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Effects of anthropogenic activities on nutrient parameters in the North Eastern Mediterranean Sea (Bay of Sığacık/Aegean Sea)

by

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Abstract

This study aims to examine the physicochemical parameters of seawater (temperature, pH, salinity, dissolved oxygen, suspended particulate matter, ammonium-nitrogen, nitrite-nitrogen, nitrate-nitrogen, and phosphate-phosphorus, burnable organic matter in the sediment), and possible effects of pollution in Sığacık Bay where different anthropogenic activities are carried out. Samples of surface seawater (0 m), bottom seawater (2 m), and sediment were collected monthly from four sampling sites between September 2013 and September 2014. Annual mean nutrient values were determined as 1.6 ± 0.14 μg.at.NH_4^+-N l^{-1}, 0.1 ± 0.01 μg.at.NO_2^--N l^{-1}, 0.8 ± 0.08 μg.at.NO_3^--N l^{-1}, 0.7 ± 0.08 μg.at.PO_4^{3-}-P l^{-1}, SPM 21.4 ± 0.33 mg l^{-1}. The BOM content in the sediment was 5.6 ± 0.39%. As a result of the study, it was determined that Sığacık Bay was polluted by anthropogenic point and non-point source pollution. According to the water quality criteria, the bay was found to be in the group of polluted seawater in terms of phosphate phosphorus.

Key words: water quality, nitrogen, phosphorus, sediment, PCA, Aegean Sea

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1. Introduction

The economic development of coastal regions can be disrupted by pollutants discharged into a given region from coastal sources. Therefore, marine coastal ecosystems are special areas that need to be protected (Adrianov 2004). Natural factors (changes in rainfall values, erosion, and coastal erosion) and anthropogenic pollution sources (industry, domestic waste, agricultural activities, etc.) have a significant impact on nitrogen and phosphate load in coastal areas (Belias et al. 2007). Furthermore, nitrogen and phosphorus concentrations play an important role in determining the ecological status of aquatic systems biologically (Pitta et al. 1999). In Turkey, which is surrounded by the sea on three sides, marine pollution and current coastal problems are constantly on the agenda. Industrial activities, maritime transport, urbanization, tourism, agricultural activities, and discharge of domestic sewage into the sea without treatment, in particular, increase the pollution of Turkish seas. This pollution affects not only surface water, but also deep seawater and even the sediment, which as a carrier can accumulate many pollutants in its structure. Research on marine pollution is essential to maintain the continuity of populations of existing species living in the seas and to enable future generations to develop in a healthier and more suitable environment. In this regard, there are numerous individual or institutional studies on physicochemical parameters and sediment samples from the Aegean Sea (Aksu 2009; Aydin-Onen et al. 2012; Başaran et al. 2006; Başaran et al. 2010; Kaymakçı et al. 2001; Kükrer & Aydın 2006; Kükrer & Büyükışık 2013; Kontaş et al. 2004; Küçüksezgin et al. 2006; Kocataş 2004; Orçun & Sunlu 2007; Sunlu et al. 2012; Kucuksezgin et al. 2019; Türk Çulha & Karaduman, 2020; Akyol et al. 2020; Kucuksezgin et al. 2021). These studies are quite extensive and efforts have been made to identify major pollution points in the Aegean Sea. However, no study has been conducted in Sığacık Bay to determine coastal pollution.

Sığacık Bay, which is one of the important fishing areas in the Aegean Sea, is also one of the important bays where many fishing boats have been fishing since the 1970s (Dereli 2010). It is an important commercial fishing area for shellfish and fish harvesting (Özcan & Katağan 2009). Fishing activities in the region are not limited to local fishing boats. With the arrival of some trawlers from the Black Sea and the Mediterranean Sea in the bay, fishing activities and the number of ships in the region are increasing rapidly (Dereli 2010). There is insufficient information on seawater pollution caused by the operations (bilge dumping) of fishing vessels, travel ships and yachts. The marina and the newly established tourist hotel, which contribute to the tourist development of the district, lead to an increase in the human population in the holiday season. Large tourist complexes that have been developed in recent years and the marina, which serves many foreign and domestic tourists every year, make it necessary to evaluate this region in terms of pollution. In addition, a fish farm continued intensive aquaculture operations in this region between 1992 and 2010. Orçun & Sunlu (2007) investigated the effect of these aquaculture operations on water quality during this period. This study aims to examine the water quality at the sampling sites selected in the coastal areas of Sığacık Bay, which is constantly developing and contributing to the economy with its tourist location, growing population, marina, and intensive fishing activities. It assesses adverse effects on the water column and sediment, especially in coastal areas exposed to anthropogenic pollution. In line with this objective, the following issues were investigated:

- physical parameters of seawater temperature (T), pH, salinity (S), dissolved oxygen (DO);
- nitrite-nitrogen NO_2^--N, nitrate-nitrogen NO_3^--N, phosphate-phosphorus PO_4^{3-}-P, ammonium-nitrogen NH_4^+-N, suspended particulate matter (SPM) values;
- sediment particle analysis and burnable organic matter (BOM %) values.

The data obtained were then compared with previous studies conducted in the Aegean Sea and with nutrient levels (Weast 1987) found in clean and polluted seawater.

2. Materials and methods

2.1. Sample collection

The study was carried out at four different sampling sites (Sarıkovalar, Sakızönü, Sarıinler, and Minarettaşı Sta.) in Sığacık Bay (Aegean Sea) between September 2013 and September 2014. Sarıkovalar Sta. (38°11′52″N; 26°47′08″E) is located near the marina and near the place where freshwater flows into the sea at a low flow rate. The water color change can be observed especially in the rainy season, as a large amount of water flows from this stream into the sea. In Sakızönü (38°12′11″N; 26°46′51″E), the second site, there is a fish farm that was shut down in 2010. Until 2010, gilthead seabream (*Sparus aurata*) and European seabass (*Dicentrarchus labrax*) were bred in net cages in this area. The third site, Sarıinler (38°12′13″N; 26°46′12″E), was selected as a location representing the opposite side of the newly built tourist hotel in the region. This is an area with high tourist traffic, especially in summer. It is located within the camping area and was selected as it may be affected by pollution originating from human activities. Minarettaşı (38°12′24″N; 26°46′17″E) is the fourth site selected a reference site (Fig. 1).

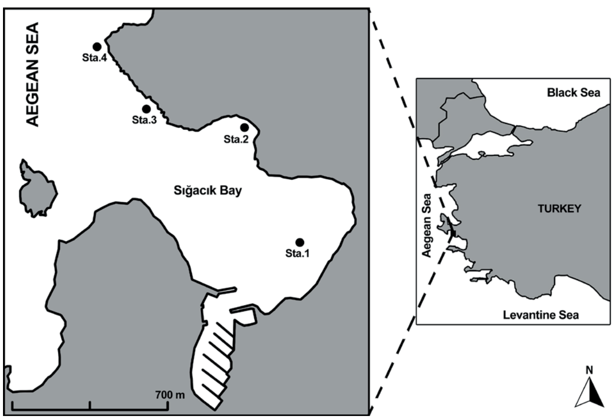

Figure 1

Study area

2.2. Method

Seawater samples were collected monthly from the surface (0 m) and from a depth of 2 m using a Nansen bottle water sampler (Hydrobios). Physicochemical parameter values of seawater were measured in situ using a WTW Multi 3420 hand-held portable multi-parameter. Seawater samples were transported to the Laboratory of Water Quality and Pollution at Izmir Katip Çelebi University in a cold box, and ammonium-nitrogen, nitrite-nitrogen, nitrate-nitrogen, and phosphate-phosphorus analyses were performed according to Egemen & Sunlu (2003), Parsons et al. (1984), Strickland & Parsons (1972), Wood (1975). A Hach Lange DR 6000 brand spectrophotometer was used for measurements. The determination of suspended particulate matter (SPM) in seawater was carried out using the gravimetric method according to Stirling (1985). In addition, to determine the benthic structure at the sampling sites, the grain size and BOM (%) in sediment samples collected by scuba diving (SCUBA) were classified according to Buchanan (1984).

All statistical analyses were performed using Microsoft Excel and the SPSS 23.0 © software package, and statistical significance was set at $p < 0.05$. Normality of the data was tested using both the Kolmogorov–Smirnov and Shapiro–Wilk tests and homogeneity of variance was examined using the Levene test. If data were normally distributed ($p > 0.05$), one-way analysis of variance (ANOVA), which is a parametric test, was used to compare changes in physicochemical and nutrient variables across the months. Otherwise, the Kruskal–Wallis test, which is one of the non-parametric alternatives, was used to find any significant differences in physicochemical and nutrient variables across the months. Since ANOVA and the Kruskal–Wallis test can provide an answer as to whether the difference is significant ($p < 0.05$), the Tukey (parametric data) and Mann Whitney U tests (non-parametric data) were employed to determine which months are statistically significantly different from other months.

In addition, Pearson's correlation coefficient analysis was applied to verify the existing relationships (physicochemical, nutrient variables and BOM). The correlation methods investigate whether there is an association relationship between two variables. Of these methods, Pearson's correlation coefficient is one of the commonly used test statistics. It determines the magnitude of the association or correlation, and the direction of the relationship between two continuous measures. If it is equal to +1, it means that there is a perfect relationship, i.e. the first variable increases whenever the other variable increases and vice versa. Similarly, if it is equal to −1, it means that there is a perfect but reverse relationship, i.e. the first variable increases while the other variable decreases and vice versa (Akgül 2021). If a statistical significance (p) value is less than 0.05, then the calculated relationship is assumed to be statistically significant; otherwise, it means that there is no statistically significant correlation between two variables of interest. Physicochemical and nutrient variables were transformed by logarithm (x+1), except pH. Principal component analysis (PCA) was applied to asses the physicochemical parameters measured in water samples collected in Sığacık Bay and to assess their temporal and spatial changes. PCA analyses were performed using the Past v. 3.20 statistical software package (Hammer et al. 2001).

3. Results

3.1. Physicochemical parameters

The seasonal physicochemical parameters and SPM values of water samples collected from four sites selected in Sığacık Bay are presented in Fig. 2. In this study, temporal and spatial distribution of nutrients in relation to physicochemical parameters was assessed. The annual mean values of the physicochemical parameters (T, S, pH, DO, SPM) were 20.3 ± 0.34°C, 39.0 ± 0.03‰, 8.3 ± 0.01, 9.2 ± 0.06 mg l^{-1}, 21.4 ± 0.33 mg l^{-1}, respectively. While there was no statistically significant differences between the sampling sites in terms of physicochemical parameters ($p > 0.05$), seasonal differences were found significant ($p < 0.05$), except SPM. Regarding the seasons, the highest temperature was measured in summer (23.9°C) and the lowest in winter (16.5°C). These differences were determined between summer and winter seasons at a depth of 0 m and 2 m of Sta. 1. The highest value of salinity was determined in summer (39.2‰) and the lowest in winter (38.7‰). The highest pH value was measured in summer (8.4) and the lowest in winter (8.3). The highest value of DO (one of the important parameters) was determined in spring (9.7 mg l^{-1}) and the lowest

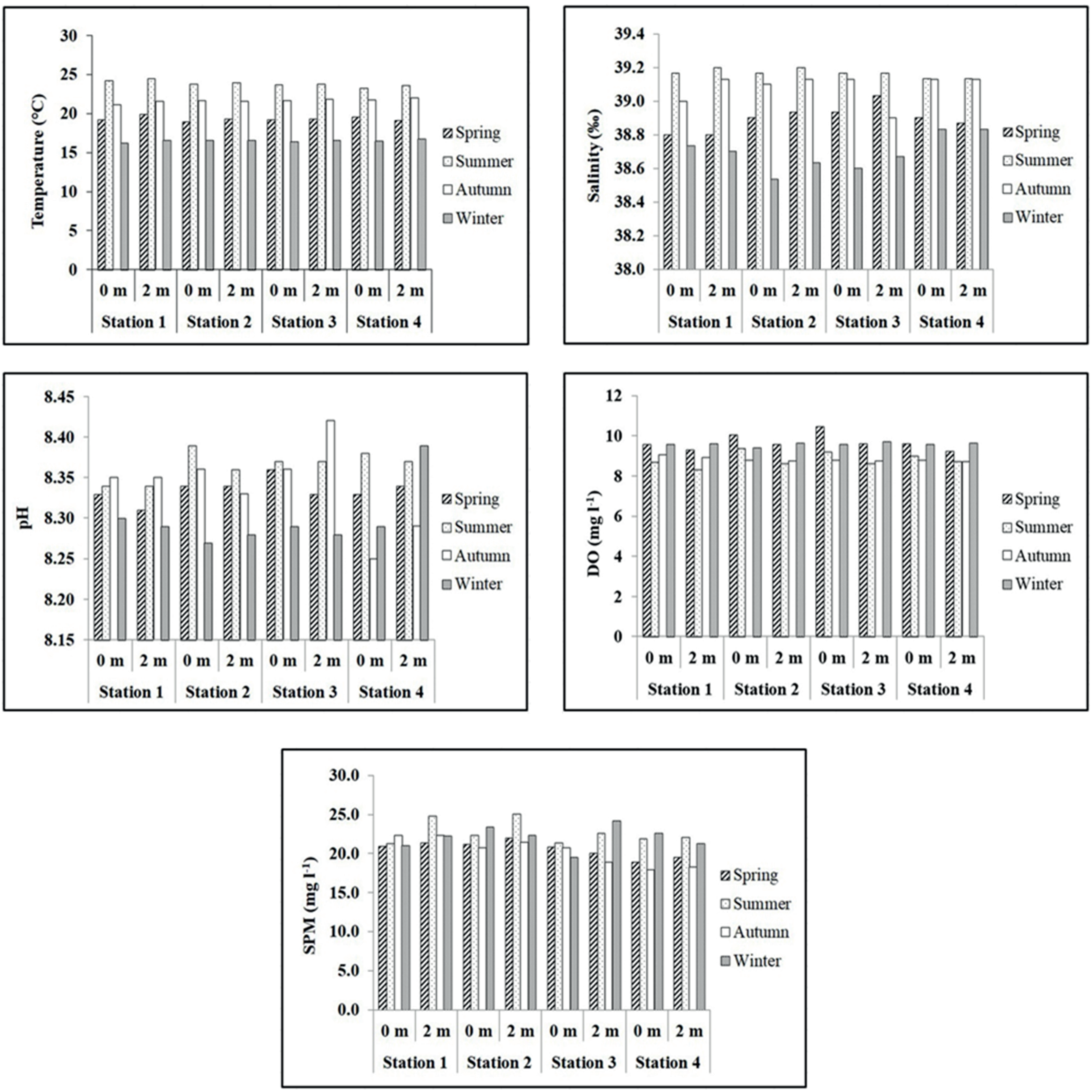

Figure 2

Seasonal physicochemical parameters and SPM values of water samples in Sığacık Bay (Stations = Sampling sites).

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in summer (8.8 mg l^{-1}). These differences were determined between spring and autumn at a depth of 0 m and between the seasons of spring–summer and summer–winter at a depth of 2 m at Sta. 3. In Sığacık Bay, the highest SPM was determined in summer (22.6 mg l^{-1}) and the lowest in autumn (20.3 mg l^{-1}).

3.2. Nutrient parameters

Seasonal variations of nutrient parameters in seawater sampled from Sığacık Bay are presented in Fig. 3. The annual mean values of ammonium-nitrogen, nitrite-nitrogen, nitrate-nitrogen, and phosphate-phosphorus were respectively: 1.6 ± 0.14 μg.at.NH_4^+-N l^{-1}, 0.1 ± 0.01 μg.at. NO_2^--N l^{-1}, 0.8 ± 0.08 μg.at.NO_3^--N l^{-1}, and 0.7 ± 0.08 μg.at.PO_4^{3-}-P l^{-1}. Statistically significant differences were found for all nutrient parameters seasonally ($p <$ 0.05). No significant differences were found for other parameters at sampling sites ($p > 0.05$). The ranking of the sampling sites according to the determined ammonium-nitrogen values was as follows: Sta. 1 1.8 > Sta. 2 1.6 > Sta. 4 1.5 > Sta. 3 1.4 μg.at.NH_4^+-N l^{-1}. The highest ammonium-nitrogen value was measured in winter (1.9 μg.at.NH_4^+-N l^{-1}), while the lowest in autumn (0.7 μg.at NH_4^+-N l^{-1}). According to the determined nitrite-nitrogen values, Sta. 1 (0.2 μg.at.l^{-1}) was characterized by the higher value compared to other sites (0.1 μg.at.l^{-1}). The highest nitrite-nitrogen value was measured in winter (0.2 μg.at.l^{-1}), while the lowest in spring and autumn (0.1 μg.at.l^{-1}). The ranking of the sites according to the determined nitrate-nitrogen values was as follows: Sta. 1 – 1.0 > Sta. 3 – 0.8 > Sta. 4 – 0.7 = Sta. 2 – 0.7 μg.at NO_3^--N l^{-1}. The highest nitrate-nitrogen value was measured in spring (1.1 μg.at.l^{-1}), while the lowest in summer (0.3 μg.at.l^{-1}). The phosphate value was higher at Sta. 1 and Sta. 2 (0.8 PO_4^{3-}-P l^{-1}) than that at Sta. 3 and Sta. 4 (0.7 PO_4^{3-}-P l^{-1}). The highest phosphate-phosphorus value was measured in spring (0.8 μg.at.l^{-1}), while the lowest in autumn (0.2 μg.at.l^{-1}; Fig. 3).

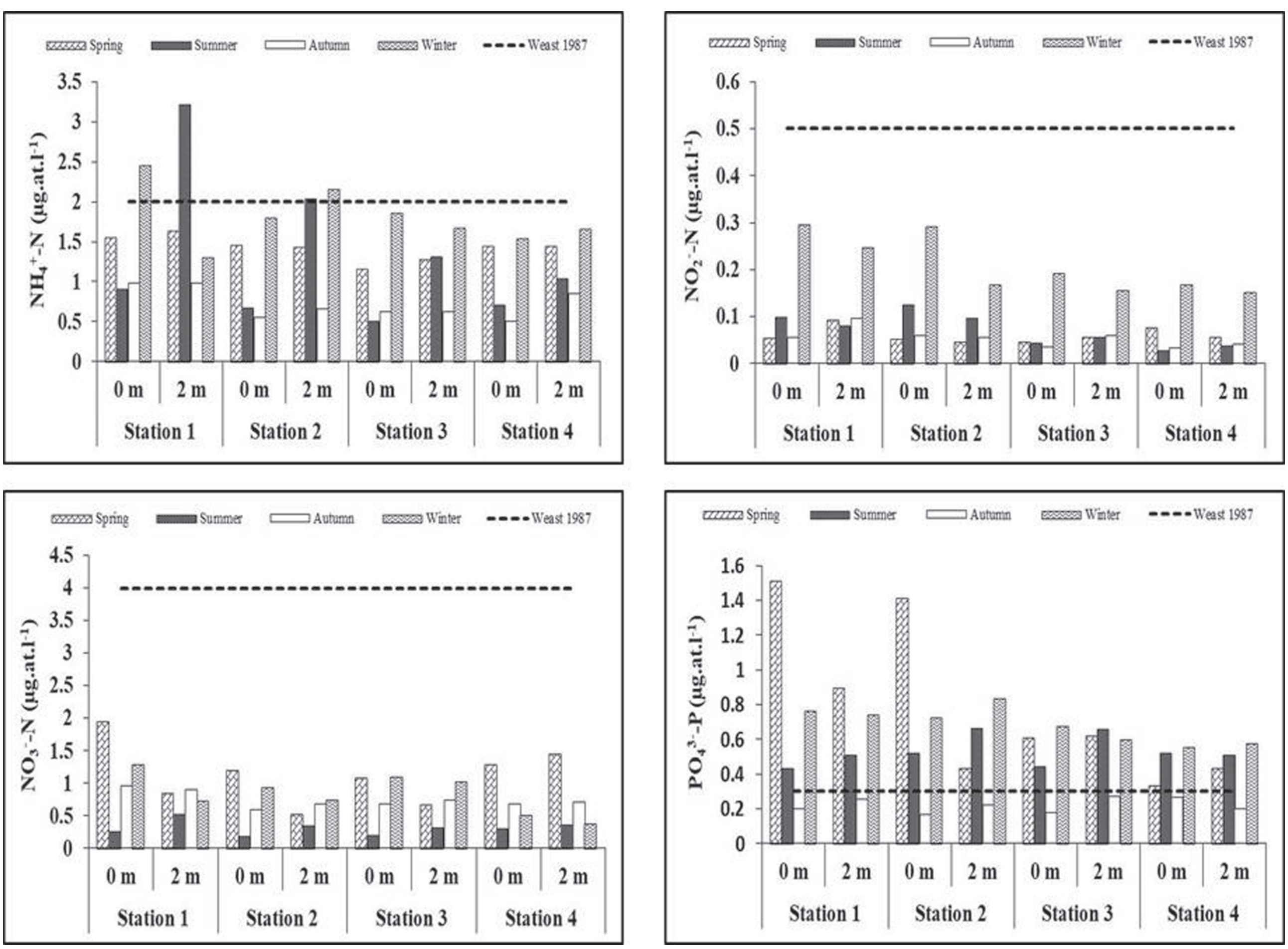

Figure 3

Seasonal changes in nutrient parameters in Sığacık Bay (Stations = Sampling sites)

3.3. Granulometric analysis and BOM in sediment

Sediment samples collected from four sampling sites were classified according to sediment grain size (Fig. 4). Sediment samples collected from Sta. 1 (42.4%) and Sta. 2 (43.6%) were classified as very fine sand with a grain size of 125 µm. Sediment samples collected from Sta. 3 (59.5%) were classified as coarse sand with a grain size of 500 µm to 1 mm, and sediment samples collected from Sta. 4 (63.8%) were classified as very coarse sand with a grain size of 2–4 mm (Fig. 4). The ranking of the sites according to the determined BOM was Sta. 4 – 6.4% > Sta. 2 – 5.8% > Sta. 1 – 5.1% > Sta. 3 – 5.0%. The annual mean BOM determined in the study was 5.56 ± 0.39%. The highest BOM was determined in winter with 5.8%, while the lowest BOM was determined in spring with 5.1%. The difference between the mean BOM values measured in the sediment by sampling site and season was not statistically significant ($p > 0.05$; Fig. 4).

Pearson's correlation coefficient method was used to determine whether correlations between any two measures were statistically significant in this study. Table 1 summarizes the correlation coefficients and the corresponding statistical significance (*p*) values calculated using SPSS version 23 in this study. Statistically significant correlations in this table are indicated in bold. Among these significant correlations, negative values indicate an inverse correlation between variables. Only SPM and BOM measures do not correlate with other variables. Principal component analysis (PCA) was applied to multivariate data derived from the analysis of water quality parameters performed on surface water samples collected in Sığacık Bay. In this study, two PCA factors were extracted and they explain a cumulative variance of 76.11%. PC1 (Component 1) explains most of the data variance (60.24%), and PC2 (Component 2) accounts for 15.86% of the data variability (Table 2). The distribution of factor scores (sample locations) and factor loadings (physicochemical parameters and nutrient parameters) are presented in Fig. 5. PC1 explains 60.24% of the total cumulative variance related to positive loadings of DO (0.368), NH_4-N

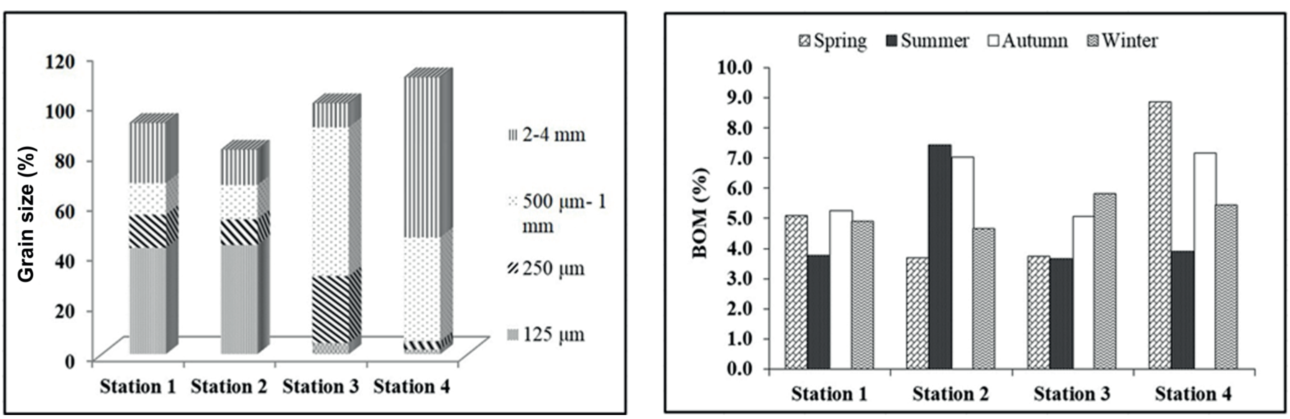

Figure 4

Grain size and BOM variation in the sediment (Stations = Sampling sites)

Table 1

Correlation coefficient (r) of physicochemical and nutrient values and BOM

	S	T	DO	pH	NH_4	NO_2	NO_3	PO_4	SPM
S	1								
T	**.934****								
DO	**–.724****	**–.813****							
pH	**.623****	**.609****	**–.320***						
NH_4	**–.627****	**–.516***	.459	–.453					
NO_2	**–.731****	**–.697****	.395	**–.536***	**.706****				
NO_3	**–.633****	**–.592****	**.524***	–.465	.268	.177			
PO_4	**–.542***	–.417	**.599****	–.257	**.617****	.319	.338		
SPM	–.033	.081	–.014	.217	.482	.392	–.416	.326	
BOM	.015	–.031	–.142	–.145	–.179	–.002	.266	–.384	–.381

** Correlation significant at the 0.01 level (two-tailed)

* Correlation significant at the 0.05 level (two-tailed)

Table 2

Loadings of experimental variables on the two rotated principal components for the whole data set

	Component	
Variable	PC1	PC2
Salinity	−0.4317	0.1219
Temperature	−0.4226	0.1758
DO	0.3684	0.0388
pH	−0.3047	0.3387
NH_4	0.3508	0.4458
NO_2	0.3417	0.1625
NO_3	0.2819	−0.5594
PO_4	0.2954	0.5476
Eigenvalues	4.8194	1.2690
Variance (%)	60.242	15.863

(0.351), NO_2-N (0.342), and negative loadings of S (−0.432) and T (−0.423). PC1 explains 15.86% of the total cumulative variance related to positive loadings of pH (0.339), NH_4-N (0.446), PO_4-P (0.548), and negative loadings of NO_3-N (−0.559).

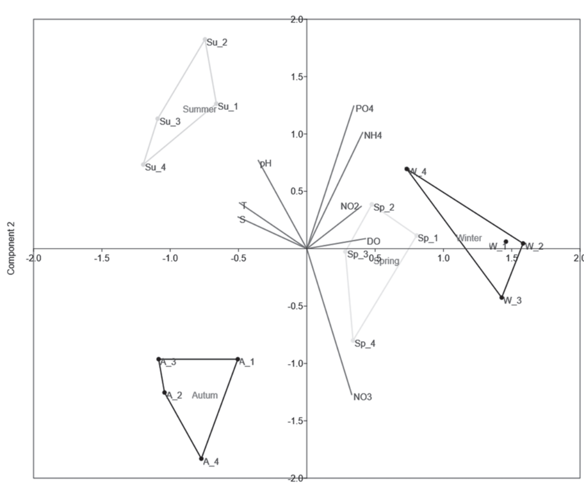

Figure 5

PCA indicating the characteristics of different sampling sites with respect to different physicochemical and nutrient parameters

4. Discussion

4.1. Physicochemical parameters

In this study, physicochemical parameters and nutrient changes were investigated in Sığacık Bay where different facilities associated with anthropogenic activities (marina, tourist hotel, fishing shelters, old fish farm, residential area, land-based pollution sources) are located. In addition, limit values are shown in the figures by comparing the expected parameter values for clean and polluted seawater (Weast 1987). Water temperature is one of the most important environmental variables that affect the range and abundance of aquatic organisms, as well as the chemical structure of water and biological reactions in water (Soundarapandian et al. 2009). Water temperature values measured at the sampling sites in Sığacık Bay are correlated with air temperature. Water temperature varied seasonally (highest in summer and lowest in winter), which was also confirmed by statistical analysis ($p < 0.05$). The sampling sites selected for this study in Sığacık Bay are mostly exposed to southeast and north-northeast winds during autumn and winter (Table 3; TSMS 2022). In addition, due to boat traffic in the marina and the currents generated by fishing boats, water mixing increases in certain periods. Similar results were obtained in Ildır Bay (Aegean Sea; Türk Çulha & Karaduman 2020). We consider that this difference in water temperatures is mostly due to these activities. In this study, the annual water temperature was determined (20.34 ± 0.34°C) to be lower than the water temperature reported by Orçun & Sunlu (2007) and Kaymakçı et al (2001). The variation in water temperature may vary from region to region. These differences may be due to the number of sampling locations and their depth, as well as measurement methods, river water inflow in the region, or sea currents. Similar results regarding the formation of

Table 3

Precipitation and wind conditions in Sığacık Region; N – north; NNE – north-northeast; S – south; SE – southeast; SSW – south-southwest (TSMS 2022)

Months	Wind (m/sn)	Precipitation (mm = kg/m²)	Temperature (°C)
September 2013	*N* 13.3	8.4	22.8
October 2013	*NNE* 13.4	107.2	16.3
November 2013	*SE* 12.7	179.0	14.4
December 2013	*N* 17.7	5.2	7.9
January 2014	*SE* 15.6	140.6	11.5
February 2014	*NNE* 9.9	63.8	10.9
March 2014	*NNE* 13.7	98.8	12.4
April 2014	*SSW* 10.6	83.2	15.8
May 2014	*SE* 13.3	4.4	19.5
June 2014	*S* 14.4	21.8	23.5
July 2014	*NE* 14.6	--	26.4
August 2014	*NNE* 13.5	0.2	27.4

low temperature in winter were also reported by Kucuksezgin et al. (2019). According to Pearson's correlation test, temperature showed positive correlation with salinity (r = 0.934, p < 0.01), pH (r = 0.609, p < 0.01), while negative correlation was found between temperature and DO (r = –0.813, p < 0.01). The correlation results found for temperature, salinity and DO were similar to the data of Kucuksezgin et al. (2019). The water temperature value determined in Sığacık Bay is consistent with the results of previous studies conducted in other regions (Table 4).

The pH is one of the chemical properties of the environment that is essential for vital functions of aquatic organisms, such as survival, metabolism, physiology, and growth (Ramanathan et al. 2005). The determined normal pH value of seawater varies between 8.2 and 8.7 (Kocataş 2004). The mean pH value determined in this study was 8.3 ± 0.01. The pH values measured at the sampling sites were similar to each other throughout the research period. The pH value varies depending on the biological events in water and seasons (Soundarapandian et al. 2009).

Table 4

Physicochemical values determined in different regions of the Aegean Sea*

Region	Temperature (°C)	Salinity (‰)	pH	DO (mg l^{-1})	Ref.
İzmir Bay	13.8–27.2	33.35–42.41	7.54–8.29	5.8–10.0	Aksu 2009
Aegean Sea	16.8–25.2	38.1–39.6	8.09–8.39	6.7–8.6	Aydin-Onen et al. 2012
Ildır Bay	14.0–24.5	33.97–41.00	7.85–8.48	5.2–9.2	Başaran et al. 2006
İzmir Bay	17.3–19.6	34.43–36.60	7.63–7.87	4.42–7.87	Kaymakçı et al. 2001
İzmir Bay (inner)	11.00–27.60	31.12–39.66	7.34–8.12	0.60–12.80	Kükrer & Büyükışık 2006
Karşıyaka marina	8.8–27.6	35.97–42.85	7.4–8.4	4.51–12.7	Kükrer & Aydın 2006
Salih island	16.0–29.0	--	7.6–8.3	4.4–10.4	Başaran et al. 2010
Sığacık Bay	18.33	39.67	8.12	8.18	Orçun & Sunlu 2007
İzmir Bay	8.9–28.2	31.93–44.85	7.4–8.7	3.86–14.40	Sunlu et al. 2012
Ildır Bay	19.95 ± 0.54	38.97 ± 0.06	8.31 ± 0.01	8.88 ± 0.10	Türk Çulha & Karaduman 2020
Aegean coast	15.7–22.3	38.2–39.9	8.02–8.24	6.3–7.9	Kucuksezgin et al. 2021
Sığacık Bay	20.3 ± 0.34	39.0 ± 0.03	8.3 ± 0.01	9.2 ± 0.06	this study

Salinity is the most important parameter that distinguishes seawater from other natural waters (Kocataş 2004). It is an important parameter in ecological and chemical processes (Aydin-Onen et al. 2012). The mean salinity value determined in this study was 39.0 ± 0.03‰. The highest salinity values were measured at the sampling sites in summer, and the lowest in winter. Water temperature, which increased due to the increase in air temperature starting from April, increased more in the summer season, and the accompanying evaporation caused an increase in the salinity of seawater (Table 3). A decrease in the salinity value was observed with the onset of precipitation in October. This situation, together with the effect of winds, resulted in a homogeneous mixing of the water column. Akyol et al. (2020) determined that the salinity value was high in the Aegean Sea between August and September. Similar results regarding the formation of high salinity in summer and low in winter were reported by Kucuksezgin et al. (2019), Kaymaz & Özdemir (2019), Aydin-Onen et al. (2012) and Orçun & Sunlu (2007). The salinity results obtained in this study are consistent with data from other studies conducted in Izmir Bay (Table 4).

A seasonal difference was determined in the surface water at Sta. 4 in summer and autumn. In general, the pH of the marine environment is low in winter and high in summer (Geldiay & Kocataş 2012). In this study, the pH value of seawater started to increase with increasing water temperature in April. As the water temperature decreased in November, the pH value decreased too. Similar results regarding higher pH in winter compared to summer were also reported by Kaymaz and Özdemir (2019). According to Pearson's correlation test, pH was positively correlated with salinity (r = 0.623, p < 0.01), temperature (r = 0.609, p < 0.01), and negatively correlated with DO (r = –0.320, p < 0.05). The correlation results found for pH and DO were similar to those obtained by Kucuksezgin et al (2019). Although the mean pH value obtained in this study is higher than the pH value obtained in other studies, it is consistent with other studies conducted in Izmir Bay (Table 4).

The amount of dissolved oxygen (DO) in seawater varies between 0 and 10 mg l^{-1} (Kocataş 2004). It was determined that the amount of DO decreases in periods with high temperatures. The annual mean DO value determined in the study was 9.2 ± 0.06 mg l^{-1}. The fact that the annual change in DO is inversely proportional to water temperature follows from the fact that solubility of gases is inversely proportional to temperature (Kükrer & Büyükışık 2010). The most striking result of the study is that the highest DO value was determined in March at the 1st, 2nd, and 3rd sites. The fact that the same DO values were determined at all depths may be due to fluctuations caused by the prevailing winds as well as precipitation in the region in March (Table 3). In their study, Orçun & Sunlu (2007) observed that precipitation in the region started in February and intensified in March. DO values determined at a depth of 0 m and 2 m were found to be statistically significantly different depending on the season. This difference may be due to changes in the rate of biotic events (photosynthesis and respiration) as well as the effect of abiotic factors (water temperature, salinity, surface layer; Kükrer & Aydın 2006). The mean DO value determined by Orçun & Sunlu (2007) in Sığacık Bay is lower than the DO value determined in this study. This is because the researchers took samples from the region where cage farming was carried out at that time. DO concentrations in marine environments are related to water temperature and salinity. In addition, significant negative correlations were found between dissolved oxygen and pH ($r = -0.320$, $p < 0.05$), temperature ($r = -0.813$, $p < 0.01$), and salinity ($r = -0.724$, $p < 0.01$). DO values are similar or higher compared to other studies (Table 4).

4.2. Nutrient parameters

Nutrients are found in seawater in the form of mineral nitrogen, nitrite, nitrate, and ammonium. The presence of nitrogenous compounds has a significant effect on the growth and development of phytoplankton species, which are the basic organisms of primary production. Nutrients are also one of the monitored parameters used to determine water pollution (Boto & Wellington 1988). The ammonium-nitrogen value (1.8 ± 0.37 μg.at.l^{-1}) was higher at Sta. 1 (marina area) compared to other sites. It is considered that ship traffic in the marina, currents caused by fishing boats, and terrestrial inputs play an active role in this increase. Considering the seasonal distribution, an increase in ammonium-nitrogen was determined due to the entry of terrestrial inputs (freshwater, including stream water) into the marine environment in winter when precipitation is high. River water inflow also has an effect on this increase. Physicochemical properties are significantly affected by freshwater flow during the rainy season. Precipitation also causes significant changes in temperature, salinity, flow patterns, DO, and nutrients (Aydin-Onen et al. 2012). To determine the precipitation season, precipitation data of the Seferihisar meteorological station for the period from September 2013 to August 2014 were analyzed (Table 3) and it was determined that the highest precipitation occurred between October 2013 and April 2014. The highest precipitation was determined in November 2013 with 179.0 mm (TSMS 2022). Accordingly, the increase observed in ammonium-nitrogen in the water column during the rainy season is more striking. As reported by Orçun & Sunlu (2007), the ammonium value increased in Sığacık Bay with the increase in freshwater input during the rainy season. A similar result was obtained in another study conducted in the Aegean Sea (Aydin-Onen et al. 2012). Changes in ammonium-nitrogen values show similarities and differences depending on the geographical structure, industrialization and urbanization of a given region (Table 5). When the results of the study were compared with the established values of the ammonium-nitrogen parameter for clean and polluted seawater (polluted seawater > 2 μg.at.l^{-1}), the determined ammonium-nitrogen mean value (1.6 μg.at.NH_4^+-N l^{-1}) is close to, but does not exceed, the polluted seawater limits (Weast 1987). The mean nitrite-nitrogen concentration values were determined as Sta. 1 – 0.2 ± 0.03, Sta. 2 – 0.1 ± 0.03, Sta. 3 and Sta. 4 – 0.1 ± 0.02 μg.at.NO_2^--N l^{-1}, respectively. The ranking of the sampling sites according to the determined ammonium-nitrogen values was Sta. 1 – 1.8 > Sta. 2 – 1.6 > Sta. 4 – 1.5 > Sta. 3 – 1.4 μg.at.NH_4^+-N l^{-1}. Changes in nutrients were mostly detected in surface water at all sites. Similar to ammonium-nitrogen, the highest concentration of nitrite-nitrogen was determined in the winter season when there is a high precipitation rate. The nitrite-nitrogen values obtained in the study are lower than the values determined by Orçun & Sunlu (2007) in Sığacık Bay. Moreover, when the results were compared with the results of other studies listed in Table 5, it was found that the nitrite nitrogen values were very low. When comparing the results of this study with the clean seawater limits (0.01–0.5 μg.at.l^{-1}) reported by Weast (1987), it was found that the mean nitrite-nitrogen value (0.1 μg.at. NO_2^--N l^{-1}) was within the clean seawater limits. The nitrate-nitrogen values measured at the sampling sites were as follows: Sta. 1 – 1.0 ± 0.19, Sta. 2 – 0.7 ± 0.14, Sta. 3 – 0.8 ± 0.15, and Sta. 4 – 0.7 ± 0.19 μg.at.NO_3^--N l^{-1}. In terms of seasons, the highest nitrate-nitrogen value was determined in spring and the lowest in summer. Orçun & Sunlu (2007) reported that the increase in nitrate-nitrogen in spring is due to the conversion of ammonium-nitrogen and nitrite-nitrogen to nitrate. The highest NO_3^--N concentration (4.1 μg.at.l^{-1}) was determined in March, i.e. the beginning of spring. A similar situation was

Table 5

Nutrient parameter values determined in different regions of the Aegean Sea (μg.at.l-1); (*) – unit μM; (**) – orthophosphate phosphorus

Region	NH_4^+-N	NO_2^--N	NO_3^--N	PO_4^{3-}-P	Ref.
İzmir Bay	0.1–11.4	0.0–6.43		0.0–1.2	Aksu 2009
Aegean Sea*	0.10–25.6	0.01–1.5	0.19–7.0	0.17–6.8**	Aydin-Onen et al. 2012
Ildır Bay	0.0–9.07	0.0–0.44	0.0–1.12	0.0–0.61	Başaran et al. 2006
Brezilian coasts	--	0.00–0.89	0.48–31.41	0.02–1.79	Costa et al. 2014
İzmir Bay	0.0–65.7	0.0–5.5	0.0–7.60	0.0–12.0	Kaymakçı et al. 2001
Karşıyaka Marina	0.06–40.72	0–25.9	0.19–24.9	0.87–17.6	Kükrer & Aydın 2006
İnner and Middle Bay*	0.11–50	0.29–16		0.14–2.9**	Kontaş et al. 2004
İnner and Middle Bay*	0.21–2.4	0.12–8.6		0.32–4.5**	Küçüksezgin et al. 2006
İzmir İnner Bay*	0.23–22.28	0.00–3.51	1.54–11.77	0.00–5.96	Kükrer & Büyükışık 2010
Homa Lagoon	0.91–41.43	--	0.27–15.75	0.08–1.80	Kutlu & Büyükışık 2014
Sığacık Bay	0.0–13.5	0.0–3.25	0.1–5.1	0.0–5.5	Orçun & Sunlu 2007
Strymonikos Bay*	0.00–1.71	0.15–1.05	0.00–34.4	0.03–0.87	Pavlidou & Georgopoulus 2001
Iyon Sea	0.1–3.7	0.0–0.22	0.1–2.9	0.0–0.2	Pitta et al. 1999
Lisbon Bay (Portugal)*	0.28–7.30	0.29–16.23		0.20–1.38	Silva et al. 2008
İzmir Bay*	0.00–40.94	0.00–28.99	0.00–21.35	0.00–31.43	Sunlu et al. 2012
Ildır Bay	0.03–7.55	nd–0.87	0.11–6.03	nd–1.15	Türk Çulha & Karaduman 2020
Sığacık Bay	1.6	0.1	0.8	0.7	this study

found in this study. Kucuksezgin et al. (2021) stated that high nitrate concentrations are affected by precipitation, low rates of nutrient uptake by phytoplankton, nitrogen fixation and intense nutrient inputs from fresh water. A similar situation was observed in this study. Considering the seasonal variation of nitrogen, it is generally high in winter, decreases suddenly in spring due to rapid development of phytoplankton species, and disappears in summer due to increase in surface water temperature (Geldiay & Kocataş 2012). When other studies on ammonium nitrogen were reviewed, it was determined that the nitrate levels measured in this study are higher than the ammonium values reported by Başaran et al. (2006) and Pitta et al. (1999). On the other hand, the nitrate levels measured in this study were lower than the results reported in other studies listed in Table 5. When comparing the results of this study with the clean seawater limits (0.5–1 μg.at.l^{-1}) reported by Weast (1987), it was found that the mean nitrate-nitrogen value (0.8 μg.at. NO_3^--N l^{-1}) was within the clean seawater limits. The phosphate-phosphorus values measured at the sampling sites were Sta. 1 – 0.8 ± 0.20, Sta. 2 – 0.7 ± 0.18, Sta. 3 – 0.7 ± 0.12, and Sta. 4 – 0.6 ± 0.11 μg.at.PO_4^{3-}-P l^{-1}. The high amount of phosphate detected in the region indicates that non-point inputs (domestic, tourism activities, marina area, agricultural) from terrestrial sources directly affect the surface waters. The distribution of phosphate phosphorus concentration in the environment varies. Phosphate-phosphorus values at Sta. 1 and Sta. 2 were similar to each other and were high in spring and winter. The highest phosphate phosphorus concentration (3.9 μg.at.l^{-1}) was determined in April in spring. Orçun & Sunlu (2007) stated that the large amount of phosphate determined was due to the introduction of phosphates with fish feed, the proliferation of benthic algae in bottom water, and the phosphate migration from the sediment to the water column. The phosphate-phosphorus value determined in their study in the cage region corresponding to Sta. 2 in this study was 1.1 μg.at.l^{-1}. The phosphate-phosphorus value determined in this study was 0.7 μg.at.l^{-1}. This site, where cage farming was carried out during the study by Orçun & Sunlu (2007), has not been operated since 2010. These results reveal that the phosphate value at this point decreased after aquaculture activities ended. While the seasonal distribution of phosphate in the marine environment showed the lowest values in summer, it increases in autumn and reaches its maximum level in winter (Geldiay & Kocataş 2012). The highest phosphate value in this study was determined in spring and winter. Compared with the results of other studies listed in Table 5, our results for phosphate-phosphorus were similar or different. When comparing the results of this study with the polluted seawater limit (0.30 μg.at.l^{-1}) reported by Weast (1987), it was found that the mean phosphate-phosphorus value (0.7 μg.at. PO_4^{3-}-P l^{-1}) was higher than the polluted seawater limit. The most striking result is that the phosphate phosphorus value at all sampling sites exceeded the polluted seawater limit. According to Pearson's correlation test, PO_4 was positively correlated with DO ($r = 0.599$, $p < 0.01$) and NH_4 ($r = 0.617$, $p < 0.01$) and negatively correlated with salinity ($r = -0.542$, $p < 0.05$). This result indicates that the amount of phosphate and ammonium increases due to terrestrial inputs, despite the decreasing water temperature and salinity in winter and spring when precipitation is high. Kaymaz & Özdemir (2019) and Samsunlu & Akça (1999) reported that the continuous rainfall input from rivers entering Marmaris Bay contributes to the increase in phosphate content in water. In addition, they stated that there are many components that affect the physicochemical composition of seawater, such as tourism activities (port operations, daily boat tours, excessive use of shores, bilge waters, etc.), rainfall runoff and solid waste from rivers. The SPM concentration in seawater varies between 17.3 mg l^{-1} and 32.2 mg l^{-1} (Violintzis et al. 2009). The mean SPM value determined in this study was 21.4 ± 0.33 mg l^{-1}. When analyzing the SPM values measured at each site, it was found that the SPM values at Sta. 1 and Sta. 2 were higher than at the other sites. The reason for this is that the marina, with many fishing boats passing through, is very close and this area is the discharge point for terrestrial water inputs. Sediment uplift due to wave action and currents is one of the major factors affecting SPM (Resgalla et al. 2007). The seasonal variation of SPM was as follows: summer (22.6 mg l^{-1}), winter (22.0 mg l^{-1}), spring (20.6 mg l^{-1}) and autumn (20.3 mg l^{-1}). It is considered that domestic waste, as well as waste from the marina and the hotel may be the cause of the high level of SPM values, especially in summer. Türk Çulha & Karaduman (2020) observed that the SPM value in Ildır Bay was high in summer (23.0 mg l^{-1}) and stated that this increase is due to the effect of the organic load in the environment. Demirak et al. (2006) found that the coastal water quality varies seasonally due to quality change that may occur in freshwater coming from land to coastal regions as population increases due to tourism, especially in the summer months.

According to the results of the PCA analysis, the first PC accounted for 60.24% of the total variance and was associated with temperature, salinity, DO, nitrite and ammonium. The second PC, accounting for 15.86% of the total variance, was associated with pH, ammonium, nitrate and phosphate. Seasonal and environmental factors (precipitation, wind, current, terrestrial inputs, stream currents, etc.) can alter the surface water quality in the seas. The surface water quality in Sığacık Bay changes depending on the seasons (physicochemical parameters and nutrients). The obtained results are supported by one-way ANOVA and PCA analysis.

4.3. Granulometric values and BOM in sediment

Sediment is generally formed as a result of the erosion of the terrestrial environment and its transport to the marine environment via rivers and the accumulation of suspended solid particles at the seabed (Aydın & Sunlu 2004). The particle analysis of sediment samples showed that the particle size in the bottom structure of Sığacık Bay gradually increases from the coast. While the sediment structure in the coastal area shows characteristics of fine gravel sand, deep regions have characteristics of coarse sand. Çulha (2004) reported that there is a continuous landslide toward the sea on the coast of the Sinop Peninsula when the sea is rough, resulting in the formation of sediment structure at the bottom in the form of silt and mud. We believe that the algal species *Posidonia oceanica*, common in the bottom structure, died due to unfavorable bottom structure in its habitat, and this situation contributed to the increased organic matter content in the environment. The annual BOM amount determined in Sığacık Bay was 5.6 ± 0.39%, the maximum value was determined at the reference site (Sta. 4). The reference site selected in this study is located just beyond of the newly built hotel and away from all other sites. The high increase in the sediment pollution indicates that the organic load from these regions is accumulated at this site. Aydın & Sunlu (2004), Türk Çulha et al. (2017) and Taş et al. (2007) reported that high BOM values in their study regions were due to the high human activity, wind and water movements, terrestrial inputs, and ship traffic. In this study, the highest amount of BOM was determined in autumn and winter characterized by high precipitation. Also other studies reported that the highest BOM values were determined in winter (Aksu 2009; Türk Çulha & Karaduman 2020).

5. Conclusion

In conclusion, the high nutrient concentrations in water sampled in the coastal areas of Sığacık Bay indicate that water quality is directly affected by various anthropogenic activities in the study area. It has been observed that Sığacık Bay and its surroundings are exposed to human-induced organic matter pollution rather than industrial origin. The surface waters of Sığacık Bay have been affected by pollution from both point and non-point sources, especially during the rainy seasons (autumn and winter). This situation caused fluctuations in physicochemical and nutrient concentrations in water. In addition to environmental factors, the surface waters of Sığacık Bay will be negatively affected over time by tourism, the marina and increasing human population. We believe that continuous and regular monitoring of water quality in Sığacık Bay, which is located in a developing region that contributes to the economy, would be beneficial.

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