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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)-HCO_3, Na-Ca-Cl, Na-Mg-(Cl)-HCO_3, Na-Mg-Ca-(Cl)-HCO_3 and Ca-Na-Mg-(Cl)-HCO_3 type waters during the groundwaters display Na-Cl, Na-HCO_3, Na-Mg-(Cl)-HCO_3, Na-Mg-HCO_3, Na-Mg-Ca-(Cl)-HCO_3, Mg-Ca-Na-(Cl)-HCO_3 and Mg-Ca-Na-(Cl)-HCO_3 type waters. The Na-Cl type waters are originated from deep reservoir during the others can be considered as diluted Cl-HCO_3 water type. The plot of $\delta^{18}O$ versus δD shows that the geothermal waters are enriched in $\delta^{18}O$ and δD 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 δD 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^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Si^{4+} and B^{3+} were analysed by ICP-OES methods, while the analyses of anions such as F^{-}, SO_4^{2-}, Cl^{-} and NO_3^{-} were performed by IC methods. The values of HCO_3^{-} and CO_3^{2-} 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, HCO_3 type. The samples of geothermal waters plot on Cl-SO_4-HCO_3 diagram [Figure 3] that shows deep reservoir originated waters which are confirmed by [2].

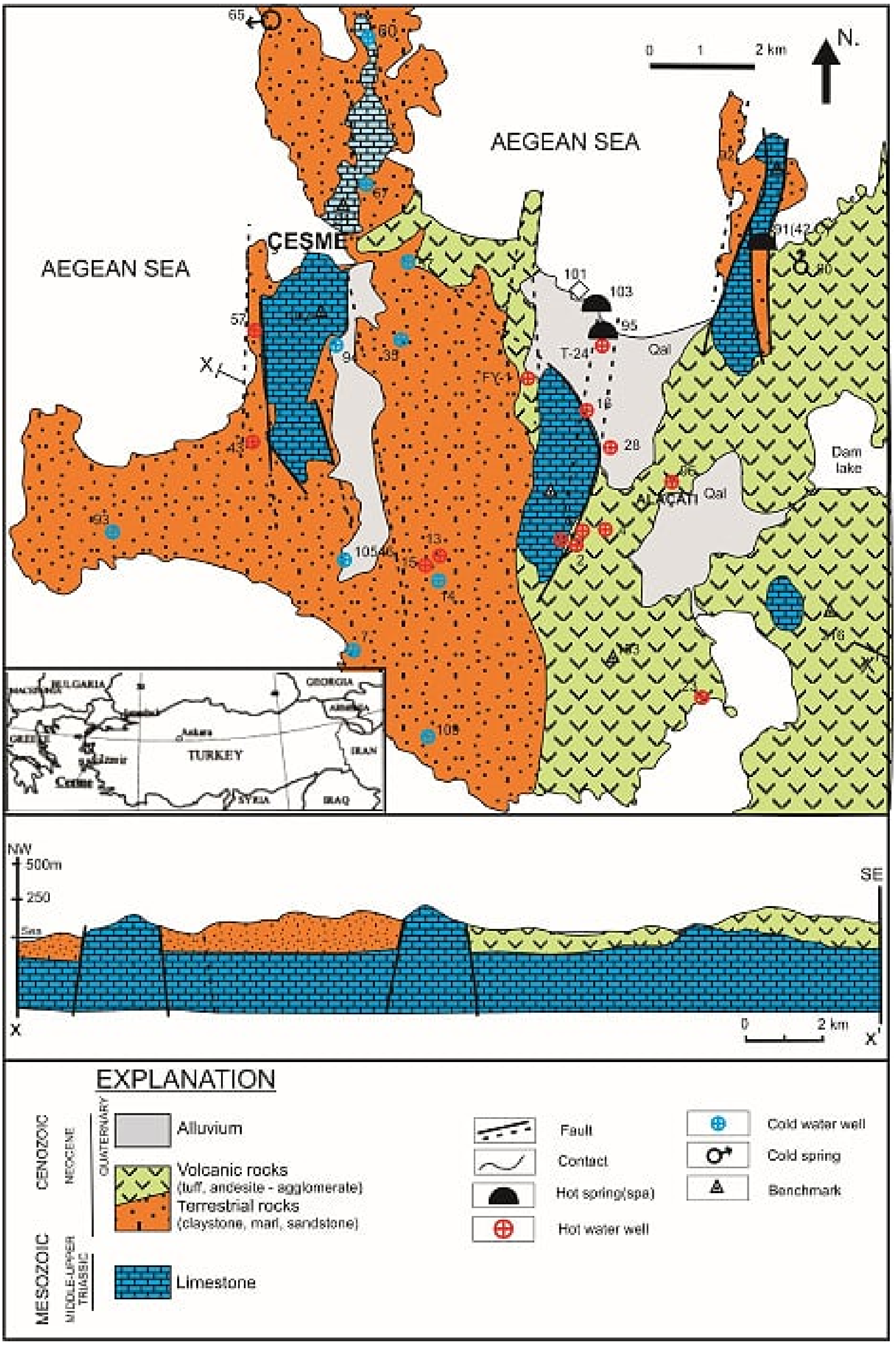

Figure 1. Geological map of Çeşme and environs with sample locations of geothermal waters [2]

Table 1. Results of hydrogeochemical analyses of geothermal waters in Çeşme and environs [2; 3; 4)

Sample	Location	T (ºC)	pH	Eh (mV)	EC (µS/cm)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	B^{+3} (mg/l)	SO_4^{-2} (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	HCO_3^- (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	Ilıcalar	40	7.46	73	57100	13400	437	855	1187	4.9	2987	21566	0.1	317.2
EB_1	Cumali	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		1920	112	15	99	34		41	278		328
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

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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		4.1	
4											
5											
6	0.026	1.07	0.01	0.29	0.13	0.023	27.21		0.02		0.008
9											
13	0.098	2.17	0.017	1.46	0.25	0.007	111.8		0.03		0.012
15											
16											
23	0.495	7.83	0.03	2.13	0.14	0.49	8.1		18		0.67
28											
57	0.046	1.11	0.002	0.34	0.14	0.008	13.7		0.001		0.008
91	0.127	2.4	0.27	0.7	0.06	0.017	28.71		0.05		0.037
92	0.193	2.9	0.28	0.62	0.098	0.028	27.9		0.07		0.037
95	0.187	5.51	0.025	0.63	0.9	0.025	52.9		0.12		0.33
103											
T24							42				
FY1				0.01			21				

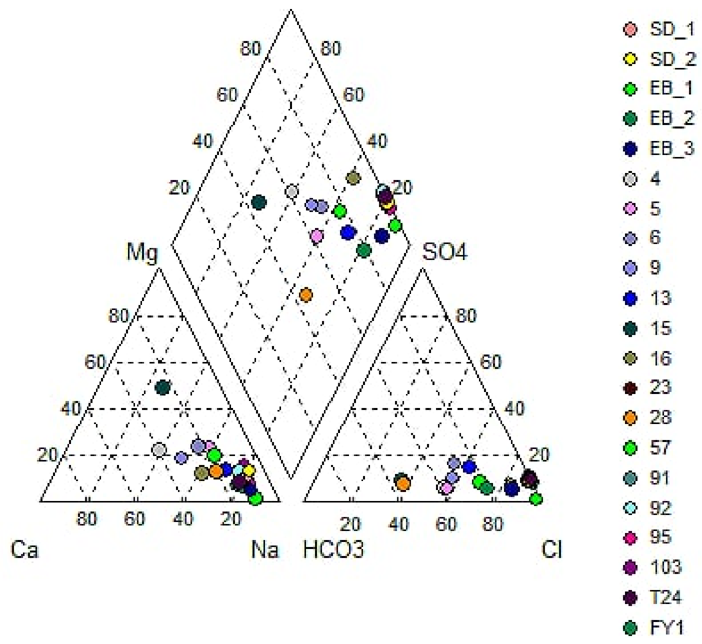

Figure 2. Geothermal waters of Çeşme and environs in Piper diagram [2; 3; 4].

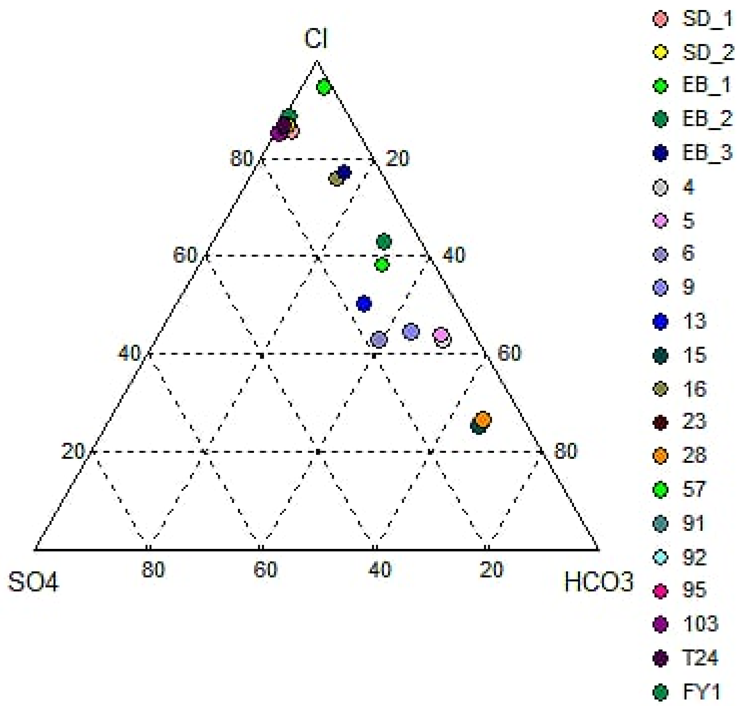

Figure 3. Cl-SO_4-HCO_3 triangular diagram of geothermal waters in Çeşeme and environs [2; 3; 4].

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 us 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 comfirmed by [2].

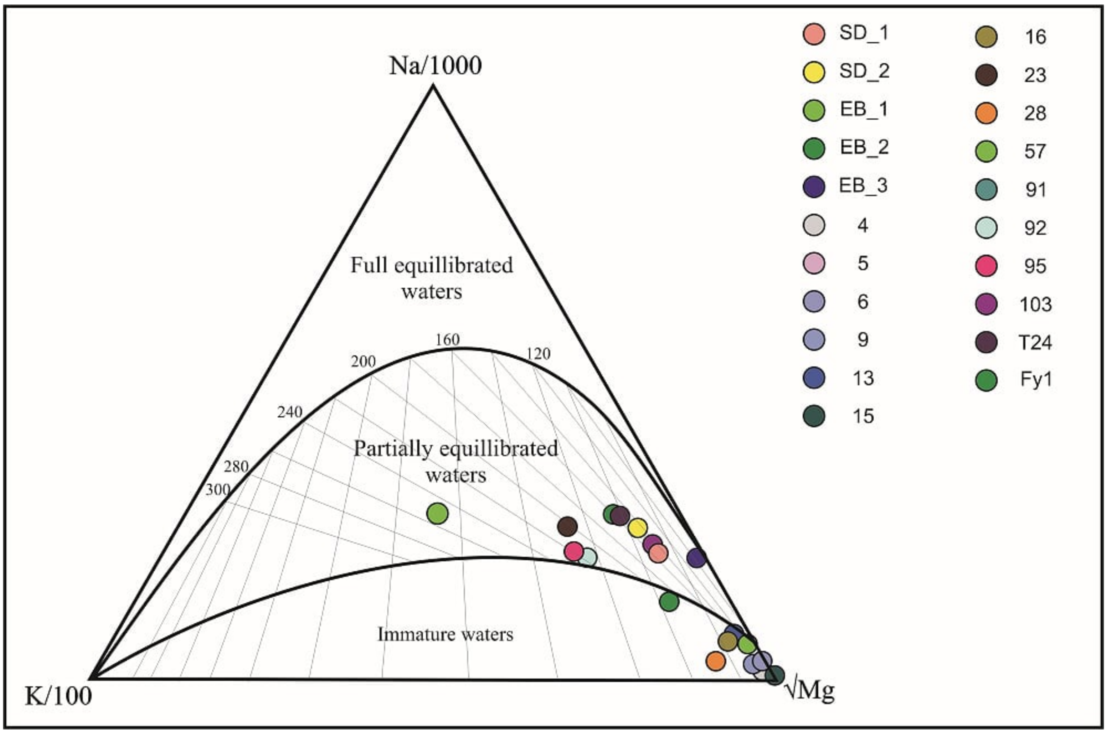

Figure 4. Na-K-Mg triangular diagram of geothermal waters in Çeşme and environs [2; 3; 4].

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 δD 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 δD 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.

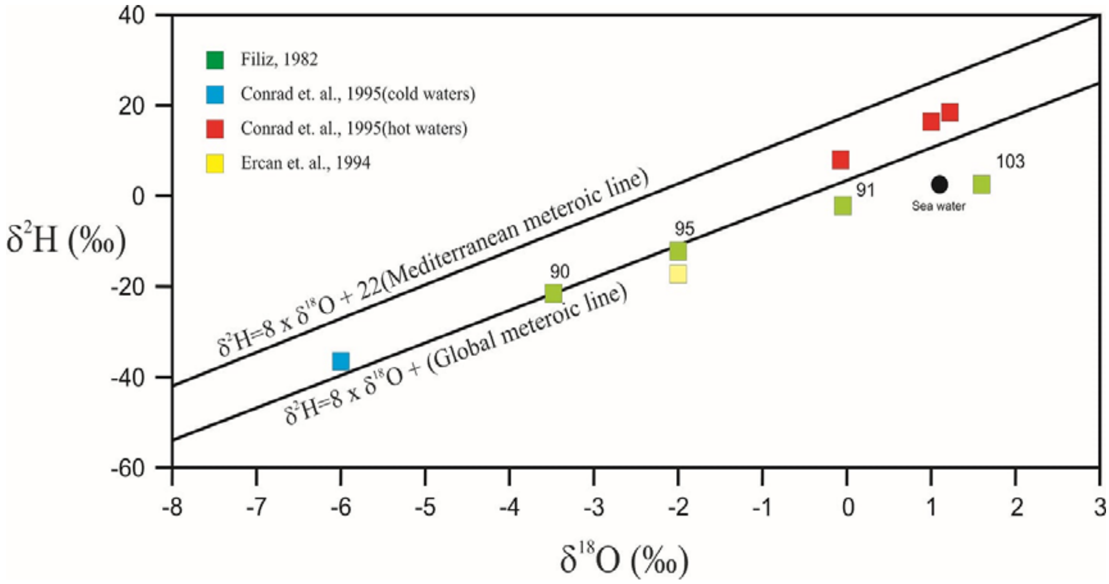

Figure 5. $\delta^{18}O$ versus δD in geothermal waters of Çeşme and environs [2; 3; 4].

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)-HCO_3 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 the 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 us 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 comfirmed by [2].

Acknowledgements

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