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HYDROGEOCHEMICAL AND ISOTOPIC INVESTIGATION OF NASRETTIN HOCA SPRINGS, ESKİŞEHİR, TURKEY

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Hydrogeochemistry,
Isotope,
Protection area,
Trace element,
Sivrihisar-Eskişehir,
Turkey

Abstract

The aims of this study are to investigate the water quality, the contamination and water-rock interaction of the Nasrettin Hoca springs, with an ultimate aim of establishing protection measures. Within the scope of this study, the springs in and around the catchment area, Bağbaşı springs, Hatip spring, Ali spring, Saracık Fountain and Babadat spring, were investigated. The springs are of Ca-Mg-HCO_3 type when basic hydrogeochemical features are considered, are under the influence of marble-limestone and metaophiolitic units located in the recharge area and are of shallow circulation. The trace element contents of the springs show the influence of the carbonate rocks comprising the reservoir (Sr) and the basement rocks (Ni, Al). The protection areas of Nasrettin Hoca springs against contamination are determined as three different zones by considering the hydrogeologic and topographical features of the region and the Turkish Standards.

1. Introduction

1.1. The Aim of the Study

The study area is located in Central Anatolia, about 120 km northeast of Ankara which is the capital of Turkey (Figure 1). The hydrogeological investigations, aimed at characterizing the hydrogeological properties of the formations and hydrogeochemistry of the water resources, concentrated on the whole Eskişehir basin rather than focusing on the current study area (Süral and Eser, 1998; Demiroğlu, M., 2008; Çelmen, 2008), therefore this study can be considered as the first detailed one regarding the hydrogeology and water chemistry of Nasrettin Hoca spring area.

The drinking and domestic water supplies in inner Anatolia are mostly in contact with the evaporite rocks during recharge-storage-circulation-discharge stages due to the widespread occurence of these rocks throughout the region. Therefore, the water quality is adversely affected by the geologic units and by the contribution from the geothermal fluids (Çelik, 2002; Çelik and Yıldırım, 2006; Çelik et al., 2008; Çelmen and Çelik, 2009). In Inner Anatolia Region, Nasrettin Hoca springs are one of the most important fresh water resources located very close to the capital city of Turkey, Ankara. The average yearly precipitation recorded between years 1924-2005 in Sivrihisar meteorological station is 393.2 mm; thus, in such a semi-arid region, where fresh water is of vital importance, these resources should be protected against point and/or non-point source contaminations, especially against the anthropogenic ones. Establishment of protection areas against contamination requires the knowledge of the hydrogeologic setting as well as the groundwater quality (Demirel, 1988; Doerfliger et al., 1999; Elhatip and Afsin, 2001). Therefore, this study is carried out to investigate these water springs and to evaluate their potentials.

The aims of this study are to investigate the water quality of seven springs located around Nasrettin Hoca town in Sivrihisar district, to evaluate the recharge and discharge mechanisms of Bağbaşı springs, to compare the chemical properties of the spring waters to the geology of the study area, to determine protection areas against possible contaminants. In order to achieve the objectives, in-situ physicochemical measurements were carried out on a monthly basis for a hydrologic

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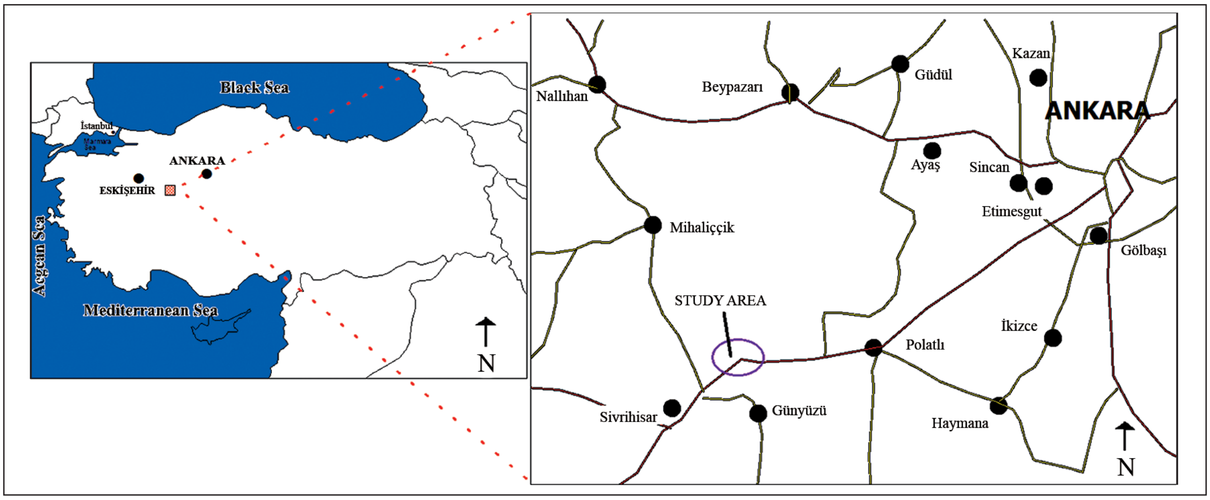

Figure 1- Location map of the study area (not to scale).

year for Bağbaşı spring group (BK-1, BK-2, and BK-3) having an average yield of 157 l/s during the study period. The measurements were carried out four times in a year for the rest of the springs.

2. Geological and Hydrogeological Background

There are four basic rock sequences exposed in the study area which are, from bottom to top, Paleozoic metamorphics, Eocene units, Miocene units and Quaternary deposits. Paleozoic metamorphics, also called Sivrihisar metamorphics, are the basement rocks in the area and made up of Göktepe, Kertek and Eryiğit units (Figure 2). Göktepe unit is made up of serpentinite, metabasite, amphibolite and thin marble bands with chert additions. Above the metaophiolitic basement, thin to medium layered, metachert bearing, dark colored marble and layered metabasites are present (Demiroğlu, 2008). Due to the extensive alteration of these units to clay minerals and also due to the limited and discontinuous presence of the marbles, these units were assumed to be impermeable. Kertek unit marbles, another unit making up the Paleozoic metamorphics, are medium to thick layered and have black-gray chert bands. These bands increase in amount towards Göktepe unit. It is possible to observe thin lamination in micaschists, whereas calc-schists and quartz-schists show moderate lamination. Aplite and quartize veins have been developed in the schists parallel to the folding and lamination (Demiroğlu, 2008). The diabase dykes observed in the western parts of the area cut the whole series. The schists and the aplite and quartzite veins inside Kertek unit are slighlty permeable to impermeable; the marbles lying above are permeable. However, the continuity of the water flow inside the marbles is prevented by the diabase dykes. Marbles are believed to contribute to the recharge of Nasrettin Hoca springs. Besides, one of the springs, namely Babadat spring, is fed by the marbles and is discharged from the alluvium contact. Lastly, Eryiğit unit, the upper sequence of Sivrihisar metamorphics, is comprised of fine grained, quartz bearing feldspathic schists, phyllites and thick layered, fractured marbles having a massive appearance from place to place. Schists and phyllites are impermeable, whereas the marbles are permeable. Eryiğit unit outcrops in a narrow area around southwestern part of the study area and has no importance regarding the water potential of the basin.

The Eocene units, namely Sivrihisar granodiorite, expose around south and west of Koçaş (Figure 2). The granodiorites have low primary porosity but have secondary porosity and permeability developed by weathering and discontinuity planes. Çelmen (2008) stated that Hamamkarahisar thermal springs, located around the area, are recharged through the discontinuity planes inside the granodiorites; however, in general these units can be considered as impermeable in the study area.

The Miocene units consist of Hisar, Çakmak and Mercan formations. Hisar formation contains coarse grained, matrix supported sandstones formed in a lakeshore environment. It is possible to observe decreasing grain size away from the basement rocks so this formation was interpreted as fan deposits. Hisar formation is located in the recharge area of Nasrettin Hoca springs. Although there is no observable spring discharge from these units, it is believed that they play an improtant role in the recharge of the Nasrettin Hoca springs and they are described as permeable.

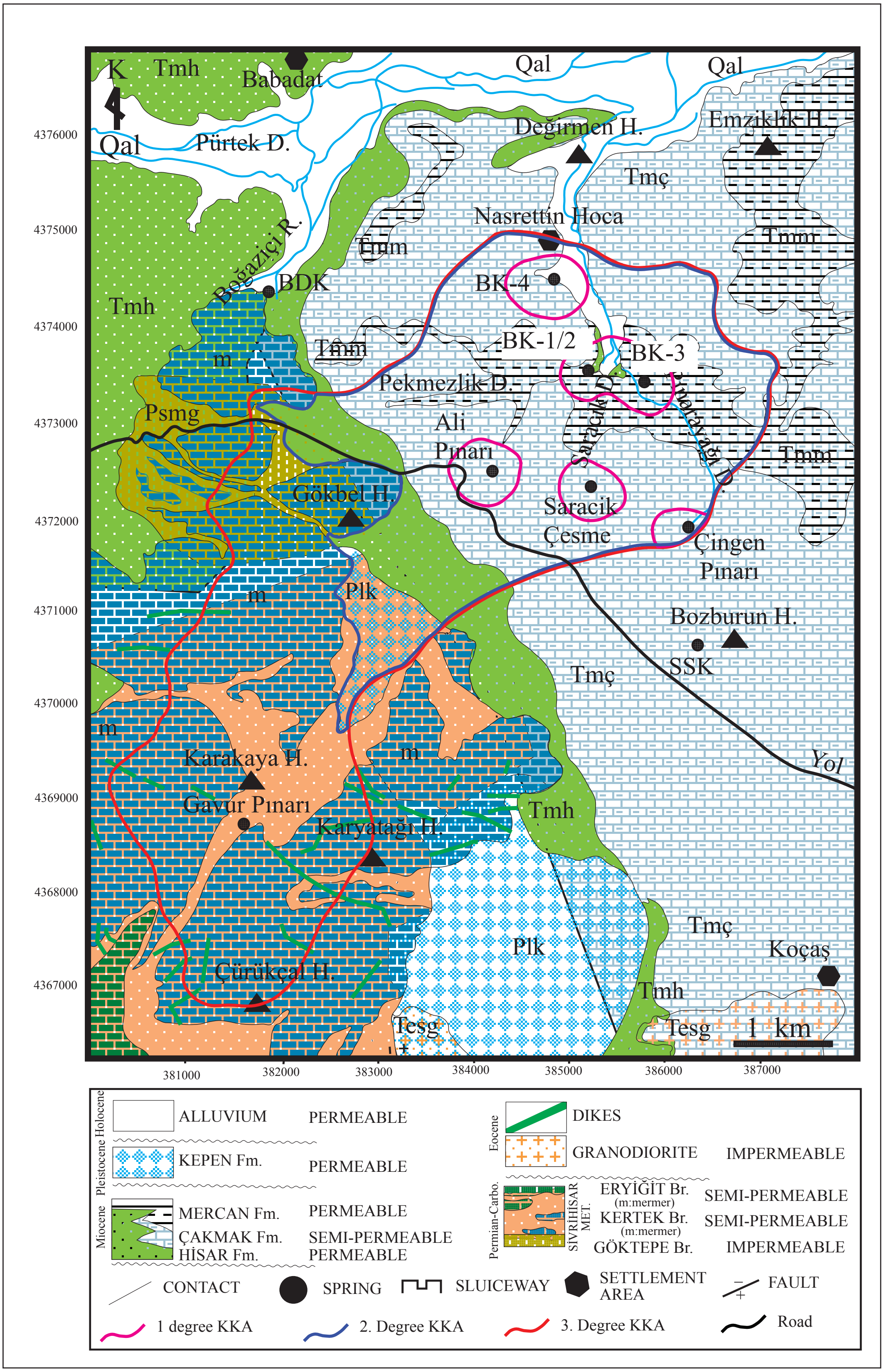

Figure 2- Hydrogeology map of the study area (Modified from Süral and Eser, 1998; Demiroğlu, 2008).

Çakmak formation, conformably lying upon the Hisar formation, can be described as sand, silt and clay alternation, medium-thick bedded limestone and white, green, brown marn, pebblestone with gypsum and peat addition. There are both permeable and impermeable units inside this formation and due to this attribute, some springs springs (Ali spring, Saracik fountain, Cingen and Hatip springs) were developed along the impermeable contacts. The discharges of these springs are less than 1 l/s throughout the year. Clayey and marly levels act as impermeable barriers during the formation of these springs. This formation, having low yield, is defined as semi-permeable. Mercan formation, having lateral and vertical transition with Çakmak formation, can be found above Hisar formation during the shallow lake environment conditions. Mercan formation consists of an alternation of thin-medium-thick bedded limestone, cherty limestone, marn and claystone.

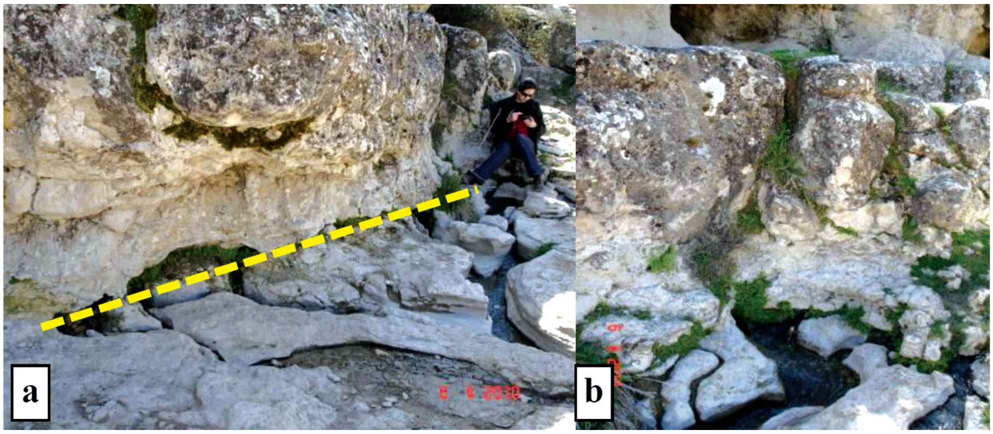

Figure 3- Appearance of the Bagbasi spring (BK-2) a) remote view b) up close view. The discharge of the spring is shown with a yellow line.

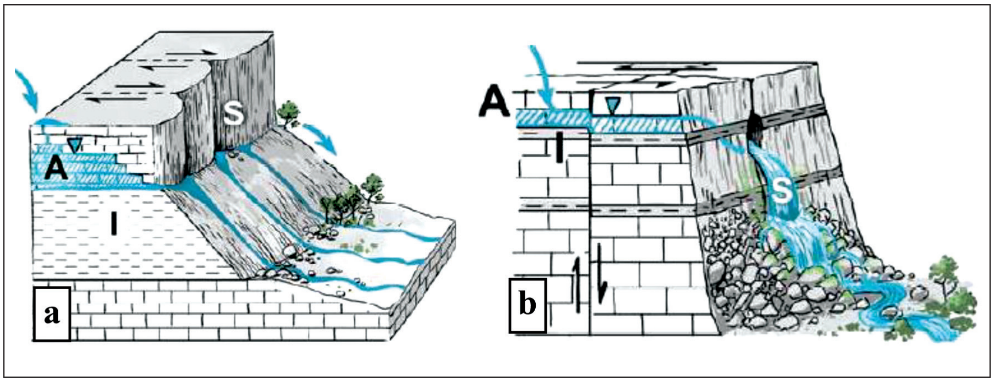

Figure 4- Hillslope (a) and gushed (b) spring occurences (A: Aquifer, I: Impermeable basement, S: Spring) (from Springer and Stevens, 2009)

Surficial karstification can be observed in a limited area where the limestones are fractured and where clay content decreases. Bagbasi springs recharge from Paleozoic units, where they are also stored and they discharge from Mercan formation along the strata planes (Figure 3). There are some vertical fracture developments in the limestones which play an important role in the spring discharges. Similar spring occurences are described by Springer and Stevens (2009) as hillslope and gushed (Figure 4a and b). Although this formation contains impermeable marns, it also discharges high yield springs therefore it can be described as permeable.

Pleistocene Kepen formation, located along the hillside of Karyatağı and Karakaya hills, is another unit inside the catchment area of Nasrettin Hoca springs (Figure 2). This formation has a loose texture and it contains angular pebbles. Although it is considered as permeable, no water flow can be observed. It is highly possible that this formation acts as an infiltration zone (i.e. vadose zone) during the recharge of the springs.

Quaternary alluviums in the study area are made up of pebble, sand, silt and clay sized particules. There is no visible water discharge point in the alluvium units located around Purtek and Dedebağ streams however, Babadat spring (BDK) discharge from the contacts between marbles and the alluvium. The yield of the spring was measured to be 38 l/s in May 2010. It should also be noted that there is usage of groundwater through wells around Purtek stream bed. Alluvium units in the region were interpreted as a high-yield aquifer besides constituting the productive agricultural fields in the study area (Demiroğlu, 2008; Demiroğlu and Örgün, 2010).

3. Sampling and Field Studies

Within the scope of this study, springs around Nasrettin Hoca town, Bağbaşı (BK-1, BK-2, BK-3), Hatip (BK-4), Babadat (BDK), Ali (AP), Gavur springs (GP), Saracık fountain (SCK), and Hamamkarahisar (HK) springs were sampled to trace the hydrochemical behaviour of Bağbaşı spring group during a water year. In situ pH, temperature and electrical conductivity measurements were carried out by using GIS-F460 and WTW-350i Multi-analysers. Samples for major cation and trace element analyses and anion analyses were collected separately in 500 ml HDPE plastic bottles, preserved at 4 °C prior to analyses. The samples to be used for major and trace element analyses were acidified to pH<2 by using ultra pure HNO_3. Concentrations of F-, NO_3^-, PO_4^{-3}, and HCO_3^- were measured by using a PALINTEST 200 spectrophotometer, major cation and trace element contents were determined with an Inductively-Coupled Plasma Optic Emission Spectroscopy (ICP-OES) at the laboratories of Ankara University Department of Geological Engineering.

Samples for stable isotope ($\delta^{18}O$ and δD) and tritium (^3H) analyses were collected in 1000 ml HDPE plastic bottles. Oxygen-18 and deuterium ratios were determined on a Micromass 602C mass spectrometer using standard methods at the laboratories of the Turkish State Hydraulic Works (DSİ). Tritium contents were determined by a liquid scintillation counting system (Packard Tri Carb 2260 XL) after electrolytic enrichment. Analytical uncertainities of the individual measurements are estimated to be within ±0.3 ‰ for $\delta^{18}O$ and ± 1‰ for δD. The analytical precision of the tritium measurements are about ±1 TU.

4. Results and Discussion

4.1. Hydrogeochemical Facies

Groundwater is recharged naturally by rain and snow melt and its chemistry is modified through various chemical reactions from recharge to discharge. For instance, some elements can be transferred between the water and solid mineral phases during dissolution/precipitation of carbonate, silicate, sulphide and/or evaporate minerals along flow paths. The most influential groups of minerals on water chemistry are the most soluble groups, carbonates and evaporates. Silicates, being a member of the most important and common rock-forming mineral group, can be considered as the least soluble mineral group, having little effect on water chemistry. Determination of the major and trace element contents of the water and interpretation of these results help in issues like identifying the water-rock interaction on the surface or under ground and the exact mechanisms of this interaction.

Results of the field chemical data, trace element results for water and rock samples and isotope analyses results of water samples are reported in tables 1, 2, 3 and 4 respectively. According to table 1, pH ranges from 7.30 to 8.34, reported to be lowest in BK-1 and highest in Gavur spring. Electrical Conductivity (EC) values vary between 338.6 µS/cm (BK-3) and 965 µS/cm (BK-4). Time-dependent changes in the spring EC values show a decreasing trend from April to December 2010 without showing excessive fluctuations (Figure 5). The high EC value, pertaining to BK-4, is attributed to the seepage of the sewage through a septic tank located 50-100 m away

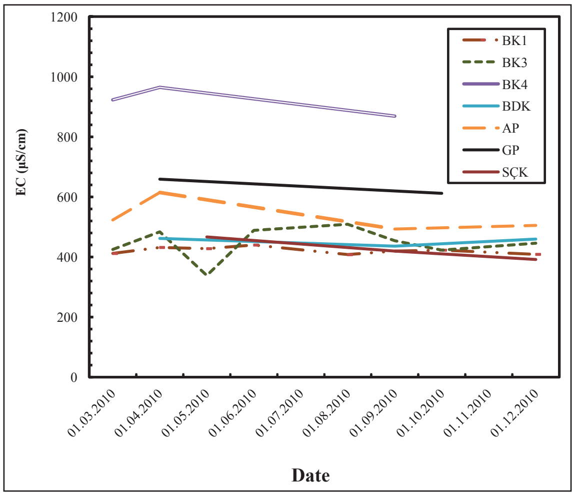

Figure 5- Time-dependent change of the spring EC values

from this spring. This finding is also supported by nitrate and phosphate test results.

The major ion analyses results of the springs were evaluated by using Schoeller and Piper diagrams. According to Schoeller diagram, the chemical characters of all the samples are more or less similar, the dominant ions are Ca-Mg and HCO_3 i.e. the samples are of Ca-Mg-HCO_3 type and the samples are predominantly recharged from carbonate rocks (marble, limestone) (Figure 6). The increase in sulfate ion concentration in sample BK-4 is predicted to be related to antropogenic contamination (Table 1).

When the trace element analyses results of both water and rock samples are evaluated together (Table 2 and table 3), it can be seen that the trace element contents of the water samples are influenced by the aquifer formations, namely marbles and limestones, together with the metamorphic rocks making up the impermeable basement. Strontium (Sr) and nickel (Ni) are the most prominent trace elements present in the water samples (Table 2). Sr is abundant in the carbonate rocks outcropping around Bagbasi spring area. Ni and Aluminum (Al) is observed in the water samples in low concentrations and when their distribution in the rocks is taken into consideration, it can be seen that this element is more abundant in metamorphic rocks instead of carbonates (Table 3). To sum up, the trace element contents of the springs show the influence of the carbonate rocks comprising the reservoir (Sr) and also the rocks comprising the impermeable basement (Ni, Al). It is also noteworthy that the samples with the highest EC values (BK-4 and SCK) are also enriched in trace elements relative to the rest of the samples.

Table 1- Field chemical data and major ion content of the spring samples for April (4), May (5), June (6), August (8), September (9), October (10), December (12). All of the samples were collected in 2010 (N: Not available).

Sample ID	T (°C)	pH	EC (µS/cm)	Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	SO_4^{-2}	HCO_3^-	NO_3^-	CBE (%)
BK-1/4	22.5	7.3	432	8.4	1.6	119.4	22.3	10.4	0.0	158.6	1.28	2,6
BK-3/4	17.3	7.56	484	15.0	2.8	120.3	24.3	6.9	13.8	159.9	0.65	1,0
BK-4/4	14.3	7.49	965	27.6	4.2	186.0	32.6	46.1	29.5	202.0	N	3,1
BK-1/5	23.8	7.61	428	64.2	1.3	91.4	18.6	3.7	0.0	193.3	N	0,9
BK-3/5	17.4	7.63	338.6	14.6	2.6	176.1	23.0	9.2	18.4	213.3	N	4,0
BK-1/6	25.6	8.25	440	6.2	1.1	253.9	15.8	5.1	0.0	241.6	N	8,8
BK-3/6	20.4	7.92	489	11.6	2.3	253.8	19.6	6.6	8.3	241.1	N	4,4
BK-1/8	23.2	7.61	408	6.4	1.2	203.0	16.4	6.5	0.0	195.2	N	7,6
BK-3/8	17.8	7.68	509	14.9	3.4	142.6	24.0	3.6	13.9	187.0	N	3,8
BK-1/9	22.5	7.71	420	5.9	1.1	258.7	16.8	5.3	1.0	246.4	N	3,1
BK-3/9	17.2	7.57	454	12.3	2.2	192.1	19.5	4.6	18.0	195.2	N	8,0
BK-4/9	16.5	7.59	869	23.4	3.8	192.8	33.0	67.0	44.6	170.2	N	1,4
BK-1/10	20.1	7.7	423	7.3	1.4	130.4	19.9	4.5	3.2	168.7	N	2,1
BK-3/10	14.7	7.73	471	13.2	2.4	172.6	21.6	18.7	4.1	211.7	2.96	5,7
BK-1/12	16.9	7.78	409	8.3	1.4	100.4	19.4	0.0	1.2	143.7	3.20	1,2
BK-3/12	16.8	7.55	446	14.7	2.5	122.9	21.3	12.2	1.0	167.9	3.60	3,0
BK-1/3	21	7.81	412	7.7	1.3	143.5	16.9	1.6	0.0	185.4	0.95	1,4
BK-3/3	16.2	8	425	13.3	2.3	122.1	19.2	1.0	11.8	162.6	3.36	5,8
BK-4/3	124	8.92	923	29.5	3.8	133.9	29.7	10.3	14.9	192.9	28.00	0,3
BDK/4	20.9	7.5	462	87.6	1.3	88.8	19.4	6.6	0.0	215.6	N	2,1
BDK/9	22	7.68	436	10.2	1.5	103.2	22.8	5.0	0.0	148.4	0.18	0,3
BDK/12	16	8.18	460	12.9	1.6	119.7	21.4	0.0	3.5	170.1	3.12	2,7
AP/4	13.4	7.78	615	18.0	1.0	125.1	27.4	13.3	0.0	179.3	7.50	2,0
AP/9	20.3	7.54	493	17.6	1.0	131.4	26.7	8.3	2.9	184.5	N	0,7
AP/12	14	7.64	505	17.1	0.9	115.3	22.8	0.0	5.3	168.4	N	2,3
AP/3	11	8.3	523	11.0	1.5	104.1	21.4	3.1	0.0	150.1	6.40	1,7
GP/4	12.5	7.63	659	29.3	2.2	154.3	22.0	7.0	46.7	179.6	0.55	0,5
GP/10	17.4	8.34	612	15.9	1.4	150.5	11.8	10.2	7.4	142.6	N	0,2
SCK/5	14.4	7.51	467	18.9	4.2	112.4	22.5	3.6	0.0	173.9	N	0,4
SCK/9	15.1	7.87	420	16.6	3.6	103.4	20.0	5.5	7.4	144.5	1.32	3,7
SCK/12	13.8	7.8	392	16.4	3.4	97.4	17.2	5.5	3.7	138.9	6.00	4,1

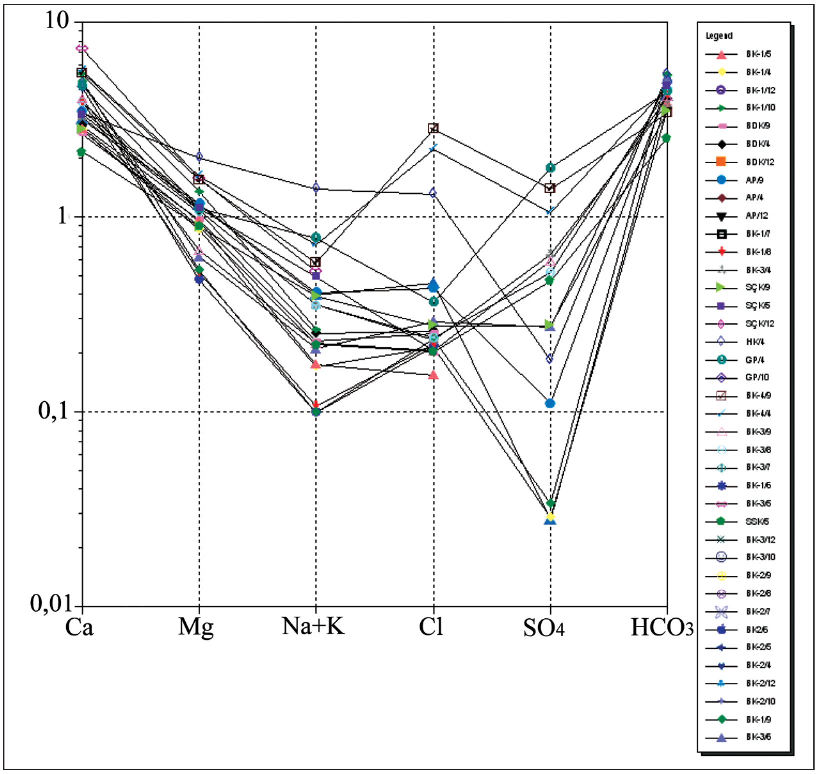

Figure 6- Schloeller diagram of the springs

Table 2- Trace element contents of the springs in ppb. N: Under detection limit. Except for SÇK all the analyses were carried out in samples collected in April. Sample SÇK was collected in May.

Sample ID	Al	Li	Ni	Sr
BK-1	N	N	0.067	0.409
BK-3	0.009	N	0.117	0.578
BK-4	N	0.045	0.13	1.282
BDK	0.005	N	0.083	0.337
AP	N	0.03	0.125	1.027
GP	N	N	0.118	0.489
HK	N	0.04	0.185	0.634
SÇK	0.016	0.028	0.155	0.832

4.2. İsotopic Properties of the Springs

In hydrogeology, isotope data are used to facilitate the analyses of hydrologic and hydrogeologic problems and also to support the conventional methods. Environmental isotopes contribute to the investigations related to the origin, flow and evolution of groundwater, its renewability and the subsurface processes affecting its quality, and to the studies related to groundwater and surface-water interactions (Clark and Fritz, 1997). The isotopes of oxygen and hydrogen are used extensively in hydrogeologic investigations as markers of water source and as ideal tracers since they are present in water in its natural state since their behaviour in the hydrologic system is known thoroughly.

4.2.1. Relationship of Oxygen-18 ($d^{18}O$) and Deuterium (dD)

The δD and $\delta^{18}O$ values in precipitation and fresh waters generally plot close to a straight line that is the Global Meteoric Water Line (GMWL). This line, determined by Craig (1961) and presented in Equation $\delta D = 8\ \delta^{18}O + 10$ (‰ SMOW), defines the relationship between $\delta^{18}O$ and δD in worldwide fresh waters.

Local Meteoric Water Lines (LMWL) may also exist, having slightly different slopes and intercepts than the GMWL, as a result of differences in altitude, local climate and distance from the moisture source (Rozanski et al., 1993). If groundwater $\delta^{18}O$ and δD values plot near the present precipitation water line for the sampling area, the waters are likely meteoric in origin, that is to say, derived from precipitation without subsequent modification. If they do not plot along this line, they have been impacted by some physical or chemical process prior to recharge, or during the groundwater's journey through the aquifer

Table 3- Whole rock analyses results for the rock samples. BK2 and BK4: Mercan formation, GP1, GP2,GP3,GP4, GP5: Sivrihisar metamorphics- Kertek unit, KC1, KC2, KC3, KC5, KC6: Sivrihisar metamorfics- Göktepe unit.

Sample ID	BK2	BK4	GP1	GP2	GP3	GP4	GP5	KC1	KC2	KC3	KC5	KC6
Element												
Na_2O	0.08	0.08	1.66	0.07	0.48	0.07	0.09	0.07	0.24	0.07	0.08	0.16
MgO	0.14	6.93	8.69	3.32	4.53	0.47	4.28	3.94	4.46	4.06	7.25	0.35
Al_2O_3	1.17	3.89	14.27	19.77	17.82	1.05	0.48	12.37	12.81	11.65	1.59	0.75
SiO_2	4.29	18.19	46.09	51.35	51.10	86.80	1.36	44.18	47.82	44.87	8.55	6.97
P_2O_5	0.01	0.08	0.07	0.15	0.12	0.03	0.00	0.08	0.07	0.06	0.04	0.01
SO_3	0.18	0.34	0.09	0.11	0.12	0.13	0.04	0.14	0.56	0.15	0.39	0.69
Cl	0.03	0.02	0.00	0.01	0.00	0.00	0.02	0.02	0.23	0.06	0.03	0.05
K_2O	0.23	0.85	0.16	4.51	4.19	0.64	0.01	2.93	3.03	2.93	0.41	0.02
CaO	54.73	28.97	7.74	0.58	1.48	0.19	53.48	7.58	6.40	6.43	33.83	43.60
TiO_2	0.07	0.18	0.56	0.45	0.28	0.07	0.02	0.66	0.72	0.67	0.10	0.03
V_2O_5	0.00	0.01	0.04	0.03	0.01	0.05	0.00	0.02	0.03	0.03	0.01	0.00
Cr_2O_3	0.01	0.01	0.04	0.05	0.04	0.00	0.00	0.05	0.06	0.04	0.01	0.00
MnO	0.01	0.06	0.15	0.14	0.07	0.00	0.01	0.04	0.03	0.04	0.05	0.00
Fe_2O_3	0.58	1.72	9.00	6.98	4.93	0.82	0.10	6.52	5.66	6.34	1.17	0.02
LOI	38.44	38.90	11.74	12.63	14.97	9.68	39.84	21.86	17.86	22.89	46.97	47.49
Ni	10.70	47.10	107.00	34.60	15.50	7.40	3.40	206.60	175.70	174.70	44.00	1.00
Sr	167.37	400.00	193.10	47.50	154.50	3.60	252.60	147.30	144.60	143.10	429.90	73.00

(Clark and Fritz, 1997). For local investigations, like this study, it is important to compare surface water and groundwater data with local meteoric water line. International Atomic Energy Agency (IAEA) and World Meteorological Organization (WMO) have a station in Ankara where the content of hydrogen and oxygen isotopes in precipitation has been surveyed. Ankara LMWL defined by Equation $\delta D = 8\ \delta^{18}O + 10.63$ (‰ SMOW) was obtained by using the data from the database called Global Network of Isotopes in Precipitation (GNIP) (IAEA/WMO, 2004; Sayin and Özcan Eyüpoğlu, 2005). Since IAEA Ankara station is close to the study area, Ankara LMWL was used in this study.

At a given location, the seasonal variations in $\delta^{18}O$ and $\delta^{2}H$ values of precipitation and the weighted average annual $\delta^{18}O$ and $\delta^{2}H$ values of precipitation remain fairly constant from year to year because the climatic conditions such as temperatures and the vapor source are almost constant (Clark and Fritz, 1997). Generally, rain in the summer is isotopically heavier (more positive values) than rain in the winter due to the seasonal temperature differences. Springs recharged by direct precipitation are expected to reflect these seasonal variations mostly. The isotope analyses results presented in table 4 are evaluated in light of this information. According to table 4, the $\delta^{18}O$ values range between -8.31‰ and -10.87‰ and the δD values range between -63.55‰ and -76.06‰. Tritium (^{3}H) contents of the springs lie between 1.3-4.25 TU, lowest value belonging to AP, whereas the highest ones belonging to GP and BK-4.

Accordingly, if the results taken from the same location in different seasons are considered, it is possible to observe seasonal variations in some of the samples. For instance, when $\delta^{18}O$ results for May 2010 and September 2010 are compared for sample BK-1, it can be seen that there is almost a 1 ‰ enrichment in this isotope. The samples collected in May 2010 and September 2010 can be considered to represent winter ($\delta^{18}O$= -10.66 ‰) and summer precipitations ($\delta^{18}O$ = -9.75 ‰), respectively. Thus, the summer precipitation recharging this spring is isotopically heavier than that of winter precipitation, just like expected. Likewise, a seasonal enrichment in the heavier isotope contents in other samples (enrichments for BK-4 and GP are 0.5 ‰ and 0.4 ‰, respectively) can be observed.

In order to understand the relationship between oxygen-18 (^{18}O) and deuterium (D), the results were plotted and presented in Figure 7 together with GMWL and Ankara LMWL. According to this figure, some of the samples plotted along the GMWL, whereas some of them showed deviation. Generally, it is known that deviations from meteoric water line are caused by different processes like evaporation, condensation, water- rock interactions, mixing of waters having different origins and seasonal effects (Clark and

Table 4- Oxygen-18 ($\delta^{18}O$) and deuterium (δD) signature and Tritium (^3H) content of the spring samples within the study area (Numbers after slash are calendar months. 4: April, 5: May, 6: June, 8: August, 9: September, 10: October). All of the samples were collected in 2010.

Sample ID	$\delta^{18}O$	δD	T(TU)
BK-1/4	-10.4	-73.4	2.85
BK-3/4	-9.85	-71	2.75
BK-4/4	-9.69	-68.6	4.20
BK-1/5	-10.7	-72.4	1.90
BK-3/5	-9.98	-70.5	2.20
BK-1/6	-9.24	-71.5	1.95
BK-3/6	-9.99	-70.9	1.80
BK-1/8	-10.2	-73.3	3.65
BK-3/8	-9.7	-72.2	2.75
BK-1/9	-9.75	-73.1	3.45
BK-3/9	-9.58	-71.3	3,00
BK-4/9	-9.05	-67.7	3.35
AP/4	-9.43	-68.3	1.30
AP/9	-9.29	-68.2	1.45
GP/4	-10.9	-76.1	4.25
GP/10	-10.5	-75.7	2.95
SCK/9	-8.31	-63.6	3.75

Fritz, 1997). The deviations from the GMWL in the samples from the study area are due to the evaporative enrichment of these samples and according to Figure 7, there is an evaporation line formed.

4.2.2. Relationship of Elevation and Oxygen-18 ($\delta^{18}O$)

Oxygen-18 content of precipitation changes with changing altitude, temperature, latitude etc. At higher altitudes where the average temperatures are lower, precipitation will be isotopically depleted. For $\delta^{18}O$, this depletion is about 0.15‰ and 0.5‰ per 100-m rise in altitude. This altitude effect can be used in distinguishing groundwaters recharged from different altitudes (Clark and Fritz, 1997). Normally, springs showing seasonal variations in discharges (i.e. dry in summer and increasing discharges in winter) and having different discharge elevations can be used to reveal out the relationship of $\delta^{18}O$ with altitude. Unfortunately, for the study area, there is no data available regarding precipitation from different altitudes. The relationship of elevation and $\delta^{18}O$ was revealed out in a study carried out in Beypazarı trona area located about 80 km north-east of the Nasrettin Hoca springs (Apaydin, 2004) on the same latitude with the study area. According to Apaydin (2004), the depletion in $\delta^{18}O$ per- 100-m rise in altitude is 0.44‰ and for May 2000, the equation relating altitude to $\delta^{18}O$ is defined as $\delta^{18}O$ = -0.0044* (elevation) – 4.811. Considering the proximity of Beypazarı trona area to the study area and two sites being under the influence of similar climatic conditions, the Equation given by Apaydin (2004) was adapted to this study and the calculated recharge elevations came out be ranging between 1000 m and 1380 m (Table 5). As suggested by today's topography, the highest topographic elevation is 1690 m and observed around Çürükçal hill (Figure 2). Therefore, all the sampled springs are recharged from an area between Çürükçal and Gökbel hills.

Table 5- The discharge elevations recorded in the field and the recharge elevations calculated by Apaydın 2004.

Sample ID	Discharge Elevation (m)	Recharge Elevation (m)
BK-1	929	1329
BK-2	930	1007
BK-3	936	1175
BK-4	930	1109
BDK	914	1202
AP	987	1202
GP	1180	1377
SCK	986	1202
HK	918	1241

4.3. Evaluation of Tritium Data

The tritium contents of the sampled springs are correlated with Electrical Conductivities (EC) (Figure 8). Accordingly, the springs with high EC values also contain high tritium (GP and BK-4). This finding can be verified by the facts that GP is located upstream of the basin and BK-4 is contaminated by the sewage wastes. Although BK-1, BK-3 and BDK springs have similar characteristics, sample AP has lower tritium content (Figure 8).

4.4. Conceptual Hydrogeological Model of Nasrettin Hoca Springs

Bağbaşı springs, located in the northeastern edge of the 26 km² basin area, discharges from Miocene Mercan formation along 10 different points. Gavur Spring is located close to the peak of recharge area,

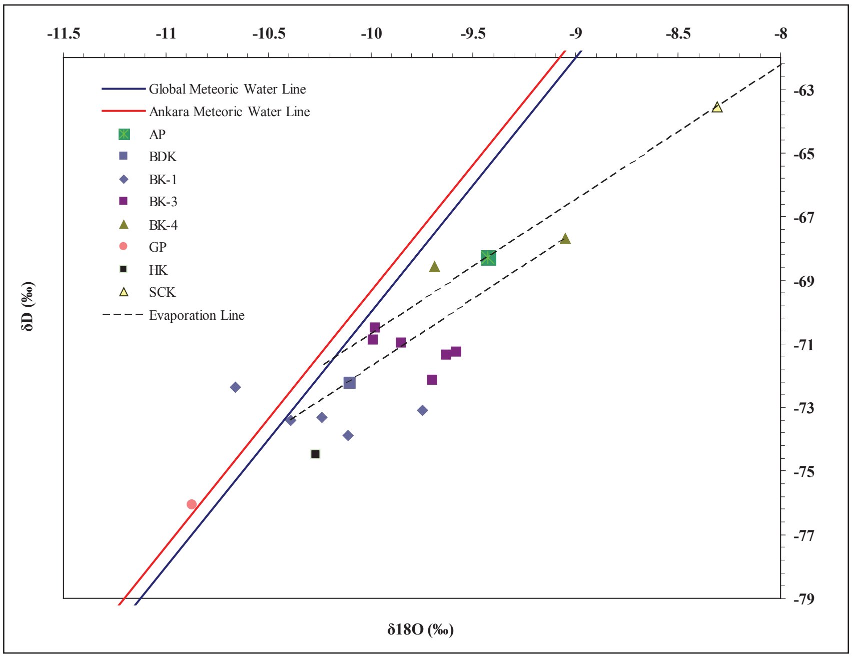

Figure 7- $\delta^{18}O$- $\delta^{2}H$ graph of the springs

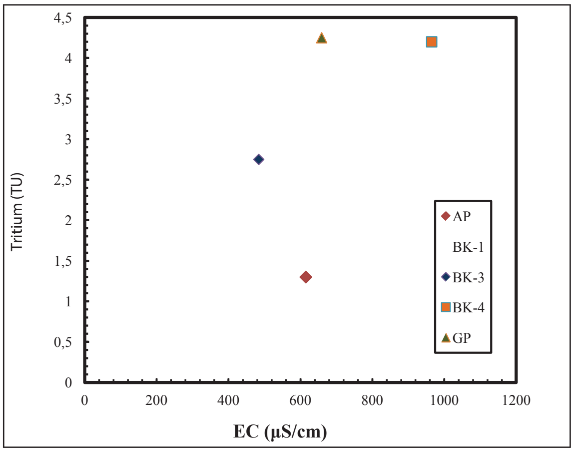

Figure 8- Tritium vs EC graph of the sampling points

whereas Ali-Hatip and Saracık springs are located close to Bağbaşı springs, when both altitude and distance is considered (Figure 2). The average yearly discharge of Bağbaşı springs is 125 l/s, whereas the discharges of other springs located in the basin area are less than 1 l/s.

The basement rocks outcrop in high altitude areas between Çürükçal and Gökbel-Karanlık hills located in southwestern part of the basin. Fractured marbles, lying over Sivrihisar metamorphics, provides the percolation of rain towards the saturated zone thereby providing recharge to the aquifer system. These units are also responsible from the Ca-Mg-HCO^3 character of the waters. Impermeable Göktepe and Kertek units are located beneath the marbles. Diabase dykes slow and partially prevent the water flow in marbles. Miocene units, located in northeastern half of the basin unconformably overlies the basement units and transmit the water from marbles to the springs. The groundwater flow in Miocene units usually reaches to discharge points through pebblestones-sandstones and clayey limestones. These waters gain their hydrochemical identity along the flow paths by dissolving the minerals in permeable and impermeable units during percolation, storage and flow. The isotopic features of the springs show that the springs are recharged along the foots of the Çürükçal and Gökbel hill areas between elevations 1000-1300 m (Figure 2). Miocene siltstone-marl units located nearly horizontal and they won't recharge the springs with their impermeable character. The groundwater flow in saturated zone takes place in a heterogenous environment involving different lithologies, therefore this heterogeneous structure should be taken into consideration when protecting the springs.

4.5. The Protection Areas of Nasrettin Hoca Springs

According to the hydrochemical analyses results gathered during the investigation period, nitrate levels in the springs range between 0.18 mg/l and 28 mg/l and, sample BK-4 can be considered as the most contaminated whereas BDK and GP, are the least contaminated among other samples. The nitrate concentrations in the springs located along the northern part of the study area, except BK-4, are between 0.65 mg/l and 3.6 mg/l. Although these values does not exceed the maximum allowable concentrations set by Turkish Standards (TS-266, 2005) it can still be assumed that agricultural activities have already been affecting these springs. On the other hand, the southern part of the basin is geologically suitable for the construction of stone and sand quarries and these springs can directly be affected by such activities as well.

Three different protection areas were constituted in this study to conserve the water quality of these springs, being prone to contamination (Figure 2). First (Absolute) protection area was established in vicinity of the springs within a circular area having a diameter of 300 m. Second (Short range) protection area was established by considering the lithologies and other factors capable of transporting the contaminants. Third protection area was determined as the basin area (2). When designating the boundaries of these areas, Water Contamination and Control Regulations, Legislation to protect water resources and Basin Protection Regulations were taken into account (TS-266, 2005).

5. Conclusion

In the study, the springs around Nasrettin Hoca town were investigated and it has been found out that the groundwater reservoir units are the marbles, pebblestones-sandstones and clayey limestones; the impermeable basement is made up of schists, metaophiolites, marns and claystones. When the hydrogeochemical features are considered, the sampled springs are of Ca-Mg-HCO^3 type, are under the influence of marble-limestone (i.e. carbonate rocks) and the basement rocks (Göktepe and Kertek units) as suggested by the trace element contents.

The recharge elevations of Nasrettin Hoca springs, according to $\delta^{18}O$ content, came out to be between 1000 m and 1380 m These elevations correspond to the areas located towards the south of the basin, where the marbles and Pliocene-Miocene aged pebbles and sandstones outcrop.

The contaminants in Nasrettin Hoca springs are generally lithology-related. However, there is one particular sample, BK-4, which is contaminated by the fosseptic wastes with regard to nitrate and phosphate and has high EC values. The Protection Areas of the springs are evaluated herein and determined as three different zones by considering the hydrogeology and the topographical features of the study area and Turkish standards.

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