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# Waste Water Disposal of Kizildere Geothermal Power Plant: Impact on the Great Menderes River Water Quality

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## ABSTRACT

Kizildere Geothermal Power Plant (KGPP) was installed in 1984 with an installed capacity of 20.4 $MW_e$. It is a single flash design with an average 11.5% steam ratio. The waste fluid from the separators which is 88.5% of the total flowrate, is treated in three ways: some part of the fluid is used for district heating system of a town nearby, a small fraction of the fluid is injected back to the reservoir and the rest is discharged to the Great Menderes River through a 1.8-km long channel.

The Great Menderes River Basin has populated farmland and rapidly developing urban and suburban areas. Its agriculture and industrial sectors are highly developed. In this study, the impact of KGPP waste water discharge into the Great Menderes River is studied. Water samples are collected from 20 sampling locations once a month including separator exit of nine production wells, waste water channels and the River for one year. The samples are analyzed and evaluated to determine the contribution of KGPP into the River water pollution.

## 1. INTRODUCTION

Geothermal resources are considered as renewable energy sources in the view of peoples suffering from global warming problem. On the other hand, due to absence of insufficient regulations on the use of geothermal resources, the environment is negatively affected. To evaluate the impacts of geothermal applications onto the environment, it is the priority to determine the elemental concentrations in the geothermal fluid. Generally, re-injection is the method to control used geothermal fluid, but, in fact, some of the geothermal fluid is discharged to the environment and the negative impact appears at this stage.

During either electricity generation or direct use applications, gas and liquid phase of pollutants are discharged or emitted to the environment (Brown, 1995, 2000; Rybach, 2005; Simsek and Gunduz, 2007; Paoli and Loppi, 2008). Generally, in the liquid phase of geothermal fluid Li, B, As, Hg, dissolved $H_2S$ and $NH_3$ are present, while the gas phase may include $CO_2$, $H_2S$, $NH_3$ and trace amounts of Hg, B, $CH_4$, $C_2H_6$ and Rn. The concentrations of these elements define the degree of the environmental impact. For instance, boron is one of the trace elements in the growth of plants, but if it is above the irrigation standards, it has negative effects (Nicholson, 1993; Brown, 1995; Akar, 2007; Koc, 2007). Even though the plant or crop is resistant to the element, the limit concentration for boron in Turkish Irrigation Standard (2004) and Turkish Water Pollution Control Regulation (2004) is given as 2 mg/L (Table 1). The irrigation with geothermal fluid contaminated water causes soil pollution due to accumulation of these elements in the soil (Akar, 2007; Koc, 2007).

The exposure of the geothermal fluid to the atmosphere defines the behavior of the compounds in the fluid. The environmental pH and oxygen could change the dissolved $H_2S$ and $NH_3$ into the oxygenated form of $SO_4^{2-}$ and $NH_4^+$. Their chemistry depends on pH and oxygen availability; as a result they can end up in the atmosphere (Nicholson, 1993; Brown, 1995).

**Table 1: Quality parameters are used irrigation water categories (Water Pollution Control Regulation, 2004).**

| | | Irrigation water categories | | | | |
|---|---|---|---|---|---|---|
| **Quality criteria** | | **Class I (highly suitable)** | **Class II (suitable)** | **Class III (usable)** | **Class IV (with coucious)** | **Class V (severe)** |
| $EC_{25}x10^6$ | (µS/cm) | 0-250 | 250-750 | 750-2000 | 2000-3000 | > 3000 |
| Changeable sodium persent (Na%) | (Na%) | < 20 | 20-40 | 40-60 | 60-80 | > 80 |
| Sodyum adsorbsiyon ratio(SAR) | (-) | < 10 | 10-18 | 18-26 | > 26 | - |
| Sodium-carbonate residue (RSC) | (mg/L) | < 66 | 66-133 | > 133 | - | - |
| Chloride ($Cl^-$) | (mg/L) | 0-142 | 142-249 | 249-426 | 426-710 | > 710 |
| Sulfate ($SO_4^=$) | (mg/L) | 0-192 | 192-336 | 336-575 | 575-960 | > 960 |
| TDS | (mg/L) | 0-175 | 175-525 | 525-1400 | 1400-2100 | > 2100 |
| Boron | (mg/L) | 0-0.5 | 0.5-1.12 | 1.12-2.0 | > 2.0 | - |
| $NO_3^-$ or $NH_4^+$ | (mg/L) | 0-5 | 5-10 | 10-30 | 30-50 | > 50 |

**Figure 1: Kizildere Geothermal Field and Plant, general view.**

**Figure 2: Discharge channel.**


**Figure 3: Location of the Great Menderes River.**

Kizildere Geothermal Power Plant (KGPP) with a total fluid production of 900 t/h has been operating for 25 years. It is a single flash design with 9 production and 1 re-injection wells (Figure 1). 88.5% liquid of the total fluid production had rejected completely to the Great Menderes River by a 1.8 km long channel (Figure 2) between 1984 and 2002. In 2002, a district heating system is implemented to Saraykoy Town which is at 14 km distance to the Plant. 360 t/h geothermal liquid has been used at Saraykoy District Heating System, then is rejected to the Great Menderes River again at another location. Only 200 t/h geothermal fluid is re-injected since 2004. Kizildere Geothermal Field (KGF) is surrounded with agricultural areas and the Great Menderes River has been used for irrigation. The River is the longest river of the region with a total length of approximately 530 km, 40% of which is located in the region of Denizli city where the KGF is in the vicinity (Figure 3).

In this study, environmental impacts of discharged contaminants present in the Kizildere geothermal fluid to the Great Menders River are evaluated.

## 2. MATERIAL AND METHODS

A sampling program in the interval of one month was repeated during July 2006-June 2007, for 11 months. In September 2006, sampling program was not conducted due to overhaul of the Plant. The separator exits of 9 production wells, 4 locations on the discharge channel, cooling tower and 6 locations on the River are determined as sampling locations (Figure 4, Table 2).

**Table 2: Sampling locations and abbreviations.**

| | |
|---|---|
| **Wells** | KD6, KD13, KD14, KD15, KD16, KD20, DK21, KD22, R1 |
| **T** | Turbine |
| **SK** | Cooling tower |
| **IB** | Management building |
| **TB** | Office building |
| **M** | Guesthouse |
| **R1K** | Discharge channel for R1 well |
| **KK** | Discharge channel for the all wells except R1 |
| **TK** | Discharge channel after R1K and KK flows combined |
| **TKNDY** | TK and the Great Menderes River mixing location |
| **N1** | River 1 (150 m downstream of the mixing location) |
| **N2** | River 2 (650 m downstream of the mixing location) |
| **BK** | Buharkent bridge (5 km downstream of the mixing location) |
| **SA** | Saraykoy discharge (downstream of the Saraykoy District Heating System discharge) |
| **MT** | Downstream of the Menderes Textile Co. effluent discharge |
| **YK** | Yenice-Kamara |

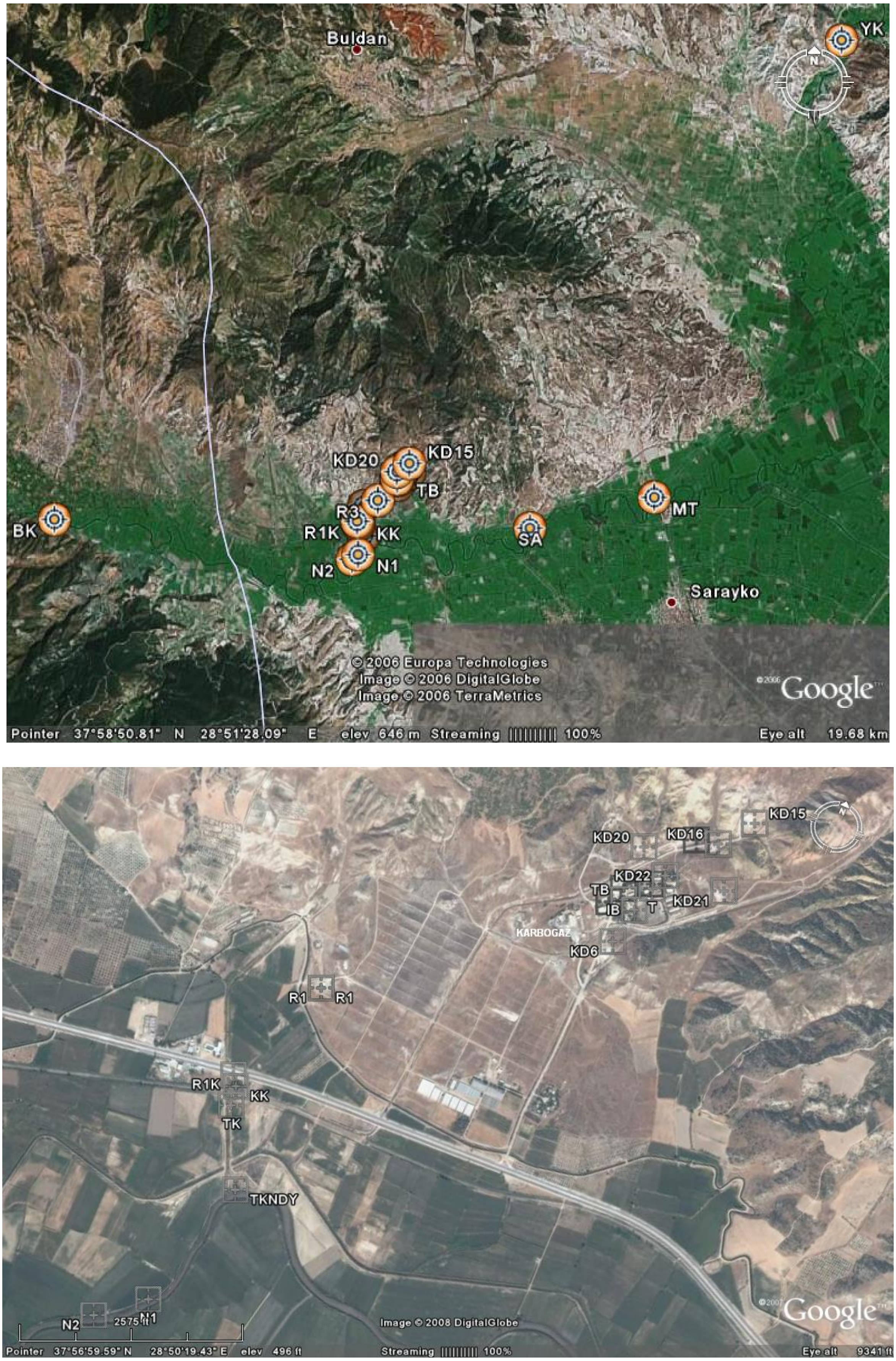


**Figure 4: Sampling locations in Kizildere Geothermal Field and the River.**

From each sampling location (in total 20), two sets of samples are collected for anion and cation analysis (Figure 5). The water samples are then stored in pre-cleaned polyethylene bottles for laboratory analysis whereas pH, temperature, electrical conductivity (EC), total dissolved solid (TDS) concentrations ($CO_3^{-2}$, $HCO_3^-$ and $Cl^-$) were determined in the field. For the ion concentration determination, the samples were taken by filtering with blue banded filter paper and for the prevention of precipitation, the pH was maintained at the level <2 by addition of concentrated $HNO_3$. The remaining major chemical constituents were analyzed using standard methods described in AWWA (1995). Bicarbonate was determined with neutralization titration and chloride with precipitation method. Gravimetric method was applied in the determination of sulphate and TDS. Ion-selective electrodes were used in the determination of flor ($F^-$). Finally, major cations which are Al, As, B, Ba, Cr, Cu Fe, K, Mg, Mn, Na, Ni, Pb, Zn, Na, Li, Sr, Ca, Si, Sb, Ag, Co, Se and Cd were determined with inductively coupled plasma mass spectroscopy (ICP-MS) at the laboratories of Chemisty Department and Center for Environment at Izmir Institute of Technology-Turkey. The anion samples were first used to determine EC, TDS and pH, then concentrations of $HCO_3^-$, $CaCO_3$, $Cl^-$, $F^-$, $SO_4^{-2}$, $NH_4^+$, $SiO_2$.

## 3. RESULTS AND DISCUSSION

Figure 6 shows the concentration variations according to sampling locations on the River. As seen in the Figure, Yenice-Kamara, the farthest sampling location, resulted in not detectable concentrations for the most of the elements except Ba, Al, Mn. It should be noted that this sampling location is not under the effect of geothermal fluid discharge and used as the reference location in this study. The concentrations of Ba, Al, Mn were measured as in the range of 0.06-0.11, 0.02-0.11, 0.03-0.28 mg/L, respectively. The ranges for temperature 7.7-21°C, for pH 7.8-8.33, and for EC 745-1444 µS/cm were determined. According to Water Pollution Control Regulation (2004) and Irrigation Standard (1991) (Table 1) the temperature, pH, physical and inorganic pollution parameter categories showed that the River water at this sampling location comply the Class I, the best quality water. The measured concentrations for Ba, Al, Mn levels are lower than the limits of the standards.

**Figure 5: River sampling (channel and the River mixing location) .**

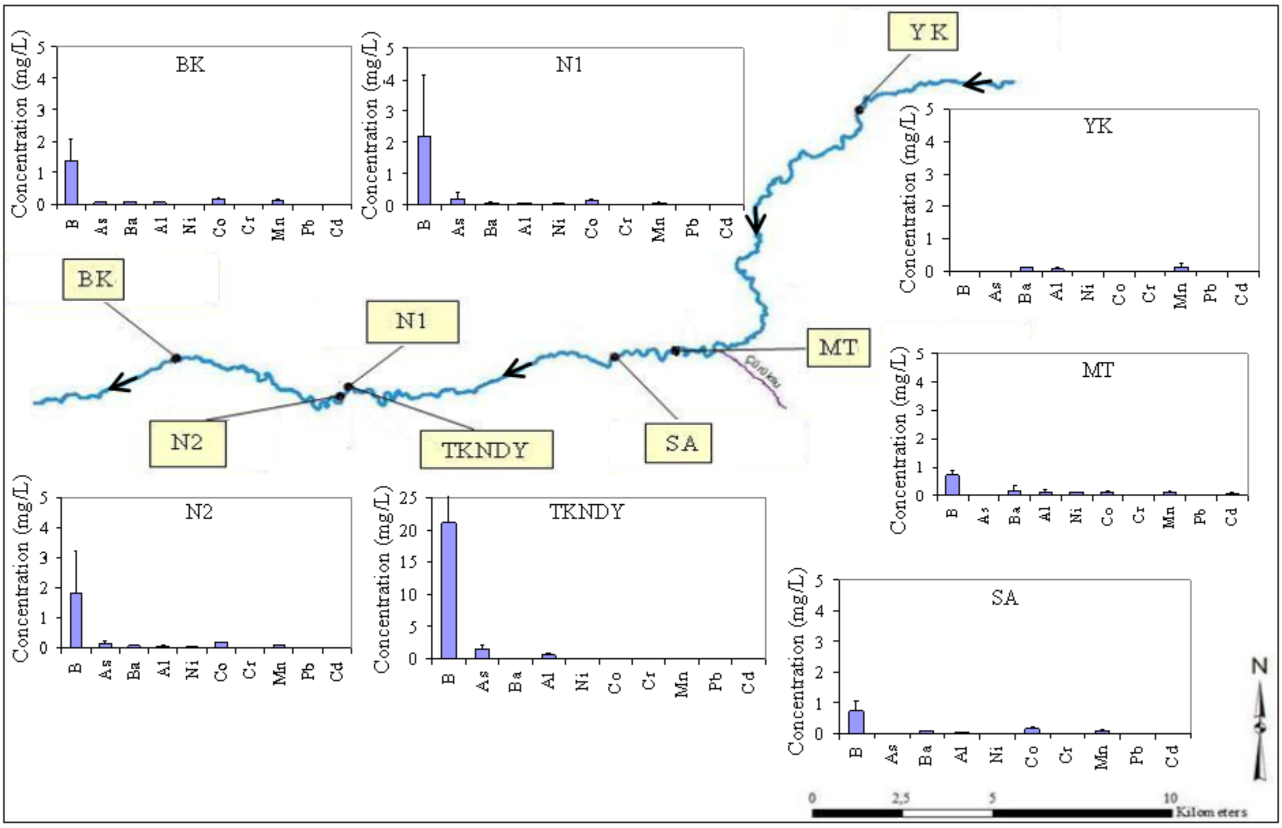


**Figure 6: Sampling locations and measured elements on the Great Menderes River.**

The next sampling location is Menderes Textile Co. where B, Ni, Co and Cd were added among the detectable elements. The values and the compounds bring up the River water into Class II. Boron concentration varies between 0.5-1.1 mg/L. Usually detectable concentrations for Ni, Co and Cd were measured in the arid season that were during August-September which the flow rate of river was quite low. The concentration during these months for Ni, Co, and Cd were 0.128-0.135, 0.11-0.19 and 0.065-0.093 mg/L, respectively. Cobalt and cadmium were above the limits of the standards. Cu, Zn, Pb, Cd, Cr and Co are the common materials in textile dyes (Brebbia and Antunes do Carmo, 2006) while Mn, Al, and Ba are elements found in the hydrothermal formations.

The results of third sampling location (Saraykoy District Heating System discharge) showed that boron concentration is increased relative to the second sampling location on the River. Especially, the quality of the River is changed to the Class III in the summer months (August) due to low water flowrate.

The similar elements with wells were detected in the sampling location where all discharge channels combines and mixes with the River water. At this location (TKNDY) B, As and Al concentrations were at the highest level. The measured values of B was 10.3-29.2 mg/L, As which was not detected before, was 0.12-1.95 mg/L; Al was in the range of 0.07-0.77 mg/L.

N1 is the sampling location 150 m downstream of TKNDY mixing point. Boron concentration started to decrease due to dilution. Unfortunately, the measured concentration was still the above of standard limits of the irrigation water. Cobalt and Manganese were not the compounds measured in the geothermal well waters, therefore, it can be concluded that geothermal fluids are not the sources of these elements in the River water.

Second location on the River (N2) is 650 m downstream of TKNDY mixing point. The water quality can be defined as Class V (severe). The last sampling location is Buharkent Bridge which is 5 km downstream of TKNDY. Boron concentration was determined as 0.8-3 mg/L. The decrease in boron concentration was observed through the sampling locations.

In the summer of 2007 there was a drought which had been fifty years ago. Therefore, when the River received water form the dam lake the concentrations of elements were lower while the other times were higher than background level due to geothermal fluid discharge.

The variation of physical and other inorganic chemical measurements through the sampling locations are given in the Figure 7-13.

Figure 7 shows the average temperature measured on the River sampling locations. The river average background temperature was around 15°C (7.7-21°C). The highest temperature was obtained at the TKNDY sampling location where geothermal fluid meets with the River.

The background (Yenice-Kamara) pH of the River is between 7.91-8.33 which is in the acceptable range for surface waters (6.5-8.5). Depending upon the sampling locations, the Menderes Textile Co. and Sarayköy District Heating Discharge locations, the slight increase in pH level was observed (Figure 8).

The electrical conductivity (EC) and total dissolved solid (TDS) concentrations imply an idea about the water salinities and are exhibited in Figure 9 and 10, respectively. The salinity is an important parameter if the surface water used in the irrigation. When the water salinity is high, the soil accumulates this salt and lost its organic content. The values for EC<700 µS/cm and TDS<450 mg/L are accepted levels for the irrigation water (Ayers ve Westcot, 1985) (Table 3). If the water EC is 700-3000 µS/cm and TDS 450-2000 ppm the water use should be under the control which is the case observed for the Great Menderes River with the measured average EC values 1010 µS/cm for Yenice-Kamara, 5040 µS/cm for TKNDY and TDS changed in a range of 470-2548 ppm.

Chloride ($Cl^-$), boron (B), and sodium (Na) are the ions depending upon their level that could be toxic in the irrigation waters. This toxicity is also related to the sensitivity of crop to these ions, and duration and frequency of irrigation. These elements can be toxic by itself or as a compound. The effect can be observed as decrease in the yield of the crop. Chloride is the most toxic one caused the dryness on the leaves. It is reported that if chloride concentration in the water is above 0.3% the most of tree types could be damaged. In the irrigation water this level is classified as no damage if chloride concentration is <140 ppm. If it is in the range of 140-350 ppm water should be used cautiously while the value is above 350 ppm, it should not be used according to Table 3. On the other hand, Turkish Irrigation Standards (1991) has higher toleration classifying as 426-710 ppm can be used cautiously (Table 1).

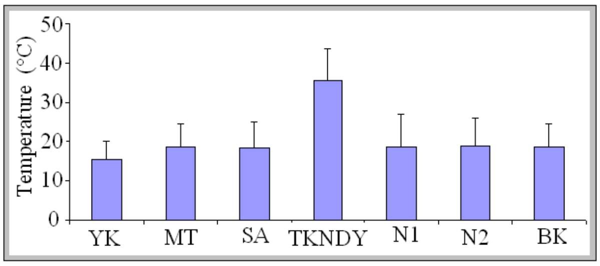


**Figure 7. Average temperature on the River.**

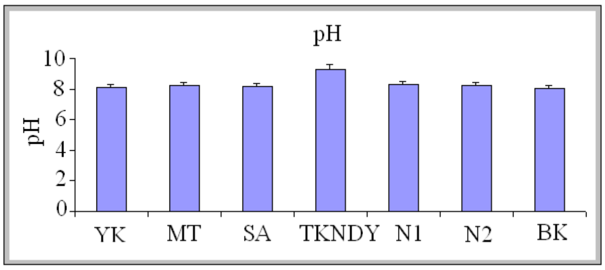


**Figure 8: Measured average pH on the River.**

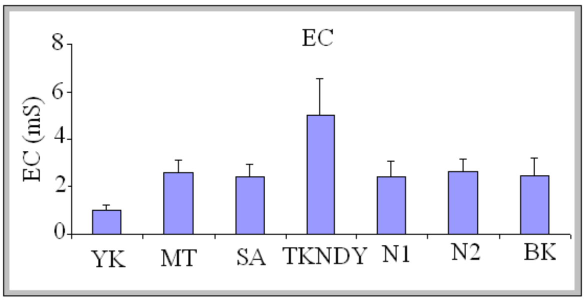


**Figure 9: Average electrical conductivity (EC) on the River sampling locations.**

**Table 3: Irrigation water quality criteria classification (Ayers & Westcot, 1985).**

| Potential irrigation problem | | Unit | Degree of restriction on use | | |
|---|---|---|---|---|---|
| | | | None | Slight to moderate | Severe |
| Salinity (effects crop water availability) | EC<br>TDS | µS/cm<br>mg/L | <700<br><450<br>>700 | 700-3,000<br>450-2,000<br>700-200 | >3,000<br>>2,000<br><200 |
| Permeability (effects infiltration rate of water into soil) | SAR = 0–3<br>SAR = 3–6<br>SAR = 6–12<br>SAR = 12–20<br>SAR = 20–40 | and EC= | > 700<br>> 1,200<br>> 1,900<br>> 2,900<br>> 5000 | 700–200<br>1,200–300<br>1,900–500<br>2,900–1,300<br>5,000–2,900 | < 200<br>< 300<br>< 500<br>< 1,300<br>< 2,900 |
| Specific ion toxicity (effects sensitive crops) | Sodium[1]<br>Chloride[1]<br>Boron | SAR<br>mg/L<br>mg/L | < 3.0<br>< 140<br>< 0.7 | 3.0–9.0<br>140–350<br>0.7–3.0 | > 9.0<br>> 350<br>> 3.0 |
| Miscellaneous effects (effects susceptible crops) | Nitrate–nitrogen<br>Bicarbonate<br>pH | mg/L<br>mg/L<br>- | < 5<br>< 90<br>Normal range | 5–30<br>90-500<br>6.5-8.4 | >30<br>>500 |

[1] Surface irrigation.

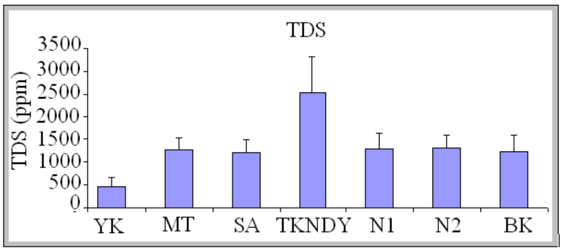


**Figure 10: TDS concentrations on the River sampling locations**

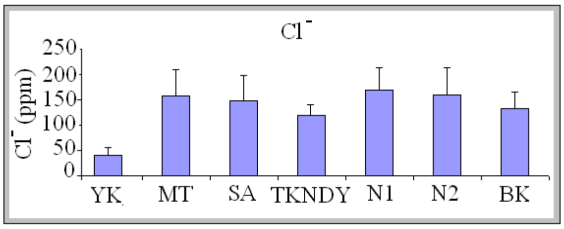


**Figure 11: Average Chloride ($Cl^-$) concentrations.**

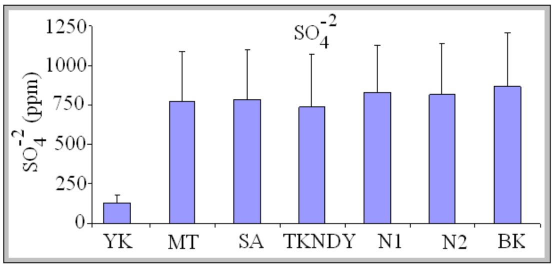


**Figure 12: Measured average sulphate ($SO_4^{-2}$) concentrations.**

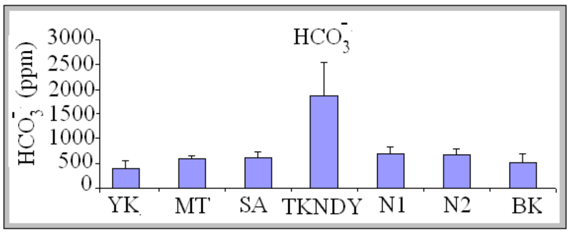


**Figure 13: Bicarbonate ($HCO_3^-$) concentrations.**

Figure 11 shows that the $Cl^-$ concentrations on the River is suitable for Turkish Irrigation Standard but in the caution range for Ayers and Westcot, 1985.

The sulphate ($SO_4^{-2}$) is the anion of $CaSO_4$ (gypsum) containing rocks. $SO_4^{-2}$ is a mineral which can be dissolved during the passage of water from these rocks. The other way is the atmospheric deposition of this compound to the water. Fertilizers, industrial waste water discharges can also cause the contamination of sulphate in river water. If the concentration is in the range of 500-750 ppm it is not toxic for plants and animals while it could be a temporary laxative effects in human. In the irrigation water the range should be in 0-575 ppm, the cautiously use is necessary in the range of 575-960. Above the value of 960, the water should not be used (Table 1). Sulphate concentrations of sampling locations are given in Figure 12.

Bicarbonate ($HCO_3^-$) ion increases the pH (>8.5), react with calcium and magnesium ions and forms the undissolved forms of these ions left the sodium ion into water. In irrigation water $HCO_3^-$concentration should be <90 ppm (Table 3). The concentrations measured in the River (Figure 13) show that the highest concentration is encountered at TKNDY. It is known that geothermal fluids contain high amounts of bicarbonate ions. The levels that determined in the wells are 1717-3056 ppm.

## 4. CONCLUSIONS

In this study, the effects of the geothermal fluid discharge on the chemical environment were evaluated. For this purpose the Great Menderes River was chosen due to being dicharge receiver water body of the geothermal fluid of Kizildere Geothermal Power Plant. Yenice-Kamara was the reference location to define the River water quality while the other sampling locations were chosen to observe different discharge contributions. TKNDY was the sampling location for seeing the geothermal discharge effects on the River. As a result the River was affected due to the discharge of geothermal fluid. The most of the inorganic pollution parameters were coming from TKNDY discharge location and changing the water quality from acceptable to not acceptable range for the irrigation purposes.

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