Hydrochemical evaluation of a heavy contaminated shallow aquifer diluted by Delice River waters, Central Anatolia, Turkey

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Abstract

The aim of this study is to hydrochemically evaluate the dilution with infiltrating waters from the Delice River into a shallow alluvium aquifer which is heavily contaminated. Whereas the hydrochemical content of the Delice River water has a conductivity of 1,610 μS/cm and total dissolved solids of 938 mg/l, the hydrochemical content of the shallow aquifer groundwater displays spatial variations in conductivity (between 2,340 and 9,360 μS/cm) and total dissolved solids (between 1,669 and 5,957 mg/l).

The hydrochemical parameters (Na^+, SO_4^{2-}, Cl^-, boron, HCO_3^-), which characterise the different components of the groundwater, allowed the determination of the origin of groundwater contamination. The shallow alluvium aquifer groundwater contamination has been partly diluted by the Delice River waters.

The origin of the contamination is Çevirme Formation lithologic units, lying southwest of the study area, underlying the aquifer and consisting of claystone and gypsiferous marls.
Keywords: Delice River, shallow aquifer, surface water/groundwater relation, hydrochemistry, lithologic contamination, dilution.

1 Introduction

The study area, 190 km east of Ankara (Turkey), is located in the Kızılırmak basin (fig. 1). Surface water of the area is represented by the Delice River and Cender creek. The Delice River extends along the shallow alluvium aquifer and has a hydraulic connection with the aquifer.

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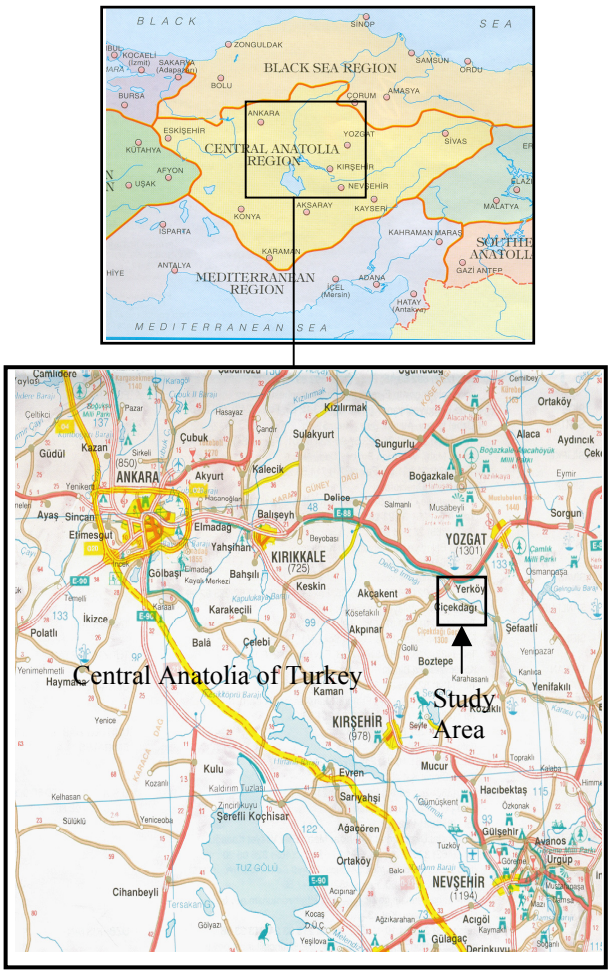

Figure 1: Location maps of the study area.

The aim of this study is to hydrochemically evaluate the dilution with infiltrating waters from the Delice River into the shallow alluvium aquifer which is heavily contaminated. In this regard, a total of 3 thermal and mineral, 3 surfaces and 13 groundwater samples were collected in table 1. Temperature (T), pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured in the field. Salinity problems have been also studied and suggested the best water structure in the other parts of the Kızılırmak basin (Çelik and Yıldırım [1]).

Table 1: Hydrochemical analyses results of the waters (sampling date: 14 November 1998) (Çelik [4]).

Sample No	pH	T (°C)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	TDS (mg/l)	EC (µS/cm)	Boron (mg/l)
Cender creek												
C1	-	-	200	74.4	635	19.7	450	1,220	256	2,551	4,230	1.76
Delice River												
D1	8.0	-	93.6	29.7	144	6.8	154	179	349	876	1,378	0.30
D2	8.3	-	100	41.3	220	11.2	177	262	345	938	1,610	0.40
Alluvium aquifer												
AB13	8.2	14	118	73.9	195	6.5	93	508	432	1,323	2,340	0.30
YK6	6.5	15.9	177	72.9	635	18.1	510	933	481	1,742	4,770	1.51
IHL	8.7	15.4	94.4	48.1	465	20.0	326	603	400	1,994	3,500	0.97
SE9	7.5	16	128	84.6	294	10.0	246	563	479	1,669	2,760	0.50
DO4	7.6	15.9	124	62.7	393	11.3	336	544	471	1,975	3,420	0.49
HIP12	7.4	15.3	182	33.5	295	8.0	180	565	493	1,993	3,170	0.78
BG3	7.0	13.7	151	35.5	510	21.6	415	775	424	2,469	3,940	1.40
KC11	7.4	15.7	368	112	475	8.9	331	1,784	257	3,360	5,760	0.95
MK7	6.6	15.5	144	63.2	715	17.0	672	1,070	329	3,062	5,220	1.50
OA5	6.5	15.7	334	140	980	26.0	562	2,323	395	4,000	6,600	1.82
MK17	6.8	14.5	506	165	1,080	25.0	615	3,019	248	4,751	8,250	3.13
HK	6.9	16.4	384	86.5	1,310	6.5	580	2,880	657	5,345	8,060	2.85
HK10	6.6	12.4	388	151	1,500	8.7	947	3,237	465	5,957	9,360	2.22
Thermal waters												
B1	6.6	43.7	154	1.5	1,500	115	2,080	363	750	5,324	8,820	3.46
U1	7.8	43	709	31	2,560	70	4,876	377	59	9,286	15,000	4.94
KO1	6.7	36	1,260	12	4,320	120	7,749	305	73	13,762	19,600	7.44

2 Hydrogeology and hydrology

Gündüz [2] explained that the oldest rock in the study area is composed of rhyolite, rhyodasite, and dacite. These units, called the Kötüdağ volcanite member, are fractured and fissured. Canik [3] states that the contact between the

volcanite member and granites is suitable for deep groundwater circulation by means of permeability. The Çevirme Formation, consisting of conglomerate, limestone, claystone, and gypsiferous marls, unconformable overlies the Kötüdağ volcanite member. This formation is overlain by the Deliceırmak Formation, which is composed of conglomerate, sandstone and siltstone (fig. 2). The alluvium is composed of gravel, sand and clay sized materials. According to Çelik [4], while the Delice River recharges into the alluvium aquifer about at the centre of the river (near D2), the Delice River is recharged by alluvium aquifer at the lower part of the river (fig. 3).

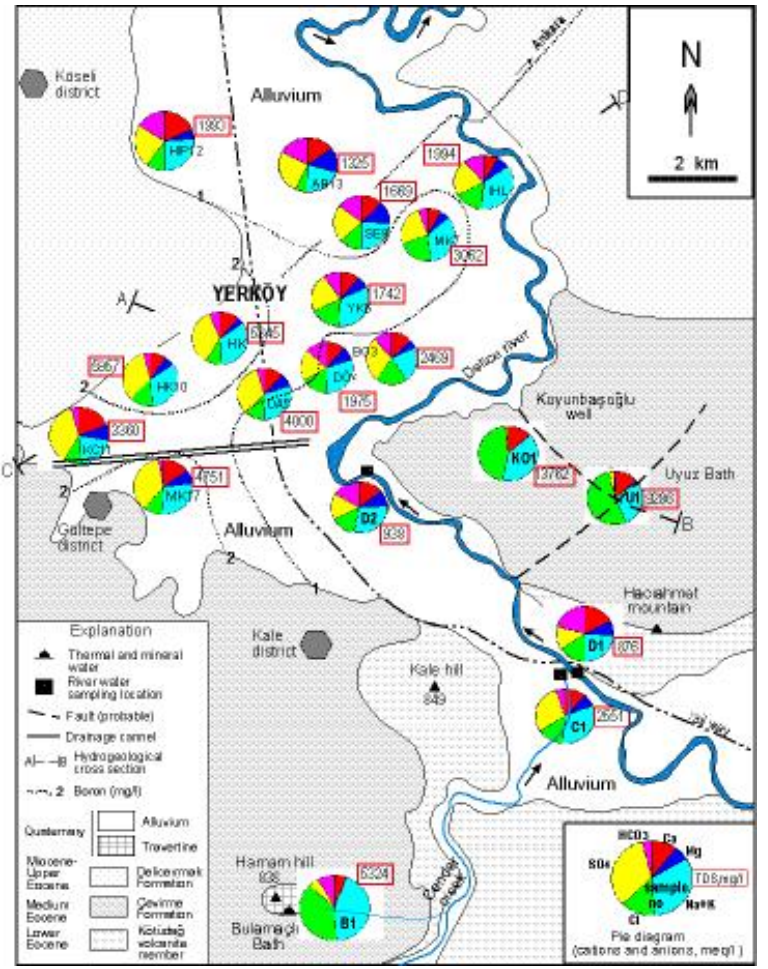

Figure 2: Hydrogeological map of the study area.

There are three types of waters in the study area. Those are surface waters, shallow alluvium aquifer waters and, thermal and mineral waters. The Delice

River and the Cender Creek comprise the surface water network of the study area. The Cender Creek joins the Delice River in the southeast of the area. The Delice River flows through the eastern part of the alluvium aquifer (fig. 2). Discharge of the Cender Creek is estimated as 10-30 l/s. On the basis of measurements conducted at D1 site of the Delice River, discharge was found to be 4.94 and 9.47 m^3/s for November 1998 and May 1999, respectively by Çelik [4]. Wells drilled in the alluvium aquifer are generally shallow (10-15 m). Bulamaçlı bath (B1), Uyuz bath (U1) and Koyunbaşoğlu bath (KO1) are of thermal and mineral waters. According to Canik [3], Bulamaçlı bath spring issues through the fault. Discharge of the spring is 1.45 l/s and its temperature is 44.5°C. According to Gündüz [2], the well for the Uyuz bath is located on two buried faults (fig. 2). The water temperature of Koyunbaşoğlu well was measured as 36°C in November 1998 and 36.9°C in May 1999 (Çelik [4]).

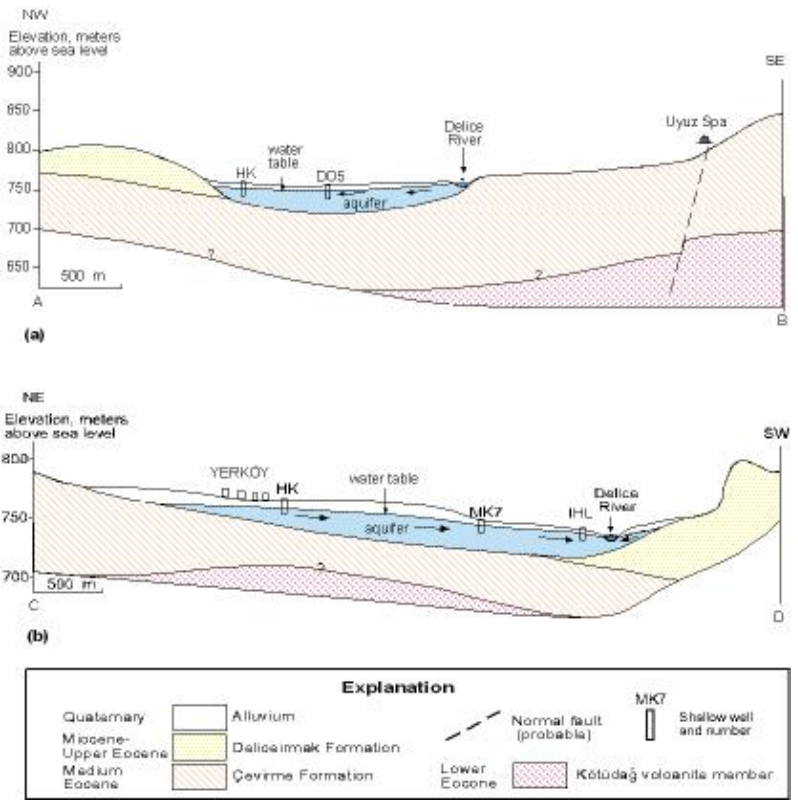

Figure 3: Hydrogeological cross-sections of the study area (modified from Çelik [4]).

3 Hydrochemical evaluations

On the basis of results of the water analyses, Schoeller diagram is drawn (fig. 4). Thermal and mineral waters have Na^+ and Cl^- hydrochemical facies ($Na+K>Ca>Mg$; $Cl>SO_4>HCO_3$). The Delice River waters have dominant Na^+ cation, but have not any dominant anion (fig. 4). The anions are about same level in the river waters. Shallow alluvium aquifer waters have about same hydrochemical facies (Na^+ and SO_4^{2-}). According to Schoeller diagram, thermal and mineral waters are a different water type from the Delice River and the alluvium aquifer waters.

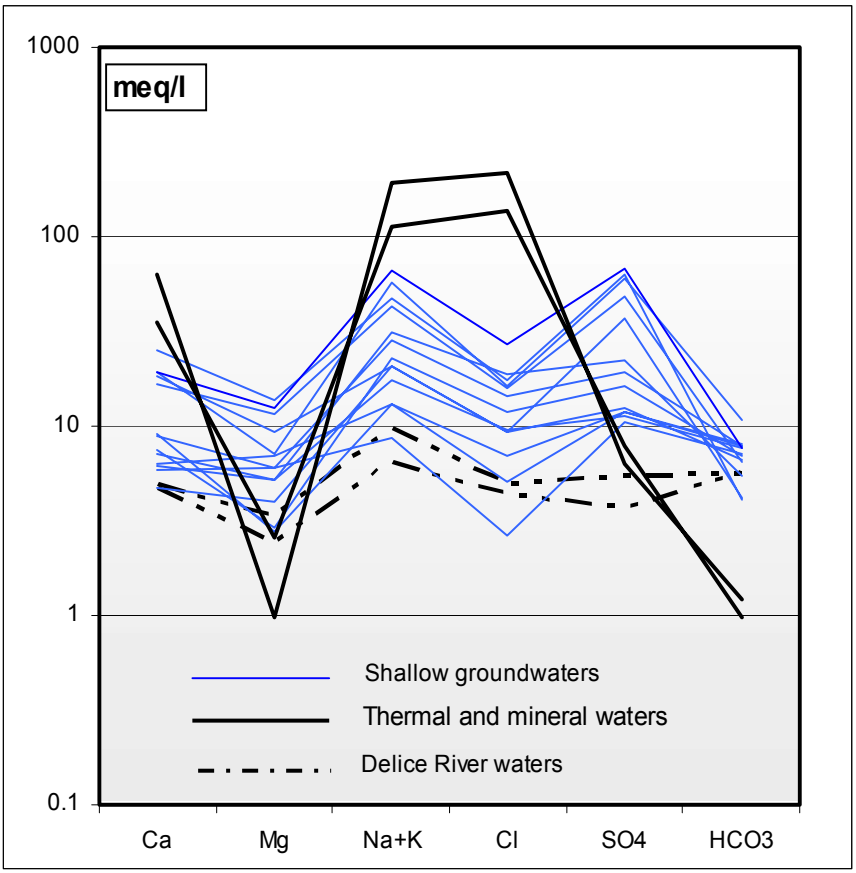

Figure 4: Schoeller diagram of the waters in the study area.

Also, pairs of measured parameters are plotted in x-y diagrams (composition diagrams). The data plot is on straight lines, revealing a positive correlation of Ca, Mg, Na, Cl and SO_4 with TDS (fig. 5). Especially, strong correlations exist between Na-TDS (R^2: 0.88; R: 0.93), SO_4-TDS (R^2: 0.94; R: 0.97). Whereas, ion

concentrations of Na and SO_4 are the lowest in the Delice River (D2), the ion concentrations are the highest in the alluvium aquifer well (Well no. HK10) (fig. 6). Therefore the Delice River (D2) and the alluvium aquifer samples (Well no. HK10) may be end members. Mixing rate calculations was made between the Delice River waters and the alluvium aquifer waters (fig. 7). Equation (1) can be written as follows (Mazor [5]).

$$C_s = C_{\text{end member1}} X + C_{\text{end member2}} (1\text{-}X) \quad (1)$$

C_s : ion concentrations of samples (meq/l)
$C_{\text{end member1}}$: ion concentration of the first end member (meq/l)
$C_{\text{end member2}}$: ion concentration of the second end member (meq/l)
X : mixing rate (%).

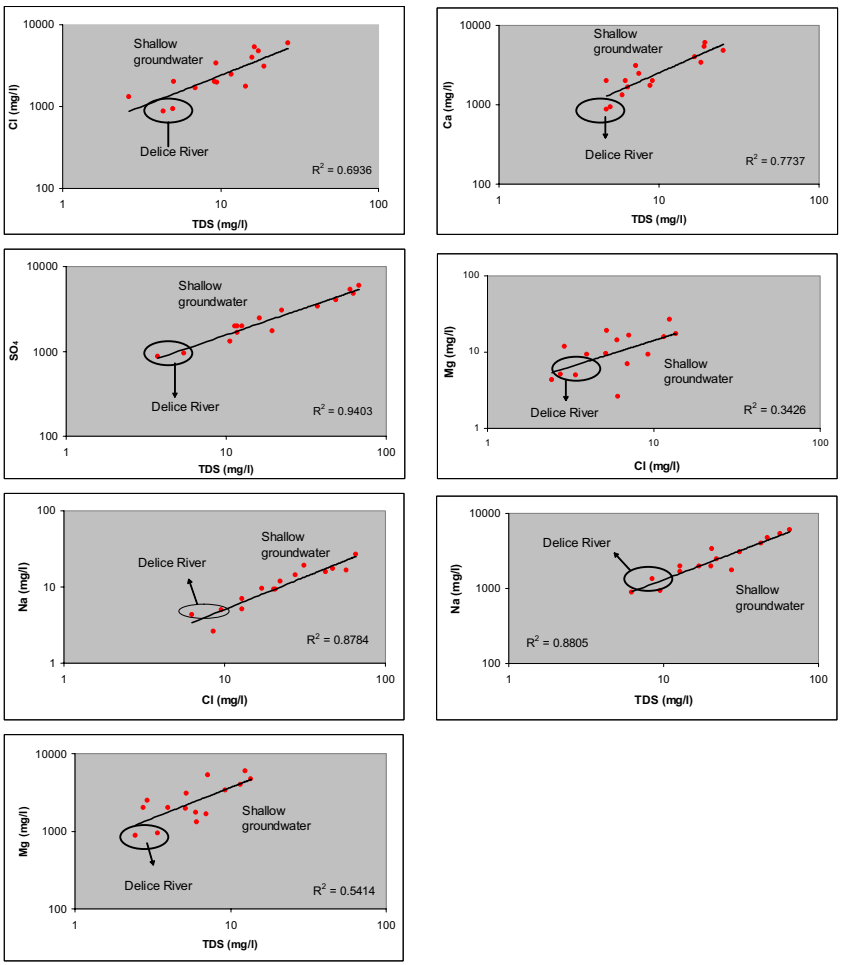

Figure 5: Compositional diagrams of the shallow alluvium aquifer groundwaters and the Delice River samples (Total dissolved solids and the ions are of mg/l).

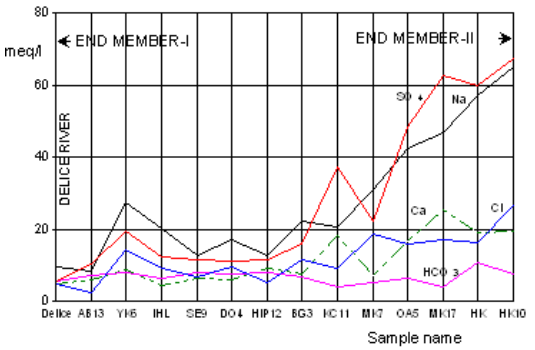

Figure 6: Variation of the ions (anion and cation) between end member-I and end member-II.

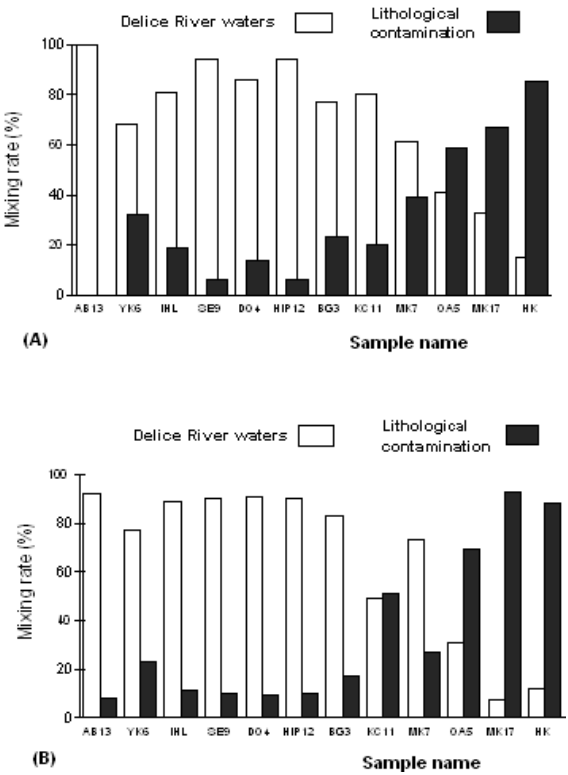

Figure 7: Sodium (A) and sulphate (B) mixing rates into the shallow alluvium aquifer well waters from the Delice River waters.

Since the major ions of Na and SO_4 have been typically increased through the alluvium aquifer, mixing rate calculations are conducted for these ions. According to the mixing calculations, a lot of well waters (AB13, YK6, IHL, SE9, DO4, HIP12 and BG3) have been fairly diluted by the Delice River waters. A few wells have been contaminated by lithology. These are of MK7, KC11, OA5, MK17 and HK wells (fig. 7). According to Mazor (1991) [5], clay and shale rocks often contain salt and gypsum. The rocks have high salinity (900-2,000 mg/l), Cl^- dominant anion, followed by SO_4 and Na major cation. Gypsum has high salinity (2,000-4,000 mg/l), dominant anion is SO_4, dominant cation is Ca, followed by Mg and Na. Salinity (TDS) is between 1,669 and 5,957 mg/l in the study area. As the major ions have been diluted by the Delice River waters, also boron contamination of the alluvium aquifer has been decreased by the same way. A solute in water will move from an area of greater concentration towards an area where it is less concentrated. This process is known as molecular diffusion. The diffusion will occur as long as a concentration gradient exists, even if the fluid is not moving, which can be expressed as Fick's first law (Fetter [6]). The origin of the high salinity and the boron contamination of the alluvium aquifer are Çevirme Formation units which are mainly claystone and gypsiferous marls. The contaminated shallow alluvium aquifer area is about 130 km^2 in the Yerköy plain.

4 Conclusions

Whereas the hydrochemical content of the Delice River water has a conductivity of 1,610 μS/cm and total dissolved solids of 938 mg/l, the hydrochemical content of the shallow aquifer groundwater displays spatial variations in conductivity (between 2,340 and 9,360 μS/cm) and total dissolved solids (between 1,669 and 5,957 mg/l).

The hydrochemical parameters (Na^+, SO_4^{2-}, Cl^-, boron, HCO_3^-), which characterise the different components of the groundwater, allowed the determination of the origin of groundwater contamination. The shallow alluvium aquifer groundwater contamination has been diluted by the Delice River waters. According to mixing calculations, a lot of wells (AB13, YK6, IHL, SE9, DO4, HIP12 and BG3) have been fairly diluted by the Delice River waters. A few wells have been contaminated by lithology. These are of MK7, KC11, OA5, MK17 and HK wells.

The origin of the contamination is Çevirme Formation lithologic units, lying southwest of the study area, underlying the aquifer and consists of claystone and gypsiferous marls.

In order to remediate the waters of the shallow alluvium aquifer, firstly Na, SO_4 and boron ions may be diluted by the Delice River waters. For this, irrigation strategy may be applied in the Yerköy plain with pumping from channels recharged from the Delice River.

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