AQUATIC RESEARCH
E-ISSN 2618-6365
Aquatic Research 8(3), 186-206 (2025) • https://doi.org/10.3153/AR25019
Research Article

Temporal and spatial status of environmental variables and pollutants in Çardak Lagoon (Çanakkale Strait)

A. Suat ATEŞ, Yeşim BÜYÜKATEŞ, Seçil ACAR

Cite this article as:
Ateş, A.S., Büyükateş, Y., Acar, S. (2025). Temporal and spatial status of environmental variables and pollutants in Çardak Lagoon (Çanakkale Strait). *Aquatic Research*, 8(3), 186-206. https://doi.org/10.3153/AR25019

Çanakkale Onsekiz Mart University Faculty of Marine Sciences and Technology Çanakkale, Türkiye

ORCID IDs of the author(s):

A.S.A. 0000-0002-4682-1926
Y.B. 0000-0002-4402-4587
S.A. 0000-0002-6426-8095

Submitted: 28.03.2025
Revision requested: 24.05.2025
Last revision received: 26.05.2025
Accepted: 27.05.2025
Published online: 01.07.2025

Correspondence:
A. Suat ATEŞ
E-mail: asuatates@yahoo.com

Available online at
http://aquatres.scientificwebjournals.com

ABSTRACT

The objective of this study was to analyse the correlation between domestic pollutants, specifically organic matter, anionic detergent, and suspended solids, and environmental variables such as temperature, salinity, and sediment grain size in Çardak Lagoon on a seasonal basis. Samples were obtained using 5 L Nansen bottles at a depth of 1 m from the surface waters across 6 stations within the lagoon, as well as from 1 station situated on the seaward side. The collection period for the latter was from October 28, 2018, to June 28, 2019. The study demonstrated that the primary indicators of water pollution, namely NH^{+}_{4} and anionic detergents, were consistently found at very low levels throughout the year in the study area.

Keywords: Domestic pollutants, Environmental variables, Çardak Lagoon, Turkish traits system

Introduction

Coastal lagoons are of ecological significance as they represent a distinct transition zone between the terrestrial and marine environments (Tagliapietra et al., 2009). However, the water quality of coastal lagoons worldwide has deteriorated owing to large discharges of nitrogen and phosphorus from domestic and industrial wastewater, as well as urban drainage. Anthropogenic stress, stemming from coastal development (including domestic and industrial development, as well as agriculture), is a salient feature of the coastal areas of lagoons (Vitousek et al., 1997; Abidi et al., 2018). Eutrophication has been identified as the most significant impact observed in coastal lagoons, particularly in those with inland water inputs and limited exchange with the sea (Soria et al., 2022). The increase in nutrients observed in coastal ecosystems has been linked to primary eutrophication, accumulation of organic matter at the bottom, and loss of biota (Arévalo et al., 2013). The excess nutrient content in lagoon waters, the primary stress factor, was predominantly attributable to agricultural, industrial, and domestic waste inputs. The chemical and biological factors that cause pollution include nutrient enrichment and the excessive accumulation of organic carbon, pathogens, and heavy metals (Crossland et al., 2005). The high percentage of dissolved organic nitrogen in the lagoon water is likely due to the recycling of nitrogen, which is presumably attributable to the recycling of organic matter in both the water column and sediment (Christian et al., 1998). Hypoxia in water causes anthropogenic eutrophication, and hypoxic conditions are temporally and spatially variable (dependent on both chemical and physical variables). Under hypoxic conditions, there is a known increase in nutrients, accompanied by changes in trophic levels and an increase in habitat degradation (Kennish & Paerl, 2010; Cloern, 2001). The development of a hypoxic environment can be attributed to the accumulation of organic matter, which exceeds the system's carrying capacity. The impact of environmental factors on fisheries and aquaculture yields, as well as the degradation of ecosystems, has been extensively researched (Karydis, 2009).

Coastal ecosystems are generally categorised through the utilisation of trophic indices, which predominantly rely on the concentrations of nutrients and chlorophyll-*a* (Cotovicz et al., 2013). Photophilous algal blooms, coupled with anoxic conditions and elevated chlorophyll-*a* levels in aquatic environments, serve as indicators of nutrient enrichment. The degradation of lagoonal regions within the Mediterranean Sea is chiefly attributable to the release of untreated domestic wastewater (Mozetic et al., 2008). The introduction of domestic wastewater into the coastal zones of the Mediterranean Sea has been shown to induce eutrophication, with potentially severe repercussions for the lagoon ecosystem when the standard thresholds for eutrophication are exceeded. Natural stressors, such as elevated temperatures and storms, can accelerate eutrophication in lagoons and decrease dissolved oxygen levels in deeper waters. Coastal lagoons are aquatic systems characterised by diminished regeneration capabilities, attributed to their restricted freshwater inflow and their interconnection with marine environments. Significant freshwater influxes coupled with minimal volumes result in diminished salinity levels. However, these salinity levels can experience sudden fluctuations due to storm activity at sea (Soria et al., 2022). Sea surface temperature and precipitation also significantly modify the lagoon environment (Anthony et al., 2009). The coastal areas of such lagoons are rich in organic matter due to their hydrological and trophic status (Mesnage & Picot, 1995; Lardicci et al., 1997, 2001). Numerous studies have focused on understanding the spatial and temporal patterns of all variables closely related to trophic state and water quality in lagoons (Karydis, 1983; Pérez-Ruzafa et al., 2005; Gikas et al., 2006; Coelho et al., 2007; Souchu et al., 2010; Lucena-Moya et al., 2012; Abidi et al., 2018; Acquavita et al., 2015; Cotovicz et al., 2013; Diamantopouloua et al., 2018). Recent studies (Specchiulli et al., 2010; Ponti et al., 2011; Molinaroli et al., 2014; Acquavita et al., 2015; Amos et al., 2017) on the lagoonal areas of the Mediterranean Sea were predominantly conducted along the Italian coast. Studies on this subject have been conducted along the Spanish coastline of the Mediterranean Sea. For instance, Menendez et al. (2004) examined the sediment characteristics of the Tancada Lagoon in eastern Spain. Additionally, Perez-Ruzafa et al. (2005) investigated the temporal and spatial variation of environmental variables, including nutrients and chlorophyll-*a*, in the Mar Menor Lagoon (southern Spain). In the southern Mediterranean, the lagoon ecosystems of the eastern Moroccan coast have been studied by Ruiz et al. (2006) and Bloundi et al. (2008) for their susceptibility to anthropogenic impacts. About the Tunisian Coast, Ayache et al. (2009) addressed the impact of environmental pressures on three lagoon sites (Merja Zerga, Morocco; Ghar El Melh, Tunisia; Manzala, Egypt) on the Tunisian Coast. Primary studies on this subject in Greek Lagoons were performed by Gikas et al. (2006), Diamantopoulou et al. (2008), and Avramidis et al. (2013, 2017). A few studies have been previously conducted on the Turkish Traits system. Noteworthy among these are the investigations by Topçuoğlu et al. (1999), who studied the effects of domestic pollution in Küçükçekmece Lagoon (northern Marmara Sea), and by Altun et al. (2009), who investigated physico-chemical variables and domestic pollution factors in the same area. Çardak Lagoon was designated a "first degree natural protected area" by the decision of the

Edirne Cultural and Natural Heritage Protection Board dated 06.08.1996 and numbered 3298. A rich natural habitat surrounds the lagoon. Çardak Lagoon, situated on the Anatolian northeastern coast of Çanakkale Strait, is one of the 12 lagoon areas that collectively comprise the Turkish Straits System. This lagoon boasts a shoreline length of 4.3 km, an area of 1.2 km^2 and an average depth of 1.3 m.

Materials and Methods

Sampling Area

The Study area was the Çardak Lagoon in the northeast of the Çanakkale Strait (GPS coordinates; İst. 1; 40˚22´906˝ N, 26˚43´103˝ E, station. 2; 40˚23´053˝ N, 26˚43´264˝ E, ist. 3; 40˚23´203˝ N, 26˚43´491˝ E, ist. 4; 40˚23´345˝ N, 26˚43´399˝ E, ex. 5; 40˚23´278˝ N, 26˚42´988˝ E, ist. 6; 40˚23´236˝ N, 26˚42´800˝ E, ist. 7 (reference); 40˚22´931˝ N, 26˚42´768˝ E), and one reference station outside the lagoon at depths between 1-1.8 m (Figure 1).

Water Quality Analysis

The lagoon's quality variables, namely temperature, salinity, pH, and dissolved oxygen solubility, were assessed in situ using the YSI 600 QS Multiprobe System (Yellow Springs Instruments) at designated sampling points throughout the study (Figure 2). Concurrently, nutrient concentrations were evaluated by collecting water samples with a 5 L Nansen sampler.

Concentrations of nutrients such as NO^-_2, NO^-_3, NH^+_4, PO^-_4-P, and SiO^-_2 were then quantified using a Jasco brand UV spectrophotometer using the appropriate chemical and biological analytical methods established by Strickland and Parsons in 1972. To quantify the chlorophyll-*a* concentrations, 5-litre water samples were carefully collected from each site using a 5-litre water sampler. Each sample was then subjected to in-situ vacuum filtration using a 7 mm GF/F filter, which was subsequently wrapped in aluminium foil and frozen in preparation for analysis. Spectrophotometric analysis, following extraction with 90% acetone, was conducted by the methodology outlined by APHA (1995). The total suspended solids (TSS) were quantified gravimetrically after filtration of the water samples through GF/C filters, as articulated by Clesceri et al. (1998). In the context of total phosphorus (inorganic and organic phosphate) analysis, it is imperative to note that all forms of phosphorus undergo a chemical reaction, resulting in the conversion to orthophosphate. (TIN = Total Nitrogen - Organic Nitrogen) (Water on Web, 2009). Analysis of chemical oxygen demand (COD) was performed using the open reflux method in conjunction with established protocols for assessing water and wastewater, as detailed by Eaton and Franson (2005). Spectrophotometric analysis for the quantification of anionic surfactants was performed using a standardised protocol, as described by APHA in 1995, which employed methylene blue.

Anionic Detergent Analysis

Anionic detergents were determined in 500 mL samples taken from the lagoon water (Figure 4). The solution was alkalised by the addition of 1 N NaOH, using phenolphthalein as an indicator. A volume of 10 mL of chloroform and 25 mL of methylene blue was used. Measurements were made using a UV spectrophotometer operating at a wavelength of 652 nm.

Redox Potential Measurements

In situ measurements of redox potential (Eh) were conducted using a pH meter equipped with a redox potential probe, immediately after sediment sampling across the autumn, winter, spring, and summer seasons.

Sediment Organic Matter and Granulometric Analysis

Sediment characteristics were analysed using a 393 cm^{-3} acrylic sediment core (Figure 3,4). This was used to determine the organic matter and particle size in the soft sediments of the lagoon. A total of 28 core samples were taken from the soft sediments at each sampling point during each sampling period for both analyses. The particle size analysis of the sediment was conducted by the methodology outlined by Allen (1997). The organic matter percentage (OM%) content was quantified by calculating the difference between the dry weight of the sediment (dried at 80°C for 24 hours) and the residue after combustion at 450°C for 2 hours (Parker, 1983). The analysis is based on the oxidation of organic substances in water using permanganate in acidic media. Potassium permanganate was utilised as the oxidising agent in this procedure. Following the oxidation process, the organic matter content of the sample was determined in terms of oxygen by back titration of the solution.

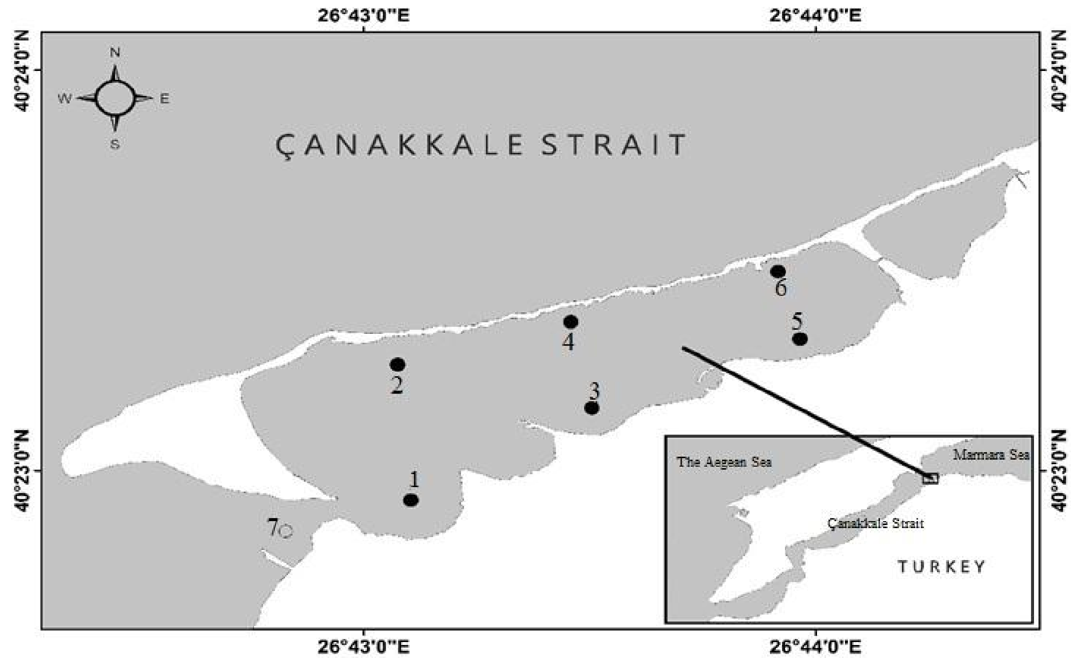

Figure 1. Map of the study area showing the sampling points

Figure 2. Measurements of water quality variables *in situ*

Data Analysis

All variables were analysed using multiple regression and MANOVA (Multiple Analysis of Variance) tests, facilitated by the appropriate statistical software. The analysis of environmental variables in the seawater samples collected from the specified sampling stations was conducted using one-way analysis of variance and Tukey's HSD tests to identify any significant differences between the stations. Additionally, correlation analysis was employed to investigate the relationships between the environmental variables examined in the lagoon water. Pearson's correlation coefficient (r) was used to calculate the correlations between environmental variables and pollutant variables using the PAST 4.02 software. Correlations between environmental and pollutant variables were determined statistically according to principal components analysis (PCA) (Jolliffe, 2002).

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Figure 3. Sediment samplings

Figure 4. Anionic detergent and granulometric analyses.

Results and Discussion

Water Quality, Nutrients, Chlorophyll-a, Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Anionic Surfactants

Water quality variables demonstrated seasonal variations, with temperatures ranging from 7.57°C to 27.34°C, with the highest value recorded in the summer of 2019. Salinity varied between 20.17‰ and 24.40‰, whereas pH levels remained within the characteristic ranges of seawater, oscillating from 7.78 to 8.56. DO levels showed variability, ranging from 5.90 mg/L to 9.51 mg/L, whereas NH^+_4 levels remained consistently minimal, below 0.01 mg/L at all stations throughout the study period. The PO_4-P values varied between 0.01 and 0.03 mg/L, while the total phosphate values exhibited variation between 0.02 and 0.17 mg/L. The maximum total nitrogen value recorded was 0.99 mg/L. The highest recorded NO_2+NO_3 value (0.195 mg/L) was observed in the autumn of 2018. The highest Chl-*a* value (12.85 µg/L) was observed in summer 2019, while the highest TSS value (71.33 mg/L) was recorded in winter 2019. Correlation analysis revealed a significant negative linear relationship ($p < 0.001$) between Chl-*a* and TSS values, and total suspended solids (TSS) values, suggesting that the system's load was predominantly terrestrial rather than phytoplanktonic. Furthermore, COD values (mg/L) were higher in autumn and winter than in other seasons, whereas anionic surfactant values (mg/L) were lower in autumn and winter than in other seasons. The mean values of all the environmental variables throughout the year during the sampling period are presented in Table 1.

Table 1 shows the descriptive statistics of the seasonal values of the water quality variables assessed in the lagoon water within the study area. Variance analysis revealed no statistically significant differences in water temperature variations among the stations (Table 1, $p > 0.05$). The analysis revealed no statistically significant differences in salinity values among the stations, regardless of seasonal variation (Table 1, $p > 0.05$). Similarly, no substantial seasonal variation in pH was observed. Nevertheless, a comparative analysis of the stations indicated that Station 1 demonstrated significantly lower values than its counterparts (Table 1, $p < 0.05$). The dissolved oxygen levels measured at Station 1, situated in close geographical proximity to the reference station, surpassed those observed at the other stations. This observation aligned with the results noted at the reference station (station 7). The oxygen levels recorded at alternative stations within the lagoon were found to be inferior. Nonetheless, the variance analysis indicated that there were no statistically significant differences in DO values among the stations (Table 1, $p > 0.05$).

The results of the analysis of variance, which show the differences in nutrient levels between stations obtained during the study, are presented in Table 1. NH^+_4 values, which are one of the indicators of water quality pollution, are at very low levels (less than 0.01 mg/L) in all stations and seasons during the study. Contrarily, the PO^-_4-P values, another indicator of pollution, demonstrated a range of 0.01-0.03 mg/L, with the lowest values recorded during the autumn and winter periods, and the highest values recorded during the spring and summer periods. Nevertheless, the inter-station variation in PO^-_4-P levels between stations was not statistically significant. Analysis of variance revealed no statistically significant differences between stations for the change in TP (Table 1, $p > 0.05$). Although there were differences between the stations in terms of the TN values, these differences were not statistically significant. Silicate levels recorded during the summer months were significantly higher than those recorded during the autumn, winter, and spring periods. However, statistical analysis revealed no statistically significant differences in silicate levels among the different stations (Table 1, $p > 0.05$). The NO^-_2+NO^-_3 values recorded during the autumn months were higher than those recorded during the other seasons. However, when the difference between the stations was analysed, it was evident that the NO^-_2+NO^-_3 values of the reference station were higher than those of the other stations, on average. However, this difference was not statistically significant. The TIN: P ratios recorded during the autumn and winter periods were notably higher than those recorded during other periods. A comparative analysis of the data reveals that the TIN:P ratio at station 4 is lower than that observed at the other stations, and the TIN: Si ratio at station 6 is significantly higher than that at the other stations. (Table 1, $p > 0.05$).

Table 1. Spatiotemporal variability in water chemistry, nutrients, chlorophyll-*a* (Chl-a), total suspended solids (TSS), chemical oxygen demand (COD), and anionic surfactant (AS) values were measured in the study. The one-way analysis of variance results for water quality variables are presented based on Tukey's HSD test

Variable	Station	Mean±SD	Min.	Max.	Variable	Station	Mean±SD	Min.	Max.
T (°C)	St. 1	15.59±6.77	8.46	24.75	pH	St. 1	7.97±0.19	7.78	8.20
	St. 2	16.74±8.07	7.86	27.34		St. 2	8.29±0.08	8.18	8.37
	St. 3	15.61±7.21	7.69	25.20		St. 3	8.18±0.09	8.05	8.26
	St. 4	15.53±6.61	7.96	24.07		St. 4	8.32±0.09	8.23	8.43
	St. 5	15.89±7.85	7.57	26.31		St. 5	8.25±0.15	8.07	8.40
	St. 6	16.33±7.88	7.68	26.54		St. 6	8.34±0.20	8.14	8.56
	St. 7, ref.	16.19±7.03	8.72	25.46		St. 7, ref.	8.25±0.09	8.12	8.35
S (‰)	St. 1	21.91±1.69	20.29	23.92	DO (mg/L)	St. 1	8.18±1.49	6.11	9.51
	St. 2	22.01±1.37	20.78	23.92		St. 2	7.76±1.19	6.85	9.50
	St. 3	21.79±1.20	20.76	23.00		St. 3	7.21±1.08	6.15	8.17
	St. 4	22.04±1.37	20.77	23.69		St. 4	7.07±1.01	5.99	8.27
	St. 5	22.04±0.88	20.80	22.85		St. 5	7.18±1.12	6.16	8.47
	St. 6	21.87±0.84	20.74	22.74		St. 6	7.08±0.81	5.90	7.69
	St. 7, ref.	22.04±1.93	20.17	24.40		St. 7, ref.	7.76±0.37	7.41	8.20
PO^{-}_4 (mg/L)	St. 1	0.02±0.012	0.01	0.03	NH^{+}_4 (mg/L)	St. 1	0.01±0.00	0.01	0.01
	St. 2	0.015±0.006	0.01	0.02		St. 2	0.01±0.00	0.01	0.01
	St. 3	0.013±0.005	0.01	0.02		St. 3	0.01±0.00	0.01	0.01
	St. 4	0.015±0.006	0.01	0.02		St. 4	0.01±0.00	0.01	0.01
	St. 5	0.01±0.00	0.01	0.01		St. 5	0.01±0.00	0.01	0.01
	St. 6	0.015±0.01	0.01	0.03		St. 6	0.01±0.00	0.01	0.01
	St. 7, ref.	0.01±0.00	0.01	0.01		St. 7, ref.	0.01±0.00	0.01	0.01
TP (mg/L)	St. 1	0.048±0.026	0.02	0.07	TN (mg/L)	St. 1	0.480±0.206	0.30	0.74
	St. 2	0.029±0.013	0.02	0.04		St. 2	0.230±0.126	0.10	0.37
	St. 3	0.026±0.009	0.02	0.04		St. 3	0.427±0.170	0.25	0.66
	St. 4	0.035±0.018	0.02	0.05		St. 4	0.162±0.047	0.10	0.20
	St. 5	0.051±0.066	0.02	0.15		St. 5	0.498±0.379	0.20	0.99
	St. 6	0.065±0.073	0.02	0.17		St. 6	0.498±0.379	0.20	0.99
	St. 7, ref.	0.052±0.072	0.02	0.16		St. 7, ref.	0.262±0.075	0.20	0.35
NO_2+NO_3 (mg/L)	St. 1	0.083±0.04	0.04	0.13	SiO_2 (mg/L)	St. 1	0.367±0.241	0.15	0.60
	St. 2	0.071±0.059	0.04	0.13		St. 2	0.563±0.442	0.20	1.20
	St. 3	0.071±0.059	0.02	0.13		St. 3	0.292±0.225	0.05	0.55
	St. 4	0.036±0.02	0.01	0.06		St. 4	0.575±0.561	0.20	1.40
	St. 5	0.088±0.074	0.03	0.20		St. 5	0.555±0.632	0.17	1.50
	St. 6	0.088±0.063	0.03	0.18		St. 6	0.186±0.156	0.02	0.40
	St. 7, ref.	0.094±0.041	0.05	0.14		St. 7, ref.	0.487±0.477	0.20	1.20
Chl-*a* (µg L^{-1})	St. 1	3.64±3.84	1.61	9.39	TSS (mg/L)	St. 1	11.00±4.62	6.80	17.60
	St. 2	2.64±1.52	1.06	3.96		St. 2	8.07±2.74	4.30	10.20
	St. 3	3.39±2.27	1.09	5.75		St. 3	22.1±22.5	3.80	54.40
	St. 4	2.96±2.26	0.97	6.19		St. 4	9.35±4.85	4.00	15.60
	St. 5	2.59±2.13	1.31	5.76		St. 5	19.1±24.8	3.20	56.00
	St. 6	4.47±5.61	1.07	12.85		St. 6	28.4±29.7	7.20	71.30
	St. 7, ref.	1.49±0.44	1.05	1.98		St. 7, ref.	15.98±8.36	7.70	24.40
COD (mg/L)	St. 1	127.9±52	76.00	198	AS (mg/L)	St. 1	0.045±0.022	0.02	0.07
	St. 2	152.1±102.8	76.00	295		St. 2	0.027±0.016	0.02	0.05
	St. 3	105.0±55.2	40.00	158		St. 3	0.032±0.014	0.02	0.05
	St. 4	87.5±64.1	40.00	181		St. 4	0.040±0.014	0.02	0.05
	St. 5	120.5±111.8	40.00	277		St. 5	0.034±0.011	0.02	0.05
	St. 6	148.3±98.1	53.00	277		St. 6	0.035±0.012	0.02	0.05
	St. 7, ref.	101.5±79.6	40.00	207		St. 7, ref.	0.032±0.016	0.02	0.05

The results of the analysis of variance showing the differences between the stations in the values of Chl-*a* and suspended solids are presented in Table 1. Chl-*a* levels are higher in summer and autumn than at other times. A check was made to determine if the difference between the stations was significant; however, the reference station had a lower Chl-*a* value than the other stations. Nonetheless, this difference was not large enough to be considered significant (Table 1, $p > 0.05$). Correlation analysis showed a significant negative linear relationship ($p < 0.001$) between Chl-*a* and suspended solids, indicating that the loading to the system is terrestrial rather than phytoplanktonic. However, analysis of variance shows that the differences in suspended solids between stations are not statistically significant. Analyses of Chemical Oxygen Demand (COD) and anionic detergent concentrations were conducted on a seasonal basis, with the results of the analysis of variance illustrating the differences between stations as shown in Table 4. After a thorough analysis of the COD values at the different stations, it was found that both the reference station (station 7) and the other station had lower values compared to their counterparts; however, the observed differences were not statistically significant (Table 1, $p > 0.05$).

Anionic detergent values are also presented in Table 1. When comparing the anionic detergent values between the stations, it was found that the values recorded for Stations 1 and 4 were slightly higher than those recorded for the other stations; however, these differences were not statistically significant (Table 1, $p > 0.05$). Additionally, the recorded COD values were higher in autumn and winter compared to the other seasons. In comparison, the anionic detergent values were lower in fall and winter compared to the other seasons.

Granulometry

Sediment composition in the sampling area was as follows: 71.59% sand, 20.16% gravel + shell, and 8.19% mud (clay + silt). The highest sand ratio was observed at station 6, with a value of 92%. Conversely, the highest levels of mud (clay+silt) content (16.71%) and the highest gravel+shell ratio (25.64%) were recorded at station 5 (Table 2).

The Amount of Organic Matter in Water and Sediment

As presented in Figure 5, the quantity of organic matter present in the water and sediment varies with the time of year.

Seasonal Correlations Between Environmental and Pollutant Variables in the Study Area

Relationships between environmental and pollutant variables measured seasonally in the lagoon water are presented in Table 3. Based on Pearson's correlation coefficient, the strongest positive correlations (r = 0.96, 0.94; $p < 0.05$) are observed between PO4 in water and TP and SiO_2 content. Conversely, the lowest correlations (r=0.01; r=0.02, $p < 0.05$) are found between anionic detergent concentration and the total nitrogen (TN), and suspended solids (SSM) and coarse sand and shell fraction in the sediment. The variable with the highest positive correlation (r=0.89, $p < 0.05$) with Chl-*a* levels, which is the determinant of primary production in the water, was the lagoon water temperature.

Principal component analysis (PCA) biplot analysis was employed to summarise the variance structure of the multivariate environmental data and to visualise the relationships between variables (Figure 6). The analysis showed that the first and second principal components (PC1 and PC2) accounted for a significant proportion of the total variation (PC1: 28.44% and PC2: 24.65%). For example, environmental factors such as temperature, salinity, and pH showed positive and significant loadings along the PC1 axis. This illustrates the relationship between temperature and salinity. On the other hand, pollutant variables such as silt+clay percentage, NO_2+NO_3, TP, and ACM had significant effects on the PC2 component, suggesting a connection with the features of nutrients and sediment. The angles formed between the vectors illustrate the degree to which the variables are related. A positive correlation is indicated by variables that are positively related, while a negative correlation is indicated by variables that are inversely related. For example, there is a positive correlation between OM% and TP. As a result, the PCA analysis effectively highlighted the most significant differences between the environmental variables. Of particular importance were the physico-chemical variables and nutrients, which played a key role in distinguishing the samples. These results are crucial for understanding the primary factors driving the observed environmental variation within the study area.

Table 2. Mean seasonal percent granulometry ratios recorded at stations

	Particle type %							
Factor	**Clay+silt**	**Very fine sand**	**Fine sand**	**Medium sand**	**Coarse sand**	**Very coarse sand**	**Gravel and shell**	**Coarse gravel and shell**
Stn, 1	14.16	13.89	18.04	9.43	8.91	11.46	14.74	9.3
Stn, 2	3.17	10.96	15.93	19.57	**16.49**	15.72	10.47	7.65
Stn, 3	13.24	7.25	7.92	9.85	12.82	**17.3**	**19.72**	11.83
Stn, 4	5.27	20.08	**43.68**	7.1	8.91	6.42	4.12	4.36
Stn, 5	**16.71**	**23.66**	9.27	7.17	7.75	9.76	11.85	**13.79**
Stn, 6	3.29	13.67	43.94	**25.06**	6.16	3.91	2.59	1.38
Stn, 7, ref,	1.49	3.1	15.26	17.55	15.88	**17.3**	16.11	13.25
Mean	8.19±6.27	13.23±7.06	22.00±15.32	13.67±4.04	10.98±4.08	11.69±5.34	11.37±6.24	8.79±4.65

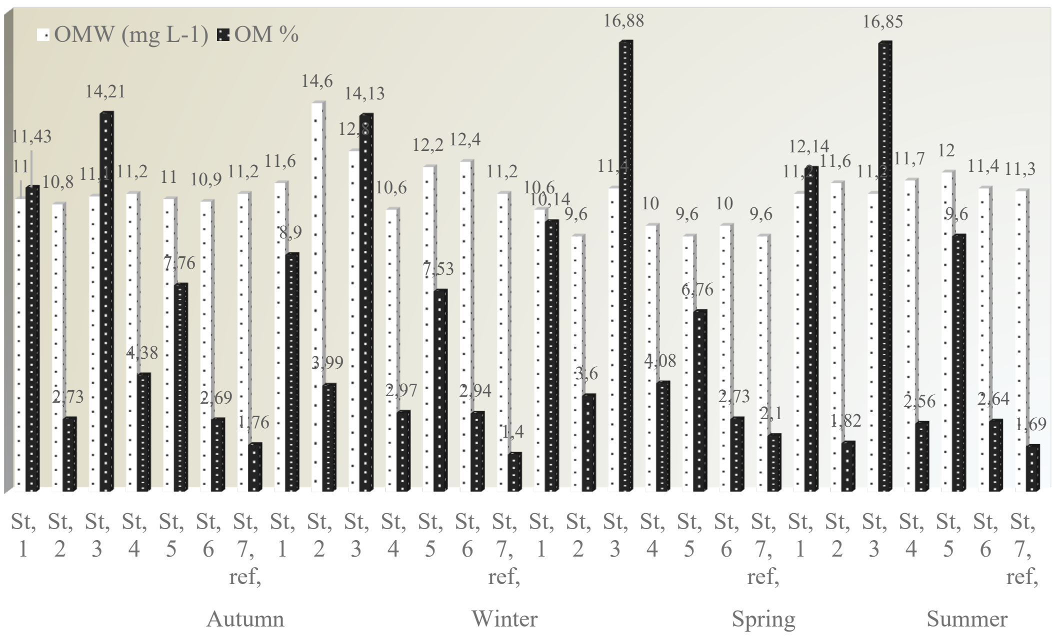

Figure 5. Spatio-temporal amount of organic matter in the water and sediment measured in the Çardak Lagoon

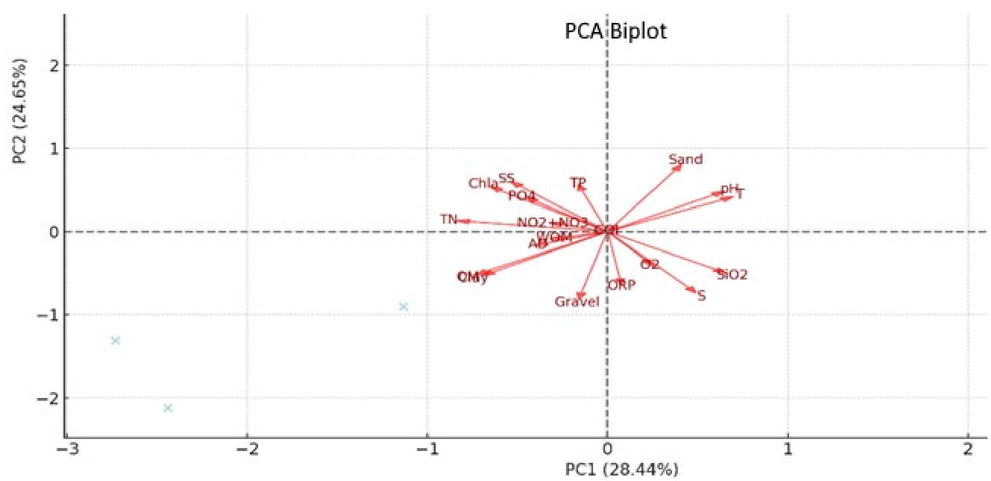

Figure 6. PCA ordination diagram showing the correlations between environmental variables and pollutants

Table 3. Seasonal correlations between environmental and pollutant variables in Çardak Lagoon
OM %: Oragnic matter in sediment, SOM: Organic matter in water (mg/L), C+S: Clay+Silt, T: Temperature, S: Salinity,
DO: Dissolved Oxygen (mg/L), Chl-*a*: Chlorophyll-*a* (($\mu g\ L^{-1}$), TP: Total phosphate (mg/L), TN: Total Nitrogen (mg/L), NO2+NO3: Nitrate+Nitrogen (mg/L),
TSS: Total Suspend Solid (mg/L), COD: Chemical Oxygen Demand,
AD: Anionic Detergent (mg/L), PO-4: Phosphate mg/L), S: Sand, CS+Sh.: Coarse Sand + Shell
(Pearson correlation r, p<0.05).

Variables	OM %	SOM	C+S %	T (ºC)	S (‰)	DO	ORP	pH	Chl-*a*	SiO_2	TP	NO_2+NO_3	TN	TSS	COD	AD	PO_4	S %	CS+sh%
OM%		-0,62	-0,97	0,91	-0,67	-0,08	-0,12	0,78	0,71	0,36	0,76	-0,58	0,08	-0,92	-0,76	0,42	0,63	0,30	0,36
SOM	-0,62		0,42	-0,24	0,25	0,57	-0,12	-0,57	-0,01	0,50	-0,03	0,08	-0,55	0,60	0,44	-0,79	0,21	0,04	-0,36
C+S %	-0,97	0,42		-0,97	0,78	-0,16	0,05	-0,66	-0,87	-0,56	-0,83	0,55	-0,02	0,93	0,67	-0,18	-0,76	-0,47	-0,19
T (ºC)	**0,91**	-0,24	-0,97		-0,71	0,22	-0,19	0,66	**0,89**	0,72	0,93	-0,66	-0,18	-0,83	-0,70	0,09	0,89	0,41	0,23
S (‰)	-0,67	0,25	0,78	-0,71		-0,62	-0,55	-0,07	-0,90	-0,44	-0,41	-0,06	-0,46	0,88	0,06	0,29	-0,48	-0,91	0,45
O2	-0,08	0,57	-0,16	0,22	-0,62		0,56	-0,58	0,63	0,59	0,09	0,35	0,13	-0,19	0,51	-0,93	0,35	0,84	-0,82
ORP	-0,12	-0,12	0,05	-0,19	-0,55	0,56		-0,66	0,19	-0,27	-0,52	0,86	0,88	-0,27	0,72	-0,47	-0,40	0,77	-0,88
pH	0,78	-0,57	-0,66	0,66	-0,07	-0,58	-0,66		0,24	0,19	0,73	-0,87	-0,34	-0,49	-0,99	0,77	0,50	-0,35	0,86
Chl.-*a*	0,71	-0,01	-0,87	**0,89**	-0,90	0,63	0,19	0,24		0,78	0,73	-0,29	0,03	-0,80	-0,29	-0,34	0,81	0,77	-0,24
SiO2	0,36	0,50	-0,56	0,72	-0,44	0,59	-0,27	0,19	0,78		0,81	-0,55	-0,57	-0,30	-0,32	-0,47	0,94	0,38	-0,03
TP	0,76	-0,03	-0,83	**0,93**	-0,41	0,09	-0,52	0,73	0,73	0,81		-0,87	-0,54	-0,57	-0,81	0,12	0,96	0,12	0,45
NO_2+NO_3	-0,58	0,08	0,55	-0,66	-0,06	0,35	**0,86**	-0,87	-0,29	-0,55	-0,87		0,74	0,24	0,93	-0,45	-0,74	0,39	-0,82
TN	0,08	-0,55	-0,02	-0,18	-0,46	0,13	**0,88**	-0,34	0,03	-0,57	-0,54	0,74		-0,39	0,46	0,01	-0,55	0,52	-0,56
SSM	-0,92	0,60	**0,93**	-0,83	**0,88**	-0,19	-0,27	-0,49	-0,80	-0,30	-0,57	0,24	-0,39		0,46	-0,18	-0,50	-0,62	0,02
COD	-0,76	0,44	0,67	-0,70	0,06	0,51	0,72	-0,99	-0,29	-0,32	-0,81	**0,93**	0,46	0,46		-0,68	-0,61	0,34	-0,86
AD	0,42	-0,79	-0,18	0,09	0,29	-0,93	-0,47	0,77	-0,34	-0,47	0,12	-0,45	0,01	-0,18	-0,68		-0,17	-0,62	0,83
PO_4	0,63	0,21	-0,76	**0,89**	-0,48	0,35	-0,40	0,50	0,81	**0,94**	**0,96**	-0,74	-0,55	-0,50	-0,61	-0,17		0,28	0,22
Sand %	0,30	0,04	-0,47	0,41	-0,91	0,84	0,77	-0,35	0,77	0,38	0,12	0,39	0,52	-0,62	0,34	-0,62	0,28		-0,78
CS+sh %	0,36	-0,36	-0,19	0,23	0,45	-0,82	-0,88	**0,86**	-0,24	-0,03	0,45	-0,82	-0,56	0,02	-0,86	0,83	0,22	-0,78	

This study clarifies the temporal and spatial interactions between domestic pollutants and environmental factors recorded in different areas of the Çardak Lagoon, located in the charming settlement of Çardak Town, within the Laspseki district, adjacent to the Çanakkale Strait. The importance of geographical and temporal variation is crucial in the examination of ecological systems. Nonetheless, it is often not possible to assess both types of variability at the same time. This problem is similar in studies of aquatic ecosystems, tend to be ephemeral in time or area. A large number of comparative studies are needed to clarify the spatial and temporal variations observed in lagoon areas. These studies are essential for understanding models that can be formulated for the efficient management of lagoons (Acquavita et al., 2015). Coastal lagoons are highly productive eutrophic ecosystems (Specchiulli et al., 2008) and play a significant role in regulating human impacts on coastal areas (Arévalo et al., 2013). However, such ecosystems are often subject to eutrophication, leading to a deterioration in their overall quality (Arévalo et al., 2013; Arima et al., 2013; Acquavita et al., 2015; Coelho et al., 2007; Arvamidis et al., 2013; Amos et al., 2017).

Recent studies show that the enrichment of nutrients and sediment particle size in lagoons have a significant impact on the stress levels observed in biota (Lardicci et al., 1997; Specchiulli et al., 2010). The main obstacles identified in lagoons are summer denitrification, increased surface temperatures, relatively low water flow, increased consumption of dissolved oxygen due to an excess of organic matter, and an increase of photophilous algae and bacterial communities (Sylasios & Theocharis, 2002). The temporal variability of water chemistry in coastal lagoons is a widely recognised characteristic of these ecosystems, and represents a major challenge in the efforts to accurately define them. Therefore, relying on isolated measurements of water chemistry may not be sufficient for the comprehensive characterisation of these lagoonal areas (Lucena-Moya et al., 2012).

Table 4 outlines the values of physico-chemical variables recorded in previous studies within the lagoon areas of the Mediterranean and northeast Atlantic coastlines. Environmental factors, such as dissolved oxygen levels, temperature variations, and salinity influence the complexity of biotic communities and numerous biogeochemical cycles (i.e., naturally occurring substances involved in the cycling of elements such as sulfur and nitrogen) within lagoon environments (Rosenberg et al., 2001). The differences in the measurements collected from different areas of the Mediterranean, together with the figures reported in this study, show minimal variations. Temperature and salinity are the most variable parameters of water quality. The highest temperature, reaching an impressive 39.0‰, was recorded in the lagoon of Bizerte, Tunisia, while the lowest temperature of 0.27‰ was observed in the lagoon of Klisova, located in western Greece. The lowest water temperature recorded was 3.4°C in Homa Lagoon, found in the eastern Aegean Sea, while the highest was 32.2°C, noted in Myrtari Lagoon, situated in western Greece. The decomposition of organic matter in the sediment leads to an increased concentration of nutrients in the water column (Arvamidis et al., 2017; Kennish & Paerl, 2010).

The hydrological dynamics of coastal lagoons, known for their high biomass and productivity (Reizopoulou et al., 1996), combined with their limited connectivity, result in a marked accumulation of organic matter in their sediments. It is generally accepted that the level of organic matter in sediments is closely related to sediment particle size (Tyson, 1995). However, the organic matter concentration in coastal lagoons is typically higher than that observed in coastal marine ecosystems (Tyson, 1995; Afli et al., 2009a). In addition, human activities can increase this percentage to about 2% (De Falco et al., 2000). Several previous studies have assessed the organic matter concentration in sediments of different Mediterranean lagoons (Khedhri et al., 2016). In this study, the values ranged from a low of 1.26% to a high of 29.1% during the summer season in the Boughrara lagoon (eastern Tunisia). The study found that the lowest amount of organic matter in the sediment (1.4%) was observed in February 2019, while the highest amount (16.88%) was found in April and June 2019 at the reference site.

Sediment particle dimensions are an important environmental factor in the analysis of lagoon areas (Avramidis et al., 2013). Several research efforts have focused on the sediment particle dimensions across the Mediterranean lagoons (Table 5). This research has shown that the highest sand proportion (97. 29%) and lowest sand proportion (6. 75%), percentage of sand in the sediment, as well as the highest (21. 59%) and lowest (21.59%) percentages of mud proportion in the sediment, were observed during the autumn and winter seasons. Coastal lagoons with high light penetration are characterised by elevated nutrient concentrations. Phosphorus and nitrogen inputs lead to eutrophication within the lagoons. Many detailed studies have been carried out on the extent of anthropogenic stress on these other Mediterranean lagoons. The different levels found in these studies are shown in Table 6. The median values of nutrient concentrations in the Çardak Lagoon were found to be lower than those observed in other Mediterranean lagoons. It is recognised that human activities are the main factor leading to spatial variability in water chemistry. The mean annual concentration of NO^{-}_{2}+NO^{-}_{3} in the lagoon water was found to be 0.076 mg/L.

Table 4. Physico-chemical variables recorded in coastal lagoons at different locations in the Mediterranean Sea and the North-east Atlantic

Locality	Values	T (°C)	S (‰)	DO (mg/L)	pH	Reference
Güllük Lagoon (Eastern Aegean Sea)	Ort.	19.53±3.48	10.65±0.88	7.32±0.69	8.00±0.08	Egemen et al. (1999)
Homa Lagoon (Eastern Aegean Sea, Türkiye)	Min./Max.	3.4-26.6	33.1-61.6	2.3-9.6	8.0-8.8	Can et al. (2009)
Bizerte Lagoon (North Tunisia)	Min./Max.	10.0-30.6	21.4-38.4	4.3-9.3	-	Boukef et al. (2012)
Myrtari Lagoon (Western Greece)	Min./Max.	9.6-32.2	2.45-19.5	5.9-11.1	7.51-8.47	Avramidis et al. (2013)
Marano and Grado Lagoons (Italy)	Mean	6.32-26.0	17.2-28.7	7.0-10.8	-	Acquavita et al. (2015)
Almargem (A) and Salgados (S) Lagoons (Southern Portugal)	Mean	S.; 20.9±3.49/A.; 21.8±4.59	S.; 8.2±5.25/A.; 13.1±7.96	S.; 10.2±5.07/A.; 8.9±1.61	S.; 8.6±0.61/A.; 8.3±0.39	Coelho et al. (2015)
Saros Bay Lagoons (Northeastern Aegean Sea)	Min./Max.	18-27.7	0.8-57.9	-	7.9-8.9	Barut et al. (2015)
Klisova Lagoon (Western Greece)	Min./Max.	7.6-28.1	0.27-13.63	0.42-9.08	7.5-9.2	Avramidis vd. (2017)
Çardak Lagoon (Turkish Straits System	Mean.	15.98±7.01	21.95±0.85	7.46±1.12	8.22±0.09	This study

S: Salinity T: Temperature DO: Dissolved oxygen

Table 5. Sediment particle values recorded in coastal lagoons at different localities in the Mediterranean and northeastern Atlantic

Locality	Sand %	Clay+silt %	Coarse sand +Shell %	Reference
Thau Lagoon (Southern France)	23.8-91.6	8.0-76.2	0.2-0.6	De Casabianca et al. (1997)
Cadiz Lagoon (Southern Spain, Atlantic)	3.68	96.32	-	Drake & Arias (1997)
Tancada Lagoon (Eastern Spain)	Mean: 23.35	Mean: 76.55	-	Menendez et al. (2004)
Cabras Lagoon (Western Sardinia Island)	Mean: 5.11	Mean: 94.87	-	Magni et al (2005)
Obidos Lagünü (Batı Portekiz, Atlantik)	-	4-98.40	-	Carvalho et al. (2005)
Venice Lagoon (Northern Adriatic)	Mean: 19	Mean: 0.3	-	Molinaroli et al. (2014)
Bizerte Lagoon (Tunisia)	20-80	17-80<	<15	Afli et al. (2009b)
Karavasta Lagoon (Albania, Adriatic)	Mean 6.11	Mean. 93.88	-	Munari et al. (2010)
Myrtari Lagoon (Western Greece)	42-72.81	18.87-62.10	-	Avramidis et al. (2013)
Saros Bay Lagoons (Northeastern Aegean Sea)	2.71-86.29	0.73-96.18	0.51-36.32	Barut et al. (2015)
Homa Lagoon (Eastern Aegen Sea, Türkiye)	15-45	48-85	-	Can et al. (2009)
Almargem and Salgados Lagoons (Southern Portugal, Atlantic)	Mean A.; 81.4/S.; 71.0	Mean A.; 15.6/S.; 19.6	-	Coelho et al. (2015)
Çardak Lagoon	46.75-97.29 Mean: 71.59	0.27-21.59 Mean: 8.19	2.15-48.11 Mean: 20.16	This study

Although no significant irregularities are noted in the annual nutrient values in the study area, which is characterised by shallow water (mean 1.3 m), the NH^{+}_{4} value remains below 0.01 mg/L throughout the year. Nonetheless, the peak levels of total nitrogen reached 0.99 mg/L and total phosphorus at 0.17 mg/L. Ligorini et al. (2023) found that the highest nutrient levels were recorded in winter in three lagoons located on Corsica Island. Nutrient levels were also found to be low during the winter season in this study. About 83% of the phosphorus pollution detected in marine and lagoon ecosystems is attributed to industrial and wastewater discharges. Detegent accounts for 32-70% of phosphates in wastewater (Sarı, 2005). Detergent concentrations in surface water samples collected from lagoons have been examined in prior studies. Among these studies, Stora & Arnoux (1983) reported detergent concentrations ranging from 31.19 to 62.90 mg/L in the Etang de Berre lagoon (southern France). In Türkiye, anionic detergent levels were found to remain below 0.50 mg/L throughout the year in the Güllük lagoon (eastern Aegean Sea) (Egemen et al., 1999).

Topçuoğlu et al. (1999) recorded the highest detergent concentration as 0.228 mg/L at the surface (0 m) in the Küçükçekmece lagoon area in April. The average seasonal concentration of anionic detergents in the study area is 0.035 ±0.015 mg/L, while a notably higher level of 0.116 mg/L was found in Küçükçekmece lagoon. The presence of suspended solids in water serves as a significant source of physical pollution, leading to various detrimental effects, including increased turbidity, elevated toxicity levels, and reduced dissolved oxygen content (Tavora et al., 2019). In this context, Carvalho et al. (2011) reported a minimum suspended concentration of 21 mg/L during the winter season, with a maximum of 153 mg/L reached during the spring season within the Obidos Lagoon of western Portugal. The Çardak lagoon showed an average seasonal concentration of suspended solids of 16.29 mg/L.

Relationships Between Environmental and Pollutants Variables

Relationships between environmental factors in Mediterranean lagoons have been analysed in many studies. As noted by Kormas et al. (2001), Logarou, Rodia, and Tsoukalio found that among the environmental variables evaluated in the lagoons of the Amvrakikos Gulf in western Greece, salinity and temperature had the strongest positive correlation ($r = 0.73$; $p < 0.001$).

Despite the presence of a weak negative correlation between the chlorophyll-*a* values and the salinity/temperature metrics recorded in these three lagoons, they have relatively high nutrient contents (excluding PO^{-}_{4}) compared to the Amvrakikos Gulf. This study found a robust positive correlation ($r = 0.88$; $p < 0.05$) between lagoon water temperature and oxidation-reduction potential (ORP). Specchiulli et al. (2008) reported a positive correlation ($r = 0.83$; $p < 0.001$) between chlorophyll-a levels and temperature, and a significant negative correlation ($r = -0.93$; $p < 0.001$) between temperature and dissolved oxygen concentrations in the Orbetello Lagoon, located on the northern Adriatic coast. The researchers identified the strongest positive correlation between NH^{+}_{4} and temperature ($r = 0.75$; $p < 0.001$) and the weakest negative correlation between NO^{-}_{2} and TP ($r = -0.55$; $p < 0.001$) in the Varano lagoon of the Adriatic Sea. The present study has revealed a robust positive correlation ($r = 0.89$, $p < 0.05$) between seasonal chlorophyll-*a* concentrations and water temperature, as observed within the Orbetello Lagoon. Furthermore, a modest positive correlation was observed ($r=0.22$; $p < 0.05$), which contrasts with the correlation coefficient observed between water temperature and dissolved oxygen levels in the Orbetello Lagoon. Souchu et al. (2010) studied the relationships between environmental variables in a total of 20 lagoons in the eutrophicated south of France and the island of Corsica in the western Mediterranean Sea between 1998 and 2002. The highest correlation ($r = 0.92$; $p = 0.0001$) between the environmental variables measured in these 20 lagoons was found between TN and TP. In a study by Pérez-Ruzafa et al. (2005) conducted in the Mar Menor lagoon (south-eastern Spain), which is one of the largest lagoons in the western Mediterranean, the strongest correlations among the environmental variables of the lagoon water were observed between Chl-*a*+2 and temperature (r=0.93), salinity (r=0. 93), and NO^{-}_{2} (r=0.81). In another study, Cañedo-Argüelles et al. (2012) identified a moderate negative correlation ($r = -0.68$) between pH and NO_3 in the Remolar lagoon (northeastern Spain). Conversely, there exists a strong negative correlation ($r = -0.87$, $p < 0.05$) between the summer months and the other periods of sampling for NH^{+}_{4}, dissolved oxygen saturation, and Chl.-*a* recorded in the waters of the Ria Formosa Lagoon (southern Portugal), located in the northeast Atlantic outside the Mediterranean ecosystem. Nevertheless, markedly significant differences ($p \leq 0.01$) were found between the annual means of most water variables in Almargem and Salgados lagoons, situated in southern Portugal (Coelho et al., 2015).

Furthermore, only the concentration of Chl-*a* in the water showed considerable variability, while the variability between the annual means of sediment variables in the same lagoons was not significant. The strongest positive correlation ($r = 0.96$, $p < 0.05$) was observed between the concentrations of PO^{-}_{4} and TP in the water. Avramidis et al. (2013) reported that the amount of PO^{-}_{4}-P in Myrtari Lagoon (western Greece), which was recorded between <0.01-0.03 mg/L throughout the year, decreased significantly in 2010 and 2011 compared to previous years (especially the phosphate increase observed in 2001-2002 with a maximum of 1.79 mg/L). They explained this situation in terms of the increased dissolved oxygen concentrations in the water of Myrtari Lagoon.

In shallow lagoons, the movement of pollution or its dilution is mainly influenced by the interaction between rainfall and the intense wave action caused by strong winds. The accumulation of organic matter, mainly due to domestic pollution, has been observed to occur mainly during the summer and autumn seasons, which are characterised by lower wind speeds (1-12 km/h) and little wave action. The water discharged from the outfall has a lower specific mass than that of the lagoon water, but wave action can promote horizontal stratification and subsequent dispersion away from the outfall, all while avoiding direct contact with the surface. Regarding the lagoon's water quality, variability and inconsistency in the measurement of certain environmental variables (e.g. %OM in sediment, organic matter in water, chlorophyll-a, nutrients, suspended solids, COD, anionic detergents), especially in the seaward regions, may be misleading. The effects of the wind and the intensity of the strong waves observed in the study area may contribute to a decrease in pollution. The dynamic tides of the currents and waves, primarily influenced by the strong north and southwest winds, facilitate a significant transfer of pollutants, especially from the lagoon, to the shallow water environment of the study area, with an average depth of 1.3 meters. Peak %OM values of 12.1% and 16.88% were recorded during the summer season, correlating with wind speeds of 1 km/h. In contrast, the percentage of organic matter (%OM) decreased to 8.90% and 1.13% during the winter sampling period, which was characterised by wind speeds between 39 and 49 km/h. Nevertheless, the seasonal mean of %OM in the sediment at the seaward stations of the lagoon varied between 2.7% and 3.9%.

The observed variation in the physico-chemical properties of the lagoon water can be attributed to the waves and currents induced by the strong winds in the Çanakkale Strait. In contrast to other seasons, the elevated salinity levels observed in February 2019 suggest that the study area is more influenced by the Çanakkale Strait current system during the winter months. The water quality data collected in this study are in close agreement with the results of previous studies conducted in the region; the observed discrepancies are likely due to seasonal variations and terrestrial inputs (Uzundumlu & Büyükateş, 2019).

The concentrations of NH_4^+, a crucial parameter in evaluating water quality, were consistently low across all monitoring stations and throughout all seasons. This is in marked contrast to the findings of multiple studies conducted at various times during the study period in a region adjacent to the area under investigation (Büyükateş et al., 2017). The levels of phosphate (PO-P) and silicate (SiO_2), critical indicators of water pollution, are markedly diminished compared to the findings of previous study conducted by Büyükateş et al. (2017) in the Çanakkale Strait, notable variations in the concentration of suspended solids in the lagoon water were observed both across different stations and throughout various seasons within the study area. These fluctuations may be indicative of the lagoon being influenced by both terrestrial inputs and the dynamic impacts of substantial wave action and strait currents. The concentration of phosphate (PO) in aquatic environments is intricately connected to the presence of anionic detergents. Levels of anionic detergents and phosphates in surface waters increase during the summer months, primarily due to heightened cleaning activities, in contrast to other seasons. This study observed a notable consistency in the concentrations of detergents and phosphates in the surface water of the lagoon across various seasons. The peak Chlorophyll-a levels observed during the summer months can be attributed to two main factors: an increase in air temperature and the subsequent phosphate run-off from the terrestrial surroundings of the lagoon. The analysis of chlorophyll-a and suspended solids measurements recorded in the study area indicates that the observed system load is mainly due to terrestrial inputs. According to the findings of Kanarska and Maderich (2008), the mean concentration of suspended solids in the water column of the Dardanelles was measured to be 1.65 mg/L. Despite the influence of erosion, transport processes, and wave dynamics, significantly elevated values can be observed within the study area and its neighbouring coastal regions. The annual mean concentration of suspended solids in the study area, which ranges from 8.07 to 28.1 mg/L, can be attributed to the interaction of transport dynamics with vigorous wave activity.

Table 6. Nutrient levels recorded in lagoon areas in the Mediterranean and eastern Atlantic

Locality	NH^{+}_{4} (µM)	NO^{-}_{2} (µM)	NO^{-}_{3} (µM)	Chl.-*a* (µg L^{-1})	PO^{-}_{4} (µM)	Reference
Güllük Lagoon (Western Türkiye)	14.66±4.09	0.61±0.21	3.67±2.79	5.5±3.40	0.08±0.07	Egemen et al. (1999)
Vistonis Lagoon (Northeastern Aegean Sea)	Mean: 25.5	-	Mean: 125.4	Mean: 39.6	Mean: 104.5	Gikas et al. 2006
Lapalme Lagoon (Southern France)	2.85	48±11.8	0.15±0.1	1.9±0.7	0.31±0.0	Carlier et al. (2008)
Bizerte Lagünü (Kuzey Tunus)	-	-	-	3.3- 5.0 (ort.min./maks.)	-	Boukef et al. (2012)
Marano and Grado Lagoons (Italy, Northern Adriatic)	0.04–26.4 (3.97)	0.03–12.2 (1.00)	0.12–368 (59.0)	0.06–111 (1.31)	0.05-522 (5.44)	Acquavita et al. (2015)
Klisova Lagoon (Western Greece)	0.22-13.48	Low throughout the year	0.026-0.42	-	Low throughout the year	Avramidis et al. (2017)
Senillar de Moraira Lagoon (Eastern Spain)	Mean: 3.0 µmol L^{-1}	-	50-180 µmol L^{-1}	1-5 µmol L^{-1}	0.6-9.2 µmol L^{-1}	Camacho et al. (2012)
Almargem (A) and Salgados (S) Lagoons (Southern Portugal)	S.; 56.0±123.0/A.; 3.2±3.0	S.; 5.7±7.79/A.; 0.7±0.61	S.; 17.9±29.82/A.; 26.8±42.41	S.; 158.5±177.95/A.; 3.0±3.43	S.; 65.2±42.04/A.; 1.3±0.76	Coelho et al. (2015)
Çardak Lagoon	<0.01	NO_2+NO_3 0.015-0.135		0.97-12.85	<0.01-0.03	This study

Conclusion

The designated protection zone within the study area experienced a progressive decrease in depth over time, which was attributed to the accumulation of organic matter in the sediment. The sediment of the lagoon showed robust populations of photophilic algae, particularly during the spring and summer months. The increased growth rate of these photophilic algal populations suggests a significant influx of nutrients into the ecosystem. Excessive nutrient inputs have been shown to act as a catalyst for lagoon pollution. Robust wave dynamics, generally associated with strong wind conditions, enhance the considerable dispersion of pollutants throughout the study area. Although the prevailing winds in the lagoon are expected to mitigate the effects of the discharge, significant pollution indicators have been detected in the vicinity of the discharge sites. The majority of Mediterranean lagoons have eutrophic trophic status, with the most pristine examples being Mar Menor in Spain, Amvrakikos in Greece and Mare Piccolo in Italy. To mitigate the risks to these regions, it is imperative to adopt robust resource management strategies that ensure the protection of pristine estuaries.

Compliance with Ethical Standards

Conflict of interest: The author declares no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: Ethics committee approval is not required for this study.

Data availability: The data will be made available upon request from the author.

Funding disclosure: This study was derived from the results of the COST Action Project 117Y510, supported by TÜBİTAK.

Acknowledgements: -

Disclosure: -

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