



Determination of groundwater parameters for drinking and agricultural use in the coastal region of Engiz Aquifer System, Samsun (Turkey)

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Received: 22 August 2018 / Accepted: 20 February 2019 / Published online: 11 March 2019
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Abstract

The aims of this study are to evaluate the physico-chemical properties of groundwater in the Engiz Aquifer System, determine the sea water intrusion, and investigate suitability of groundwater for both agricultural and drinking purposes of Samsun City in Turkey. It was interpreted whether groundwater was suitable for drinking and the parameters analyzed were checked according to the standards determined by the Turkish drinking water standard (TSE 266 2005). The use of groundwater for irrigation purposes was classified based on the Water Pollution Control Regulation of the Turkish Republic, Criteria for Inland Surface Water Classification (WPCR 2004). The groundwater samples of the Engiz Aquifer System were analyzed for major anion and cations, trace elements, pH, EC, and TDS. The groundwater samples are Ca-Mg-Na-SO₄ and Ca-Mg-Na-Cl water types. The groundwater samples are not suitable for drinking because of the high levels of Na, Al, As, Fe, and Ni. Besides, %Na and SAR values indicate that the water is suitable for only salt-tolerant and semi-tolerant crops under suitable irrigation circumstances. According to the Mg Hazard and PI values, 30 and 70%, respectively, of the groundwater samples are not suitable for irrigation in the basin. It is thought that the groundwater salinity is increasing in the future because the groundwater wells are close to the Black Sea coast and there is some intrusion of saline marine waters.

Keywords Groundwater · Hydrochemistry · Coastal aquifer · Engiz Aquifer System · NE Turkey

Introduction

Today, discussions on climate change and its possible consequences are increasing. Most of these discussions are focused on surface water systems. The amount of rainfall in many dry

Editorial Handling: Mingjie Chen

Highlights

- The Eastern Black Sea Region is a very important area in Turkey in points of hydrogeological and hydrochemical properties.
- The objective of the study is studying the hydrochemical properties of Engiz Aquifer System.
- Drinking and agricultural use of the groundwater is determined in the region.

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regions of the world is very low and therefore the surface flow is very low. In this case, the use of underground water is increasing. The effects of climate change on underground waters are long term and can be very extensive. One of the most obvious consequences of this is the problem of sea water initiative in coastal aquifers. As in our country, groundwater is the only freshwater source in many countries of the world, especially in the dry and semi-dry regions where surface water is low. Groundwater resources are affected by global warming in various ways. In the coming years, the increase in sea water level due to climate change will cause the sea water to intervene in the continents and especially in the groundwater systems (Sherif and Singh 1999).

Globally, 2.5 billion people use groundwater for drinking and irrigation purposes (UNESCO 2012). At recent years, all fresh water sources like groundwaters, streams, and springs are at risk because of the increase in demand (UNESCO 2012).

The most sensitive topic at world scale is deterioration of water quality because of many natural and anthropogenic activities. The factors affecting groundwater quality are land use,

infiltration rate, geological and geochemical processes, and human activities (Freeze and Cherry 1979).

The groundwater levels in shallow alluvial aquifers are constantly decreasing and groundwater quality is descending because of agricultural activities and industrialization (Guo and Wang 2004; Tolera et al. 2017; Haritash et al. 2017; Dişli 2017).

The deterioration of groundwater quality in the Syrian coastal aquifer is mainly the result of seawater intrusion in the aquifer (Allow 2011). Overpumping of groundwater and the resulting deterioration of groundwater resources are a major concern in arid areas. The water demand is primarily satisfied by groundwater which is pumped from shallow alluvial aquifers (Kalbus et al. 2016). Groundwater contamination is a serious issue as it leads to the depletion of fresh groundwater resources. Seawater intrusion is a groundwater contamination that affects socio-economic activities, as it threatens sustainability including that of agriculture in coastal areas (Baharuddin et al. 2012). The overexploitation of the Wadi El Natrun aquifer is a big problem in Egypt and has to be stopped to prevent contamination of the aquifer by seawater advance and subsequently increasing of groundwater salinity (Hussein et al. 2017).

The chemical parameters in groundwater are used to determine the quality of water. Sodium absorption ratio (SAR), residual sodium carbonate (RSC), and Kelly ratio values are important criteria which are used to designate the suitability of irrigation water (Edjah et al. 2017; Koffi et al. 2017; Sadashivaiah et al. 2008; Ghoraba and Khan 2013).

The hydrogeochemical characterization of groundwater helps to assess the trend of salinization and freshening of the groundwater. Critical problems affecting the aquifer include a thin aquifer which is connected/surrounded by saltwater on all the sides and destruction of existing dune morphology by conversion of barren land to the residential area which causes a reduction in their barrier effect to seawater intrusion (Sathish and Elango 2016). Coastal aquifers are generally subjected to seawater intrusion and groundwater quality degradation. The groundwater quality of the coastal southeastern Tunisia is evaluated to check its suitability for irrigation purposes. Assessment of the groundwater quality indicated that only 7% of the water is considered suitable for irrigation purposes (Agoubi et al. 2011). The hydrogeochemical evolution and quality assessment of groundwater in Ghana show that this study by extension will reflect the chemistry of groundwaters in the southern parts of Burkina Faso since the climate, vegetation, soil types, geology, and the socio-cultural settings are the same (Anim-Gyampo et al. 2018).

The fact that surface water resources tend to decrease all over the world leads people to use groundwater. However, the use of groundwater in the present day causes the degradation of these waters both in quality and quantity. In the case of aquifer systems, especially in the sea shore, in case of

groundwater withdrawal, the sea water flows to the groundwater area and groundwater is salinized. Groundwater sources in our country are facing depletion risk because of rapid increase in population and industrialization. Besides the three sides of our country are surrounded by the sea, the aquifer systems at the seaside are at risk.

In Samsun, which is located in the Black Sea region and its surrounding areas, the use of groundwater is rapidly increasing in the last 10 years due to the increase in population and irrigation activities. As a result, the quality of groundwater has deteriorated. With this article, the quality of groundwater and its suitability for agricultural use will be determined. As a result, this aquifer in the seashore will guide the decision makers about how to use groundwater.

Especially for the aquifers near coasts, the overdraft of groundwater decreases the water level, and thus results to sea water intrusions towards the inland areas. Using salt water for irrigation both decreases the plantation yield and cause saltiness and sodium problems for soils (Al-Senafy and Abraham 2004; Elkrail et al. 2012; Akoyeton 2013).

Groundwater in recent years has become a premium source of potable water supply for most regions in Turkey, especially in the Black Sea Region, where the agricultural economy of the region depends heavily on groundwater. The depth to the groundwater table in the region is very close to the earth surface. The aquifer systems located in the Black Sea Region are near the sea side and are in danger of salt water intrusion (Karaca 2017).

In Engiz Aquifer System (Samsun, Turkey), groundwater is threatened with salinization, rapid population growth, and pollution due to agricultural activities. The main purposes of this study are to determine the chemical parameters in groundwater, to investigate the suitability of groundwater for agricultural irrigation purposes, and to determine a possible Black Sea water intrusion.

Study area, geology, and hydrogeology

The Engiz Aquifer System is located eastern in Black Sea Region of Turkey and between 41° 10'–41° 45' N latitude and 35° 30'–36° 15' E longitude. The basin is located in the delta ridge formed by the Kızılırmak Basin and covers an area of 151 km² (Fig. 1). The Kızılırmak Basin lies within the wet-temperate climate zone. Rainfall in the basin is every month throughout the year. According to the meteorological data collected from Samsun Meteorological Service during 1950–2015, the annual average temperature in the area is 14.5 °C and the mean annual total precipitation is 706 mm.

Seven different units are distinguished in the study area. The oldest unit is Late Cretaceous-aged tuff, tuffite, sandy limestone, sandstone, and shale. Late Cretaceous-Late



Fig. 1 Geological map of the Engiz Aquifer System (Samsun, NE Turkey) (Karaca 2017)

Paleocene-aged unit is composed of sandstone, sandy limestone, limestone, and siltstone. Late Paleocene-Early Eocene-aged unit consisted of limestone, sandy limestone, and marl. Early-Middle Eocene-aged unit is formed of limestone, thin-stratified sandstone, and marl. Middle Eocene-aged unit is comprised of basalt, trachyte, and pyroclastic. The youngest units are Pleistocene-aged old alluvium and Quaternary-aged actual alluvium in the Engiz Aquifer System (Keskin 2011) (Fig. 1).

The groundwater part was found in the old alluvium and largely occurs in the actual alluvium in the study area. Alluvium is composed of gravel, sand and silt, and shallow and unconfined aquifer. The groundwater level is located 3.05–14 m below the surface, at a medium depth of 7.45 m. The groundwater level is very close to the earth and is on the Black Sea seashore. Groundwater is the main water source for public use and agriculture in the study area (Karaca 2017) (Fig. 2).

No studies have been conducted in the Engiz Aquifer System until 2017 regarding the presence of Black Sea water intrusion. Also, there is no data on the salinization of

groundwater. For this reason, this study will determine the presence of sea water intrusion to the aquifer.

Methodology

The groundwater samples were gathered at 15 sampling points from deep wells in residential area of the Engiz Aquifer System because of the public stress (Fig. 2). The samples were collected during the period of June 2016 and October 2016, i.e., arid and rainy season. Samples were filled in the polyethylene bottles after 15 min pumping. pH, EC, TDS, DO, and temperature parameters were measured in the field using a YSI model portable multiparameter. Polyethylene bottles of 2000 ml volume (pre-washed with distilled water) were used to collect each sample for the analysis of anion-cation and trace element. Specification of these compositions of the groundwater samples was made at the General Directorate of State Hydraulic Works (DSI), 7. Regional Directorate, Quality and Control Laboratory SAMSUN. This analysis was applied according to the TS EN ISO standards. CO₃ and HCO₃

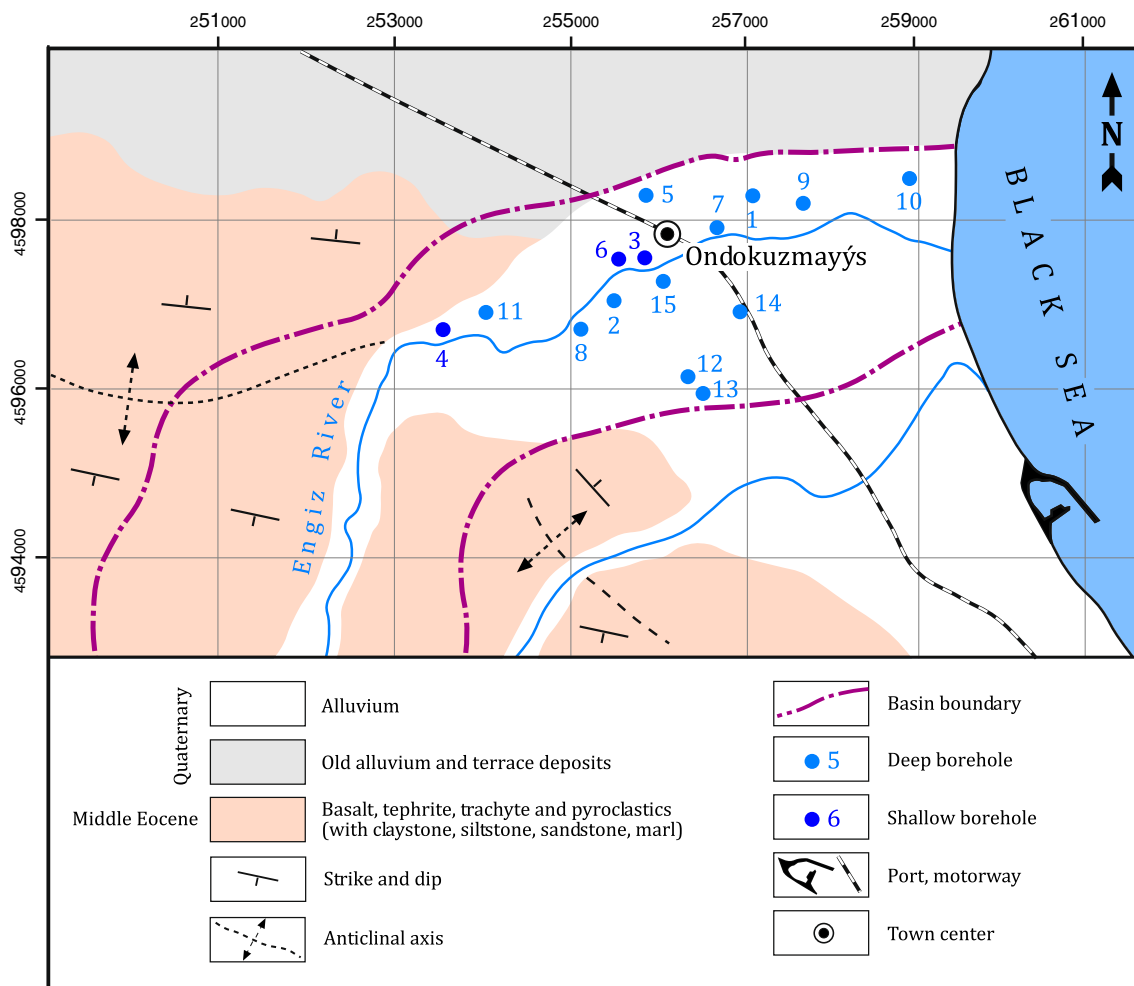


Fig. 2 Sampling locations in the Engiz Aquifer System (Karaca 2017)

concentrations were analyzed by using TS 3790 EN ISO 9963-1; Ca, Mg, Na, K, NH_4 were analyzed using atomic absorption spectrometry TS EN ISO 14911; and SO_4 , Cl, NO_3 , NO_2 were analyzed using ion chromatography TS EN ISO 10304-1 methods. Trace elements (Al, As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, Zn) were analyzed by using EPA standards.

AquaChem 2014.2 was used to utilize for the schematic representation of the water samples and characterized the quality of groundwater. In order to determine the water quality in the Engiz Aquifer System, chemical analysis results of groundwater samples were evaluated by using some methods. This assessment is comprised of the the saturation index (SI), the ion balance, SAR (Richards 1954), sodium percentage (%Na) (Wilcox 1955), total hardness (TH), RSC index (Eaton 1950), Kelly ratio (KR) (Kelley 1963), magnesium hazard (Paliwal 1972), and permeability index (PI) (Doneen 1964).

Sodium adsorption ratio (Richards 1954)

$$\text{SAR} = \text{Na}^+ / (\text{Ca}^{2+} + \text{Mg}^{2+} / 2) 1/2$$

Percent sodium (Wilcox 1955)

$$\% \text{Na} = [(\text{Na}^+ + \text{K}^+) \times 100] / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^+)$$

$$\text{TH} = (\text{Ca}^{2+} + \text{Mg}^{2+}) \times 5$$

Residual sodium carbonate (Eaton 1950)

$$\text{RSC} = (\text{HCO}_3^- + \text{CO}_3^{2-}) - (\text{Ca}^{2+} + \text{Mg}^{2+})$$

Kelly ratio (Kelley 1963)

$$\text{KR} = \text{Na}^+ / (\text{Ca}^{2+} + \text{Mg}^{2+})$$

Magnesium hazard (Paliwal 1972)

$$\text{Mg Hazard} = (\text{Mg}^{2+}) / (\text{Ca}^{2+} + \text{Mg}^{2+})$$

Permeability index (Doneen 1964)

$$\text{PI} = (\text{Na}^+ + \sqrt{\text{HCO}_3^-}) \times (\text{Na}^+ + \text{Ca}^{2+} + \text{Mg}^{2+})$$

All ionic concentrations are in milliequivalent/liter.

Results and discussion

During the June 2016 and October 2016 periods, to determine the water quality in the Engiz Aquifer System, groundwater samples at 15 sampling points were gathered, and major anion and cation and trace element analysis was done. The analysis results were examined, and the drinking and irrigation water suitability was determined (Tables 1, 2, and 3).

Chemical analysis of the groundwater samples was performed at the General Directorate of State Hydraulic Works

(DSI), 7. Regional Directorate, Quality and Control Laboratory SAMSUN. In this laboratory, our country engaged in the work of the accreditation, and the only authorized institution TURKAK (Turkey Accreditation Agency) has been accredited every year since 2000.

Groundwater samples were assessed according to the TSE 266 (2005) and WPCR (2004). WPCR (2004) divide the waters into four classes. According to this classification, Class I water is identified as high quality, Class II water is identified as slightly contaminated, Class III water is identified as contaminated, and Class IV water is identified as highly contaminated water.

According to the physical analysis results, the mean pH value of groundwater samples is 7.31. EC values ranges from 273 to 1615 and the mean value is 865.47. TDS values are between 185 and 1098; the mean value is 588.57 and the water samples are classified Classes I and II. When examined in terms of French Hardness (FH), the hardness values of the water samples are between 15.1 and 151.2. Accordingly, groundwater samples are generally in the hard-very hard water class (Table 1).

For Na^+ , the limit value defined in TSE 266 is 200 mg/l. Accordingly, the water samples numbered 10, 11, and 13 are not suitable for drinking purposes. The average Cl^- value in groundwater samples is 38.21 and varies between 2.45 and 141.36. In terms of Cl^- value, it is in Class I and Class II. When the water samples were examined from the standpoint of Al, it was seen that samples 4, 7, 11, and 15 were above the standard value of 200 $\mu\text{g/l}$, according to TSE 266. For As, the limit value defined in TSE 266 is 10 $\mu\text{g/l}$, and samples numbered 2, 3, 8, 9, 10, and 12 exceeded the limit values. For Fe, the drinkable limit is 200 $\mu\text{g/l}$ and samples with numbers 1, 3, 4, 5, 7, 10, 11, and 15 exceeded this and are not suitable for drinking. When the Ni results are examined, the samples numbered 5, 6, 8, 12, 13, and 15 are not in accordance with TSE 266. According to the WPCR (2004) in terms of Fe and Ni, water classes are in Classes I and II. For nitrate, the limit value for NO_3 in TSE 266 is 50 mg/l. Accordingly, groundwater samples numbered 10 and 12 are not suitable for drinking (Table 2).

The Piper trilinear diagram (Piper 1944) is a useful instrument for the interpretation of the hydrochemical facies and chemical relations in groundwater samples. In the Engiz Aquifer System, groundwater samples are Ca-Mg-Na- SO_4 and Ca-Mg-Na-Cl water types, and very few are Ca-Mg-Na- HCO_3 water type. In the Piper diagram (Fig. 3a), about 80% of the groundwater samples are of the Ca type and 20% of the samples are of Na and Mg water type, and most groundwater samples are Cl and SO_4 . The chemical data in the central field are found in the 1, 4, 6, and 9 fields. In all samples, the alkaline earth metals (Ca^{2+} and Mg^{2+}) exceed alkali metal cations (Na^+ and K^+) and the points fall into field 1. Almost all the groundwater samples exhibited dominance of $\text{SO}_4 + \text{Cl}$ over $\text{CO}_3 +$

Table 1 Results of physical and chemical analysis of the Engiz Aquifer System

Sample location	Sample type	Sampling date	T (°C)	pH	EC (µS/cm)	TDS	FH	Ca	Mg	Na	K	HCO ₃	SO ₄	Cl	Water Type
1	Groundwater	June 2016	23.6	7.36	616	419	29.3	88.27	17.53	51.95	3.40	11.18	3.43	4.81	Ca-Na-Mg-Cl
		October 2016	22.5	7.67	701	477	32.9	101.26	18.07	49.33	2.94	9.59	22.61	28.79	Ca-Na-Mg-Cl
2	Groundwater	June 2016	23.0	7.26	746	507	27.1	77.92	18.58	30.50	3.21	23.82	10.97	6.50	Ca-Mg-Na-HCO ₃
		October 2016	22.6	7.27	816	555	45.7	149.14	20.67	31.16	1.89	6.67	55.74	33.02	Ca-Mg-Na-SO ₄
3	Groundwater	June 2016	24.0	7.48	467	318	15.1	44.84	9.50	15.85	1.51	10.50	5.05	2.45	Ca-Mg-Na-HCO ₃
		October 2016	22.5	7.61	423	288	18.4	60.19	7.91	16.54	1.80	6.74	30.74	15.42	Ca-Na-Mg-SO ₄
4	Groundwater	June 2016	23.5	7.33	525	357	22.3	62.96	16.09	22.32	9.63	6.03	3.50	3.80	Ca-Mg-Na-Cl
		October 2016	22.5	7.28	695	473	35.5	98.81	25.82	31.10	10.56	12.26	34.46	40.07	Ca-Mg-Na-Cl
5	Groundwater	June 2016	23.7	7.08	1036	705	30.1	81.63	23.45	29.51	2.80	6.68	15.69	5.62	Ca-Mg-Na-SO ₄
		October 2016	22.5	7.12	998	679	55.3	175.52	27.36	28.26	1.73	8.92	84.14	31.92	Ca-Mg-SO ₄
6	Groundwater	June 2016	23.8	7.09	1394	948	45	133.12	28.69	61.71	3.10	8.94	11.01	27.461	Ca-Na-Mg-Cl
		October 2016	22.4	7.46	1337	909	62.4	198.17	31.38	68.02	3.00	13.01	66.07	41.36	Ca-Na-Mg-Cl
7	Groundwater	June 2016	24.3	7.35	878	597	27.5	80.41	17.89	26.44	3.37	21.77	49.03	5.64	Ca-Mg-Na-SO ₄
		October 2016	22.5	7.44	648	441	35.6	118.17	14.13	23.95	1.27	6.79	53.16	26.96	Ca-Mg-Na-SO ₄
8	Groundwater	June 2016	24.8	7.31	1028	699	31	90.761	20.26	28.92	1.72	10.46	9.77	6.44	Ca-Mg-Na-Cl
		October 2016	22.5	7.22	1085	738	59.5	90.30	28.95	32.68	3.43	14.29	52.57	68.22	Ca-Mg-Cl
9	Groundwater	June 2016	25.6	7.34	1141	776	39.3	109.90	28.50	35.45	3.99	17.81	9.40	12.92	Ca-Mg-Na-Cl
		October 2016	22.5	7.23	1172	797	49.8	138.90	36.56	46.63	8.51	19.59	91.68	78.02	Ca-Mg-Na-Cl-SO ₄
10	Groundwater	June 2016	25.6	7.54	579	394	151.2	371.02	142.38	174.60	32.91	18.16	58.941	57.74	Ca-Mg-Na-SO ₄
		October 2016	22.1	7.67	840	571	107.8	101.53	200.23	267.20	96.86	6.96	71.73	79.10	Mg-Na-Ca-Cl
11	Groundwater	June 2016	26.7	7.30	763	519	32.3	32.641	58.61	376.15	21.49	20.20	6.60	140.56	Na-Mg-Cl
		October 2016	22.3	7.30	809	550	45.9	53.78	17.64	25.42	2.48	8.58	72.57	28.85	Ca-Mg-SO ₄
12	Groundwater	June 2016	25.0	7.13	1594	1084	66.7	211.99	33.47	56.47	5.69	6.41	33.231	13.09	Ca-Mg-Na-Cl
		October 2016	22.4	7.17	1615	1098	94.5	246.55	80.14	96.06	2.53	2.34	30.32	25.20	Ca-Mg-Na-SO ₄
13	Groundwater	June 2016	24.8	7.07	274	186	80.3	174.04	89.441	122.33	2.79	6.75	28.591	51.74	Ca-Mg-Na-Cl
		October 2016	22.5	7.12	273	185	96.2	188.38	19.45	397.89	4.39	6.03	89.76	70.20	Na-Mg-Ca-SO ₄
14	Groundwater	June 2016	24.9	7.29	968	658	46.7	91.28	58.09	188.37	1.22	7.64	18.42	65.23	Na-Mg-Ca-Cl
		October 2016	22.4	7.35	879	598	30	54.69	39.79	33.09	4.61	9.25	42.63	43.46	Mg-Ca-Na-Cl
15	Groundwater	June 2016	25.0	7.21	904	614	51.3	169.14	21.44	29.62	2.22	6.58	18.15	5.35	Ca-Mg-Na-SO ₄
		October 2016	22.5	7.30	760	517	34.5	106.51	18.65	26.95	1.91	11.28	76.60	26.27	Ca-Mg-Na-SO ₄
	Min value		22.1	7.07	273	185	15.1	32.64	7.91	15.85	1.22	2.34	3.43	2.45	
	Max. value		26.7	7.67	1615	1098	151.2	371.02	200.23	397.89	96.86	23.82	189.76	141.36	
	Mean		23.5	7.31	865.47	588.57	49.97	130.06	42.36	80.82	8.23	10.77	48.55	38.21	
	St.Dev.		1.27	0.17	340.33	231.42	30.07	70.57	43.7	101.32	17.99	5.47	47.39	36.67	
TSE 266	(Max. values)					6.5–9.5		2500						200	

Concentrations of ions and TDS are in milligram/liter. (–) not analyzed
St.Dev standard deviation, italic values indicated that these values are above the standard values

Table 2 Results of trace element analysis of the Engiz Aquifer System

Sample location	Sample type	Sampling date	Al (µg/l)	As (µg/l)	Cd (µg/l)	Cu (µg/l)	Cr (µg/l)	Fe (µg/l)	Mn (µg/l)	Ni (µg/l)	Pb (µg/l)	Zn (µg/l)	NH ₄ ⁺ (mg/l)	NO ₃ ⁻ (mg/l)
1	Groundwater	June 2016	5.98	2.15	1.87	2.94	—	33.89	0.30	9.85	0.70	35.86	—	3.85
		October 2016	39.26	1.72	—	8.22	1.58	319.32	0.57	4.16	0.41	35.99	—	17.82
2	Groundwater	June 2016	43.03	10.10	1.89	5.29	1.53	147.73	0.02	16.49	4.67	42.20	—	4.52
		October 2016	42.77	—	—	50.58	1.53	123.65	0.03	5.64	0.55	32.77	—	17.27
3	Groundwater	June 2016	0.71	26.50	1.87	18.91	3.59	28.34	0.04	11.69	0.89	21.91	0.08	1.37
		October 2016	155.49	—	—	38.77	1.04	265.80	0.14	3.22	1.08	38.71	—	5.18
4	Groundwater	June 2016	—	—	1.87	16.16	2.10	29.21	0.03	8.61	0.80	4.85	—	1.78
		October 2016	558.17	—	—	19.99	2.39	826.40	0.61	7.30	2.30	29.92	—	22.90
5	Groundwater	June 2016	—	—	1.88	1.26	0.78	23.33	0.64	21.60	0.65	5.57	—	3.34
		October 2016	84.48	—	—	55.21	1.39	222.19	1.26	9.71	1.57	26.73	—	14.87
6	Groundwater	June 2016	—	—	1.88	3.21	0.86	31.08	0.02	22.32	0.70	12.28	0.37	6.82
		October 2016	15.19	—	—	9.18	1.58	117.16	0.01	7.37	0.38	28.78	—	40.76
7	Groundwater	June 2016	8.32	—	1.87	8.21	0.66	40.17	0.91	17.64	0.86	12.18	8.24	2.59
		October 2016	243.37	0.30	—	—	—	621.82	0.81	17.73	0.24	55.84	—	14.22
8	Groundwater	June 2016	—	10.22	1.88	1.96	1.27	37.77	0.09	21.78	0.69	18.69	—	2.61
		October 2016	51.18	—	—	7.47	0.91	165.08	0.47	10.41	0.55	47.80	—	27.21
9	Groundwater	June 2016	5.57	—	1.90	7.38	—	71.02	0.77	7.38	0.78	13.03	—	4.85
		October 2016	65.60	29.32	—	29.00	1.06	168.25	0.60	7.12	0.71	35.53	—	16.82
10	Groundwater	June 2016	20.22	20.45	1.87	27.97	4.33	75.69	0.18	13.16	1.06	6.91	—	11.51
		October 2016	94.14	20.86	—	22.20	7.43	334.28	0.22	5.43	3.06	24.40	—	51.92
11	Groundwater	June 2016	13.4	—	1.91	7.78	3.99	59.5	0.24	19.98	1.03	23.87	—	3.90
		October 2016	484.52	0.86	—	23.05	1.25	530.55	0.93	6.95	—	37.35	—	13.02
12	Groundwater	June 2016	16.98	13.62	1.87	14.15	2.39	48.95	0.03	22.02	0.77	18.37	—	7.38
		October 2016	45.98	—	—	37.10	1.13	117.32	0.01	6.72	0.37	22.73	—	51.70
13	Groundwater	June 2016	47.27	—	1.87	18.42	7.25	79.09	0.02	22.52	0.83	40.12	—	10.83
		October 2016	38.19	1.63	—	—	2.33	144.32	0.04	5.65	—	24.32	—	43.37
14	Groundwater	June 2016	20.01	—	1.88	22.24	3.53	3.53	0.14	17.34	0.98	17.31	—	4.07
		October 2016	37.57	1.34	—	5.4	0.91	128.72	0.11	5.29	2.04	53.37	—	18.05
15	Groundwater	June 2016	25.24	—	1.89	5.57	4.47	128.97	1.04	22.72	0.9	22.99	—	0.00
		October 2016	282.50	0.34	—	1.12	1.27	612.90	0.83	9.10	0.71	42.99	—	13.13
	Min value		0.71	0.3	1.87	1.12	0.66	23.33	0.01	3.22	0.24	4.85	0.08	0
	Max. value		558.17	29.32	1.91	55.21	7.43	826.4	1.26	22.72	4.67	55.84	8.24	51.92
	Mean		94.04	9.96	1.88	16.74	2.28	186.32	0.37	12.23	1.08	27.78	2.9	14.59
	St.Dev.		143.84	10.5	0.01	14.71	1.81	205.68	0.38	6.64	0.93	13.68	4.63	14.71
	TSE 266 (max. values)		200	10	5	2	50	200	50	20	20	10		

Table 3 Results of irrigation parameters of the Engiz Aquifer System

Sample location	Sample type	Sampling date	%Na	SAR	RSC	KR	Mg Hazard	PI
1	Groundwater	June 2016	28.54	1.32	-5.69	0.38	24.87	33.04
		October 2016	25.26	1.18	-6.41	0.33	22.92	29.16
2	Groundwater	June 2016	20.55	0.8	-5.06	0.24	28.44	28.82
		October 2016	13.26	0.63	-9.07	0.15	18.76	16.00
3	Groundwater	June 2016	19.35	0.56	-2.86	0.23	26.1	29.66
		October 2016	17.26	0.53	-3.56	0.2	17.97	23.96
4	Groundwater	June 2016	21.33	0.65	-4.39	0.22	29.87	23.54
		October 2016	18.62	0.72	-6.89	0.19	30.34	21.32
5	Groundwater	June 2016	18.33	0.74	-5.92	0.21	32.38	22.05
		October 2016	10.32	0.52	-10.95	0.11	20.62	12.74
6	Groundwater	June 2016	23.39	1.26	-8.9	0.3	26.43	26.14
		October 2016	19.5	1.18	-12.32	0.24	20.88	22.09
7	Groundwater	June 2016	18.32	0.69	-5.15	0.21	27.05	26.23
		October 2016	13.16	0.55	-6.98	0.15	16.62	16.92
8	Groundwater	June 2016	17.29	0.71	-6.06	0.2	27.12	22.33
		October 2016	11.23	0.58	-11.69	0.12	20.23	14.27
9	Groundwater	June 2016	17.28	0.78	-7.57	0.2	30.18	22.12
		October 2016	18.35	0.91	-9.68	0.2	30.49	21.58
10	Groundwater	June 2016	21.71	1.95	-30.12	0.25	39.01	21.41
		October 2016	84.5	3.52	-21.67	0.53	76.67	35.82
11	Groundwater	June 2016	72.18	9.06	-6.18	2.51	74.95	74.02
		October 2016	11.32	0.52	-9.02	0.12	16.05	14.42
12	Groundwater	June 2016	16.27	0.95	-13.28	0.18	20.83	17.54
		October 2016	18.24	1.35	-18.94	0.22	35.14	18.86
13	Groundwater	June 2016	25.02	1.87	-16.04	0.33	46.14	26.32
		October 2016	47.33	5.56	-19.27	0.89	51.38	48.03
14	Groundwater	June 2016	46.64	3.78	-9.27	0.87	51.47	48.56
		October 2016	20.47	0.83	-5.9	0.24	54.8	24.41
15	Groundwater	June 2016	11.6	0.57	-10.14	0.13	17.44	14.02
		October 2016	15.07	0.63	-6.7	0.17	22.59	19.89
	Min. value		10.32	0.52	-30.12	0.11	16.05	12.74
	Max. value		84.5	9.06	-2.86	2.51	76.67	74.02
	Mean		24.24	1.5	-9.86	0.34	31.92	25.84
	St.Dev.		17.09	1.83	6.07	0.45	15.89	12.52

%Na percent sodium, SAR sodium adsorption ratio, RSC residual sodium carbonate, KR Kelly ratio, Mg Hazard magnesium hazard, PI permeability index

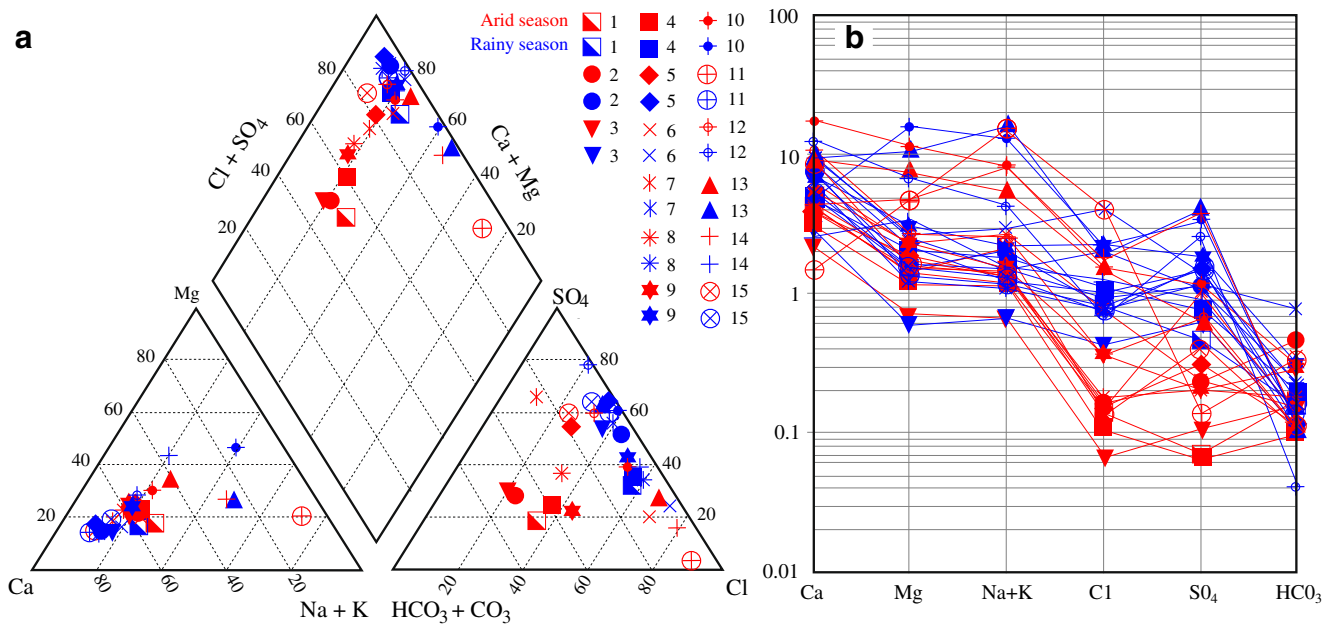
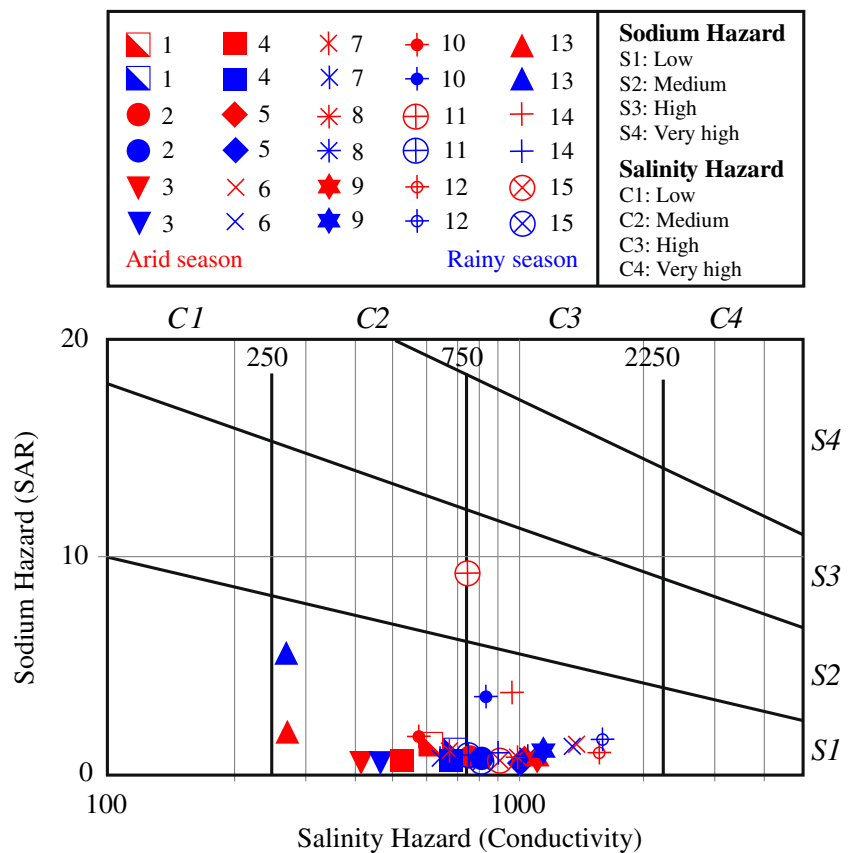


Fig. 3 Piper trilinear (a) and Schoeller (b) diagrams of the groundwater samples

HCO₃ and the points fall into field 4. The plotted points for most of the groundwater samples fall into field 6, suggesting non-carbonate hardness, while some of the samples located in field 9 point out mixed chemical character of groundwater with no one cation-anion pairs exceed 50%.

In order to visually assess the quality of groundwater in the Engiz Aquifer System, major anion and cation concentrations of the samples were plotted on the Schoeller Diagram (Fig. 3b). According to the Schoeller Diagram (Schoeller 1962), there is no dominant cation and the dominant anions in the

Fig. 4 US salinity diagram for calculated values of SAR



water samples are Cl and SO₄. The Schoeller Diagram also shows that the concentrations of all ions in the groundwater samples have a similar tendency. However, the difference between arid and rainy seasons samples is evident. Numbered 10, 11, and 13 samples show clearly differences from the others.

Agriculture is the major factor in the economic development of Samsun City in Turkey. For this reason, groundwater samples in the Engiz Aquifer System were interpreted in terms of their compatibility for agricultural irrigation, and %Na, SAR, RSC, KR, Mg Hazard, and PI values of water samples were defined (Table 3). According to these results, when groundwater samples were examined in terms of %Na, it was observed that the values ranged between 10.32 and 84.5%. According to this, groundwater samples are between the “very good” and “inconsumable” categories in terms of irrigation water. The SAR values for all groundwater samples in the Engiz Aquifer System are less than 10 (range from 0.52 to 9.06), indicating “very good” water quality for irrigation. Analyses results of the samples are shown in Fig. 4. According to United States Salinity Diagram (USSL 1954), the groundwater samples fall in the C2S1 and C3S1 category mostly. The C2S1 field indicates a “medium salinity hazard” and “low sodium hazard” and the C3S1 field indicates “high salinity hazard” and “low sodium hazard.” Such groundwater type can be exploited to irrigate salt-tolerant and semi-tolerant crops under favorable drainage conditions.

All RSC values were calculated to be negative for groundwater samples, signifying that it is not possible that bicarbonate ions would react with Ca²⁺ and Mg²⁺ ions to deposit carbonate minerals in the soil zone. The negative result means there is no likely Na damage. The irrigation water quality is defined as Class I (good) because the RSC value is negative in the study area. The Kelly ratio is an important parameter for the calculation of sodium hazard. Based on the Kelly ratios of the groundwater samples, all except the one sample (sample number 11) were found to be free from salinity hazard. According to this study, many of the samples were determined to be reliable for irrigation purposes based on the Mg Hazard. The average value of Mg Hazard is 31.92 and groundwater samples numbered 10, 11, 13, and 14 are not suitable for irrigation. Permeability index value also is a reliable indicator in groundwater suitability for irrigation. Using the PI, Doneen (1964) classified the groundwater suitability as Class I (> 75%), Class II (25–75%), and Class III (< 25%). Both Class I and Class II are classified as good for irrigation, whereas Class III water is unsuitable. In the Engiz Aquifer System, PI values ranged from 12.74 to 74.02 and the mean value is 25.84. According to the PI values, 70% of the groundwater samples in the Engiz Aquifer System belong to Class III and were therefore

categorized as unsuitable for irrigation purposes. Only 30% of groundwater samples belonged to Class II in the aquifer.

Conclusions

Groundwater utilization for fresh water resources has increased dramatically during recent 10–20 years mainly because of a rise in agricultural irrigation, human consumption, and industrial uses in the vicinity of Samsun City, which is located in the northern part of Turkey on the Black Sea coast. Decrease in water quality and deterioration of groundwater quality in the region is the most important problem. For this reason, studies are being undertaken by various private and public organizations to determine the quality and quantity characteristics of the water resources in the basin.

In this study, the groundwater of Engiz Aquifer System was investigated for Ca-Mg-Na-SO₄, Ca-Mg-Na-Cl, and Ca-Mg-Na-HCO₃ water types. The suitability of groundwater resources for irrigation was evaluated using quality parameters, e.g., Na%, SAR, RSC, KR, Mg Hazard, and PI. Groundwater samples according to Na% and SAR values are classified “very good” to “inconsumable” water quality for irrigation. Based on the United States Salinity Diagram, most of the groundwater samples belong to C2S1 and C3S1, indicating medium-high salinity hazard and low sodium hazard, which can be used for salt-tolerant and semi-tolerant crops under suitable drainage situation. According to the RSC values, the groundwater quality is good for irrigation. Many of the samples were determined to be reliable for irrigation purposes based on the Mg Hazard and groundwater samples numbered 10, 11, 13, and 14 are not suitable for irrigation. According to the PI values, 70% of the groundwater samples in the Engiz Aquifer System belong to Class III and were classified as not suitable for irrigation. Only 30% of groundwater samples belonged to the Class II in the aquifer.

Most of the pumping wells and the groundwater levels in the area are shallow and near the Black Sea coast. Therefore, the salinity of groundwater is increasing, and the quality is deteriorating because the groundwater wells are close to the Black Sea coast and there is intrusion of saline waters to groundwater. For this reason, systematic monitoring of the groundwater quality is required. Besides, pumping should be stopped in deep wells near the Black Sea shore. New wells should be opened away from the Black Sea coast and the pumping flow rate should be reduced in the wells.

Acknowledgments The authors thank Assistant Prof. Hakan ERSOY for his helpful comments on the manuscript. Special thanks are due to “American Manuscript Editors” service to improve the English writing of this article.

Funding information The study was supported by the Scientific Research Fund of Karadeniz Technical University, Project number 5515

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