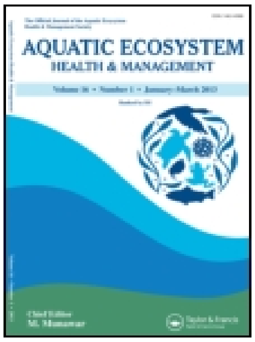

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This study aimed to determine the physicochemical characteristics of the water quality and trophic state of Akgöl Lagoon located in the eastern Mediterranean. Cluster analysis clearly revealed the spatial heterogeneity classifying sampling stations as saline and freshwater/brackish water sites. A multivariate analysis of variance followed by principal component analysis supported that salinity was major factor affecting physicochemical water quality variations in the lagoon. As salinity was mainly governed by freshwater inflows depending on agricultural irrigation, it can be proposed that water quality was significantly influenced from freshwater use by human activities. The parameters used as predictors (total nitrogen, total phosphorus, chlorophyll a *and Secchi disk transparency) yielded different trophic states for the lagoon. However, as chlorophyll is a better predictor than the other indices, it was concluded that the Akgöl Lagoon is at mesotrophic status.*

Keywords: Göksu Delta, Ramsar site, salinity

Introduction

Coastal lagoons, which represent less than 1% of the earth's surface but comprise 13% of the earth's coastline, are accepted as a transitional media between terrestrial and marine ecosystems (Plus et al., 2006). They have high spatial and temporal physicochemical variations produced by salinity and temperature gradients, and limited volumes (Loureiro et al., 2006). Therefore, they are among the most dynamic and complex aquatic environments characterized by multiple interfaces and features that result from their limited exchanges with the adjacent sea and their ability to accumulate nutrients from the whole of their catchment. Various human activities such as hydrological transformations and terrestrial nutrient loading have had significant impacts on ecosystem health of lagoons (Pereira et al., 2009; Roselli et al., 2009).

Mediterranean lagoons, which are characterized by shallow waters and limited circulation, are ecosystems particularly sensitive to freshwater inflows and human activity (Roselli et al., 2009). Among them, the Akgöl Lagoon is the largest in the Göksu Delta, is one of the most significant wetland areas in the Eastern Mediterranean. The

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Göksu Delta, which is included in the Ramsar List of Wetlands of International Importance, is located to the south of Mersin (Turkey), where the Göksu River, with a 10,000 km^2 catchment area, reaches the Mediterranean Sea. The Delta, surrounded by the Taurus Mountains on the north and northeast, is split in two by the Göksu River. There are two shallow lakes, Paradeniz and Akgöl, on the east and the west, respectively. The Akgöl Lagoon (12 km^2) is the largest lake of the delta. The lagoon is fed by a few freshwater resources and is unconnected with surface flow of the Göksu River. These inflows are used for irrigation, and overflows drain by concrete channels into the lagoon. Therefore, water level is the highest during irrigation period, while average water level in the Akgöl Lagoon fluctuated between 0.4 and 1.2 m during winter depending on precipitation. The Akgöl Lagoon drains into the Paradeniz Lagoon and is not directly connected to the sea. Saline water reaches to the Akgöl Lagoon via the Paradeniz Lagoon (Keçer and Duman, 2007).

There is still limited data on the trophic state of the Lagoon, although there are studies related to heavy metal and pesticide pollution in surface waters and groundwater of the Delta (Ayaş et al., 1997; Barlas, 2002; Ergene et al., 2007; Demirel et al., 2011) as well as phytoplankton diversity in the Lagoon (Roselli et al., 2013). This study aims to overcome the lack of information and to gain a better understanding of physicochemical water quality and trophic state of Akgöl Lagoon by using monitoring data between April 2013 and March 2014.

Methods

This study was conducted between April 2013 and March 2014 in order to determine seasonal variations of water quality in the lagoon. Monthly water samples were collected from six stations. Station 1 represents the sea connection of the lagoon while Stations 5 and 6 were close to freshwater inflows. The other stations were chosen from the central area to reflect the general characteristics of the lagoon. While Stations 2 and 3 were located near the southern coast, station 4 was selected from the middle part of the lagoon (Figure 1).

Temperature (T), pH, electrical conductivity (EC), salinity (S), total dissolved solids (TDS), dissolved oxygen (DO) and chlorophyll *a* (Chl *a*) were measured in situ by using Hydrolab DS5 Multiparameter sonde (OTT Hydromet, Loveland, CO, USA). Secchi depth transparency (SD) was measured by Secchi disc. Total suspended solids (TSS), total hardness (TH), total alkalinity (TA), soluble reactive phosphorus (SRP), total phosphorus (TP), total nitrogen (TN), chlorophyll *a* (Chl *a*) and chemical oxygen demand (COD) were analysed according to the selected methods of Standard Methods (APHA et al., 1998).

Trophic State Index (TSI) developed by Carlson (1977) was used for characterising trophic state of the lagoon. TSI uses total phosphorus, Secchi disc transparency and chlorophyll *a* to define the status at a numerical value from 0 to approximately 100.

$$\mathrm{TSI(SD)} = 10 * (6 - \ln\mathrm{SD}/\ln 2)$$

$$\mathrm{TSI(CHL)} = 10 * (6 - (2.04 - 0.68 * \ln\mathrm{CHL})/\ln 2)$$

$$\mathrm{TSI(TP)} = 10 * (6 - \ln(48/\mathrm{TP})/\ln 2)$$

Minimum and/or maximum extreme values, which were possible outliers, were removed from the data set. The normality of data was tested using the Shapiro-Wilk test. Normally and non-normally

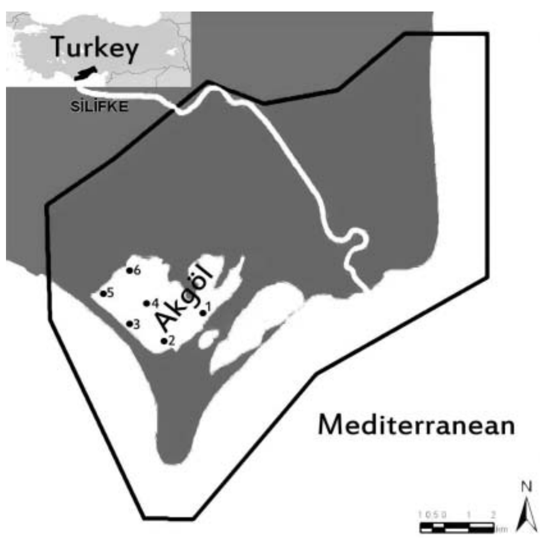

Figure 1. Akgöl Lagoon and sampling stations and coordinates (Silifke/Mersin/Turkey) (Geographical coordinates for the stations, respectively: 36°18′21.2″N - 33°58′26.01″E; 36°17′3.42″N - 33°57′8.28″E; 36°17′3.44″N - 33°56′23.86″E; 36°17′3.53″N - 33°57′12.40″E; 36°18′14.8″N - 33°55′54.91″E; 36°18′41.10″N - 33°57′1.05″E).

distributed parameters were compared using a one-way analysis of variance (ANOVA) and Kruskal-Wallis signed rank test, respectively. Tukey's honestly significant difference test (HSD) was used to discriminate significant differences. Heterogeneity of sampling stations was determined using cluster analysis (CA) which was performed on the transformed data set by means of the Ward's method. The linkage distance is reported as D_{link}/D_{max} (Simeonov et al., 2003).

In the first step of another multivariate analysis, detrended correspondence analysis (DCA) was calculated to select a linear or unimodal method. Since DCA showed short gradient lengths (<1.2 SD), a linear model was appropriate for the data. Therefore, principal component analysis (PCA) was used to accentuate variation and reduce the dimensionality in the dataset. For PCA, inter-variable relationships were scaled and scores divided by standard deviations. Data were transformed logarithmically (log $(a \times y + b)$; $a = 1$ and $b = 1$) for DCA and PCA (Lepš and Šmilauer, 2003). A multivariate analysis of variance (MANOVA) on the scores of principal components (PCs) that had eigenvalues greater than one was conducted on testing the significance and effect of independent variables. Presence of differences in variance amongst the physicochemical parameters was investigated through Pillai's Trace test which has a better tolerance for non-normal and/or small sized data (Tabachnick and Fidell, 2006). JMP8 was used for univariate tests and MANOVA while STATISTICA 10 for CA and PCA.

Results

Surface water temperatures fluctuated seasonally between 10.4 and 30.9°C (Appendix 1 in the online supplementary files [SI]). A non-parametric (Kruskal-Wallis signed rank) test revealed significant differences between the months ($x^2(11) = 68.53$, $p < 0.001$). However, spatial homogeneity of temperature between the sampling stations was insignificant ($p > 0.05$). The mean pH was recorded in a range of 9.1 and 9.4, representing alkaline conditions. The significant temporal and spatial differences of pH were not detected ($p > 0.05$).

EC and TDS were higher at Station 1 (average 6.48 mS cm^{-1} and 4.9 g l^{-1}, respectively) than those of other stations. EC and S variations in the lagoon were related to concentrations of TDS (Appendix 2 in the SI). Statistically significant differences were not observed between the sampling stations ($p > 0.05$), while clear temporal variations were detected for EC and TDS ($x^2(11) = 51.41$ and $x^2(11) = 57.66$, $p < 0.001$, respectively) which were significantly higher in January and February than those in summer months (May, June, July, August and September), indicating sea influence during winter (Tukey-Kramer HSD, $p < 0.05$). However, spatial variation in salinity (average 4.5‰) was the case ($x^2(5) = 11.68$, $p < 0.05$); Salinity in station 1 near the sea connection, was the significantly higher than those in stations 5 and 6, near freshwater inlet (Tukey-Kramer HSD, $p < 0.05$). Salinity was also significantly different in January ($x^2(11) = 44.20$, $p < 0.001$) with a similar tendency as TDS. The mean DO was between 7.5 and 8.2 mg L^{-1} and it was affected by temperature. Differences in DO values were insignificant between the sampling stations ($P > 0.05$). However, there was a significant difference between the seasons ($x^2(11) = 57.00$, $p < 0.001$); DO was significantly higher in winter than summer months (Tukey-Kramer HSD, $p < 0.05$).

SRP was determined in a range of 0.001 and 0.009 mg l^{-1} and closely related to TP. During the study period, TN and TP in surface water of Akgöl Lagoon varied in wide ranges (0.037 – 1.117 mg N l^{-1} and 0.003 – 0.071 mg P l^{-1}). A relatively stronger relation was determined between TN and TP. As in the many other parameters, the significant differences between the sampling stations were not detected ($P > 0.05$) for SRP, TP, TN and Chl *a*, while temporal variations were the case. SRP, TP and TN ($x^2(11) = 56.56$, 55.40 and 53.60 respectively, $p < 0.001$) were significantly higher in winter with high salinity than in summer months (Tukey-Kramer HSD, $p < 0.05$).

Changes of SD (average 0.26 to 0.52 m) between the sampling stations were different ($x^2(5) = 19.00$, $p < 0.01$), and SD was significantly higher in the middle part of the lagoon (Station 4) than freshwater inlet and sea connection (Tukey-Kramer HSD, $p < 0.05$). However, significant temporal variation of SD ($x^2(5) = 27.60$, $p < 0.01$) was not clear which only the months March and June could be distinguished (Tukey-Kramer HSD, $p < 0.05$). Significant relations of Chl *a* and

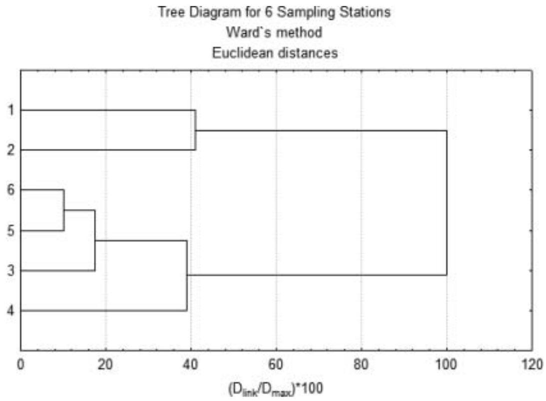

Figure 2. Dendrogram of CA for sampling stations in Akgöl Lagoon.

SD were not recorded neither between TN and TP nor between each other.

The average TSI (CHL) scores (44 – 47) at all sampling stations indicate the mesotrophic state of Akgöl Lagoon, and TSI (TP) scores (43 – 51) mostly supported this finding. However, TSI (SD) yielded highly different scores between 71 and 81 reflecting hypereutrophic status.

Cluster analysis clearly revealed the spatial heterogeneity of the lagoon system (Figure 2), the dendogram grouping stations into two major statistically meaningful clusters at D_{link}/D_{max} * 100 < 50. Cluster 1 consisted of sea connection sampling points (Stations 1 and 2) while the other four sampling stations created to Cluster 2, in which the sampling stations of freshwater inflows (Stations 5 and 6) were significantly differentiated from the others ($P < 0.05$).

Results of the PCA revealed that the first five principal components had eigenvalues greater than one and explained 76.8% of the total variation of data set. The first component (PC1), represented 32.8% of the variance, positively loaded (>0.4) with the scores of DO, EC, S, TDS, TH, TA, TN, PO4 and TP. PC1 had the highest loading scores (>0.8) for temperature that negatively loaded the axes. The second component (PC2) explained 13.5% of the total variation was majorly loaded for the high scores (>0.4) of TSS, Chl *a* and SD (Figure 3). In fact, PCA showed variation contribution of dissolved and suspended solids related variables as well as temperature. The other three components (PC3, PC4, and PC5) of the PCA represented less total variation than the PC1 and were loaded with a few variables.

PCA also made clear the temporal variation. The samples of the months between late spring and early autumn (May, June, July, August and October) when temperature was the highest were plotted on the left side of PC1 that was negatively loaded by temperature. However, the samples of the months of winter and late autumn (November, December, January and February) were plotted the right side of PC1 which was positively loaded by dissolved oxygen, dissolved solids related variables and nutrients (Figure 3).

Results of MANOVA, provide a strong support to the proposal of PCA, showed that the multivariate effect is statistically significant (all significant F' values, that is, P's < 0.001) for the current data (Appendix 3 in the SI). The results indicated that salinity had the most significant effects on PC scores because the smaller values of Pillai's Trace were more significant than larger ones ($P < 0.001$ for 1st, 2nd, 3rd and 4th PCs).

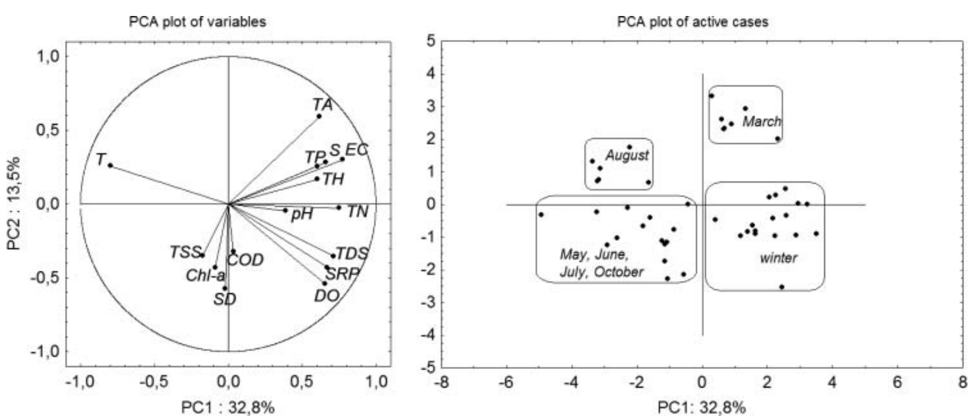

Figure 3. Biplot of loading scores of active variables and cases for the first two components of PCA.

Discussion

Surface water temperatures of Akgöl Lagoon varied depending on air temperatures. Although higher pH and lower EC values were measured during the present study than those in previous studies (Roselli et al., 2013), similar temperature variations were reported in all studies as temperature is naturally governed by climatic conditions in surface waters. However it should be noted that only four measurements in freshwater inflow areas were carried out in the previous study. A strong negative correlation between T and DO in Akgöl Lagoon suggests that DO is one of the principal factors affected by temperature changes in hydro-ecosystems. Despite the fact that oxygen solubility increases as salinity decreases, an expected relationship was not recorded between DO and S in this study.

Salinity measurements (2.41–4.03‰) in study of Roselli et al. (2013) were consistent with our study. This study also revealed that salinity was major factor affecting physicochemical water quality variations in Akgöl Lagoon. It is already a well known fact that salinity not only plays a role in understanding estuarine characteristics of a lagoon but also it can be helpful in determining water quality variations as a convenient tracer (Smith, 1994). Salinity is also closely associated with rainfall events, the incoming freshwater and sea water (Zirino et al., 2014). It can be argued that salinity, governs water quality variations in the Akgöl Lagoon, mainly controlled by freshwater and sea water inflows excluding evaporation. Indeed, water level was the highest between summer and autumn due to contribution of overflows of irrigational freshwater. Sea water inflow influenced the salinity variations during winter and freshwater inflows during summer in the Akgöl Lagoon, as supported by significant correlations of temperature with salinity, dissolved solids and electrical conductivity. The results also showed that freshwater inflow caused a dilution by nutrients. Indeed, nutrient concentrations were the higher in winter than the other seasons. In consideration to salinity and nutrient variations in the lagoon, it can be proposed that water quality was significantly affected from freshwater use by human activities in the lagoon basin.

Decrease of TN and TP in summer months could be attributed to the increase in algal and macrophytic production during spring and summer (not measured in this study). Lower nitrogen concentrations due to high macrophytic uptake were also reported in the studies because macrophyte and benthic macroalgal uptake particularly become active at high temperatures (Plus et al., 2003, 2006). However, lower concentrations during summer as compared to those in winter, in spite of agricultural discharges, was noticeable. SD and Chl *a* did not show a seasonal trend and had insignificant correlations with T, TN and TP in Akgöl Lagoon.

Transparency of water measured by the SD and Chl *a* concentration as an indicator of phytoplankton biomass is useful to determine trophic state of lakes and coastal waters (Carlson, 1977). Trophic state of Akgöl Lagoon was classified as mesotrophic depending on mean TP and Chl *a* concentrations. However, the mean TN concentrations at sampling stations represented oligotrophic status while the lagoon was classified as hypertrophic with SD transparency (Carlson, 1977; OECD, 1982). Although it may seem like there is an inconsistency, it can be proposed that Chl *a* is a better predictor of trophic state than SD as the changes in transparency may not be related to algal biomass and, TP and SD are not independent estimators of trophic state (Osgood, 1982). Therefore, it was concluded that Akgöl Lagoon is a mesotrophic lake due to Chl *a* variations.

Conclusions

Akgöl Lagoon was characterized as a shallow and sufficiently oxygenated lake with brackish water in its sea connection. Salinity was a major factor affecting physicochemical water quality variations in the lagoon. Chlorophyll *a* concentrations, as an independent predictor, support that the lagoon is a mesotrophic lake. As the main driver of nutrient supply in coastal lagoons, future studies should be focused on water level fluctuations from water quality variations concerning salinity changes and water/salt balance.

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Supplemental material

Supplemental data for this article can be accessed on the publisher's website.

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