Hydrogeological Modelling of Geothermal Waters in Cesme and Environs, Western Anatolia, Turkey

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Abstract. The geothermal fields of Çeşme are located in the western part of province capital of Izmir and can be considered as important tourist resorts with a great number of thermal hot springs which are used for thermal bathing since several years. Nowadays, the geothermal waters in the fields are used for district heating and greenhouses. In the area of Çeşme, there are sedimentary and volcanic rocks predominantly. The basement rocks are of Devonian age and consists of intercalations of sandstones, greywackes and limestones overline by Upper to Middle Triassic carbonate rocks with intercalations of sandstones and claystones. These rocks are overlain by Neogene volcanic and terrestrial sedimentary rocks. In 1995, we have measured in-situ parameters in many locations of groundwaters and geothermal waters with collection of a great number of samples for these waters. The geothermal waters are of Na-Cl, Na-(Cl)-HCO3, Na-Ca-Cl, Na-Mg-(Cl)-HCO3, Na-Mg-Ca-(Cl)-HCO3 and Ca-Na-Mg-(Cl)-HCO3 type waters during the groundwaters display Na-Cl, Na-HCO3, Na-Mg-(Cl)-HCO3, Na-Mg-HCO3, Na-Mg-Ca-(Cl)-HCO3, Mg-Ca-Na-(Cl)-HCO3 and Mg-Ca-Na-(Cl)-HCO3 type waters. The Na-Cl type waters are originated from deep reservoir during the others can be considered as diluted Cl-HCO3 water type. The plot of $\delta^{18}O$ versus $\delta^D$ shows that the geothermal waters are enriched in $\delta^{18}O$ and $\delta^D$ and located on the mixing trend between groundwaters and seawaters indicating mixing of these both different waters. The proportion of seawaters in geothermal waters seems to be very higher than groundwaters. The shift in the $\delta^{18}O$ values are related to $\delta^{18}O$ exchange between the deeply circulating meteoric waters and reservoir rocks in the area. The increase of $\delta^D$ is related to the contribution of seawaters. The geothermal waters in the area fall into fields of immature to partially equilibrated waters. In general, the reservoir temperature of the area of Çeşme is estimated to be 80 to 120 °C.

1. Introduction
The geothermal waters in Çeşme and environs are located in the western part of province capital of Izmir and represent remarkable potential for green houses, district heating and balneological uses [Figure 1]. In the area, several researchers [1; 2; Figure 1] realized studies on hydrogeological, hydrogeochemical and isotope geochemical features of geothermal waters and groundwaters. The aim of this study is to describe hydrogeological and hydrogeochemical features of geothermal waters, to test the applicability of geothermometers and to develop hydrogeological modelling of geothermal waters.
2. Geologic setting
In Çeşme and environs, the area consists of sedimentary and volcanic rocks [Figure 1; 2; 3; 4]. The basement rocks are of intercalations of sandstones, greywackes and limestones in Devonian age overlain by Mesozoic rocks. Devonian rocks play an important role for the formation of basement rocks due to their lower permeability. Mesozoic rocks are of limestones with intercalations of sandstones and claystones from Middle to Upper Triassic. The most part of the study area is covered by Neogene volcanic rocks and other terrestrial rocks.

3. Material and method
Hydrogeochemical data for geothermal waters have been obtained from geothermal wells and [2; Table 1]. The in-situ parameters such as temperatures, pH, Eh (mV), electrical conductivity (µS/cm), dissolved oxygen (mg/L) and alkalinity were measured in the field at the time of sampling collection. The anions and cations in the water samples were analysed in the Laboratory of Geothermal Energy, Groundwater and Mineral resources within the Department of Geological Engineering of the Faculty of Engineering of the Suleyman Demirel University. A part of the hydrogeochemical and isotope geochemical analyses are based on research work [2]. The cations of Na⁺, Ca²⁺, Mg²⁺, K⁺, Si⁴⁺ and B³⁺ were analysed by ICP-OES methods, while the analyses of anions such as F⁻, SO₄²⁻, Cl⁻ and NO₃⁻ were performed by IC methods. The values of HCO₃⁻ and CO₃²⁻ have been calculated by the alkalinity measurements in the field. The evaluation of the hydrogeochemical data was carried out using Aquachem 3.7 [5].

4. Results
4.1 Hydrogeology
In the study area, the intercalation of sandstones, greywackes and limestones in Devonian age form the impermeable basement rocks overlain by Middle to Upper Triassic limestones which can be considered as reservoir rocks for geothermal waters. These limestones are highly fractured and has karst forms [2]. These fractures and karst formations have given rise to this formation of hydrothermal circulation cells within these rock sequence.

4.2 Hydrogeochemistry
Results of hydrogeochemical analyses are presented in Table 1. A Piper triangular diagram shows that a part of geothermal waters are of Na-Cl type indication a mixing with seawaters [Figure 2]. An another part of geothermal waters are of Na, Ca, Mg and Cl, HCO₃ type. The samples of geothermal waters plot on Cl-SO₄-HCO₃ diagram [Figure 3] that shows deep reservoir originated waters which are confirmed by [2].
Figure 1. Geological map of Çeşme and environs with sample locations of geothermal waters [2]
**Table 1.** Results of hydrogeochemical analyses of geothermal waters in Çeşme and environs [2; 3; 4]

| Sample | Location | T (°C) | pH  | Eh (mV) | EC (µS/cm) | Na⁺ (mg/l) | K⁺ (mg/l) | Ca²⁺ (mg/l) | Mg²⁺ (mg/l) | B³⁺ (mg/l) | SO₄²⁻ (mg/l) | Cl⁻ (mg/l) | NO₃⁻ (mg/l) | HCO₃⁻ (mg/l) |
|--------|----------|--------|-----|---------|------------|------------|-----------|------------|------------|-----------|-------------|-----------|------------|-------------|
| SD 1   | Çeşme    | 39.2   | 7.31| 101.3   | 29700      | 6052       | 206       | 590        | 408        | 3.1       | 1418        | 10287     | 5.2        | 329         |
| SD 2   | İlçalar  | 40     | 7.46| 73       | 57100      | 13400      | 437       | 855        | 1187       | 4.9       | 2987        | 21566     | 0.1        | 317.2       |
| EB 1   | Çumalı   | 61.4   | 7.27| 92.4     | 29200      | 5858       | 754       | 546        | 56.3       | 14        | 170         | 10231     | 0.1        | 427         |
| EB 2   | Karakoç  | 55.1   | 7.27| 94.2     | 6710       | 1236       | 93.9      | 160        | 52.5       | 8         | 187         | 1765      | 1.15       | 847.9       |
| EB 3   | Doğanbey | 76.1   | 7.58| 112      | 10830      | 1985       | 4.22      | 195        | 59.3       | 9.4       | 267         | 3075      | 0.56       | 640.5       |
| 4      | Çeşme    | 29     | 6.5 | 112      | 1920       | 112        | 15        | 99         | 34         | 41        | 278         | 429       |
| 5      | Çeşme    | 36     | 6.3 | 2370     | 228        | 19         | 61        | 48         | 53         | 379       | 428         |
| 6      | Çeşme    | 40     | 7.3 | 1180     | 246        | 13         | 87        | 57         | 146        | 360       | 329         |
| 9      | Çeşme    | 28     | 5.7 | 1720     | 155        | 16         | 86        | 31         | 69         | 277       | 273         |
| 13     | Çeşme    | 49     | 6.6 | 3750     | 695        | 33         | 132       | 72         | 295        | 894       | 587         |
| 15     | Çeşme    | 33     | 6.5 | 1610     | 63         | 5          | 50        | 61         | 45         | 131       | 338         |
| 16     | Çeşme    | 42     | 6.8 | 6600     | 579        | 40         | 218       | 62         | 153        | 1355      | 275         |
| 23     | Çeşme    | 37     | 6.8 | 79200    | 11257      | 792        | 1298      | 590        | 2583       | 18490     | 232         |
| 28     | Çeşme    | 36     | 7.2 | 1490     | 134        | 34         | 35        | 14         | 39         | 140       | 348         |
| 57     | Çeşme    | 30     | 6.9 | 4210     | 709        | 23         | 173       | 118        | 182        | 1128      | 622         |
| 91     | Çeşme    | 42     | 6.6 | 48400    | 9150       | 804        | 1039      | 762        | 2422       | 16450     | 183         |
| 92     | Çeşme    | 42     | 6.6 | 58200    | 9922       | 894        | 1195      | 892        | 2926       | 20500     | 159         |
| 95     | Çeşme    | 58     | 6.5 | 26600    | 7108       | 631        | 677       | 367        | 1665       | 11530     | 195         |
| 103    | Çeşme    | 57     | 5.8 | 87100    | 11310      | 368        | 938       | 1203       | 3092       | 18550     | 146         |
| T24    | Çeşme    | 60     | 7.8 | 10875    | 388        | 1551       | 609       | 2983       | 20430      | 152       |
| FY1    | Çeşme    | 62     | 7.9 | 10000    | 380        | 1603       | 486       | 2422       | 19850      | 122       |
Table 1. -continue. Results of hydrogeochemical analyses of geothermal waters in Çeşme and environs [2; 3; 4]

| Sample | Li (mg/l) | Sr (mg/l) | Mn (mg/l) | Fe (mg/l) | Zn (mg/l) | Cu (mg/l) | SiO$_2$ (mg/l) | Al (mg/l) | Pb (mg/l) | O$_2$ (mg/l) | Cr (mg/l) |
|--------|-----------|-----------|-----------|-----------|-----------|-----------|---------------|-----------|-----------|-------------|-----------|
| SD 1   |           |           |           |           |           |           | 19.6          | 0.2       | 2.7       |             |           |
| SD 2   |           |           |           |           |           |           | 13.2          | 0.2       | 3.7       |             |           |
| EB 1   |           |           |           |           |           |           | 142           | 0.2       | 3         |             |           |
| EB 2   |           |           |           |           |           |           | 53.5          | 0.2       | 3         |             |           |
| EB 3   | 68.5      | 0.2       |           |           |           |           |               |           |           |             |           |
| 4      |           |           |           |           |           |           |               |           |           |             |           |
| 5      |           |           |           |           |           |           |               |           |           |             |           |
| 6      | 0.026     | 1.07      | 0.01      | 0.29      | 0.13      | 0.023      | 27.21         | 0.02      | 0.008     |             |           |
| 9      | 0.098     | 2.17      | 0.017     | 1.46      | 0.25      | 0.007      | 111.8         | 0.03      | 0.012     |             |           |
| 13     | 0.046     | 1.11      | 0.002     | 0.34      | 0.14      | 0.008      | 13.7          | 0.001     | 0.008     |             |           |
| 15     | 0.127     | 2.4       | 0.27      | 0.7       | 0.06      | 0.017      | 28.71         | 0.05      | 0.037     |             |           |
| 23     | 0.495     | 7.83      | 0.03      | 2.13      | 0.14      | 0.49       | 8.1           | 18        | 0.67      |             |           |
| 28     | 0.046     | 1.11      | 0.002     | 0.34      | 0.14      | 0.008      | 13.7          | 0.001     | 0.008     |             |           |
| 57     | 0.127     | 2.4       | 0.27      | 0.7       | 0.06      | 0.017      | 28.71         | 0.05      | 0.037     |             |           |
| 91     | 0.193     | 2.9       | 0.28      | 0.62      | 0.098     | 0.028      | 27.9          | 0.07      | 0.037     |             |           |
| 92     | 0.187     | 5.51      | 0.025     | 0.63      | 0.9       | 0.025      | 52.9          | 0.12      | 0.33      |             |           |
| 95     | 0.01      |           |           |           |           |           |               |           |           |             |           |
| 103    |           |           |           |           |           |           |               |           |           |             |           |
| T24    |           |           |           |           |           |           |               |           | 42        |             |           |
| FY1    |           |           |           |           |           |           |               | 0.01      | 21        |             |           |
Figure 2. Geothermal waters of Çeşme and environs in Piper diagram [2; 3; 4].

Figure 3. Cl-SO₄-HCO₃ triangular diagram of geothermal waters in Çeşme and environs [2; 3; 4].
By the position of geothermal waters of Çeşme and environs on Na-K-Mg [Figure 4] and a great number of geochemical cation thermometers such as Na-K, Na-K-Ca and K-Mg geothermometers, it can be concluded that the reservoir temperatures of geothermal waters range from 80 to 110 °C which are confirmed by [2].

![Figure 4](image)

**Figure 4.** Na-K-Mg triangular diagram of geothermal waters in Çeşme and environs [2; 3; 4].

### 4.3 Isotope geochemistry

The isotope geochemical results of geothermal waters and groundwater are presented in Table x which are based on [1, 6; 7]. $\delta^{18}$O versus $\delta$D is plotted on Figure 5 which also shows the worldwide meteoric line ($\delta$D=8$\delta^{18}$O + 10) of [2] and the Mediterranean meteoric water line ($\delta$D=8$\delta^{18}$O + 22) of [9]. Groundwater samples plot between local and worldwide meteoric water lines indicating their meteoric origin [2]. The geothermal waters are enriched in $\delta^{18}$O and $\delta$D and located on the mixing trend between groundwater and seawaters. Proportional, the seawater component in geothermal waters seems to be higher than that of groundwater. The shift in the $\delta^{18}$O values are related to the $\delta^{18}$O exchanges between deeply circulating meteoric waters and reservoir rocks.
5. Discussion

In Çeşme and environs, there are two types of geothermal waters. The type one is of deep reservoir of Middle to Upper Triassic limestones heated by convective heat transfer due to deeply circulating geothermal waters and the other is shallow reservoir of sandstones of Middle to Upper Triassic limestones and volcanic rocks heated by convective heat transfer from below [2]. The type one is of Na-Cl type and reflects a very high contribution of seawaters to the geothermal waters. In comparison, the type two is of mixing waters and can be considered as Na- (Ca)-(Mg)-(Cl)-HCO₃ type waters. Geothermal waters in Çeşme and environs have a high proportion of seawaters up to 92 percent [2], which percolate through faults, fractures and karstic structures, are heated in the reservoir and ascent to the surface along the N-S trending faults. The young volcanism in the area is responsible for heating of geothermal waters in both reservoirs. By the position of geothermal waters of Çeşme and environs on Na-K-Mg [Figure 4] and a great number of geochemical cation thermometers such as Na-K, Na-K-Ca and K-Mg geothermometers, it can be concluded that the reservoir temperatures of geothermal waters range from 80 to 110 °C which are confirmed by [2].

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References

[1] Filiz, Ş., “Ege Bölgesindeki önemli jeotermal alanlardaki O-18, H-2, H-3 C-13 izotoplarıyla incelenmesi,” Doçentlik Tezi, E.Ü.Y.B.F, 95 p., 1982.
[2] Gemici, Ü., Filiz, Ş., “Hydrochemistry of the Çeşme geothermal area in western Turkey,” J. Volcan. Geotherm. Res. 110, pp. 171-187, 2001.
[3] Değirmenci, S., “Sifne (İzmir) ve yakın çevresi jeotermal suların hidrojeolojik, hidrojeokimyasal ve izotop jeokimyasal özellikleri,” M. Sc. thesis, Süleyman Demirel Üniversitesi, Fen Bilimleri Enstitüsü, 56 p., 2017.
[4] Aras Pala, E., “Seferihisar (İzmir) ve yakın çevresi jeotermal suların hidrojeolojik, hidrojeokimyasal ve izotop jeokimyasal özellikleri,” M. Sc. thesis, Süleyman Demirel Üniversitesi, Fen Bilimleri Enstitüsü, 71 p., 2016.
[5] Calmbach, L., “AquaChem Computer code-Version 3.7: Aqueous geochemical analyses, plotting and modelling. Waterloo Hydrogeologic: Waterloo, Canada,” 1999.

[6] Ercan, T., Ölmazı, E., Matsudo, I., Wagoo, K., Kita, I., “Kuzey ve Batı Anadolu’da sıcak ve mineralize sular ile içerdikleri gazların kimyasal ve izotopik değerleri,” Türkiye Enerji Bülteni 1, Jeoloji Mühendisleri Odası, 1984.

[7] Conrad, M.A., Hipfel, B., Satur, M., “Chemical and stable isotopic characteristics of thermal waters from Çeşme-Seferihisar area, İzmir (W-Turkey), “ IESCA Proceedings, p. , 1995.

[8] Craig, H., “Isotopic variations in meteoric waters,” Science 133, p. 1702-1702, 1961.