotile       -1.57     27.86   29.43  Mg3Si2O5(OH)4
  Cl2(g)          -37.25    -34.67    2.59  Cl2
  Clinochlore-14A   2.16     64.72   62.55  Mg5Al2Si3O10(OH)8
  Clinochlore-7A   -1.12     64.72   65.83  Mg5Al2Si3O10(OH)8
  Clinoptilolite-Ca  -9.63    -17.77   -8.14
Ca1.7335Al3.45Fe.017Si14.533O36:10.922H2O
  Clinoptilolite-dehy-Ca -43.38    -17.74   25.64  Ca1.7335Al3.45Fe.017Si14.533O36
  Clinoptilolite-dehy-K -47.86    -25.15   22.71  K3.467Al3.45Fe.017Si14.533O36
  Clinoptilolite-dehy-Na -45.25    -19.19   26.07  Na3.467Al3.45Fe.017Si14.533O36
  Clinoptilolite-hy-Ca  -9.70    -17.77   -8.07
Ca1.7335Al3.45Fe.017Si14.533O36:11.645H2O
  Clinoptilolite-hy-K -13.85    -25.17  -11.32
K3.467Al3.45Fe.017Si14.533O36:7.499H2O
  Clinoptilolite-hy-Na -11.51    -19.22   -7.71
Na3.467Al3.45Fe.017Si14.533O36:10.877H2O
  Clinoptilolite-K -14.15    -25.18  -11.03
K3.467Al3.45Fe.017Si14.533O36:10.922H2O
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  Clinoptilolite-Na -11.52    -19.22   -7.70
Na3.467Al3.45Fe.017Si14.533O36:10.922H2O
  Clinozoisite     -3.83     35.89   39.73  Ca2Al3Si3O12(OH)
  CO2(g)           -1.77     -9.68   -7.91  CO2
  Coesite          -1.69     -4.70   -3.01  SiO2
  Cordierite_anhyd -12.69     34.77   47.45  Mg2Al4Si5O18
  Cordierite_hydr -10.33     34.76   45.09  Mg2Al4Si5O18:H2O
  Corundum          0.34     16.71   16.37  Al2O3
  Cristobalite(alpha)  -1.43     -4.70   -3.27  SiO2
  Cristobalite(beta)  -1.84     -4.70   -2.86  SiO2
  Cronstedtite-7A  15.67     30.05   14.38  Fe2Fe2SiO5(OH)4
  Daphnite-14A      1.59     49.88   48.29  Fe5AlAlSi3O10(OH)8
  Daphnite-7A      -1.68     49.88   51.56  Fe5AlAlSi3O10(OH)8
  Dawsonite         0.70      4.49    3.79  NaAlCO3(OH)2
  Diaspore          2.02      8.35    6.34  AlHO2
  Dicalcium_silicate -15.30     20.23   35.52  Ca2SiO4
  Diopside         -4.41     15.49   19.90  CaMgSi2O6
  Dolomite          3.50      5.52    2.02  CaMg(CO3)2
  Dolomite-dis      2.05      5.52    3.47  CaMg(CO3)2
  Dolomite-ord      3.51      5.52    2.01  CaMg(CO3)2
  Enstatite        -2.95      7.72   10.68  MgSiO3
  Epidote           5.54     35.46   29.92  Ca2FeAl2Si3O12OH
  Epidote-ord       5.55     35.46   29.91  FeCa2Al2(OH)(SiO4)3
  Epsomite         -3.53     -5.49   -1.96  MgSO4:7H2O
  Ettringite      -22.03     37.72   59.75  Ca6Al2(SO4)3(OH)12:26H2O
  Fayalite         -3.73     14.21   17.94  Fe2SiO4
  Fe              -28.24     28.05   56.29  Fe
  Fe(OH)2          -3.74      9.45   13.20  Fe(OH)2
  Fe(OH)3           2.89      7.92    5.02  Fe(OH)3
  Fe2(SO4)3       -38.99    -37.84    1.15  Fe2(SO4)3
  FeO              -3.29      9.46   12.75  FeO
  Ferrite-Ca        8.76     28.31   19.55  CaFe2O4
  Ferrite-Dicalcium -12.53     40.77   53.31  Ca2Fe2O5
  Ferrite-Mg        9.31     28.27   18.96  MgFe2O4
  Ferrosilite      -2.22      4.76    6.98  FeSiO3
  FeSO4           -10.49     -8.44    2.05  FeSO4
  Forsterite       -6.15     20.15   26.30  Mg2SiO4
  Foshagite       -27.39     35.76   63.15  Ca4Si3O9(OH)2:0.5H2O
  Gaylussite       -6.45      4.72   11.16  CaNa2(CO3)2:5H2O
  Gehlenite       -15.68     36.94   52.62  Ca2Al2SiO7
  Gibbsite          1.37      8.35    6.98  Al(OH)3
  Gismondine       -2.19     39.52   41.72  Ca2Al4Si4O16:9H2O
  Glauberite       -6.23    -11.70   -5.47  Na2Ca(SO4)2
  Goethite          7.84      7.92    0.08  FeOOH
  Greenalite       -2.40     18.96   21.36  Fe3Si2O5(OH)4
  Grossular        -8.59     40.00   48.59  Ca3Al2(SiO4)3
  Gypsum           -0.88     -5.44   -4.56  CaSO4:2H2O
  Gyrolite        -11.36     10.82   22.18  Ca2Si3O7(OH)2:1.5H2O
  H2(g)           -22.35    -25.48   -3.13  H2
  H2O(g)           -1.27     -0.00    1.26  H2O
  Halite           -3.81     -2.22    1.58  NaCl
  Hatrurite       -37.47     32.69   70.16  Ca3SiO5
  Hausmannite      -9.90     -1.71    8.19  Mn3O4
  HCl(g)          -13.79     -8.04    5.75  HCl
  Hedenbergite     -6.09     12.52   18.61  CaFe(SiO3)2
  Hematite         16.72     15.84   -0.88  Fe2O3
  Hercynite        -0.10     26.17   26.26  FeAl2O4
  Hexahydrite      -3.76     -5.49   -1.73  MgSO4:6H2O
  Hillebrandite   -15.05     20.23   35.28  Ca2SiO3(OH)2:0.17H2O
  Huntite           2.07     11.01    8.94  CaMg3(CO3)4
  Hydromagnesite   -5.15     23.37   28.52  Mg5(CO3)4(OH)2:4H2O
  Hydrophilite    -14.74     -3.61   11.13  CaCl2
  Hydroxylapatite   2.68     -2.01   -4.68  Ca5(OH)(PO4)3
  Ice              -0.19     -0.00    0.19  H2O
  Illite            0.73      8.33    7.60  K0.6Mg0.25Al1.8Al0.5Si3.5O10(OH)2
  Jadeite          -2.91      4.77    7.68  NaAl(SiO3)2
  Jarosite          2.88     -7.94  -10.82  KFe3(SO4)2(OH)6
  Jarosite-Na      -0.77     -6.22   -5.45  NaFe3(SO4)2(OH)6
  K               -54.71     13.39   68.10  K
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K(g)            -64.66     13.39   78.05  K
K-Feldspar       -1.08     -1.65   -0.57  KAlSi3O8
K2CO3:1.5H2O    -14.87     -1.49   13.38  K2CO3:1.5H2O
K2O             -72.72      8.19   80.91  K2O
K3H(SO4)2       -19.88    -23.51   -3.62  K3H(SO4)2
K8H4(CO3)6:3H2O -53.05    -25.34   27.71  K8H4(CO3)6:3H2O
Kainite          -9.11     -9.42   -0.31  KMgClSO4:3H2O
KAl(SO4)2       -25.56    -23.34    2.21  KAl(SO4)2
Kalicinite       -5.87     -5.59    0.28  KHCO3
Kalsilite        -2.30      7.75   10.05  KAlSiO4
Kaolinite         1.71      7.30    5.60  Al2Si2O5(OH)4
Katoite         -24.86     54.09   78.94  Ca3Al2H12O12
Kieserite        -5.21     -5.48   -0.27  MgSO4:H2O
KMgCl3          -27.85     -7.59   20.26  KMgCl3
KMgCl3:2H2O     -20.99     -7.59   13.40  KMgCl3:2H2O
KNaCO3:6H2O     -10.05      0.21   10.26  KNaCO3:6H2O
Kyanite          -1.90     12.01   13.91  Al2SiO5
Lansfordite      -2.11      2.73    4.84  MgCO3:5H2O
Larnite         -16.52     20.23   36.75  Ca2SiO4
Laumontite       -1.78     10.36   12.14  CaAl2Si4O12:4H2O
Lawrencite      -15.03     -6.62    8.42  FeCl2
Lawsonite        -0.53     19.77   20.30  CaAl2Si2O7(OH)2:H2O
Leonite         -11.08    -15.19   -4.11  K2Mg(SO4)2:4H2O
Lime            -18.68     12.47   31.15  CaO
Magnesite         0.80      2.74    1.94  MgCO3
Magnetite        16.47     25.30    8.83  Fe3O4
Manganite        -5.02     -5.19   -0.16  MnO(OH)
Manganosite      -8.37      8.66   17.03  MnO
Margarite        -0.60     36.48   37.08  CaAl4Si2O10(OH)2
Maximum_Microcline  -1.08      -1.65   -0.57  KAlSi3O8
Mayenite       -197.90    266.55  464.46  Ca12Al14O33
Melanterite      -6.14     -8.46   -2.32  FeSO4:7H2O
Mercallite      -12.36    -13.80   -1.44  KHSO4
Merwinite       -24.83     40.42   65.25  MgCa3(SiO4)2
Mesolite          2.43     14.59   12.16  Na.676Ca.657Al1.99Si3.01O10:2.647H2O
Mg              -86.03     31.02  117.05  Mg
Mg(g)          -104.68     31.02  135.70  Mg
Mg1.25SO4(OH)0.5:0.5H2O  -6.84     -2.37    4.47  Mg1.25SO4(OH)0.5:0.5H2O
Mg1.5SO4(OH)     -7.53      0.74    8.27  Mg1.5SO4(OH)
MgCl2:2H2O      -15.70     -3.65   12.04  MgCl2:2H2O
MgCl2:4H2O      -10.63     -3.66    6.97  MgCl2:4H2O
MgCl2:H2O       -18.84     -3.65   15.18  MgCl2:H2O
MgOHCl          -10.63      4.39   15.01  MgOHCl
MgSO4            -9.62     -5.47    4.15  MgSO4
Minnesotaite     -3.48      9.56   13.04  Fe3Si4O10(OH)2
Mirabilite       -5.75     -6.29   -0.54  Na2SO4:10H2O
Misenite        -81.44    -92.51  -11.08  K8H6(SO4)7
Mn              -52.01     27.26   79.26  Mn
Mn(OH)2(am)      -5.94      8.66   14.60  Mn(OH)2
Mn(OH)3         -11.53     -5.19    6.34  Mn(OH)3
Mn3(PO4)2       -17.72    -16.90    0.82  Mn3(PO4)2
MnCl2:2H2O      -11.16     -7.42    3.74  MnCl2:2H2O
MnCl2:4H2O      -10.10     -7.42    2.68  MnCl2:4H2O
MnCl2:H2O       -12.58     -7.41    5.17  MnCl2:H2O
MnHPO4            0.16    -12.78  -12.95  MnHPO4
MnO2(gamma)      -9.49    -25.62  -16.13  MnO2
MnSO4           -11.35     -9.23    2.12  MnSO4
Molysite        -28.52    -16.19   12.33  FeCl3
Monohydrocalcite   0.25      2.78    2.53  CaCO3:H2O
Monticellite     -7.90     20.19   28.09  CaMgSiO4
Montmor-Ca       -0.28      1.31    1.59  Ca.165Mg.33Al1.67Si4O10(OH)2
Montmor-K        -0.72      0.60    1.32  K.33Mg.33Al1.67Si4O10(OH)2
Montmor-Mg       -0.16      1.30    1.46  Mg.495Al1.67Si4O10(OH)2
Montmor-Na       -0.46      1.17    1.62  Na.33Mg.33Al1.67Si4O10(OH)2
Mordenite        -4.96    -10.23   -5.27  Ca.2895Na.361Al.94Si5.06O12:3.468H2O
Mordenite-dehy  -19.33    -10.22    9.10  Ca.2895Na.361Al.94Si5.06O12
Muscovite         3.41     15.06   11.65  KAl3Si3O10(OH)2
Na              -49.47     15.11   64.58  Na
Na(g)           -62.17     15.11   77.28  Na
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  Na2CO3           -8.92      1.95   10.87  Na2CO3
  Na2CO3:7H2O      -8.24      1.93   10.17  Na2CO3:7H2O
  Na2O            -53.21     11.63   64.84  Na2O
  Na2SiO3         -14.66      6.93   21.60  Na2SiO3
  Na3H(SO4)2      -17.46    -18.35   -0.89  Na3H(SO4)2
  Na4Ca(SO4)3:2H2O -12.07    -17.97    -5.89  Na4Ca(SO4)3:2H2O
  Na4SiO4         -49.63     18.56   68.20  Na4SiO4
  Na6Si2O7        -72.58     25.49   98.07  Na6Si2O7
  NaFeO2           -4.95     13.74   18.69  NaFeO2
  Nahcolite        -3.84     -3.87   -0.02  NaHCO3
  Natrolite        -2.77     14.24   17.01  Na2Al2Si3O10:2H2O
  Natron           -8.05      1.92    9.97  Na2CO3:10H2O
  Natrosilite     -15.45      2.23   17.68  Na2Si2O5
  Nepheline        -3.29      9.47   12.76  NaAlSiO4
  Nesquehonite     -2.26      2.73    5.00  MgCO3:3H2O
  Nontronite-Ca    15.44      3.40  -12.03  Ca.165Fe2Al.33Si3.67H2O12
  Nontronite-H     14.28      1.35  -12.94  H.33Fe2Al.33Si3.67H2O12
  Nontronite-K     14.93      2.70  -12.23  K.33Fe2Al.33Si3.67H2O12
  Nontronite-Mg    15.49      3.40  -12.09  Mg.165Fe2Al.33Si3.67H2O12
  Nontronite-Na    15.20      3.27  -11.93  Na.33Fe2Al.33Si3.67H2O12
  O2(g)           -34.21    -37.19   -2.97  O2
  Okenite          -7.11      3.06   10.17  CaSi2O4(OH)2:H2O
  Oxychloride-Mg   -9.04     16.80   25.83  Mg2Cl(OH)3:4H2O
  P              -100.76     25.04  125.80  P
  Paragonite        1.43     16.78   15.35  NaAl3Si3O10(OH)2
  Pargasite       -17.92     77.30   95.22  NaCa2Al3Mg4Si6O22(OH)2
  Pentahydrite     -4.10     -5.49   -1.39  MgSO4:5H2O
  Periclase        -7.80     12.42   20.23  MgO
  Phlogopite        0.60     35.62   35.01  KAlMg3Si3O10(OH)2
  Picromerite     -10.75    -15.19   -4.44  K2Mg(SO4)2:6H2O
  Pirssonite       -6.60      4.73   11.32  Na2Ca(CO3)2:2H2O
  Polyhalite      -11.73    -26.04  -14.31  K2MgCa2(SO4)4:2H2O
  Portlandite      -9.14     12.46   21.60  Ca(OH)2
  Prehnite         -2.95     27.54   30.49  Ca2Al2Si3O10(OH)2
  Pseudowollastonite  -5.61      7.76   13.37  CaSiO3
  Pyrolusite       -8.56    -25.62  -17.06  MnO2
  Pyrophyllite     -1.61     -2.09   -0.48  Al2Si4O10(OH)2
  Quartz           -0.91     -4.70   -3.79  SiO2
  Rankinite       -21.60     27.99   49.60  Ca3Si2O7
  Rhodochrosite    -0.64     -1.02   -0.38  MnCO3
  Rhodonite        -5.25      3.96    9.21  MnSiO3
  Ripidolite-14A    2.21     58.78   56.57  Mg3Fe2Al2Si3O10(OH)8
  Ripidolite-7A    -1.07     58.78   59.85  Mg3Fe2Al2Si3O10(OH)8
  Sanidine_high    -2.20     -1.65    0.55  KAlSi3O8
  Saponite-Ca       0.23     24.83   24.60  Ca.165Mg3Al.33Si3.67O10(OH)2
  Saponite-H       -0.93     22.77   23.70  H.33Mg3Al.33Si3.67O10(OH)2
  Saponite-K       -0.28     24.13   24.41  K.33Mg3Al.33Si3.67O10(OH)2
  Saponite-Mg       0.28     24.82   24.54  Mg3.165Al.33Si3.67O10(OH)2
  Saponite-Na      -0.01     24.69   24.70  Na.33Mg3Al.33Si3.67O10(OH)2
  Scacchite       -15.60     -7.41    8.19  MnCl2
  Scolecite         0.84     15.07   14.23  CaAl2Si3O10:3H2O
  Sepiolite        -7.58     21.47   29.06  Mg4Si6O15(OH)2:6H2O
  Si             -110.00     32.49  142.49  Si
  Si(g)          -177.79     32.49  210.28  Si
  Siderite          0.24     -0.23   -0.46  FeCO3
  Sillimanite      -2.48     12.01   14.49  Al2SiO5
  SiO2(am)         -2.10     -4.70   -2.60  SiO2
  Smectite-high-Fe-Mg   0.51     16.30   15.79
Ca.025Na.1K.2Fe.5Fe.2Mg1.15Al1.25Si3.5H2O12
  Smectite-low-Fe-Mg   0.13      9.95    9.81
Ca.02Na.15K.2Fe.29Fe.16Mg.9Al1.25Si3.75H2O12
  Spinel           -5.55     29.13   34.69  Al2MgO4
  Starkeyite       -4.48     -5.48   -1.00  MgSO4:4H2O
  Stilbite         -0.51     -0.35    0.17
Ca1.019Na.136K.006Al2.18Si6.82O18:7.33H2O
  Strengite        -1.85    -13.53  -11.68  FePO4:2H2O
  Sylvite          -4.89     -3.94    0.95  KCl
  Syngenite        -7.54    -15.14   -7.60  K2Ca(SO4)2:H2O
  Tachyhydrite    -28.08    -10.94   17.14  Mg2CaCl6:12H2O
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  Talc             -1.42     18.47   19.88  Mg3Si4O10(OH)2
  Tephroite        -9.23     12.62   21.85  Mn2SiO4
  Thenardite       -5.88     -6.26   -0.39  Na2SO4
  Thermonatrite    -8.79      1.95   10.73  Na2CO3:H2O
  Tobermorite-11A -29.16     34.11   63.26  Ca5Si6H11O22.5
  Tobermorite-14A -27.81     34.09   61.90  Ca5Si6H21O27.5
  Tobermorite-9A  -32.30     34.11   66.41  Ca5Si6H6O20
  Todorokite      -45.21    -91.03  -45.82  Mn7O12:3H2O
  Tremolite        -8.48     49.44   57.92  Ca2Mg5Si8O22(OH)2
  Tridymite        -1.09     -4.70   -3.61  SiO2
  Trona-K         -16.95     -5.36   11.59  K2NaH(CO3)2:2H2O
  Vivianite        -9.82    -14.54   -4.72  Fe3(PO4)2:8H2O
  Wairakite        -5.79     10.37   16.15  CaAl2Si4O10(OH)4
  Whitlockite      -0.28     -5.49   -5.21  Ca3(PO4)2
  Wollastonite     -5.39      7.76   13.16  CaSiO3
  Wustite          -2.86      8.79   11.65  Fe.947O
  Xonotlite       -41.53     46.59   88.12  Ca6Si6O17(OH)2
  Zoisite          -3.86     35.89   39.76  Ca2Al3(SiO4)3OH

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
  For ideal gases, phi = 1.
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APPENDIX-E Regulatory framework of water quality

SKKY, 2008

Regulation on Water Pollution Control (SKKY) (Official Gazette No. 26786 Date: RG-02/13/2008)

The purpose of this regulation is necessary to determine the legal and technical principles in order to prevent water pollution in line with sustainable development goals, and to protect the country's underground and surface water resources potential and ensure its best use. This regulation covers the quality classifications and usage purposes of water environments, planning principles and prohibitions regarding the protection of water quality, discharge principles and discharge permit principles of wastewater, principles related to wastewater infrastructure facilities, and monitoring and inspection procedures and principles to prevent water pollution.

Classes defined according to the quality of groundwater are given below:

- Class I: High quality groundwater

Class I waters are groundwater that can be used in drinking water (after a suitable disinfection process when necessary) and in the food industry. Groundwater in this class is suitable for all other uses. Provided that the necessary oxygen is provided only by aeration, Class I in surface waters are considered as Class I in groundwater quality.

- Class II: Medium quality groundwater

Class II waters are waters that can be used as drinking water after a treatment process. These waters can be used as agricultural water, animal irrigation water or industrial cooling water without the need for any purification process. Waters that represent the quality parameters of Class II surface waters are considered

Class II waters. However, the limits set for iron, ammonium, manganese and dissolved oxygen need not be included in waters of this class.

- Class III: Low quality groundwater

Class III waters are waters that have worse characteristics than the quality parameters given above. The place of use of these waters is determined by the degree of purification that can be provided in terms of economic, technological and health.

According to the regulation, the groundwater quality standards and the threshold values are shown in Table E1.

Table E1. Quality criteria according to the classes of internal water resources

	WATER CLASSIFICATION		
PARAMETERS	**I**	**II**	**III**
A) Physical and inorganic-chemical parameters			
Temperature (^oC)	25	25	30
pH	6.5-8.5	6.5-8.5	6.0-9.0
O_2 (mg O_2/L)[a]	8	6	3
O_2 (%)[a]	90	70	40
Chloride (mg Cl^-/L)	25	200	400[b]
Sulphate (mg $SO_4^=$/L)	200	200	400
Ammonium (mg NH_4^+-N/L)	0.2[c]	1[c]	2[c]
Nitrite (mg NO_2^--N/L)	0.002	0.01	0.05
Nitrate (mg NO_3^--N/L)	5	10	20
Phosphour (mg P/L)	0.02	0.16	0.65
Total dissolved solid (mg/L)	500	1500	5000
Color (Pt-Co birimi)	5	50	300
Sodium(mg Na^+/L)	125	125	250
B) Organic parameters			
Chemical oxygen demand (COD) (mg/L)	25	50	70
Biological oxygen demand (BOD) (mg/L)	4	8	20
Total organic cardon (mg/L)	5	8	12
Total kjeldahl-nitrogen (mg/L)	0.5	1.5	5
Oil and grease (mg/L)	0.02	0.3	0.5
Surface active substances that react with methylene blues (MBAS) (mg/L)	0.05	0.2	1
Phenolic substances (volatile) (mg/L)	0.002	0.01	0.1
Mineral oils and derivatives (mg/L)	0.02	0.1	0.5
Total pesticide(mg/L)	0.001	0.01	0.1
C) Inorganic contamination parameters[d]			
Mercury (µg Hg/L)	0.1	0.5	2
Cadmium (µg Cd/L)	3	5	10
Lead (µg Pb/L)	10	20	50
Arsenic (µg As/L)	20	50	100
Copper (µg Cu/L)	20	50	200
Chromium (total) (µg Cr/L)	20	50	200
Chrome (µg Cr^{+6}/L)	Too little to measure	20	50
Cobalt (µg Co/L)	10	20	200
Nickel (µg Ni/L)	20	50	200
Zinc (µg Zn/L)	200	500	2000
Cyanide (total) (µg CN/L)	10	50	100
Fluoride (µg F^-/L)	1000	1500	2000
Free-chloride (µg Cl_2/L)	10	10	50
Sulfur (µg $S^=$/L)	2	2	10
Iron (µg Fe/L)	300	1000	5000
Manganese (µg Mn/L)	100	500	3000
Boron (µg B/L)	1000[e]	1000[e]	1000[e]
Selenium (µg Se/L)	10	10	20
Barium (µg Ba/L)	1000	2000	2000
Aluminum (mg Al/L)	0.3	0.3	1
Radioactivity (Bq/L)			
Alpha-activity	0,5	5	5
Beta-activity	1	10	10
D) Bacteriological parameters			
Fecal coliform (EMS/100 mL)	10	200	2000
Total coliform (EMS/100 mL)	100	20000	100000

(a) It is sufficient to provide only one of the parameters concentration or percent saturation.

(b) It may be necessary to lower this concentration limit when watering chloride sensitive plants.

(c) Depending on the pH value, the free ammonia nitrogen concentration should not exceed 0.02 mg/l NH3–N.

(d) The criteria in this group give the total concentrations of the chemical species of the parameters.

(e) It may be necessary to reduce the criterion to 300 µg/l for irrigation of plants sensitive to boron.

YKBBK, 2012

Regulation on the Protection of Groundwater against Pollution and Deterioration (YKBKK) (OfficialGazette No. 28257 Date: 04/07/2012)

This regulation determines the basic conditions for preventing pollution and deterioration of the groundwater, for ensuring protection of the existing groundwater quality in good condition, for preventing groundwater pollution and deterioration, and improving the quality of the groundwater. The regulation states that the number and the types of parameters, and the threshold value to be determined for each parameter, will predicate on the groundwater body itself, considering the specific conditions that prevail at each groundwater body.

The list of minimum parameters to be taken into consideration when setting the threshold values is presented in Table E2, which was updated on May 22nd, 2015, to incorporate Nitrites and Phosphates thereto, is provided in Table E3. The limits for nitrates and active substances in pesticides are provided in Table E4.

Table E2. List of minimum parameters to be considered

Parameters			
Arsenic	Lead	Ammonium	Sulphate
Cadmium	Mercury	Chloride	Trichloroethylene
Tetrachloroethylene	Electrical Conductivity	Nitrite	Total Phosphorus/Phosphates

Table E3. Groundwater quality standards

Pollutant	Quality Standards
Nitrates	50 mg/L
Relevant metabolites, active matters in pesticides, including degradation and reactive products	0.1 µg/L
	0.5 µg/L (total)*

*"Total" relevant metabolites are the total of each plant protection product that is detected and measured in the monitoring method including degradation and reaction products

In addition, minimum parameter list to be considered when determining the threshold value is sown in Table E4 below.

Table E4. Minimum mandatory parameter list for groundwater chemistry

Parameters
Arsenic
Cadmium
Lead
Mercury
Ammonium
Chlorine
Sulphate
Trichloroethylene
Tetrachloroethylene
Electrical Conductivity

ITAS, 2005

Regulation on the Human Consumption Water Standards (ITAS) (Official Gazette No: 25730, Dated: 02/17/2005)

The physical, chemical and radiological parameters are presented in Table E5. In addition, the microbiological parameters also have legislative limits as per ITAS. These parameters are presented in Table E6.

Table E5. Human consumption water standards (ITAS, 2005)

Parameters	**Quality Standards**	**Unit**
Acrylamide	0.1	µg/L
Antimony	5	µg/L
Arsenic	10	µg/L
Benzene	1	µg/L
Benzopyrene	0,010	µg/L
Boron	1	mg/L
Bromate	10	µg/L
Cadmium	5,0	µg/L
Chromium	50	µg/L
Copper	2	mg/L
Cyanide	50	µg/L
1,2-Dichloracethane	3,0	µg/L
Epicloridine	0,10	µg/L
Fluoride	1,5	mg/L
Lead	10 (applied as 25 µg/L for drinking-use water until 31 December 2012)	µg/L
Mercury	1,0	µg/L
Nickel	20	µg/L
Nitrate	50	mg/L
Nitrite	0,50	mg/L
Pesticides	0,10	µg/L
Total pesticides	0,50	µg/L
Polycyclic aromatic hydrocarbons	0,10	µg/L
Selenium	10	µg/L
Tetrachloroethane and trichloroethane	10	µg/L
Trihalomethanes-total	100 (applied as 150 µg/L for drinking-use water until 31 December 2012)	µg/L
Vinyl Chloride (C2H3Cl/H2C)	0,50	µg/L
Indicator Parameters		
Aluminum	200	µg/L
Ammonium	0,50	mg/L
Chloride	250	mg/L
C. perfringens (including spores)	0	score/100 ml
Color	Acceptable by consumers, and no abnormal changes	
Electrical Conductivity	2500	µS/cm-1 at 20 °C
pH	≤ 9,5-6,5≤	
Iron	200	µg/L
Manganese	50	µg/L
Odour	Acceptable by consumers, and no abnormal changes	
O2	5,0	mg/L O2
Sulphate	250	mg/L
Sodium	200	mg/L
Taste	Acceptable by consumers, and no abnormal changes	
Colony count at 22 °C	No abnormal changes	
Coliform bacteries	0	score/100 ml
Total organic carbon (TOC)	No abnormal changes	
Turbidity	Acceptable by consumers, and no abnormal changes	
Radiological Quality		
Tritium	100	Bq/L
Total indicator dose	0,10	mSv/yıl

Table E6. Human consumption water microbiological standards for drinking waters and spring & fountain waters

Patrameters	**Quality Standards**
E. coli	0/250 ml
Enterococcus	0/250 ml
Coliform bacteria	0/250 ml
P. aeruginosa	0/250 ml
Sulfite-reducing bacteria with anaerobic spores	0/50ml
Pathogen Staphylococci	0/100ml
Maximum in the sample taken from the source:	
Colony count at 22 °C	20/ml
Colony count at 37 °C	5/ml

AATTUT, 2010

Regulation on the Wastewater Treatment Plants Technical Procedures Communique (AATTUT) (Official Gazette No: 27527, Dated: 03/20/2010)

The properties sought in treated wastewater to be reused in irrigation are given in Table E7. Two different classes have been created for the use of treated water in irrigation, these criteria meet the minimum requirements and additional criteria can be applied in some special applications.

Table E7. Classification of treated wastewater to be reused in irrigation

Recovery type	Treatment type	Recovery water quality[a]	Monitoring period	Application distance[b]
Class A				
a-Agricultural irrigation: Food products that are not processed commercially b-Irrigation of urban areas				
a)All kinds of food products that are irrigated by surface and sprinkler irrigation and can be eaten directly as raw	Secondary treatment[c]	pH=6-9	pH: Weekly	
b)All kinds of green field irrigation (Parks, golf courses, etc.)	Filtration[d]	BOD5 < 20 mg/L	BOD$_5$: Weekly	At least 50 m away from the wells where drinking water is continuously supplied
	Disinfection[e]	Turbidity < 2 NTUf	Turbidity: Continously	
		Fecal coliform: 0/100 mL[g,h]	Coliform: Daily	
		In some cases, specific virus, protozoa and helminth analysis may be requested.	Residual chloride: Continously	
		Residual chlorine > 1 mg/L[i]		
Class B				
a-Agricultural irrigation: commercially processed food products[m] b- Irrigation areas with restricted access c- Agricultural irrigation: Non-food crops				
a)Irrigation of products such as orchards and vineyards with flood irrigation	Secondary treatment[c]	pH=6-9	pH: Weekly	Residual chlorine: continuously - At least 90 m away from wells where drinking water is supplied.
b)Places where public access is restricted, such as grass production and cultural agriculture	Disinfection[e]	BOD5 < 30 mg/L	BOD$_5$: Weekly	If sprinkler irrigation is used, at least 30 m away from the environment where the public is located.
c)Pasture irrigation for grazing animals - Secondary treatment		TSS < 30 mg/L	TSS: Daily	
		Fecal coliform < 200 ad/100 mL[g,j,k]	Coliform: Daily	
		In some cases, specific virus, protozoa and helminth analysis may be requested.	Residual chloride: Continously	
		Residual chlorine > 1 mg/L[i]		

[a] Indicates the treated wastewater quality, unless otherwise stated.

[b] Placement to protect water resources and therefore people from the impact of treated wastewater is a limitation.

[c] Secondary treatment may include activated sludge systems, biodisc, trickling filters, stabilization ponds, aerated lagoons, etc.

[d] Can be sand filters or membrane filters such as microfiltration and ultrafiltration.

[e] Disinfectant does not limit the use of chloride as dissinfectant, also, of other disinfection methods.

[f] Recommended turbidity value should be achieved prior to disinfection. It should never exceed 5 NTU. Where TSS is used instead of turbidity, the TSS value should be below 5 mg/L.

[g] Daily mean values are characterized as 7 days. .

[h] Fecal coliform value should never exceed 14 units/100 mL.

[i] The residual chlorine value casterizes the value after 30 minutes of contact time.

[j] Fecal coliform value should never exceed 800 units/100 mL.

[k] Stabilization pools can provide fecal coliform value without disinfection.

[l] Advanced treatment should be applied.

[m] Commercially processed food products are products that undergo a physical or chemical treatment to kill pathogenic microorganisms before they are sold to the public.

Chemical quality criteria for irrigation water are given in Table E8.

Table E8. The chemical quality of irrigation water

Parameters	**Units**	**The Degree of Hazardous**		
		None	**Low-Medium Hazardous**	**Hazardous**
		Class I	**Class II**	**Class III**
		Salinity		
Electrical Conductivity (EC)	µS/cm	< 700	700-3000	>3000
Total Dissolved Solid (TDS)	mg/L	< 500	500-2000	>2000
		Infiltration		
SAR_{Tad} 0-3		EC ≥ 0.7	0.7-0.2	< 0.2
3-6		≥ 1.2	1.2-0.3	< 0.3
6-12		≥ 1.9	1.9-0.5	< 0.5
12-20		≥ 2.9	2.9-1.3	< 1.3
20-40		≥ 5.0	5.0-2.9	< 2.9
		Specific Ion Toxicity		
Sodium (Na)				
Surface irrigation	mg/L	< 3	3-9	> 9
Drip irrigation	mg/L	< 70	> 70	
Chloride (Cl)				
Surface irrigation	mg/L	< 140	140 –350	> 350
Drip irrigation	mg/L	< 100	> 100	
Boron (B)	mg/L	< 0.7	0.7-3.0	> 3.0

Drip-surface irrigation note

Saltation in the soil can be problematic for the types of irrigation system. With drip irrigation, water drops are delivered nearby the plant roots. In this way, it reduces the salinity effect in the soil by maintaining the moisture soil water due to reduction in evaporation and runoff. However, surface irrigation requires more water that needs to be distributed over land by gravity. As a result of this, when exposed to evaporation, much more saltation occurs.

Maximum permissible concentrations of heavy metals and toxic elements in irrigation waters are given in Table E9. When these elements are taken in high concentrations, effects such as damage to the leaves or regression in growth can be seen. The concentration of trace elements in domestic wastewater is generally low.

Table E9. Maximum permissible concentrations of heavy metals and toxic elements in irrigation water

Elements	Maximum total amounts that can be given per unit area, kg/ha	Maximum allowable concentrations	
		In case of continuous irrigation on all kinds of soils, the limit values are mg/l	When irrigation is done for less than 24 years on clayey soils with a pH value between 6.0-8.5, mg/l
Aluminum (Al)	4600	5	20
Arsenic (As)	90	0.1	2
Beryllium (Be)	90	0.1	0.5
Boron (B)	680	-	2
Cadmium (Cd)	9	0.01	0.05
Chromium (Cr)	90	0.1	1
Cobalt (Co)	45	0.05	5
Cupper (Cu)	190	0.2	5
Flouride (F)	920	1	15
Iron (Fe)	4600	5	20
Lead (Pb)	4600	5	10
Lithium (Li)	-	2.5	2.5
Manganese (Mn)	920	0.2	10
Molybdenum (Mo)	9	0.01	0.05*
Nickel (Ni)	920	0.2	2
Selenium (Se)	16	0.02	0.02
Vanadium (V)	-	0.1	1
Zinc (Zn)	1840	2	10

**It is the permissible concentration only in acidic clay soils with high iron content.*