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# Evaluation of Geological, Hydrogeological and Hydrogeochemical Studies to Construct a Conceptual Hydrothermal Model of the Haruniye-Duzici (Osmaniye) Hot and Mineral Waters

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**Abstract**

The main purpose of this study is evaluation of geological, hydrogeological and hydrogeochemical studies to construct conceptual hydrothermal model of the Haruniye low temperature (30-32 °C) geothermal field located in Osmaniye province in Southern Turkey.

The thermal springs have been used for health and touristic purposes since historical times. But they have been contaminated due to ancient and unplanned casually settlements around the thermal facilities.

The basement rock in the area comprised from intensively karstified Triassic aged Sulucadere Formation Jurassic aged Berke Complex overlies this basement. Quaternary alluviums, travertines and slope debris are the youngest units in the area. Sulucadere Formation and Berke Complex are the main reservoir formations in the area.

Ionic characteristics of the geothermal springs generally are Ca>Mg>Na+K and $HCO_3$>$SO_4$>Cl. Geothermometrical calculations applied to Haruniye thermal springs representing reservoir reveals 33-34 °C respectively. According to these studies, protection zones have been determined by evaluation of contamination sources and conceptual hydrothermal model of the geothermal field has been constructed.

## 1. INTRODUCTION

Thermal karst aquifers are extremely vulnerable to groundwater contamination in case of lacking of protective impervious cape rock overlying the main reservoir. Contaminants associated with agricultural and human activities are potential problems in karst terrains. The degree of this contamination in karstic system depends on the recharge type (diffuse or concentrated) and on proximity of sources of contamination. Haruniye geothermal system receives two modes recharge type, diffusive recharge from intensively kartstified carbonate rocks and concentrated recharge from Ceyhan river system and Berke Dam. Main contamination problem is the leakage of septic tanks of thermal facilities nearby to the thermal springs.

Haruniye geothermal field is located on Ceyhan river valley downstream of Berke Dam in Duzici district on south of Turkey (Figure 1). Previous geological, geophysical, hydrogeochemical and geochemical investigations at Duzici were carried out within the framework of Caglar (1950), Bulutcu (1975), Caglav and Ozmutaf (1982), Ekmekci (1992) and DSI (2003) to assess the geothermal potential of the field.

The main objective of this study is evaluation of previous and present geological, geophysical, hydrogeochemical and geochemical studies for social and economical development of the region. For this purpose 1/25000, 1/10000 and 1/5000 scaled geological and hydrogeological maps were prepared, 14 samples of thermal and cold waters were collected and analyzed for major chemical components and tritium ($^3H$) activity. Based on the evaluation of these data, protection zones are determined to protect geothermal field and thermal waters from old and unplanned settlements around the thermal field which are the main sources of the contamination. As a result of exploration studies a well (DH-2) drilled with 104 m. depth and thermal fluid obtained with 40 l/s flow rate and 32 °C temperature.

This paper including the results of the geological and hydrogeochemical investigations which have been carried out to evaluate reservoir lithologies, origin and recharge mechanism of the geothermal system and an updated conceptual geochemical model of the Haruniye geothermal field.

Haruniye has been sought for its curing warm springs and visit to Haruniye thermal springs, and healthful experience for body and soul since ancient Roman periods.

Irenopolis, an ancient city established in this region, was a thermal cure center. The coins (Photo 1) and inscriptions were belonging to Irenopolis date back to 51 A.D., Asklepios and Hygea (The God and Goddess of Health) being the common figure in the inscriptions. The representatives of the Asklepios-cult are well described, as statues or busts, alone or together, on coins printed in the name of almost all Roman Emperors lived in the city (Osmaniye Governership, 2005).

**Photo 1: An Irenopolis coin Hygea (225-226 A.D.)**

## 2. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The geology of the field has been described by Eroskay et al (1978), Ekmekci (1992), Arpat and Ozgul (1995). The investigation field located near the central Taurus Belt and Amanos Belt. In the region there is Middle-Late Triassic aged autochthonous units, Jurassic-Cretaceous aged allochthonous units, Paleocene-Miocene aged sedimentary rock and Quaternary aged volcanic and sedimentary rocks (Figure 2).

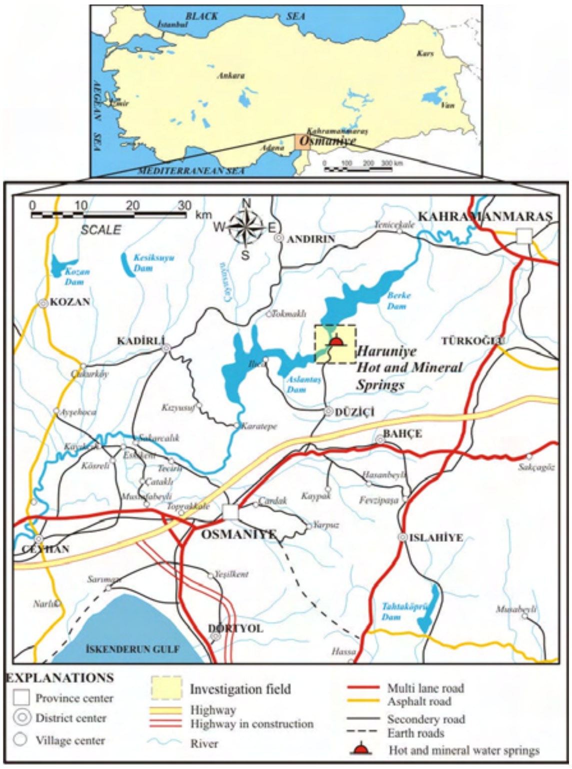


**Figure 1: Location map of study area**

Although direction of Taurus and northeastern Anatolia Mountains are E-W, Amanos belt directions are nearly to N-S. At Late Pliocene and Quaternary due to tensional tectonics like Yumurtalik fault, basalt flow, strike and slope faults have been developed.

Middle-Late Triassic aged Sulucadere Formation is the basement rock in the investigation field (Figure 2). This unit crop out on west of the springs, starts with shale and dolomite alternation and continues with dark colored, hard, thin-middle interlaminated dolomitic limestone. Sulucadere Formation is semi permeable locally. Upper level of formation which consists of jointed dolomite and karstic limestone alternation is permeable. Jurassic-Cretaceous aged Berke Complex consists of ophiolitic rocks, Berke limestones and calcschist which exposed to cataclastic deformation overlie the basement. Secondary porosities have been developed in hard and brittle dolomitic limestones and recyrstallized limestones. Around the main fault zones karstic, fissured and fractured Berke complex is permeable and constitute the main reservoir of the investigation field.

Cretaceous aged allochthonous units Somakli Complex and Kizildag Ophiolite have been formed from various lithologies. Permeable or semipermeable marinal sediments scattered in impermeable serpentine matrix have been considered as practically impermeable. Upper Maastrichtian-Paleocene aged Cona Formation which has been formed from volcanic fragments, sandstone, agglomerate and thick layers of bioclastic limestone is semipermeable units (Ekmekci, 1992). Conglomerate and sandstone levels of Kizildere Formation are permeable, whereas siltstone and shale levels are impermeable. Finally, Quaternary travertines, alluvium and slope debris are permeable units.

High mountains which have located eastern and western of the Ceyhan valley are main recharge areas. Ceyhan valley controlled main discharge system of investigation field. Most of the springs at high location are discharged from fracture zones, contact zone and karstic cavities and their average flow rate is 0.5-1 l/s. Kirkgoz Springs are the most important cold water spring of field and discharged from local lens of limestone. Haruniye hot and mineral water springs which located between Berke and Aslantas Dam have 8 spring outlets with total flow rate 90.3 l/s, and temperatures range 30.5 to 33 °C (Photo.2). Haruniye DH-2 well (flow rate 40 l/s and 32 °C) drilled in 2005 with 104 m depth (Simsek et al. 2004).

Protection zones were determined for geothermal field to protect from contaminated activities (Figure 2).

According to this study there are no human activities and residential settlements allowed around the thermal spring area and new settlement area proposed to 1km west from the spring side for thermal tourism and balneological establishments.

## 3. HYDROGEOCHEMISTRY

The results of chemical analysis of the water samples taken from the field are given in Table-1 with in-situ temperatures, pH and EC for springs and well discharged waters. Their ionic characteristics are $HCO_3 > SO_4 > Cl$; $Ca > Mg > Na + K$. Thermal waters are mainly calcium bicarbonate type.

Chemical compositions among the thermal waters shown in semi-logarithmic (Schoeller) and Triangular (Piper) diagram (Figure 3, 4). These diagrams indicate that all hot springs, mineral water spring, also DH-2 well waters originated from the same lithological (carbonate rock) units. Schoeller diagram also show that chemical composition of all hot waters, Ceyhan River, cold water springs and rain are similar. But due to gradual increase of temperature and water-rock interaction processes thermal waters are chemically more concentrated.

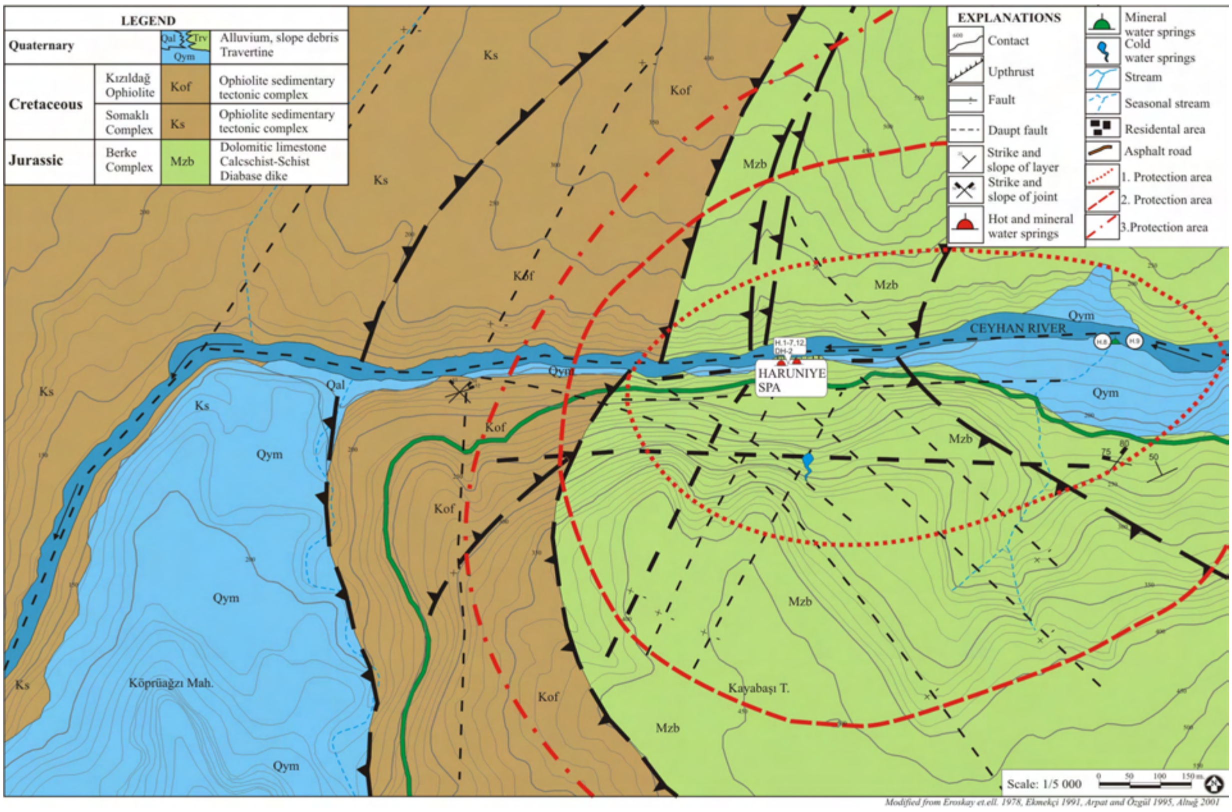


Figure 2: Hydrogeological map of investigation area.

**Photo 2: Haruniye hot and mineral water springs waterfall to Ceyhan River**

Therefore the reservoir rocks are mainly recharged from surface runoff from Ceyhan River system and infiltration from precipitations.

At the Haruniye hot and mineral water springs contamination of $NO_2$, $NO_3$ and $NH_3$ were seen (Table 1). Especially Selale, Oluklu, Hortumlu and Borulu springs which are located upper altitudes and near pollution sources. After drilled well (DH-2) clean hot and mineral water has been taken directly from fault zone from 104 meters depth.

According to the Saturation Index (SI) diagram (Figure 5), Haruniye hot and mineral waters are generally saturated with respect to quartz and Fe-minerals but they are in equilibrium with carbonate minerals indicating the main reservoir of the geothermal field is the Mesozoic limestones.

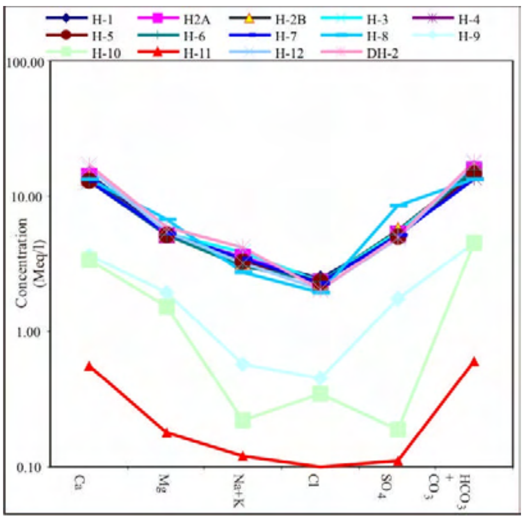


**Figure 3: Schoeller diagram of the water samples**

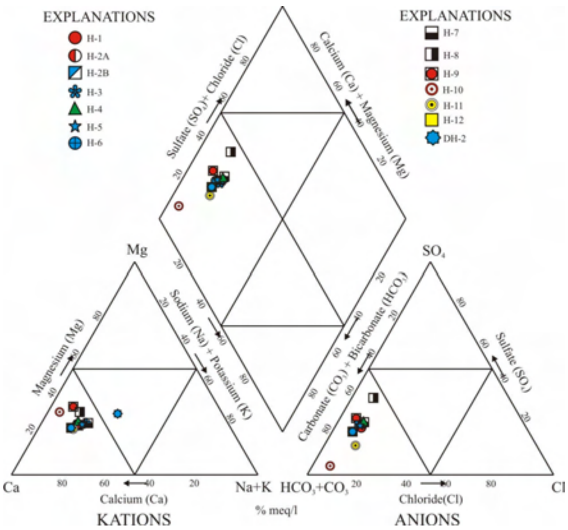


**Figure 4: Piper diagram of the water samples**

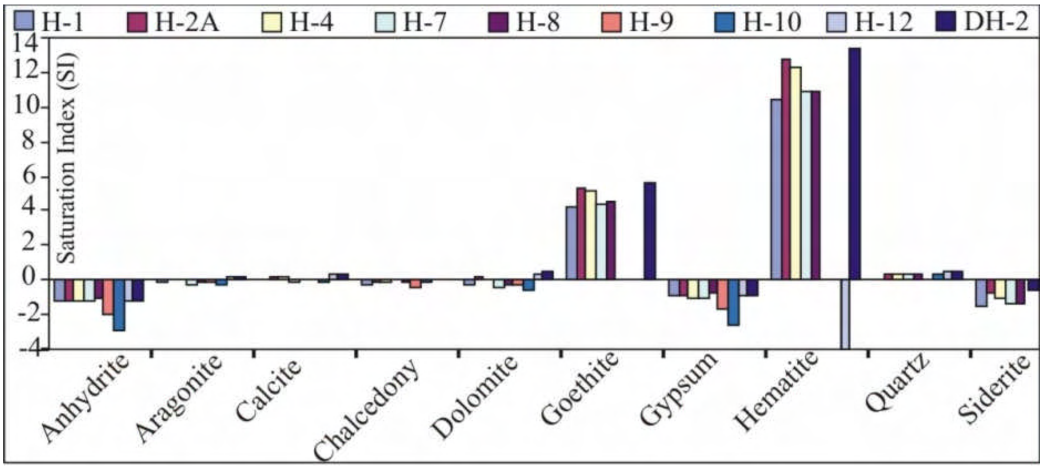


**Figure 5: Mineral saturation diagram of Haruniye springs**

**Table 1. Chemical analyses of spring waters of the study field.**

| Sample name | Samp no | T (°C) | pH | EC (μS/cm) | Ca (ppm) | Mg (ppm) | Na (ppm) | K (ppm) | Cl (ppm) | $SO_4$ (ppm) | $HCO_3$ (ppm) | $SiO_2$ (ppm) | $NO_2$ (ppm) | $NO_3$ (ppm) | $NH_3$ (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ana S.** | H-1 | 31.0 | 6.09 | 1848 | 293.0 | 64.00 | 75.00 | 6.80 | 86.85 | 246.79 | 960.6 | 9.74 | 0.03 | 0 | 2.35 |
| **Dip S.( A)** | H-2A | 31.0 | 6.33 | 1841 | 279.0 | 63.00 | 77.00 | 7.00 | 83.31 | 254.94 | 939.4 | 16.28 | 0.02 | 0 | 0.49 |
| **Dip S. (B)** | H-2B | 30.7 | 6.39 | 1833 | 274.0 | 64.00 | 71.00 | 6.50 | 83.31 | 266.58 | 939.4 | 15.27 | 0.03 | 0 | 1.22 |
| **Borulu S.** | H-3 | 30.5 | 6.44 | 1823 | 261.0 | 65.00 | 84.00 | 7.70 | 83.31 | 258.43 | 939.4 | 11.25 | 0.02 | 0 | 1.47 |
| **Hortumlu S.** | H-4 | 30.6 | 6.33 | 1810 | 260.0 | 63.00 | 72.00 | 6.80 | 79.76 | 246.79 | 823.5 | 16.28 | 0.26 | 0.128 | 0.78 |
| **Oluklu S.** | H-5 | 30.5 | 6.78 | 1794 | 261.0 | 63.00 | 71.00 | 7.50 | 83.31 | 242.14 | 902.8 | 12.75 | 0.02 | 0 | 1.05 |
| **Selale S.** | H-6 | 30.2 | 6.93 | 1804 | 262.0 | 63.00 | 65.00 | 6.80 | 83.31 | 250.29 | 939.4 | 14.26 | 0.02 | 0 | 0.73 |
| **Hanimlar S.** | H-7 | 30.6 | 6.11 | 1869 | 263.0 | 65.00 | 75.00 | 6.80 | 79.76 | 247.96 | 805.2 | 19.29 | 0.02 | 0 | 0.92 |
| **Mineral water** | H-8 | 24.3 | 6.25 | 1923 | 269.0 | 82.00 | 60.00 | 5.60 | 69.13 | 413.22 | 805.2 | 12.25 | 0.02 | 0 | 0.40 |
| **Ceyhan R.** | H-9 | 18.6 | 7.22 | 588 | 73.0 | 23.50 | 12.40 | 1.47 | 15.95 | 83.34 | 268.4 | 5.45 | 0.02 | 0.506 | 0 |
| **Kirkgoz S.** | H-10 | 16.2 | 7.13 | 531 | 68.0 | 18.50 | 4.70 | 0.60 | 12.41 | 9.09 | 268.4 | 10.33 | 0.02 | 4.820 | 0.17 |
| **Rain** | H-11 | 18.0 | 8.8 | 38 | 11.1 | 2.20 | 0.70 | 3.50 | 3.55 | 5.37 | 36.60 | 0.77 | 0.05 | 0.338 | 1.49 |
| **Ana S. **** | H-12 | 31.0 | 6.31 | 2020 | 326.6 | 66.12 | 70.43 | 6.84 | 71.65 | 237.44 | 1060 | 25.10 | 0.00 | 0 | - |
| **Haruniye W**** | DH-2 | 32.0 | 6.37 | 2040 | 339.7 | 70.77 | 91.03 | 9.60 | 72.03 | 241.07 | 1075 | 25.48 | 0.00 | 0 | - |

** (March 2005), S=Spring, W=Well, R=River

Previous and recent physical-chemical analyses reveal that temperature and chemical concentration of thermal springs decreased gradually after construction of Berke Dam due to increased hydraulic head on the upstream of the Ceyhan River. Chloride–EC graphs (Figure 6) represent this dilution process of thermal waters and gradual decrease of chemical concentration.

Reservoirs temperatures estimated by chemical silica and cation geothermometers. Cation geothermometers gave very high temperature ranges. Hot waters in the field are examined on Na-K-Mg diagrams (Giggenbach, 1988). All hot waters are located on "immature" zone (Figure 7). Therefore it is not suitable to use cation geothermometer to estimate reservoir temperature. But especially chalcedony geothermometer is given acceptable values as 34 ºC.

Tritium ($^3H$) isotope is used for understanding groundwater flow mechanism and relative ages in hydrogeological systems. According to the $^3H$-Cl diagram; Haruniye field is found to be low temperature field with a shallow circulation system and recharged from Ceyhan River and present precipitations (Figure 8).

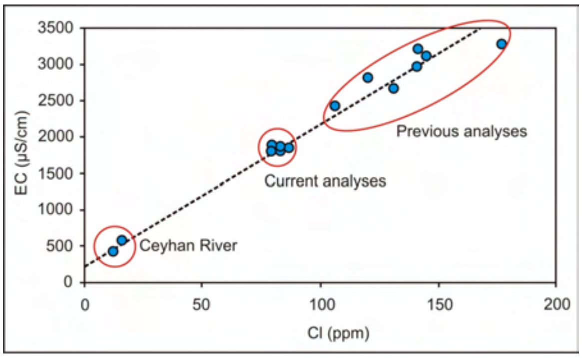


**Figure 6: Cl-EC diagram of Haruniye field**

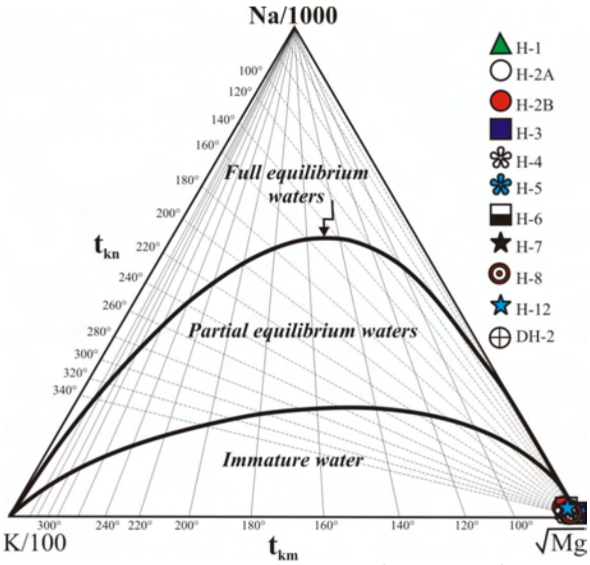


**Figure 7: The Na-K-Mg diagram of Haruniye field**

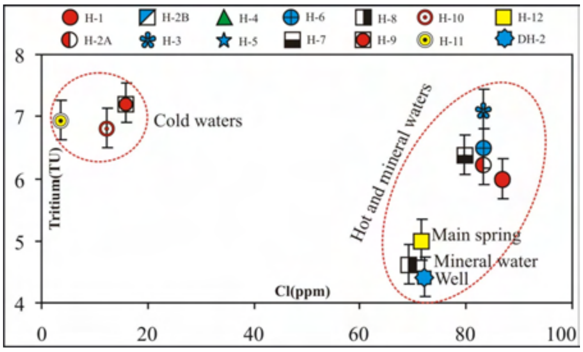


**Figure 8: Tritium-Cl diagram of Haruniye field**

According to stable isotopes O-18 and Deuterium (Table 2) there is no geothermal shift and thermal waters have meteoric origin (Ekmekci, 1992).

**Table 2: Environmental isotope analyses of study field (Ekmekci, 1992)**

| Sample name | d18O | d2H |
|---|---|---|
| Ceyhan River | -8.46 | -36.7 |
| Haruniye Main Spring | -6.72 | -55.8 |

## 4. CONCEPTUAL HYDROTHERMAL MODEL OF THE FIELD

After geological, hydrogeological, hydrogeochemical and geophysical studies; conceptual hydrothermal model of the Haruniye geothermal field constructed and DH-2 well drilled in the field (Figure 9, Photo3). According to model; geothermal reservoir recharged with meteoric waters (from present precipitations, Ceyhan River and Berke Dam reservoir). Hot and mineral waters are heated and raised from fault and fractured zones and mixed with shallow cold groundwater and discharged from the low altitude of the fault zones in the Ceyhan valley.

**Photo 3: Haruniye DH-2 well during testing.**

## 5. CONCLUSIONS

In this study; Triassic aged Sulucadere Formation and Jurassic aged Berke Complex are the main reservoir and Cretaceous aged Somakli Complex, Kizildag Ophiliote, Paleocene aged Cona Formation and Miocene aged Kizildere Formation are the cap rock of the geothermal field.

According to hydrogeochemical studies hot and mineral waters have same origin and they are classified as Ca-$HCO_3$ type water. Reservoir temperatures were estimated as 34 ºC via chalcedony geothermometry.

Low tritium amount of the Haruniye springs indicates that hot and mineral water springs are recharged from Ceyhan River and present precipitations with shallow circulation system.

Protection zones were determined for geothermal field and it was protected from contaminated activities (Figure 2). According to this study there are no human activities and residential settlements allowed around the thermal springs and new settlement area proposed 1 km west from the spring side for thermal tourism and balneological establishments.

Thermal waters to obtain from DH-2 well (40 l/s) are adequate for nearly 9500 person (per person 350 l/day) for thermal tourism facilities.

## 6-ACKNOWLEDGEMENTS

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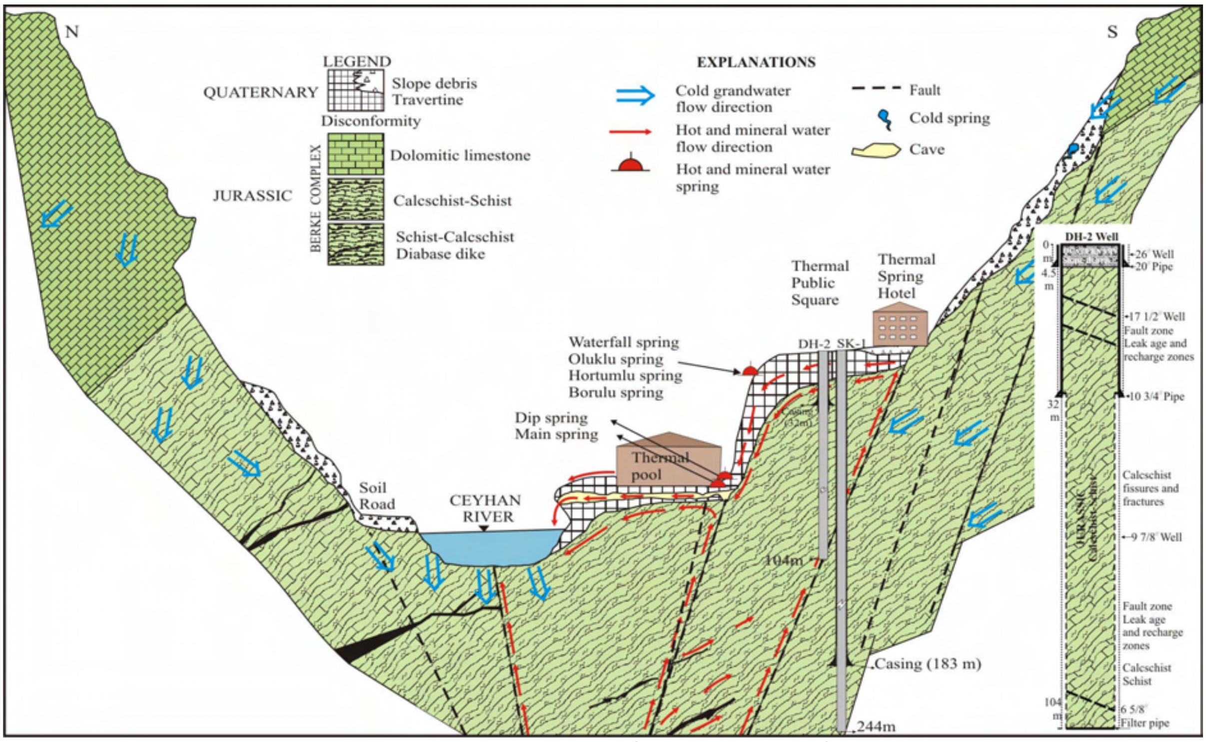

**Figure 9: Conceptual hydrothermal model of Duzici-Haruniye field and DH-2 well log**

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