Determination and evaluation of some physicochemical parameters in the Dardanelles (Canakkale Strait, Turkey) using multiple probe system and geographic information system

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Abstract The Dardanelles (Canakkale Strait) is a water passage connecting the Aegean Sea and Sea of Marmara. The average depth of the Dardanelles is 60 m; the deepest part reaches more than 100 m. Environmental parameters such as temperature, pH, salinity, dissolved oxygen and total dissolved solids were measured at different depths in the Dardanelles. The sampling period was between December 2002 and March 2003. All the data was measured by a YSI 6600 Model Multiple Probe System. Also, a Geographic Information System was used to create a tabular and spatial database, with the aim of integrating the physicochemical properties in the Dardanelles. Temperature and salinity profiles by the Geographic Information System showed that there was stratification and formation of two different water masses in the Dardanelles. The measurements showed that lower layer waters (>20 m) are saltier than upper layer waters of the Dardanelles. Therefore, the lower layer waters also hold higher values for total dissolved solids. Although the temperature and salinity characteristics of the Dardanelles are specific due to its topographic structure and some fresh water discharges, the stratification in the Dardanelles is generally similar to other parts of the Turkish Strait System (Bosphorus and Sea of Marmara) because of large salinity differences between the Aegean and Black Sea.

Keywords Dardanelles; freshwater discharge; Geographic Information System; Multiple Probe System; physicochemical parameters

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Introduction

The Turkish Straits System including the Bosphorus, the Sea of Marmara and the Dardanelles (Canakkale Strait) connects the Mediterranean and the Black Sea (Besiktepe *et al.* 1994; Polat and Tugrul 1996). The Sea of Marmara is a semi-enclosed basin with an 11 500 km^2 area and a 3378 km^3 total volume (Polat and Tugrul 1996). The Dardanelles (Canakkale Strait) which is a part of the Turkish Strait System is located between the Aegean Sea and the Sea of Marmara and has a 50 m mean depth (Polat and Tugrul 1996).

The Dardanelles is a very important water passage connecting the Aegean Sea and the Sea of Marmara. The Dardanelles has two current systems. One of the currents is derived from the Aegean Sea, where the water density is high. The other comes from the Sea of Marmara that characteristically is of low density. Aegean water is typically flowing from the southwest to northeast below the Sea of Marmara water (Polat and Tugrul 1996; Unsal *et al.* 2003; Türkoğlu and Koray 2004; Türkoğlu *et al.* 2004d; Baba *et al.* 2005).

Due to large salinity differences between the Aegean (38–39‰) and the Sea of Marmara (24–26‰), it is likely to observe intense vertical mixing of the counter-flows in the

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Dardanelles, especially near the southern exits. This way, before reaching the Aegean basin, the salinity of the Dardanelles surface flow increases at least 4–8‰. The Dardanelles surface water was more saline in the spring and winter compared to other seasons in the south eastern part of the Dardanelles. When the salinity in the surface water was low, values of total dissolved solids in the Dardanelles were lower (Unsal *et al.* 2003; Türkoğlu *et al.* 2004d) than those in other marine systems ($\geq 35.0\,mg\,L^{-1}$) (Xie *et al.* 2003). According to previous studies in the Dardanelles, the temporal cycle of pH showed fluctuations throughout the year; winter values were significantly lower (mean 8.20) than the spring (mean 8.36) and fall values (mean 8.28). DO concentrations varied from 6.75 to $10.1\,mg\,L^{-1}$ during the year, being higher in the spring and winter compared to summer (Türkoğlu *et al.* 2004e).

The main goals of this study are:

1. to determine some physicochemical parameters in the Dardanelles using Multiple Probe System (MPS)
2. to evaluate the physicochemical properties of water in the Dardanelles by Geographic Information System (GIS)
3. to determine the sources of fresh waters in the Dardanelles by Geographic Information System (GIS).

Geological and hydrogeological properties of study area

The oldest stratigraphic unit in the study area is Pre-Neogene basement rock. This is overlain discordantly by Neogene and Alluvium units that make up the dominant lithology (Figure 1). The Neogene sedimentary sequence consists predominantly of coarse grained sandstone, siltstone, lenses and/or discontinuous bands of conglomerate, marl, mudstone and claystone. It is mostly fine to medium. The sandstone is generally weakly cemented and poorly indurate. It can be easily crumbled between the fingers. The sandstone is interbedded with lenses, and thin discontinuous bands of conglomerate, marl, shale and mudstone (Baba *et al.* 2005).

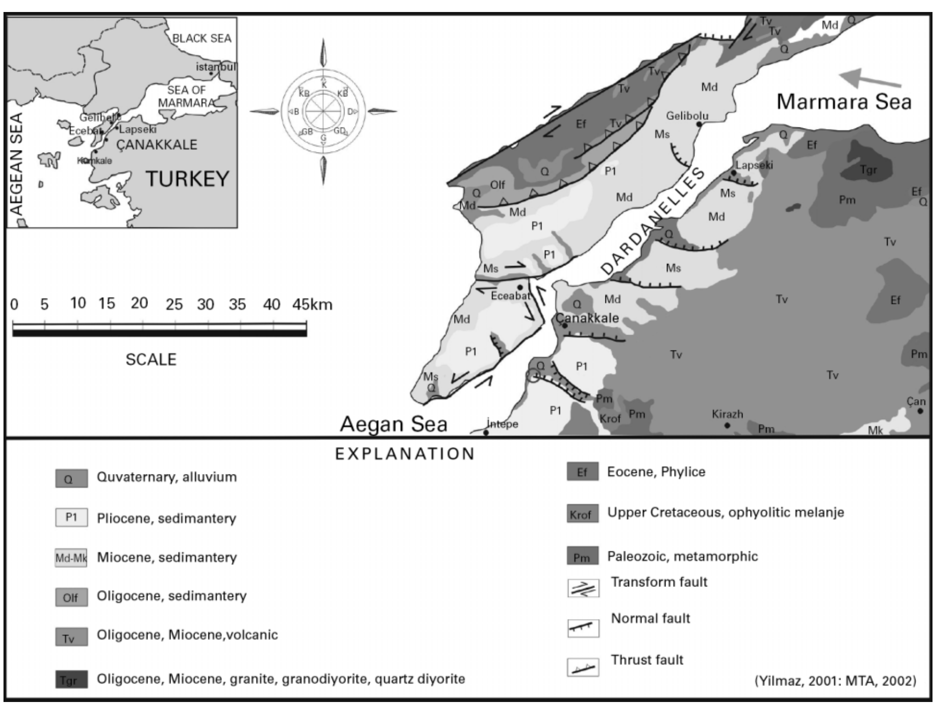

Figure 1 Geological map of the study area (Yılmaz 2001; MTA 2002)

Alluvium, which is most probably derived from sheetwash deposits, fan deposits, and coastal and wind blown sediments, has been observed along the flat terrain that extends between the foothills of the mountains and the shoreline. It is mostly fine-grained (silt and sand), and constitutes the majority of the agricultural fields of the study area.

The Neogene rocks constitute a poor aquifer due to the dominance of fine grained material. The permeability of this rock is 10^{-4} to 10^{-6} cm/s. The major aquifer of the study area, consisting primarily of Alluvium deposits, has been exploited extensively for domestic and irrigation usage. The average groundwater level in the study area is about 2 m below the surface. On the southeast Dardanelles boundary, the aquifer is mainly used by local people for irrigation and drinking water purposes (Deniz 2005; Baba and Deniz 2004).

Few studies have been done on the discharge of fresh water to the sea. The discharge of the karstic water is high in the Aegean and Mediterranean seas (Günay and Elhatip 1988; Elhatip 2003). Compared to other Neogene sedimentary sequences, the discharge of karstic water is easy to determine in sea water. Neogen sedimentary sequences are in an outcrop in the vicinity of the study area. The discharge of fresh water (coming from Neogene sequences) can be seen in the four different areas in the Dardanelles (Baba *et al.* 2005).

Materials and methods

The Canakkale Onsekiz Mart University "Research Vessel Bilim I" was used for this study. 52 points were selected within the study area for sampling in the period December 2002 and March 2003 (Figure 2).

Temperature (*T*), pH, salinity (*S*), specific conductivity (*SC*), dissolved oxygen (*DO*) and total dissolved solids (*TDS*) were measured at 1, 5, 10, 20 and 30 m depths. The physicochemical parameters were measured using a YSI 6600 Model Multiple Probe System *in situ*.

Several researchers have used a Geographical Information System (GIS) as a tool to treat data on spatial and temporal variations (ESRI 1996; Kosmas *et al.* 1997; Barazzuoli *et al.* 1999; Thwaites and Slater 2000; Hudak and Sanmanee 2003). The ArcView 3.2 GIS (ESRI 1996) was employed to develop the maps. For the mapping procedure, the point themes were

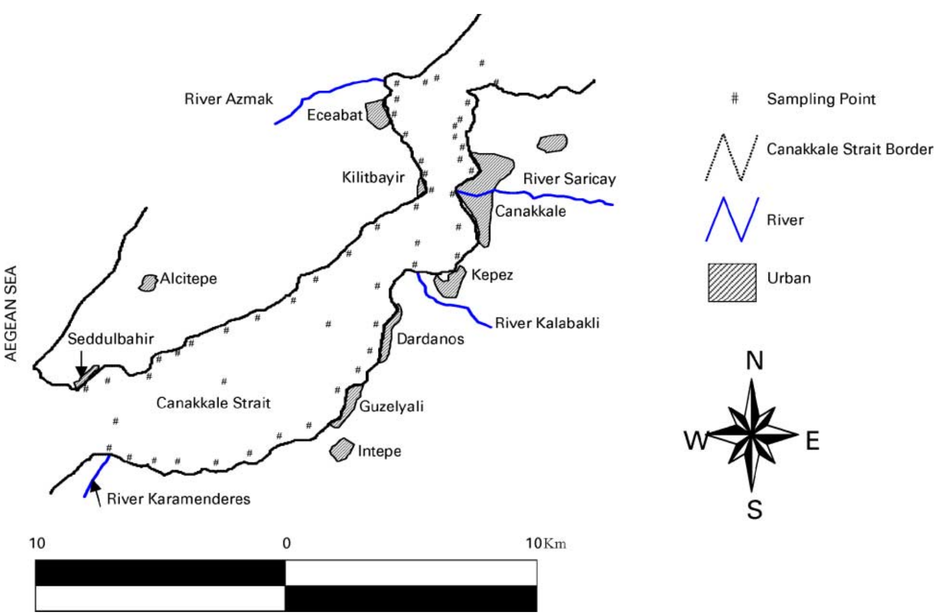

Figure 2 The Dardanelles (Çanakkale Strait) and sampling points

generated. The surface maps were then produced from the developed point themes by using Nearest Neighbour, an inverse distance interpolation technique, with 12 neighbours. The cell size for interpolation was 100 m. The study area border (Canakkale Strait border) was digitized from a topographical map scaled to 1/25 000 by using ArcInfo. Then data was exported to ArcView for mapping.

Results

Two current directions are observed in the Dardanelles (Canakkale Strait). The southwest flowing current from the Sea of Marmara is of lower density than the northeast flowing current from the Aegean Sea.

Temperature and salinity

Temperature and salinity profiles of the Dardanelles obtained by GIS showed that there was stratification and formation of two different water masses during the sampling period (Figures 3 and 4). Although temperature and salinity were in different patterns, the stratification in the Dardanelles was similar to the other parts of the Turkish Strait System (Bosphorus and Sea of Marmara) (Besiktepe *et al.* 1994; Polat and Tugrul 1996) due to large temperature and especially salinity differences between the Aegean and Black Sea. The temperature and salinity measurements showed that there was generally an increase with depth in the sampling period. A thin upper layer (<20 m) had salinity values of about 22‰ while a much thicker lower layer (>20 m) had salinity values of about 38‰ (Figures 3 and 4).

Temperature measurements were highly variable at the southern part of the Kilitbahir in the Dardanelles. The narrowing of the Dardanelles led to different temperature and salinity values to the northeast and southwest of the Narrows between Kilitbahir and Canakkale. Temperature along the southeast coasts of the Narrows (between Kilitbahir and Canakkale) was lower than the other coasts of the Dardanelles due to upwelling and especially fresh water discharges from the rivers such as Saricay, Kalabakli and Karamenderes to the surface layer (0–10 m) (Figures 2 and 3). Temperature results showed that discharges of fresh water

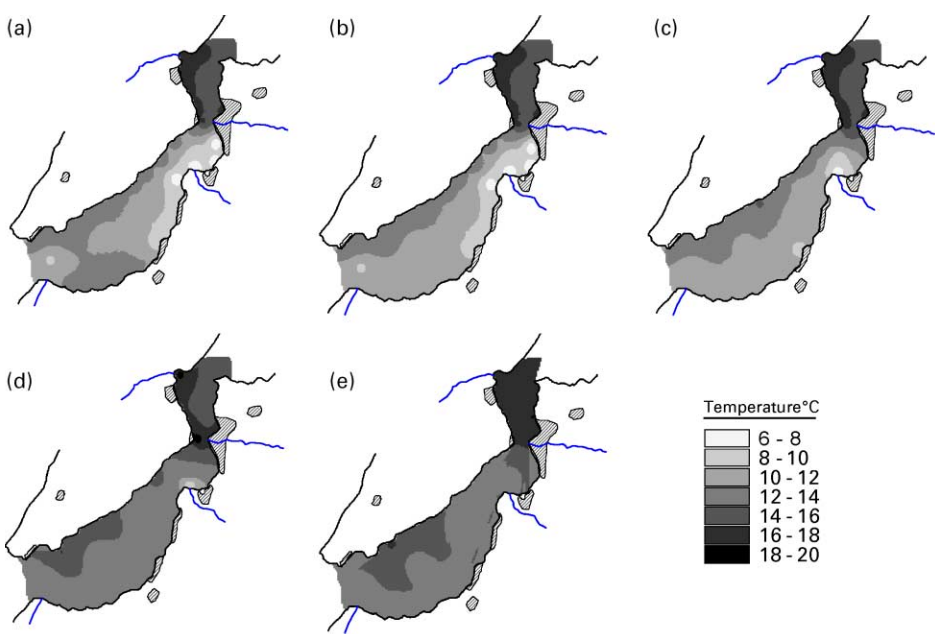

Figure 3 Distribution of temperature at different depths in the Dardanelles (a: 1 m; b: 5 m; c: 10 m; d: 20 m; e: 30 m)

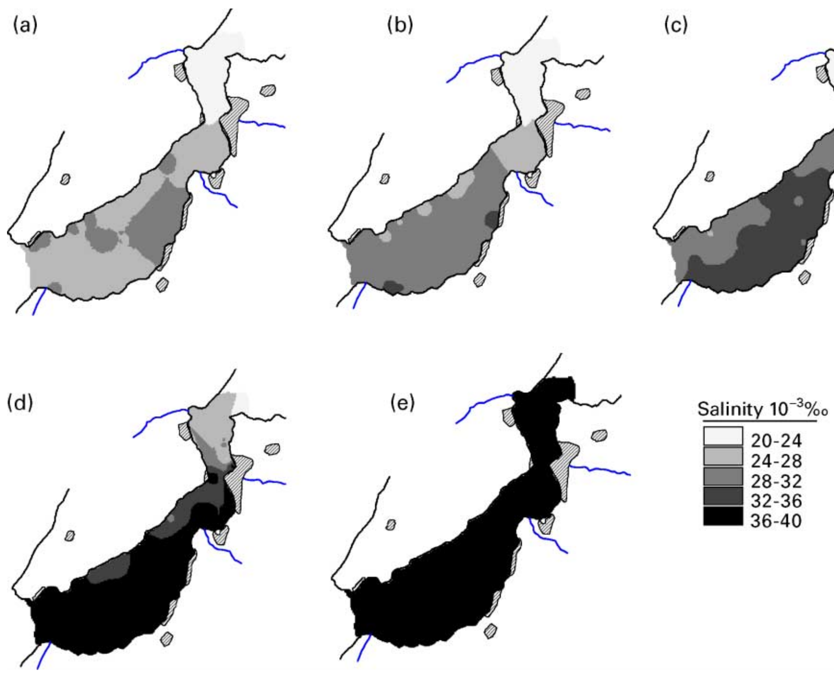

Figure 4 Distribution of salinity at different depths in the Dardanelles (a: 1 m; b: 5 m; c: 10 m; d: 20 m; e: 30 m)

into the Dardanelles can be seen in four sample locations between Dardanos and Canakkale at 1 and 5 m depths; and at one location at 10 and 20 m depths. This point was affected by an influx from the River Kalabakli (Figure 3).

pH

The mean pH of the Dardanelles is slightly basic at around 8.4. The average pH of the Dardanelles is around 9.0 from 5 m to 20 m to the northeast of the Dardanelles. pH levels of the surface layer flowing from the Black Sea to the Aegean Sea is higher than for the lower layer flowing from Mediterranean to the Black Sea. Similar to temperature, pH measurements were highly variable due to turbulence or upwelling between Kilitbahir and Cape Nara. The narrowing of the Dardanelles also led to different values from the northeast to the southwest of Kilitbahir. Therefore, pH measurements in the southeast were lower than in the northwest of Kilitbahir (Figure 5).

Dissolved oxygen (*DO*)

The concentration of *DO* was around $10\,\mathrm{mg\,L^{-1}}$ from 1 m to 5 m between Canakkale and Dardanos (Figure 6). The concentration of *DO* was about $10\,\mathrm{mg\,L^{-1}}$ at 20 m depth around the River Kalabakli. The *DO* measurements in the northeast of Kilitbahir were lower than to the southwest (Figure 6). Measurements showed that *DO* concentrations were generally saturated both in the surface and lower layer due to counter-flow in the Dardanelles and their mixture in the southeast areas of Kilitbahir Narrows.

Total dissolved solids (*TDS*)

Probe measurements showed that *TDS* values were similar to salinity values in the Dardanelles. The values ranged from 20 to $50\,\mathrm{g\,L^{-1}}$ in the Dardanelles (Figure 7). *TDS* increased with depth and distance in the Sea of Marmara. Distribution of *TDS* and salinity showed that high salinity water (Aegean Sea) can be seen from 20 m to 30 m

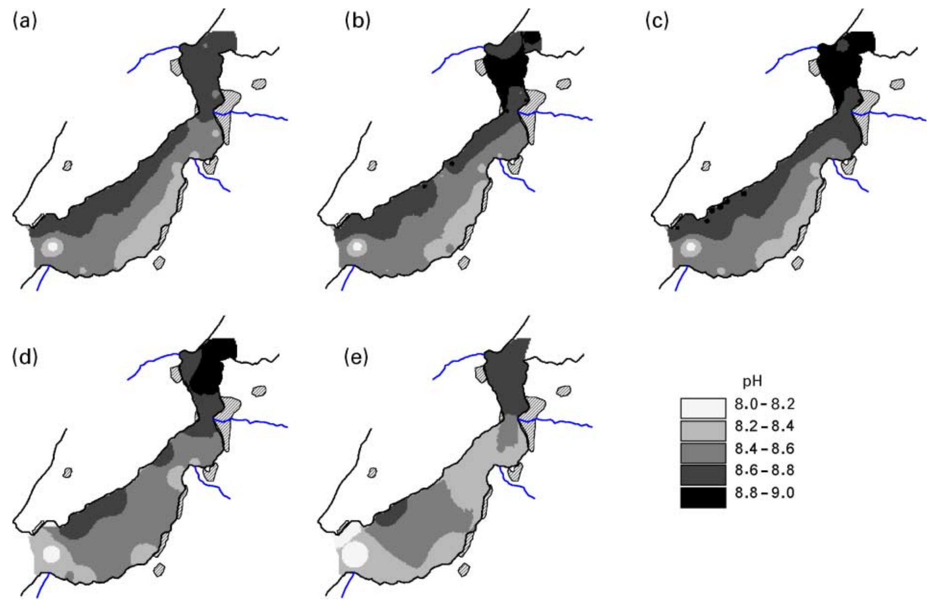

Figure 5 Distribution of pH at different depths in the Dardanelles (a: 1 m; b: 5 m; c: 10 m; d: 20 m; e: 30 m)

in the Dardanelles. *TDS* results also showed that the Aegean and Marmara water mixed up between Canakkale and Kilitbahir. The northeastern part of the Dardanelles contained lower *TDS* than the southwestern part near the mouth of the Aegean at 1 m to 10 m depth. The northeastern part of the Dardanelles contained Sea of Marmara water up to 10 m depth.

Discussion

Our measurements showed that, in general, Aegean Sea water holds high values for salinity, total dissolved solids and specific conductivity. It is known that both Marmara surface waters

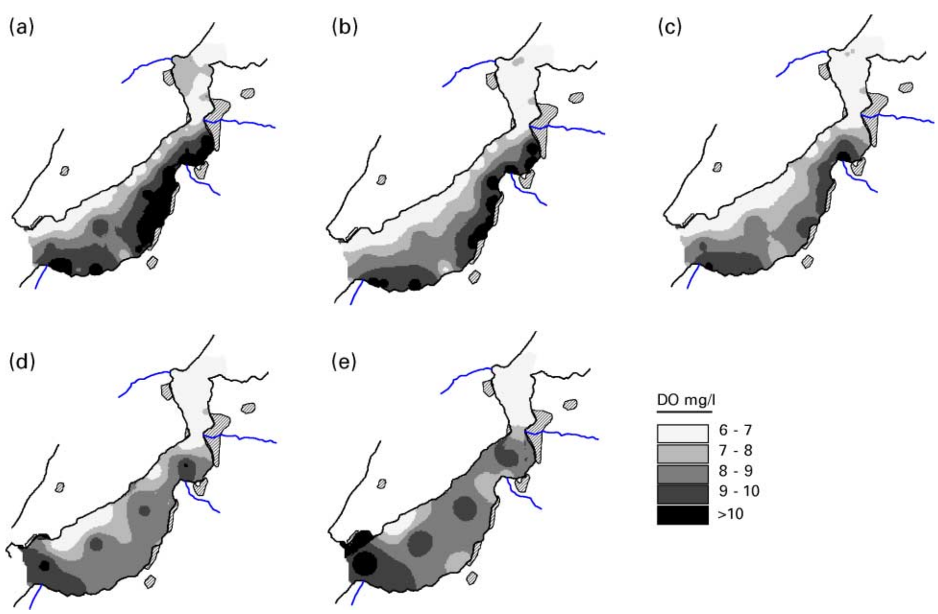

Figure 6 Distribution of dissolved oxygen (*DO*) at different depths in the Dardanelles (a: 1 m; b: 5 m; c: 10 m; d: 20 m; e: 30 m)

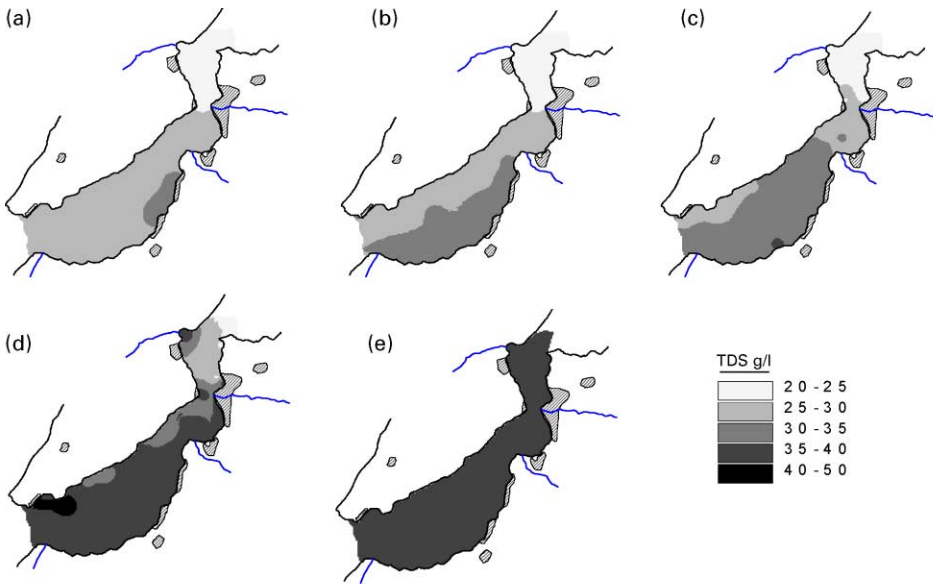

Figure 7 Distribution of total dissolved solids (*TDS*) at different depths in the Dardanelles (a: 1 m; b: 5 m; c: 10 m; d: 20 m; e: 30 m)

and Aegean deep waters of the Dardanelles hold also high dissolved oxygen (*DO*) values due to counter-flow (Besiktepe *et al.* 1994; Tugrul *et al.* 1995; Polat and Tugrul 1996). It is also known that there is an excess *DO* contribution in the upper layer waters due to high phytoplanktonic activity. Therefore, *DO* concentration in the upper layer generally reaches supersaturation values ($\geq 10\,mg\,L^{-1}$) due to high algal biomass (Unsal *et al.* 2003; Türkoğlu *et al.* 2004a–e). Oxygen enters the water by photosynthesis and the transfer of oxygen through the air–water interface. The amount of oxygen that can be held by the water depends on the water temperature, salinity and pressure. According to Unsal *et al.* (2003) and Türkoğlu *et al.* (2004e), *DO* is about $8-10\,mg\,L^{-1}$ in the surface water of the Dardanelles. Fresh waters are usually at near equilibrium with atmospheric oxygen, while supersaturation is common in the supersurface layer. This surface-supplied oxygen is diminished by consumptive demands in the supersurface layer. However, oxygen concentrations are relatively uniform but well below saturation in the Dardanelles where these demands are limited.

In accordance with the Geographic Information System (GIS) distribution of temperature, pH also showed that surface waters had lower values than those of the deep waters of the Dardanelles. It is known that algal blooms in surface waters can cause fluctuations of pH in some marine ecosystems such as the Black Sea (Türkoğlu 1999; Türkoğlu and Koray 2002, 2004) and the Dardanelles (Türkoğlu *et al.* 2004a, e). Photosynthetic consumption of CO_2 by algal blooms especially can drive pH to higher levels (Hinga 2002; Türkoğlu and Koray 2002). This is because there is low carbonic acid formation when CO_2 is consumed, and therefore low dissociation of carbonic acid into H^+ (Hinga 2002). For instance, pH values in the upper layer were lower than the deeper layer values during the algal bloom of coccolithophorid *Emiliania huxleyi* in the surface layer of the Dardanelles (Türkoğlu *et al.* 2004a, e). The situation shows that temporal and local variations of pH in the surface waters are connected with biological activity. However, pH variations may be connected with other characteristics of the water such as fresh water or wastewater discharges in the Dardanelles. Fresh water influx to the surface water of the Dardanelles may cause high phytoplanktonic activity due to high nutrient input, especially in the coast of the southern east area (Türkoğlu *et al.* 2004b, c, e). It is possible that these processes cause the excess alkalinity in the Dardanelles.

In the last several decades population growth, urban expansion and economic development have persistently raised the demand of water supply, and consequently, increased the exploitation of fresh water around the Dardanelles. This area is one of the important tourist sites in Turkey. The highest population of people is concentrated near the southeast border of the Dardanelles. Here, water is being extensively withdrawn from the alluvial aquifer and discharged into the Dardanelles. In addition, the Dardanelles is a very important water passage connecting the Aegean Sea and the Sea of Marmara. Therefore, this area has the potential to expand in the near future.

Much of the fresh water in the vicinity of the study area is discharged into the Dardanelles, Aegean Sea and Sea of Marmara. At present, the groundwater supplies appear to be sufficient enough for domestic and irrigation demands. But the population along the southeast coast of the Dardanelles is rising and the demand for freshwater is increasing.

This study has pinpointed the locations of freshwater discharge, so that if freshwater is needed in the future, it may be possible to extract it from these locations, prior to discharge into the strait or from the Dardanelles itself.

Additionally, temperature techniques to measure fresh water discharges may give more accurate results depending on many internal and external factors, including the density equilibrium between fresh and sea water, and other physical and structural properties of the coastal water-bearing formations.

Conclusion

This study showed that the Dardanelles has specific temperature and salinity characteristics due to topography and the fresh-water discharges in the system. Additionally, Multiple Probe System (MPS) and Geographic Information System (GIS) were proved to be successful tools when determining and evaluating the physicochemical properties of the Dardanelles. Although very important results were observed about hydrological characteristics of the Dardanelles by this study, long term measurements in the system are still necessary not only for deriving physicochemical balances but also for the development of ecosystem and water quality models as well as for the improved understanding of the oceanography of the system.

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