Araştırma Makalesi / *Research Article*

Application of Water Quality Index with the Aid of Geographic Information System in Eastern Thrace to Assess Groundwater Quality

Doğu Trakya Bölgesi'nde Yeraltı Suyu Kalitesinin Araştırılması Amacıyla Coğrafi Bilgi Sistemi Yardımı ile Su Kalite İndeksi Uygulaması

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ABSTRACT

Water quality assessment has always been a major part of environmental management plans. In this study, the groundwater quality and spatial distribution in the eastern Thrace region was assessed and mapped for agricultural and drinking purposes. Groundwater samples (n = 18) were collected from deep wells in the study area and analyzed for hydrochemical properties for the water quality assessment. The Water Quality Index (WQI) was calculated for the quantification of water quality for human consumption. The WQI values showed that 52 % of the groundwater samples fall in the "poor" and "very poor" category due to agricultural impact. Nevertheless, the majority of the groundwater were suitable for irrigation in terms of sodium absorption ratio (SAR), residual sodium carbonate (RSC), sodium ratio (Na%) and magnesium hazard (MH).

Keywords: Geographical Information System, Groundwater, Thrace, Water Quality Index.

ÖZ

*Su kalitesi değerlendirmesi, çevresel yönetim planlarının daima önemli bir parçası olmuştur. Bu çalışmada, Doğu Trakya B*ölgesi*'ndeki yeraltı sularının içme ve sulama amaçlı kalitesi değerlendirilmiş ve sonuçların mekânsal dağılımı haritalanmıştır. Çalışma alanındaki 18 adet derin su kuyusundan alınan örneklerin su kalitesinin değerlendirilmesi amacıyla hidrokimyasal özellikleri saptanmıştır. İnsani tüketim amaçlı su kalitesi değerlendirmesi için Su Kalite İndeksi (SKİ) hesaplanmıştır. SKİ değerleri, yeraltısularının % 52'sinin tarımsal ilaçlamadan dolayı "kötü" ve "çok kötü" sınıfında olduğunu göstermiştir. Bununla*

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beraber, sulama amaçlı olarak yeraltı sularının büyük kısmının, sodyum absorbsiyon oranı (SAR), artık sodyum bicarbonat (RSC), sodyum yüzdesi (Na%) ve magnezyum tehlikesi (MH) açısından uygun olduğu görülmüştür.

Anahtar Kelimeler: *Coğrafi Bilgi Sistemleri, Yeraltısuyu, Trakya, Su Kalite İndeksi,*

INTRODUCTION

The number of fresh water sources is very limited in the world. Although fresh water is a renewable resource, yet the world's supply of groundwater is steadily decreasing (Gleeson et al., 2012). Fresh groundwater was used for many important purposes, such as drinking and irrigation. The quality of groundwater is deteriorating due to urbanization, increasing population, and agricultural chemicals. In addition, the civil works, landslides, and the change in the rate of rain infiltration into groundwater are affecting the quality adversely (Ramesh and Elango, 2012). Groundwater is identified as cleaner and safer compared to surface water. For this reason, it is used more often than surface water in dry and semi-dry climate zones.

Pollutants threaten the quality of groundwater. Transfer of the pollutants influencing the groundwater is a function of the pollutants and aquifer. Consequently, the hydraulic conductivity and lithology of the aquifer, the precipitation, chemical and physiological properties of the pollutants, and the attenuation of the pollutants are gaining importance (Todd and Mays, 2005). Therefore, the threat of groundwater contamination must be assessed with these factors. The data related to the mentioned factors can only be provided by detailed fieldwork.

Various methods have been established to assess groundwater quality for different purposes, such as irrigation or drinking (Wilcox, 1955; Ayers and Westcot, 1985; Aller et al., 1987; Simsek and Gunduz, 2007; Boyacioglu, 2010). The management and quality monitoring of water resources can be maintained primarily by tracing parameters related to the standards defined by international and national organizations, such as the World Health Organization (WHO) and Environmental Protection Agency (EPA). With traditional techniques, the assessment based on the comparison of water quality parameters is simple in application and detailed. However, it is also very difficult to interpret the existing data so that the decision makers can make plans for the water resources.

The quality of the groundwater cannot be assessed with only a few parameters due to the spatial variation of multiple pollutants. Common parameters used for water quality assessment are; microbial parameters such as different groups of bacteria; non-microbial parameters such as pH, turbidity etc., and for irrigation waters, electrical conductivity (EC), sodium absorption ratio

(SAR), etc. Various pollutant parameters can be measured and addition of new parameters is inevitable (Abbasi and Abbasi, 2012).

The water quality index (WQI) is a method for water quality analysis for different purposes. A WQI can be defined as the rating (grading), reflecting the compound (integral) impact of the different water quality parameters. Main advantage of the WQI is to reduce the many chemical and physical parameters into one number. WQI has been used worldwide largely in many water quality analysis (Gazzaz et al., 2012; Massoud, 2012; Iticescu et al., 2013; Lobato et al., 2015; Lobo et al., 2015). WQI mapping under the structure of the WQI is very important for water quality management. Many researchers have successfully assessed water quality worldwide by using WQI and geographical information systems (GIS) (Srivastava et al., 2011; Bairu et al., 2013; Magesh and Chandrasekar, 2013; Sadat-Noori, 2014; Selvam et al., 2014;).

The link among various data became simpler to determine with the introduction of Geographical Information Systems (GIS). GIS and spatial analysis help to model the water quality parameters and spatial distribution reliably and accurately by means of the integration of the laboratory analysis and geographical data. Thus, the water quality parameters and pollutant distribution maps could be easily generated by GIS (Gibrilla et al., 2011; Gorai and Kumar, 2013; Kumari et al., 2014). WQI study results, with the aid of maps generated by GIS, have helped political authorities (legislators) for prevention and precautions of groundwater safety (Jasmin and Mallikarjuna, 2014; Shabbir and Ahmad, 2015).

Deep aquifer of the study area in Thrace was exploited by boreholes for irrigation and drinking purposes. During the last decade groundwater levels are in decline and this alarming situation necessitates the present study for the evaluation of groundwater quality in order to design proper water management plans in east of Eastern Thrace. Hence, the aim of this study is to determine the groundwater quality for irrigation and drinking purposes in the study area by the help of traditional water quality analysis approach, and GIS to generate WQI map.

STUDY AREA

The study area covering 1476 km^2 was located west of İstanbul in the eastern Thrace region between the 27°30’ and 28°12’ east longitudes and the 41°02’ and 41°58’ north latitudes. The most populated cities of the region (Çorlu, Ergene, and Çerkezköy) are also in the study area (Figure 1).

Figure 1. Location map of the study area.

Şekil 1. Çalışma alanının yer bulduru haritası.

The study area had an annual temperature varying from -10 °C to 30 °C with the hottest months in July and August and the coldest months in January and February. The annual precipitation average was about 509 mm with a minimum and maximum of 72.2 mm and 180.3 mm, respectively (DSI, 2003). The region is influenced by semi-arid climate. Agriculture is common for the area, producing 13% of the wheat and 75% of the sunflowers in Turkey (TUIK, 2015).

The general geology of the study area is presented in Figure 2. Geological structures in the area consist of two main rock groups: Tertiary aged sedimentary rocks and Quaternary basaltic rocks. Tertiary aged sedimentary rocks include conglomerate and sandstone (Ergene formation, Tme), sandstone with claystone intercalations (Trakya formation,Tnt), Kurtdere Member(Tmk) consisting of sandstone, conglomerate and claystone intercalated with siltstone (Danişmen formation, Tod). These rocks outcrop in a large area. Quaternary basaltic volcanic rocks (Karatepe basalt, Qk) and Holocene sediments overlie the sedimentary rocks unconformably. Alluvium (Q) constitutes the youngest unit, and has a large extension in the study area (Çağlayan and Yurtsever, 1998). Ergene formation and Trakya formation form the main unconfined aquifers, due to their geological-hydrogeological characters and they have been classified as "permeable and semi permeable environment". Infiltration of rainwater and rivers constitutes the main source of aquifer recharge. The groundwater flow direction is north-east to south-west (Figure 2). Detailed geology and hydrogeology of the study area could be found in the literature (Arkoc, 2011; 2013).

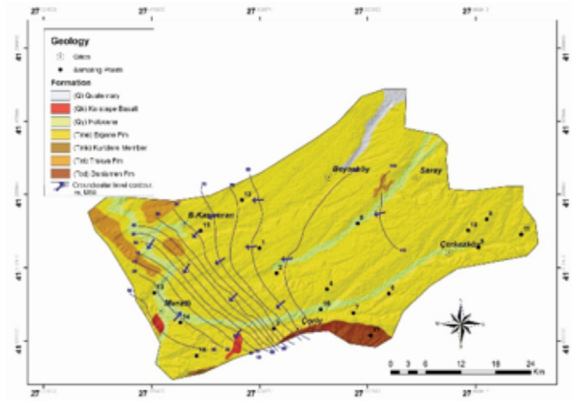

Figure 2. Geological and groundwater level map of the study area.

Şekil 2. Çalışma alanının jeoloji ve *yeraltısu seviyesi haritası.*

MATERIALS AND METHODS

The sampling well locations (n = 18) were defined in the study area to map the spatial distribution of the water quality. The sampling well depths varied from 250 to 308 m though which groundwater was taken from the Ergene formation. These wells were commonly used for irrigation or drinking purposes. All water samples were collected in polypropylene (PP) bottles washed several times with sample water prior to collection. All the collected samples were preserved in a cooler at 4 °C in the field. The samples were collected during May 2013 within the standard methods given by the American Public Health Association (APHA, 1998). The samples were analyzed for pH, total dissolved solids (TDS), and concentrations of HCO_3^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, As, and Mn. Analyses of the samples for SO_4^{2-}, NO_3^-, and HCO_3^- were done immediately on the day samples were collected. HCO_3^- was measured by titration while NO_3^- and SO_4^{2-} were determined with a Hach DR 2800 spectrophotometer. TDS and pH were measured in-situ on unfiltered water with a portable Hanna HI 98312 tester and a Toledo Mettler pH meter. Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, As, and Mn were determined with an inductively coupled plasma-mass spectrometer (ICP-ES/ ICP-MS, depending on the adequate detection limits of the instruments) analysis (ACME Labs, Vancouver, Canada). STD TMDA-70 reference material was used as a control material in the analytical measurements.

GIS Analysis

1:100 000 scale geology map of the study area was digitized in ArcGIS. Satellite images were used to generate the main topographic map of the study area in ArcGIS. The sampling well coordinates were determined by a handheld GPS instrument (Garmin eTrex) during the fieldwork and these coordinates were stored in a point attribute table with unique identification nos.(IDs) were saved as a layer in the ArcGIS (Version 10.2) software. The chemical analysis of each parameter for each well was used with this table to build the geodatabase. This geodatabase was later used to build a spatial distribution map of the water quality parameters, including the WQI for drinking water and the sodium absorption ratio (SAR), residual sodium carbonate (RSC) and magnesium hazard (MH) for irrigation water. The spatial analyst tool in the ArcGIS software was used with the inverse distance weighted raster interpolation method to map the locational distribution of the different water pollutants in the study area.

Water Quality Evaluation with WQI

The WQI was calculated to determine the quality of the groundwater in the study area for drinking purposes. Since Horton (1965), many WQI models have been proposed, but they all have limitations. The most recognized model, the weighted arithmetic mean function, was used to calculate WQI. The proposed methodology is given in the flowchart shown in Figure 3.

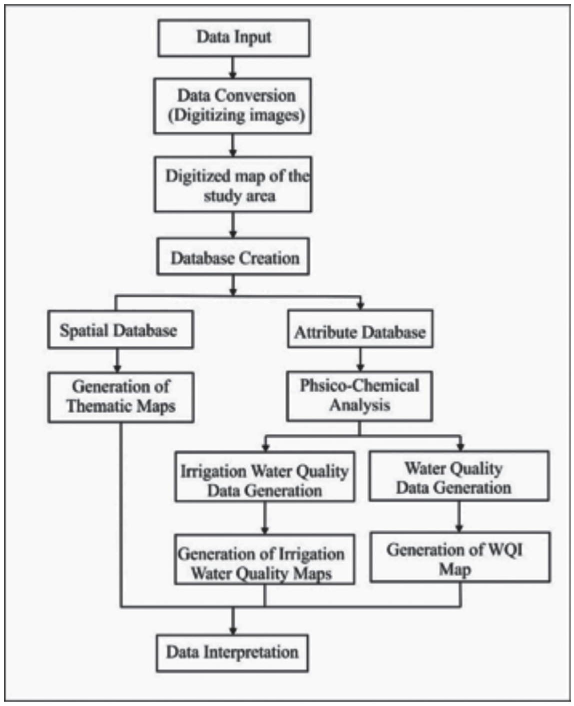

Figure 3. Flow-chart of the methodology adopted.
Şekil 3. Kullanılan metodolojiye ait akış diyagramı.

Initially, the parameters for the WQI calculation were chosen according to the WHO standards for drinking water quality. Then the weights (w_i) from 1 to 5 were assigned to these parameters according to the impact of each parameter on human health with 1 being the minimum weight and 5 being the maximum weight (Avvannavar and Shrihari, 2008). Finally, the relative weight (W_i) was calculated according to the formula given in Equation 1:

$$W_i = w_i / \sum_i^n = {}_1 w_i \quad (1)$$

In Equation 1, W_i is the relative weight, w_i is each parameter's weight, and n is the number of water quality parameters considered.

In the next step, a quality-rating scale (q_i) of each parameter was calculated according to formula given in Equation 2:

$$q_i = \frac{C_i}{S_i} \text{ x } 100 \quad (2)$$

In Equation 2, q_i is the quality rating, C_i is the observed concentration of each parameter in the water sample (mg/l), and S_i is the limit value (desirable limit) of each parameter in the WHO standard (mg/l).

As a result, the formula used to determine the aggregated WQI is given in Equation 3:

$$WQI = \sum W_i \text{ x } q_i \quad (3)$$

Water Quality Evaluation for Irrigation Purposes

Irrigation water quality has always been a major part of agricultural crop yield. The impact of the water's mineral composition on soils and plants determines the suitability of groundwater for irrigation purposes. For this purpose, several criteria, such as SAR, RSC, Na% and MH, were used to assess the quality of irrigation waters.

SAR was defined by Wilcox (1955). The experiments show that the SAR reasonably predicts the degree to which irrigation water tends to enter into a cation-exchange reaction in the soil. High values of SAR imply a hazard of sodium replacing adsorbed calcium and magnesium, a situation ultimately damaging to the soil structure (Khan and Abbasi, 2013). SAR was computed according to the relationship shown in Equation 4 with concentrations given in meq/l.

$$SAR = Na+/\sqrt{(Ca^{2+} + Mg^{s+})/2} \quad (4)$$

The RSC was calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purposes. RSC is expressed by Equation 5, in which all ionic concentrations are expressed in meq/l (Eaton, 1950).

$$RSC = [(HCO_3 + CO_3) - (Ca^{2+} + Mg^{2+})]. \quad (5)$$

Generally, calcium and magnesium in water are in equilibrium. However, if the amount of magnesium in water increases, it adversely affects soil quality by increasing the alkalinity of the soil, thus, reducing its crop yield (Szabolcs and Darab, 1964). MH is given by the formula in Equation 6 with all values in mg/l.

$$MH = [Mg^{2+} / (Ca^{2+} + Mg^{2+})] \text{ x } 100. \quad (6)$$

DISCUSSIONS

Water Quality Assessment for Drinking Purposes

Water quality is an important factor for health and safety issues associated with public health (Baba and Tayfur, 2011). Thus, the determination of a water's suitability for drinking purposes is essential. The statistical results for the physio-chemical parameters of the groundwater samples are tabulated in Table 1.

Table 1. Results of the chemical analysis of the studied parameters (mg/l).
Çizelge 1. Çalışılan parametrelerin kimyasal analiz sonuçları (mg/l).

Well	x	y	pH	EC	TDS	Alkalinityy	TH	Ca^{2+}	Mg^{+}	Na^{+}	K^{+}	Cl-	SO_4^{2-}	NO_3^{-}	As	Mn
1	553322	4569197	8,2	1550	780	610	594,2	162	46	137	1	75	29,5	20,3	0,003	0,0014
2	555556	4564899	7	481	245	488	188,2	51,5	15	31,1	2,3	15	5,99	1,3	0,007	0,002
3	555286	4555391	8	570	284	600	266,8	74,9	19	29,9	3,9	8,7	*	2,4	0,002	0,002
4	562097	4562197	7,1	835	416	732	358,4	103	25	44,3	2,8	64	*	2,4	0,003	0,0025
5	565940	4573513	7,4	1468	750	488	730,5	211	50	79	3,9	47	357	8,1	0,003	0,0111
6	570070	4561522	7,3	487	245	854	183,1	55,2	11	30,4	1,9	38	1,08	3,8	0,006	0,0009
7	565530	4558160	7	1280	633	612	597,8	174	40	69,6	3,8	60	104	20,3	0,002	0,0031
8	582545	4574397	6,6	470	230	608	182,3	52,6	12	28	1,7	17	*	1,5	0,009	0,0017
9	581513	4569573	6,1	683	343	592	271,4	41,8	41	73,4	2,4	40	6,45	1	0,001	0,0027
10	580174	4572475	7,2	723	365	601	497,4	152	29	122	0,6	34	4,28	8,7	0,002	0,0007
11	587000	4571850	7,8	987	498	512	193,6	63,5	8,5	37,5	3,5	45	5,01	0,5	0,006	0,0023
12	551000	4577411	7,9	434	219	614	246,5	70,4	17	27,6	4,8	23	202	1,2	0,002	0,0012
13	539823	4561405	7,6	523	264	792	338,2	120	9,2	48,3	3,5	9,2	6	3,1	0,002	0,0034
14	543217	4556381	8,5	763	389	544	635,9	195	37	84,3	4,2	57	1,3	2,5	0,003	0,0013
15	545712	4572112	7	343	173	794	243,6	64,3	20	39,2	2,5	18	*	7,2	0,002	0,0014
16	561300	4558750	7,8	386	198	620	651	193	41	58,4	3,9	26	7,12	3,4	0,007	0,0025
17	567788	4554303	8,2	549	280	584	205,1	54,5	17	35,4	2,5	18	*	4,4	0,002	0,0024
18	545344	4550675	8	565	288	621	255,1	45,8	34	67,5	3,2	34	*	1,2	0,002	0,002
Min			6,1	343	173	488	182,3	41,8	8,5	27,6	0,6	8,7	*	0,5	0,001	0,0007
Max			8,5	1550	780	854	730,5	211	50	137	4,8	75	357	20,3	0,009	0,0111
Mean			7,5	728	367	625,9	368,8	105	26	57,9	2,9	35	40,5	5,2	0	0
SD			0,6	355	179	100,6	186,4	58,2	13	31,3	1,1	19	91,5	5,8	0	0

* Below detection limit

** Tespit sınırı altında*

Water pH determines the solubility and microbiological availability of its chemical constituents, such as nutrients and heavy metals (Zhou et al., 2015). An optimum water pH of 7.0 to 8.5 has no direct impact on consumers (WHO, 2011). The pH of the groundwater samples in the study area varies from 6.1 to 8.5 with an average value of 7.48. This indicates that the sampled groundwater is slightly acidic to slightly alkaline. The spatial distribution of the pH concentrations is given in Figure 4a.

TDS is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water (WHO, 2011). TDS is primarily related to inorganic salts of magnesium, calcium depending on the solubility of the minerals in the geological formations. TDS values of the collected water samples showed a variation of 173 to 780 mg/l with an average of 366.67 mg/l (Table 1). As all the TDS values in the study area are found to be below 1500 mg/l, they are all suitable for drinking purposes (Figure 4b).

Figure 4c shows that all groundwater samples had higher bicarbonate alkalinity concentrations than the WHO standard (120 mg/l). Bicarbonate alkalinity concentrations in the study area vary from 488 to 780 mg/l with an average of 625.89 mg/l.

The order of the major anions according to their abundance in the study area is HCO_3^- > SO_4^{2-} > Cl^- > NO_3^-. The first dominant anion HCO_3^- was already discussed. The sulfate concentrations of the groundwater are elevated but not higher than the maximum allowable limit of 250 mg/l, according to WHO, except sample 5 with a concentration of 357 mg/l (Table 1). The spatial distribution of sulfate ion concentrations shows that 98% of the collected samples are within the maximum allowable limit of 250 mg/l (Figure 4d).

Chloride is the third dominant anion in the study area. The concentration of chloride in the study area varies from 8.7 to 75 mg/l (Table 1). None of these values exceeds the maximum allowable concentration of 250 mg/l (Figure 4e).

Nitrate is the fourth dominant anion in the study area. Nitrate can be found in the groundwater because of agricultural activity, wastewater disposal, and the oxidation of animal and human excrement. NO_3^- concentrations of the groundwater samples varies from 0.5 to 20.3 mg/l with an average value of 5.18 mg/l (Table 1). None of the concentrations in the groundwater samples exceeds the guideline value of 50 mg/l for both WHO (2005) and TS266 (2011) standards (Figure 4f).

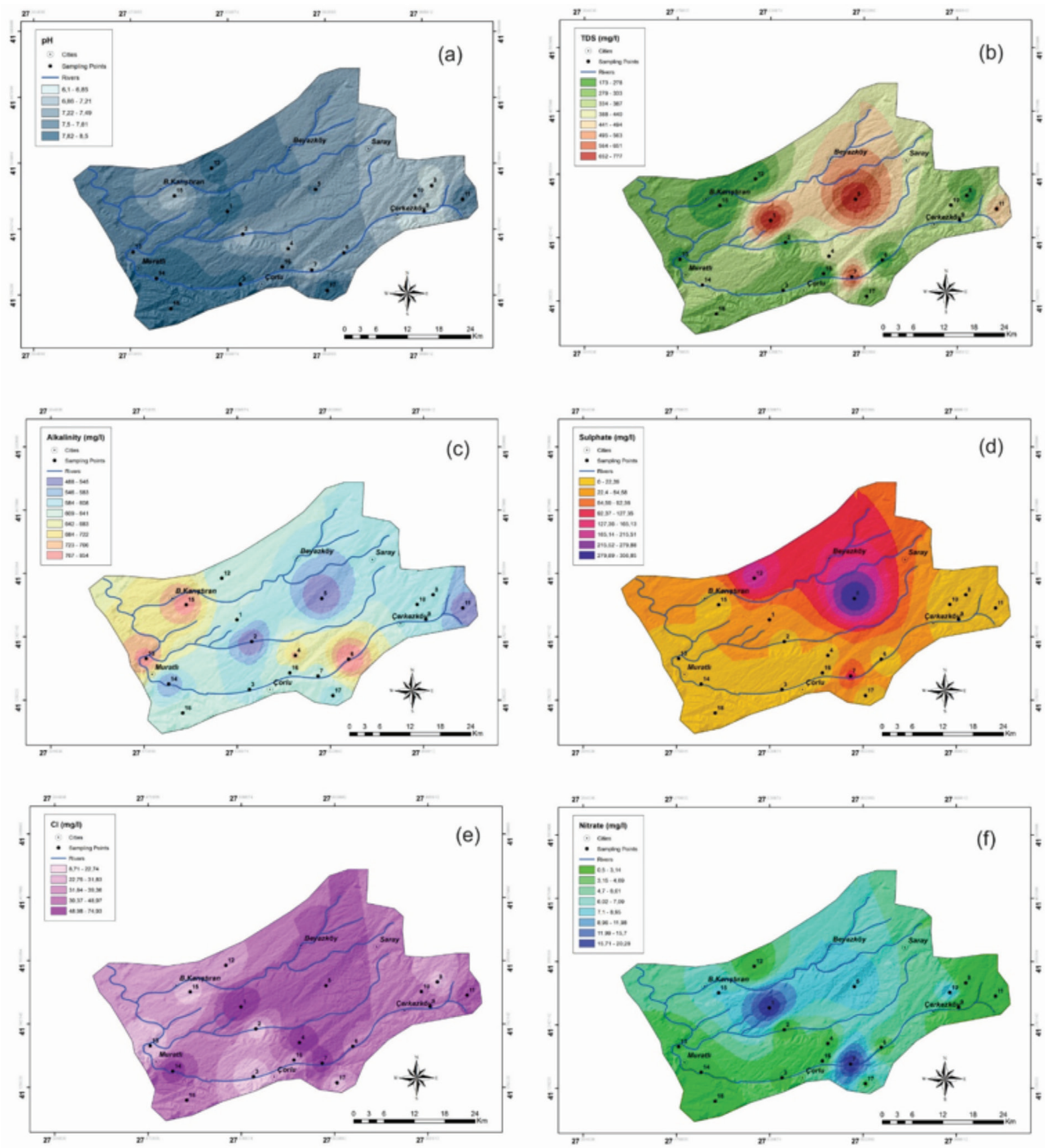

Figure 4. Spatial distribution map of pH (a), TDS (b), alkalinity (c), sulphate (d), chloride (e) and nitrate (f)

Şekil 4. pH (a), TDS (b), alkalinite (c), sülfat (d), klorür (e) ve nitrat (f) mekansal dağılım haritası.

The main cation trend in the study area is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$. The calcium concentration of the groundwater samples in the study area varies from 41.8 to 210.7 mg/l with an average value of 104.67 mg/l (Table 1). As the maximum permissible limit for calcium is 100 mg/l, only 50.88% of the samples are below the maximum permissible limit (Figure 5a). This is due to calcium carbonate minerals deposited in the aquifer matrix (Gültekin, 1998).

The second most dominant cation is sodium. The concentration of sodium in the groundwater varies from 27.6 to 136.7 mg/l with an average value of 57.94 mg/l (Table 1). The average taste threshold for sodium is 200 mg/l and none of the samples exceeds this value (Figure 5b).

The third most dominant cation is Mg. Compared to calcium, the ion concentration in the samples are low, with a range of 8.5-49.7 mg/l, and an average of 26.13 mg/l (Table 1). All of the samples area below the permissible limit of 50 mg/l. The spatial distribution of Mg is given in Figure 5c.

Potassium is the fourth most dominant cation in the study area. The potassium concentration values of the samples show a variation between 0.6 and 4.8 mg/l with an average of 2.91 mg/l (Table 1). All the groundwater samples are within the permissible upper limit (82 mg/l) for the potassium (Figure 5d).

The spatial distribution of arsenic in the study area reveals that all the groundwater samples has lower concentrations than that given by both WHO and TS266 standards (Figure 5e). The concentrations of arsenic range from 0.0013 to 0.0086 mg/l (Table 1). In addition, all of the groundwater samples contain manganese below the guideline limit (0.05 mg/l) with values of 0.0007 to 0.0011 mg/l. The spatial distribution of the manganese is given in Figure 5f.

Water Quality Assessment for Irrigation Purposes

Ion chemistry of the groundwater mainly depends on the geochemical composition of the aquifer rocks and the interaction time of the groundwater with the aquifer media. The SAR, RSC, Na%, and MH were used in this study to assess the availability of groundwater for irrigation purposes. This criterion could be a guide for farmers to avoid crop loss due to irrigation, and they could take measures to improve soil productivity and crop yields. Table 2 shows the calculated values of this criterion for each groundwater sample.

Table 2. Groundwater quality parameters of the study area.

Çizelge 2. Çalışma alanındaki yeraltısuyu kalite parametreleri.

Sample no	SAR (meq/l)	RSC (meq/l)	Na% (meq/l)	MH (meq/l)
1	2,43	6,27	33,41	31,84
2	0,61	-26,95	7,85	9,49
3	0,81	-32,35	9,41	7,6
4	0,99	-40,14	10,18	9,09
5	2,33	-30,89	23,06	21,03
6	0,50	-45,09	5,15	5,54
7	1,77	-36,21	17,46	15,81
8	0,56	-32,59	6,68	7,05
9	0,43	-35,53	5,03	16,99
10	1,47	-40,09	14,19	25,18
11	0,72	-28,68	9,03	10,77
12	0,75	-32,86	8,83	6,9
13	1,12	-43,46	10,9	9,13
14	2,05	-34,03	20,11	20,38
15	0,59	-42,82	6,18	7,54
16	1,98	-35,7	19,17	13,46
17	0,59	-32,01	7,06	9,09
18	0,46	-36,54	5,36	15,18

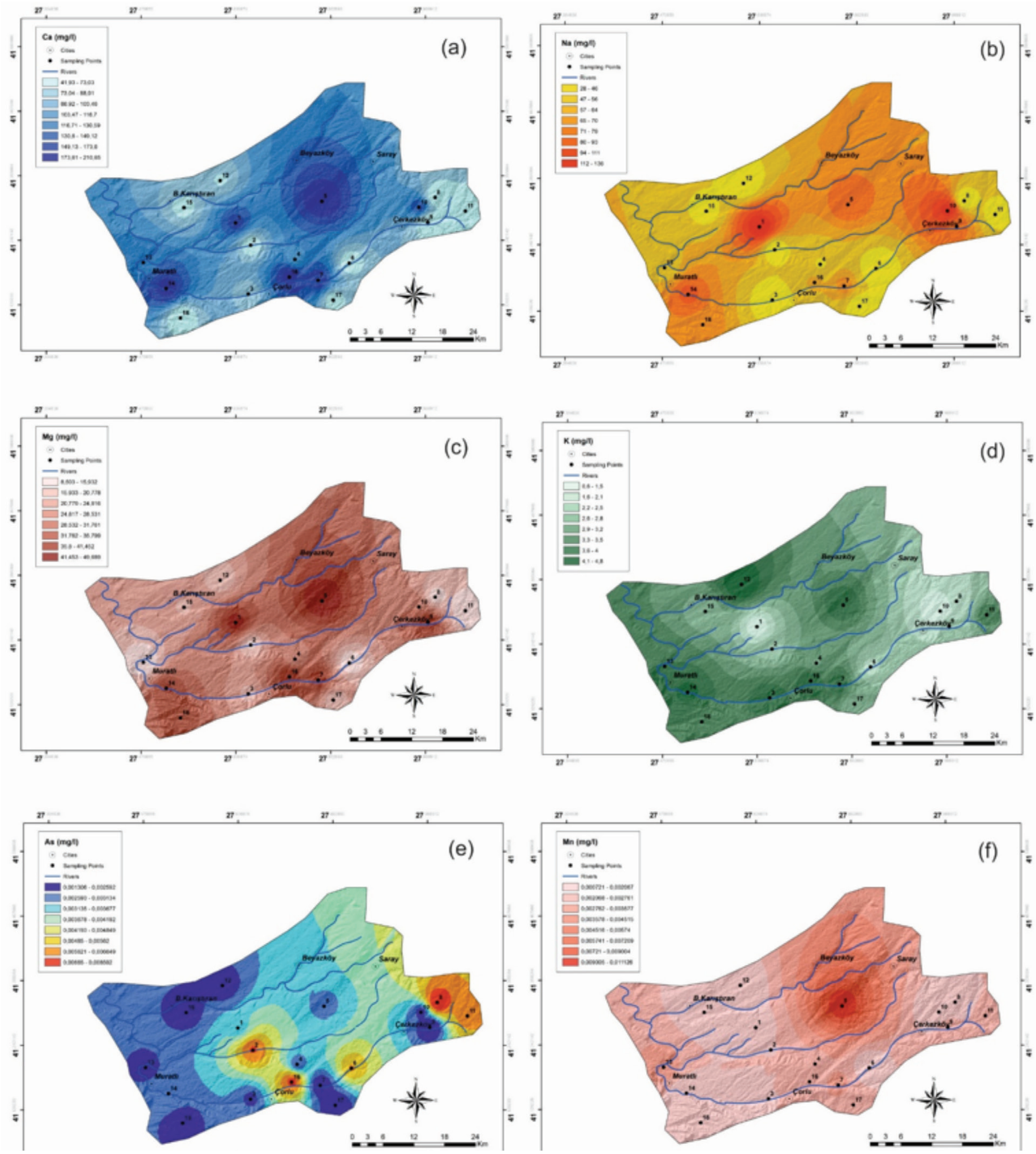

Figure 5. Spatial distribution map of calcium (a), sodium (b), magnesium (c), potassium (d), arsenic (e) and manganese (f).

Şekil 5. Kalsiyum (a), sodyum (b), magnezyum (c), potasyum (d), arsenic (e) ve mangan (f) mekansal dağılım haritası.

If the SAR values of irrigation waters rise above level 6, soil permeability and structural stability are inversely affected, and the water is defined as unsuitable (Table 3) due to the development of alkaline soil (Beltrán, 1999). In the study area, the SAR values ranging between 0.01 to 0.55 meq/l, indicate that all the samples are suitable for irrigation. The spatial distribution map of SAR is given in Figure 6a.

Table 3. Definition of SAR classes.

Çizelge 3. SAR sınıfları tanımları.

SAR (meq/l)	Water quality
0-6	Good
6-9	Doubtful
>9	Unsuitable

The RSC is used to determine the hazardous effect of carbonates and bicarbonates on irrigation water quality. If the RSC value is below 1.25, then the water is suitable for irrigation (Table 4). A negative RSC indicates that sodium buildup is improbable because adequate calcium and magnesium are in excess of what can be precipitated as carbonates. The groundwater samples were classified according to classes given in Table 4. The RSC in the groundwater varies from 6.27 to -45.10 meq/l (Table 2). Nevertheless, according to the RSC, all the samples are within the safe category for irrigation except sample no. 1 due to high carbonate concentration which could be due to the presence of minerals producing sodium carbonate. The spatial distribution map of RSC is shown in Figure 6b.

Table 4. Definition of water quality classes based on RSC.

Çizelge 4. RSC'ye göre su kalitesi sınıfları tanımları.

RSC (meq/l)	Water quality
<1,25	Good
1,25-2,5	Doubtful
>2,5	Unsuitable

Na^+ is an important cation that deteriorates the soil structure and crop yield due to high osmotic pressure in excess. The sodium ratio of the groundwater samples varies from 5.03 to 33.41 with an average of 12.17 (Table 2). The spatial distribution map shows that 92% of the samples are in the "excellent" category and the remaining 8% are in the "good" category (Table 5, Figure 6c).

Table 5. Definition of water quality classes based on the sodium percentage (% Na).

Çizelge 5. Sodyum yüzdesine (% Na) göre su kalitesi sınıfları tanımları.

Na% (meq/l)	Water quality
<20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

In groundwater, alkaline earths are in equilibrium. If the soil increases in alkalinity, such as with an excess of Mg and Ca, the crop yield will be reduced. The computed values of the MH in the groundwater of the study area are from 5.54 to 31.84 meq/l with an average of 13.43 meq/l (Table 2). If irrigation water contains more than 50 meq/l of MH, the water is considered harmful for irrigation (Table 6). The spatial distribution map of MH shows that all the samples are below an MH of 50 meq/l; thus, they can be considered as "suitable" for irrigation (Figure 6d).

According to the assessment techniques mentioned above, the majority of the groundwater of the study area is suitable for irrigation purposes.

Table 6. Definition of water quality classes based on the magnesium hazard (MH).

Çizelge 6. Magnezyum tehlikesine(MH) göre su kalitesi sınıfları tanımları.

MH (meq/l)	Water quality
<50	Suitable
>50	Unsuitable

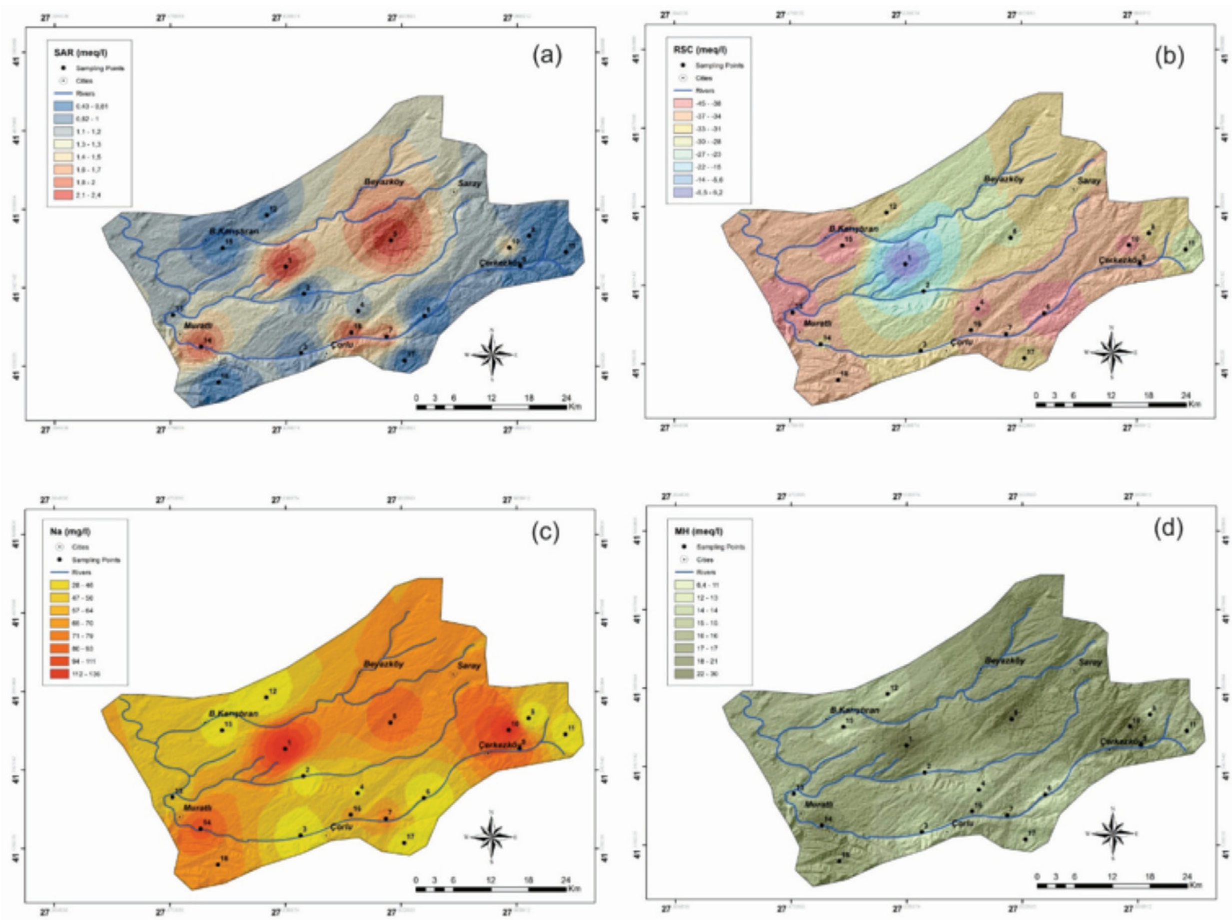

Figure 6. Spatial distribution map of SAR (a) RSC (b) %Na (c) MH (d).

Şekil 6. SAR (a), RSC (b), %Sodyum (c), MH (d) mekansal dağılım haritası.

Water Quality Index, WQI

For the calculation of the WQI, different parameters were selected and a weight was assigned to each parameter according to the estimated impact on human health (Saeedi et al., 2010; Vasanthavigar et al., 2010). Table 7 shows the assigned weight and relative weight of each parameter with WHO standards. Nitrate and arsenic receive the maximum weight of 5 due to their major importance to human health and water quality (Table 7) (Srinivasamoorthy et al., 2008). The other parameters are assigned weights from 1 to 3, according to their importance in defining water quality. The WQI of the samples, calculated with these parameters, ranges from 41 to 372.74 (Table 8). The grading of the WQI parameters is tabulated in Table 9.

Table 7. Standard values given by WHO (2011) and TS266 (2005), calculated weight and relative weight of studied parameters of the groundwater of the study area (mg/l).

Çizelge 7. Çalışılan yeraltısuyu parametrelerin*in DSÖ (Dünya Sağlık Örgütü) (2011) ve TS266 (2005) tarafından verilen standart ile hesaplanan değerleri ve bağıl ağırlıkları (mg/l).*

Parameters	WHO Standard	TS266 Standard	Weight(w_i)	Relative weight(W_i)
TDS	1000	*	3	0,094
HCO_3^-	120	*	2	0,063
Na^+	200	200	3	0,094
K^+	82	*	1	0,031
Ca^{2+}	75	*	2	0,063
Mg+	50	*	2	0,063
SO_4^{2-}	250	250	3	0,094
Cl^-	250	250	3	0,094
NO_3^-	50	50	5	0,156
As	0,05	0,01	5	0,156
Mn	0,05(p)	0,05	3	0,094
			Σ_{wi} = 32	Σ_{Wi} = 1,00

(p): provisional guideline values

Table 8. WQI values of each groundwater sample.

Çizelge 8. *Yeraltı suyu örneklerine ait SKİ değerleri.*

Sample no.	WQI	Classification
1	118,44	Poor Water
2	51,61	Good water
3	44,42	Excellent water
4	257,74	Very poor water
5	129,76	Poor Water
6	62,90	Good water
7	232,17	Very poor water
8	49,77	Excellent water
9	55,80	Good water
10	63,43	Good water
11	34,73	Excellent water
12	372,74	Unfit for Drinking
13	73,59	Good water
14	64,78	Good water
15	53,03	Good water
16	74,75	Good water
17	41,00	Excellent water
18	47,19	Excellent water

Table 9. Definition of WQI

Çizelge 9. SKİ sınıfları ve aralıklarının tanımları.

WQI Range	Type of Water
<50	Excellent
50-100	Good
100-200	Poor
200-300	Very Poor
>300	Unfit for drinking

The spatial distribution map of the study (Figure 7) shows that 5% of the samples indicated "excellent water," 41% indicated "good water," 46% indicated "poor water," 6% indicated "very poor water," and 2% indicated "unfit for drinking water," according to the classification given by Sahu and Sikdar (2008) (Table 9). The deteriorated water classes originating in wells 5 and 12 were due to elevated sulfate levels (202–357 mg/l). Elevated sulfate concentrations in the study area are due to gypsum layers within the Ergene formation (Arkoç, 2013). The poor water quality is due to high nitrate concentration (19–20.3 mg/l) compared to the rest of the study, attributable to an overdose application of fertilizers causing the leaching of nitrates into the groundwater. TDS and nitrate concentrations in the study area are generally correlated. Especially wells closer to the distal end of groundwater flow system has elevated TDS and nitrate concentrations. The relation between the water pH and arsenic content is notable. According to the distribution maps of arsenic and pH, increased arsenic values are generally accompanied by slightly increased pH values, which might mean that arsenic found in these areas is a naturally occurring substance in the nearby groundwater (Fytianos and Christophoridis, 2004).

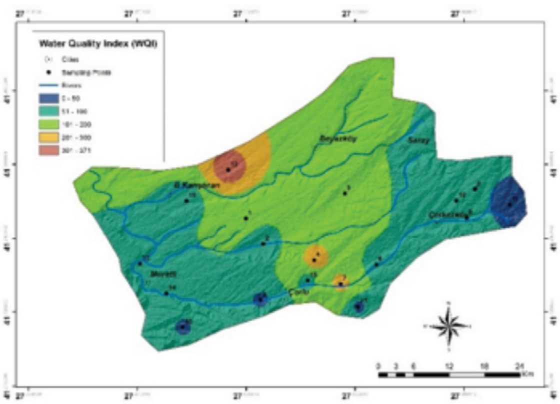

Figure 7. Spatial distribution map of WQI.
Şekil 7. SKİ mekansal dağılım haritası.

RESULTS AND CONCLUSIONS

In this study it was aimed to evaluate and map the groundwater quality of the eastern Thrace. For this purpose, spatial distributions of the groundwater quality parameters were mapped through GIS. The WQI is very productive and beneficial in abridging and reporting the monitoring data for the decision makers. This results in a more understandable water quality status and better usage of water resources in the future. However, the parameters used for defining the WQI are not exact. Various researchers have used different physio-chemical parameters of groundwater, but the addition of the WHO's metal parameters would make the WQI much more powerful. In addition, all index models depend on the expert opinion, which should be objective. One parameter with a high or low weight could easily influence the resultant WQI value.

The spatial distribution of the WQI showed that most of the groundwater in the study area are in the "poor" or "very poor" class due to sulfate and nitrate contamination. However, with respect to the SAR, RSC, Na%, and MH, the majority of the groundwater is suitable for irrigation. This study shows that the usage of GIS and WQI methods could provide more useful information for water quality assessment.

It should be noted that changes in agricultural practices and urbanization in time will affect groundwater quality by changing loads of nutrients and pollutants in the recharging groundwater. These changes also will affect the distribution maps of the pollutants. This study could be a baseline for the authorities to establish a groundwater management plan in the study area in the future.

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