

An Assessment of Shallow Groundwater Wells in an Agricultural and Coastal Area in Göksu Delta, Turkey

Esra Deniz Güner^{1*}, Senem Tekin², Galip Seckin¹

Abstract: The Göksu Delta of Turkey is an alluvial delta with intense agricultural activity and has great ecological and economic significance. The delta is environmental protection area in term of remarkable in natural life. In particular, water birds are an important point, delta chosen as Ramsar site. So, this special area is important in terms of monitoring water quality and effects of anthropogenic activities (such as agricultural). Water samples were collected monthly from 24 wells in the study area, and 13 water quality parameters were examined. The objective of the study was also to determination the water quality in wells of the Göksu Delta and assess levels of salinisation in the region. Piper diagrams and the Geographic Information Systems (GIS) was used to generate ionic ratios to evaluate water quality in the study area in an efficient manner. Overall, the groundwater examined has medium levels of salinity and low sodium content. Piper diagram shows that all the samples collected from the region are located in NaCl, KCl, Na₂SO₄ zone. The increase in groundwater salinity and amounts of Na⁺ and Cl⁻ are indicators of saltwater intrusion. Rock dissolution and ion exchange were also found to play an active role in the region. All of these factors affect the sustainability of the freshwater aquifers and lower their quality for wildlife species.

Keywords: Groundwater quality, diagram, seawater intrusion, salinity, geographical information systems (GIS)

1. Introduction

The demand for freshwater resources has been increasing gradually due to population growth, and consequently, the use of underground water resources as a source of fresh water has increased over a short period. Shallow groundwater resources are currently being used for agricultural production in many parts of Turkey. Agricultural activity results in the intense use of groundwater, which in turn can have significant effects on the quality of groundwater, particularly in shallow coastal aquifers (Trabelsi et al., 2012; Huang et al., 2013; Knight et al., 2013; Kastridis and Kamperidou, 2015). Additionally, there is natural groundwater pollution, which is due to geological formation with shallow groundwater mass, infiltration from low-quality surface water bodies,

seawater intrusion, geothermal fluids and anthropogenic groundwater pollution (Baba and Ayyildiz, 2006).

The precincts is an important part of the Mediterranean region with its tourism potential, important natural, historical and ecological heritage area. The region host a wetland site which is classified as a Wetland of International Importance according to the Ramsar Convention due to its location along bird migration route. Besides that, the area has a particular significance for being one of the few remaining areas where sea turtles lay their eggs in the world. In this area there are significant and intense agricultural activities each month of the year due to it being characterised by a typical Mediterranean Climate. With these properties, a careful examination of the

¹Cukurova University, Faculty of Engineering and Architecture, Department of Environmental Engineering, 01330, Adana, Turkey.

²Cukurova University, Faculty of Engineering and Architecture, Department of Geology Engineering, 01330, Adana, Turkey.

* Corresponding author: *egunerr@cu.edu.tr

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hydro-chemical qualities of coastal aquifer systems is crucial to assess the current condition of the aquifers, levels of saltwater intrusion, and impacts of human-environment interaction.

In this study, the water quality was examined from 24 wells samples. Physical and chemical water quality parameters were analysed over the period of a year. This study provides both an overview of the hydrochemical parameters in the delta, using hydro-chemical parameters, and evaluates the distribution of geochemical parameters and their variations using graphs and GIS maps.

2. Material and Method

2.1. Description of the study area

The Göksu Delta is situated in the Mediterranean Sea region of Turkey between latitude 35°35' N and longitudes 33°17' E (Figure 1). The Göksu Delta was formed by the deposition of alluvial material carried by the Göksu River. A wide flatness characterizes the geomorphology of the study area that has an elevation that ranges from 0 to 5 m in height above the sea. Göksu delta is in the east of the Paradeniz and Akgöl lagoons. The total area is about 15 000 ha which 226 km² is the protection area.

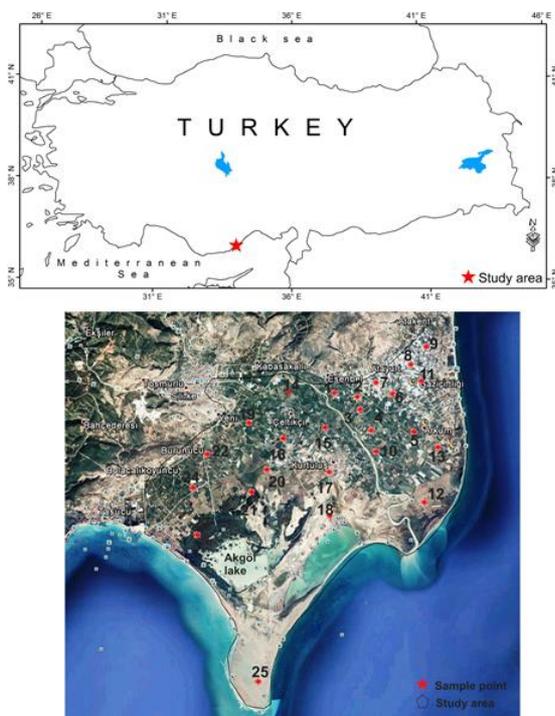


Figure 1. Sample sites in the Göksu Delta.

Meteorological data have obtained from Silifke Meteorology Directorate's TUMAS (Turkish Meteorological Archiving System) which has the most eligible data for study site and database via formal request (Table 1). Wet and mild winter combined with dry and hot summers are typical for the coastal zone around the Mediterranean Sea. The meteorological data of Silifke indicates that annual average temperature was 20.89°C, total annual precipitation was 606.8 mm, and average annual relative humidity was 55.5%, the mean annual precipitation is 43.3 mm in the Göksu Delta between May 2011 and April 2012.

Table 1. Range of meteorological parameters in the Göksu Delta

| Temperature (°C) | Relative humidity (%) | Precipitation (mm) | Temperature (°C) |
|------------------|-----------------------|--------------------|------------------|
| Maximum | 25.4 | 77.1 | 37.5 |
| Minimum | 17.0 | 30.1 | 14.8 |
| Average | 21.0 | 55.5 | 21.4 |

2.2. Sample collection and analysis

A total of 24 water wells were selected, in the Göksu Delta to represent all the study areas. Water samples from the selected wells were collected on a monthly basis over a year. pH and EC values of the samples were measured on site using; WTW brand pH-meter and an Orion brand conductivity meter. A Shimadzu ion chromatography (IC) device was used for Anion (SO₄²⁻, Cl⁻, NO₃⁻) analyses, and Optical Emission Spectrometry (ICP-OES) was used for the analysis of Cations (Ca²⁺, Mg²⁺, Na⁺, K⁺). The detection of carbonate (CO₃²⁻) and bicarbonate (HCO₃⁻) in water was made using titration of H₂SO₄ acid solution with methyl orange and phenolphthalein as indicators. Total dissolved solids (TDS) analysis was carried out using Method 2540 C. Standards to check the accuracy and precision of the analyses were provided before and during the analysis. Sodium adsorption ratio (SAR) used in the classification of water, the residual sodium carbonate (RSC) and %Na are calculated respectively according to the following formulas below. All ionic values used in these formulas are in meq/l.

The sodium adsorption ratio (SAR) was calculated by using the following formula (Ragunath, 1987):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

The residual sodium carbonate (RSC) was determined as follows (Eaton, 1950):

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

The %Na was determined as follows (Wilcox, 1955):

$$\%Na = \frac{100 \times Na^+}{Na^+ + Ca^{2+} + K^+ + Mg^{2+}}$$

3. Results and Discussion

The descriptive statistical overview of the hydrochemical data of the groundwater is presented in Table 2. The water samples obtained from the wells in the study area had pH values ranging from 7.5 to 8.19 with mean ± s.d. of 7.82-0.04, which indicates slightly alkalinity.

Distribution maps for EC, Cl⁻, TDS and SO₄²⁻ which are strong indicators of seawater intrusion, are displayed in Figure 3, clearly showing that these parameters are higher in the Göksu region. The average annual EC was measured as 1471.74 ± 1262.63 µS/cm (mean ± sd). TDS values varied from 156.61 to 3941.3, with an annual average of 807.88 ± 821.98 mg/L (mean ± sd). The examination of seawater intrusion using EC values, with the threshold value set at 1000 µS/cm, shows indicators of high EC seawater intrusion into the wells, varies with the time of the year, and possess a serious threat to water quality. The assessment of groundwater samples for salinity from the Göksu Delta showed that none of the samples met the criteria for freshwater classification (TDS<500 mg/L) in terms of total dissolved solids, all samples are classified as brackish water. Increasing salinity in coastal groundwaters is an indicator of saltwater intrusion and results in decreasing the use of the aquifer as it no longer provides high-quality irrigation water.

Table 2. Average of 12-months analytical results of water quality parameters from Göksu Delta

| Sample Point | T | PH | EC | TDS | Ca ²⁺ | Mg ²⁺ | K ⁺ | Na ⁺ | Cl ⁻ | SO ₄ ²⁻ | NO ₃ ⁻ | HCO ₃ ⁻ | CO ₃ ²⁻ |
|--------------|------|-----|--------|--------|------------------|------------------|----------------|-----------------|-----------------|-------------------------------|------------------------------|-------------------------------|-------------------------------|
| 1 | 20.7 | 7.7 | 1014 | 605.15 | 88.61 | 51.91 | 5.05 | 31.6 | 94.8 | 228.8 | 12.4 | 347.9 | 5.93 |
| 2 | 20.2 | 7.7 | 1324.6 | 796.88 | 100.4 | 48.04 | 5.69 | 77.5 | 127.74 | 251.3 | 12.2 | 381.6 | 2.58 |
| 3 | 20.3 | 8 | 667.42 | 574.69 | 85.52 | 45.52 | 4.89 | 88.2 | 212.77 | 169.3 | 12.1 | 191.1 | 17.6 |
| 4 | 20.4 | 8 | 883.67 | 392.82 | 78.23 | 20.56 | 4.88 | 108.7 | 94.02 | 226.6 | 12.1 | 211.3 | 17.1 |
| 5 | 21.2 | 7.6 | 1632 | 817.65 | 15.83 | 14.77 | 7.43 | 282 | 308.89 | 172 | 12.4 | 311 | 5.58 |
| 6 | 22.8 | 7.6 | 1208.5 | 728.74 | 63.66 | 48.29 | 14.7 | 89.34 | 98.5 | 253.7 | 12.2 | 453.7 | 2.05 |
| 7 | 21.2 | 8 | 1106.2 | 555.87 | 43.61 | 63.39 | 11.7 | 191.7 | 171.61 | 321.5 | 12.1 | 285.7 | 11.4 |
| 8 | 20.8 | 8.2 | 1014 | 523.32 | 21.39 | 20.46 | 13.6 | 134.3 | 136.69 | 138.7 | 12.4 | 240.4 | 22.4 |
| 9 | 20.4 | 8 | 1171.4 | 548.93 | 19.36 | 21.55 | 13.9 | 149.1 | 154.93 | 151 | 12.1 | 251.9 | 11.8 |
| 10 | 20.4 | 8 | 832.08 | 405.14 | 21.55 | 19.28 | 6.19 | 110.4 | 111.92 | 124.1 | 12.1 | 229 | 14.4 |
| 11 | 20.9 | 8.1 | 1104.9 | 551.18 | 28.07 | 18.22 | 11.3 | 155.9 | 123.13 | 245.7 | 12.5 | 264.9 | 21.4 |
| 12 | 22.3 | 7.7 | 5677.5 | 3941.3 | 124.8 | 125.6 | 34.5 | 880.1 | 1597.6 | 299.8 | 12.4 | 211.6 | 2.33 |
| 13 | 22.3 | 7.8 | 4629.2 | 2695.1 | 100.8 | 96.22 | 31.8 | 741.8 | 1279.4 | 207.8 | 12.9 | 234 | 4.98 |
| 14 | 20.7 | 7.8 | 753.33 | 322.7 | 56.28 | 31.54 | 3.27 | 25.72 | 112.64 | 105.6 | 12.6 | 233.6 | 9.55 |
| 15 | 20.7 | 7.7 | 949.75 | 488.31 | 136.4 | 64.44 | 4.2 | 42.05 | 185.13 | 250 | 12.7 | 289.2 | 5.08 |
| 16 | 20.5 | 7.8 | 1429.3 | 610.05 | 44.36 | 44.39 | 3.02 | 169.3 | 332.06 | 123.3 | 13 | 205.2 | 7.63 |
| 17 | 22.7 | 7.9 | 1277.6 | 568.92 | 37.35 | 27.65 | 5.99 | 149.6 | 254.34 | 130.8 | 13.3 | 196.5 | 13.8 |
| 18 | 22 | 8.2 | 3352.5 | 1517.1 | 36.68 | 29.98 | 20.4 | 452 | 543.51 | 223.5 | 13.3 | 267.6 | 23.1 |
| 19 | 21.6 | 7.8 | 265.57 | 156.61 | 31.57 | 13.4 | 4.66 | 411.1 | 100.51 | 302.3 | 12.3 | 77.75 | 9.88 |
| 20 | 20.9 | 7.9 | 601.25 | 256.4 | 45.06 | 25.96 | 2.41 | 31.8 | 72.02 | 114.2 | 12.5 | 203.5 | 9.97 |
| 21 | 20.7 | 7.6 | 633.42 | 308.15 | 36.86 | 16.64 | 2.71 | 53.44 | 77.32 | 115.7 | 12.5 | 221.7 | 2.6 |
| 22 | 23.1 | 7.6 | 924.75 | 528.17 | 96.81 | 30.69 | 6.32 | 19.51 | 123.47 | 160.7 | 12.7 | 260.7 | 2.57 |
| 23 | 21.3 | 7.7 | 2041.6 | 994.67 | 74.45 | 34.29 | 5.11 | 255.5 | 362.65 | 205.8 | 12.5 | 273.6 | 2.58 |
| 24 | 22.4 | 7.5 | 827.33 | 501.29 | 110.8 | 35.84 | 2.51 | 23.54 | 145.61 | 181.4 | 12.3 | 305.5 | 2.48 |

*The water temperature (T) is in °C, electrical conductivity (EC) is in µS/cm, and the other parameters are in mg/L.

The amount of Cl^- in the water from sample sites varied between 72 and 1598 mg/L and the Cl^- in groundwater comes from rocks, from rain water and melting snow, and from the atmosphere (Belkhir et al., 2012). Apart from these sources, the only other source of chloride in groundwater is seawater. Surface water in coastal areas has very high Cl^- content, which makes up more than half of all elements dissolved in seawater (Demir, 2008). Studies show that when Cl^- amounts are over 250 mg/L, the groundwater in question is either already intruded by saltwater or is under serious threat of intrusion (Andreasen and Fleck, 1997; Essink, 2001; Demirel, 2004; Arslan, 2011). Examining seawater intrusion using Cl^- content, with the threshold value set at 250 mg/L, we have observed indicators of seawater intrusion in wells 12, 13, 18 and 23. High levels of sulphate in groundwater may be an indicator of seawater intrusion into the coastal aquifers (Wang and Jiao, 2012; Huang et al., 2013). Examining seawater intrusion using SO_4^{2-} contents, with the threshold value set at 250 mg/L, we have observed in wells 2, 6, 7, 12, 15 and 19 that SO_4^{2-} contents were above the threshold. The average annual SO_4^{2-} amount in the Paradeniz region was found to be 914.8 mg/L. Previous studies show that, compared with seawater, clean shallow coastal aquifers have lower concentrations of sulphate (Werner et al., 2013).

The average annual values Ca^{2+} and Mg^{2+} ranged from 15.83 mg/L to 136.43 mg/L and 13.4 mg/L to 134.8 mg/L, with mean \pm s.d. of 62.43-7.35 mg/L and 39.9-5.73 mg/L, respectively. The Ca^{2+} content was higher wells in the limestone bedrocks, and the Mg^{2+} content was higher wells in the dolomite area (Jiang et al., 2009).

The Na^+ and K^+ values ranged from 19.5 mg/L to 880.0 mg/L and 2.41 mg/L to 34.46 mg/L, with mean \pm s.d. of 194.75-45.42 mg/L and 9.42-1.76 mg/L, respectively. Na^+ was relatively high compared with Ca^{2+} which indicate the probable high TDS, hardness and alkalinity of the water samples.

The average annual NO_3^- and K^+ concentrations have been observed to be 12.49 mg/L and 9.42 mg/L respectively in the study area. These value are a clear indicator of groundwater pollution in the region by agricultural activities. Several different studies have shown that the source for nitrate pollution is from different agricultural practices (Kim et al., 2005; Zhao et al., 2010;

Landon et al., 2011; Güler et al., 2012; Qin et al., 2013).

Taking into consideration the intensive agricultural activities in this area and the commercial composites that have been applied for an extended period, the high NO_3^- content may be due to agricultural fertilizers. The main component of fertiliser, NH_4^+ is easily oxidized into NO_3^- by the nitrification process (Kim et al., 2005). Also, K^+ concentration in natural groundwater is usually expected to be less than 5 mg/L (Ltd., 2004). K^+ concentrations above this level might be an indication of fertilizer-related pollution. The average annual K^+ value of 9.42 mg/L observed in the study area is a clear indicator of agricultural pollution in the groundwater of the region.

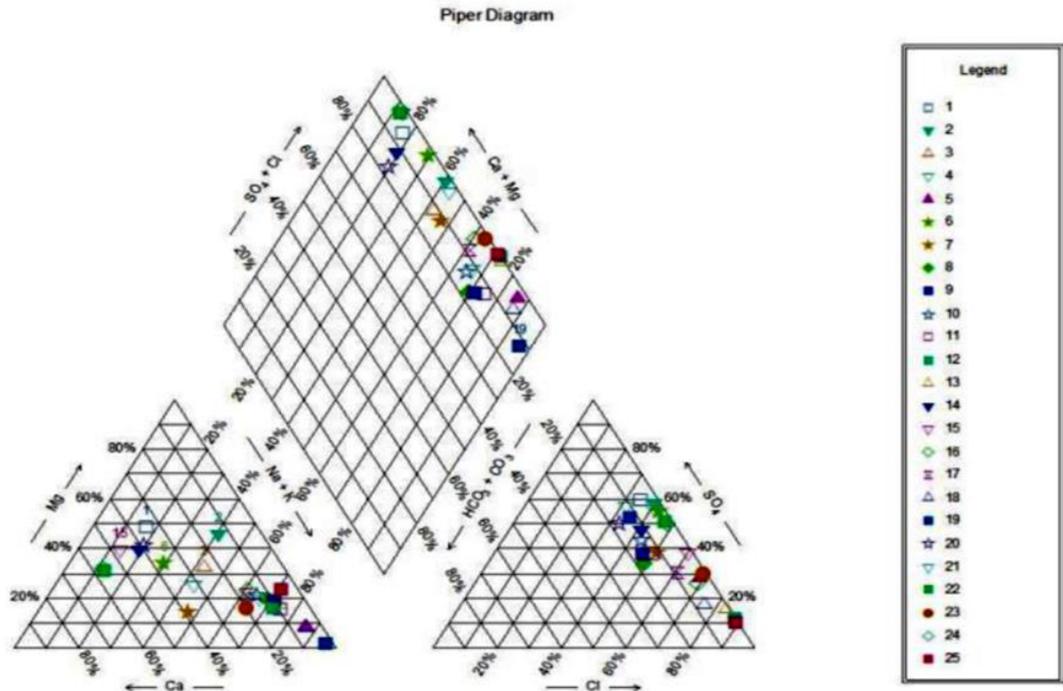


Figure 2. Major ion composition of groundwater at Göksu Delta represented using the Piper diagram (Piper, 1944)

Piper diagrams is developed to display different types of waters understand and define the water composition of different classes. Piper diagram was used to conduct origin and hydro-chemical facies analyses of the sampling sites (Fig.2). Piper diagram shows that all the samples collected from the region are located in NaCl, KCl, Na₂SO₄ zone. Waters located in this zone, such as seawater and highly brackish water, have high chloride, sodium or potassium content. In addition, in Relatively high amounts of SO₄²⁻ and Ca²⁺ shown in the piper diagram indicate a process of mixing. Sulfate may have remained in the region due to the dissolution of the small amount of gypsum rocks found throughout the delta and due to vaporization as a result of over-irrigation, and calcium may have resulted from the dissolution of calcite rocks. Also, the samples are very rich in the anionic species, especially the chloride content is high. The main reason for this is the deep sea circulation in the northern part of the well field. According to Figure 2 wells 11, 14, 20 and 22 are most likely calcium sulphate and anhydrite origin. Sulphate enrichment throughout the region indicates that the

groundwater aquifer it is recharged by water from evaporitic lithologies. Samples 9, 13, 23 and 25 show that clearly intrusion salt water. When looking at well 23, it shows that Akgöl lake has been subjected to saltwater intrusion. In terms of contents anions, Cl⁻ > SO₄²⁻ > HCO₃⁻+CO₃²⁻ whereas the cation contents show the following relationship: Na⁺+K⁺ > Mg²⁺ > Ca²⁺

On the basis of RSC and SAR values, which are parameters commonly used to assess water salinity, the water samples are classified as “fresh water” (RSC and SAR values, respectively, were - 1.93 ± 3.65 and 5.13 ± 4.86 (mean ± sd) as seen in Table 3. The %Na value is an important parameter for groundwater that indicates whether the water is suitable for use as irrigation water in agriculture. The average annual %Na value was found to be 47.59 ± 24.08 (mean ± sd) in the study area. On this basis,, the water samples are classified as having “moderate salinity”. Over the one-year period of study, during which several parameters were measured, total hardness varied between 101.11 and 835.48, with an average value of 320.93 ± 181.74 mg CaCO₃/L (mean ± s d). This average value measured in the delta indicated

“very high salinity”. In terms of Cl⁻ amounts measured throughout the year (8 ± 10.57 meq/L

(mean \pm sd)), the groundwater in the delta is classified as having “moderate salinity”.

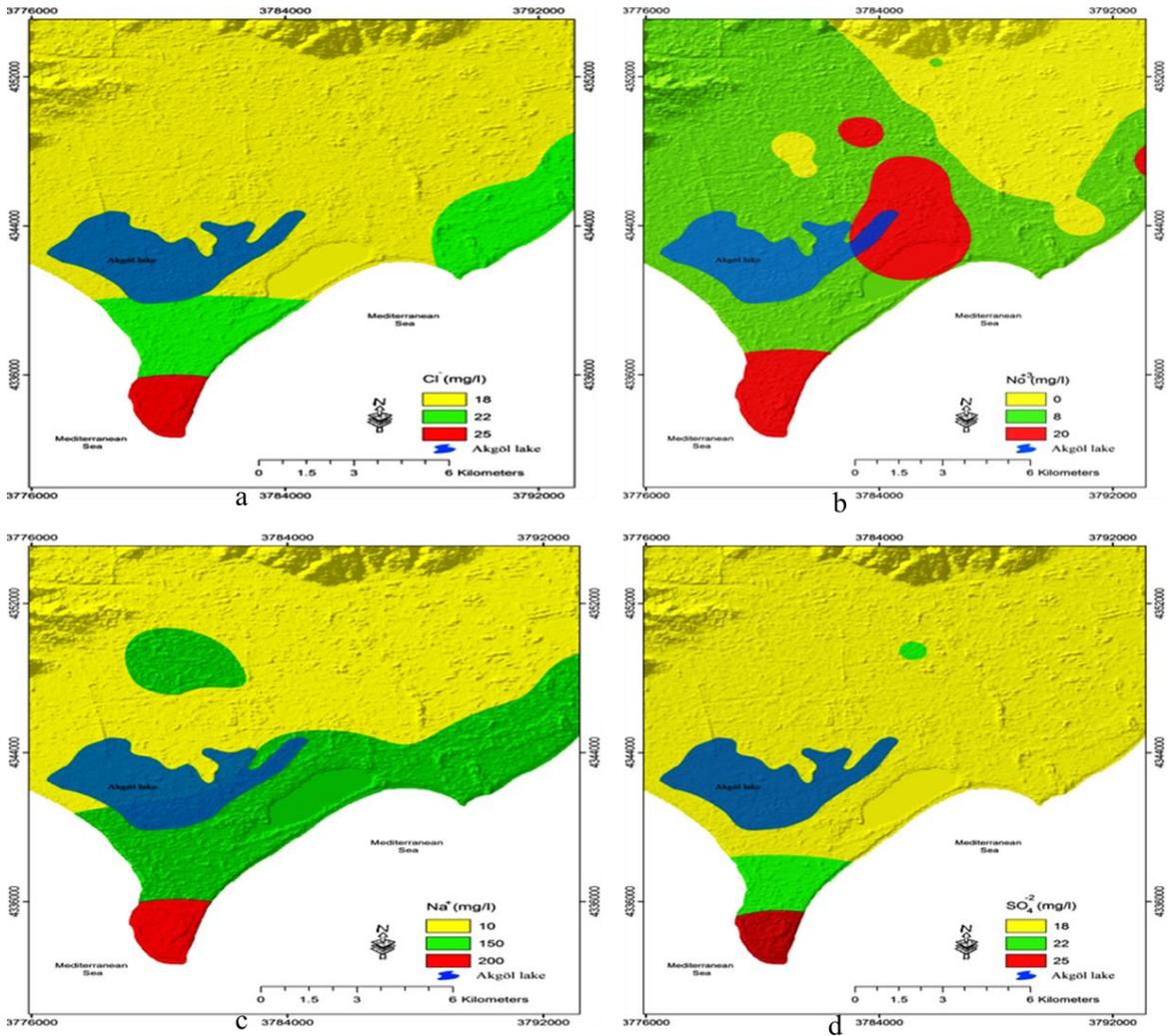


Figure 3. GIS maps showing the distribution for Cl⁻ (a), NO₃⁻ (b), Na⁺ (c), and SO₄²⁻ (d) in Göksu Delta

Table 3. Groundwater classification based on parameters

| Class | Fresh | Slightly saline | Moderately saline | Highly saline | Very highly saline | Seawater | Avegare This work |
|--|-------|-----------------|-------------------|---------------|--------------------|----------|-------------------|
| Parameter (Unit) | | | | | | | |
| Cl ⁻ (meq/L) | <2.8 | 2.8-7.1 | 7.1-14.1 | 14.1-28.2 | 28.2-282.2 | >282.2 | 8 |
| TDS (mg/L) | 0-500 | 500-1500 | 1500-7000 | 7000-15000 | 15000-35000 | >35000 | 807.88 |
| EC (µS/cm) | <700 | 700-2000 | 2000-10000 | 10000-25000 | 25000-45000 | >45000 | 1471.74 |
| Total Hardness (mg CaCO ₃ /L) | <75 | - | 75-150 | 150-300 | >300 | - | 320.93 |
| %Na | <20 | 20-40 | 40-60 | 60-80 | >80 | - | 47.59 |
| RSC (meq/L) | <1.25 | - | 1.25-2.5 | >2.5 | - | - | <1.25 |
| SAR | <6 | 6-10 | 10-18 | 18-26 | >26 | - | 5.13 |

Adapted from (Konikow, 1999; Rhoades, 1992; Wilcox, 1955)

4. Conclusions

The findings of the present study show that Cl^- , SO_4^{2-} , Na^+ and HCO_3^- are the dominant ions in the region, which is a reliable indicator of seawater intrusion in the region. The EC and TDS contents varied in a range that was much wider than is normal for fresh water, which might be another indicator of seawater intrusion in the region. The Piper diagrams showed that water samples were in the same zone with seawater and brackish water, which are Cl^- and Na^+ type waters. The presence of NO_3^- , which, together with seawater intrusion, represents an issue for groundwater management in the region, may be due to the use of fertilisers.

Relatively high amounts of SO_4^{2-} and Ca^{2+} shown in the piper diagram indicate a process of mixing. Sulfate may have remained in the region due to the dissolution of gypsum rocks found throughout the delta and due to vaporisation as a result of over-irrigation, and calcium may have resulted from the dissolution of calcite rocks. Pollution distribution maps created using GIS visualize the predicted effects of seawater on the groundwater. Water extraction from the inland wells for irrigation purposes is also problematic and should be prevented. Aquifers can be fed from the surface by precipitation, or by water from rivers or other aquifers. Thus, alluvial water may have different characteristics at different points. Water resource 'planning' in the region should be replaced a 'water management' approach.

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