MONITORING AND EVALUATION OF COASTAL WATER QUALITY PARAMETERS IN FETHIYE BAY, TURKEY

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Abstract. The physical, microbiological quality parameters and plankton abundance have been monitored and evaluated in coastal waters of Fethiye Inner Bay, Turkey. The temporal and areal variations of quality parameters have been investigated through the monthly measurements at 14 locations between March 2016 and February 2017. The physical parameters measured throughout the water column were water temperature, salinity, pH, and turbidity. Besides, water samples were taken from the surface waters, and total coliform, fecal coliform, fecal streptococci, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella* detection, phytoplankton and zooplankton abundance analyses were performed in the laboratory. By using the related Turkish Standards Institution (TSE) standards, biochemical oxygen demand and dissolved oxygen levels were also determined. Results were evaluated to understand the microbiological water quality of Fethiye Inner Bay, by the Turkish Regulations for the Surface Water Quality (2016) and the Quality of Bathing Water (2006), and Directive 2006/7/EC on bathing water. For the evaluation of the results, geographic information systems (GIS) based HYDROTAM-3D that is the first coastal waters hydrodynamic, transport and water quality model developed in Turkey, was used (http://www.hydrotam3d.com/fethiye). A microbiological parameters database was established for Fethiye Inner bay coastal waters by using HYDROTAM-3D model water quality management system, accessible over the internet.
Keywords: *marine environment, pollution, HYDROTAM-3D, microbiological parameters, phytoplankton, zooplankton, biochemical oxygen demand, dissolved oxygen, Fethiye Bay*

Introduction

People take the water from the hydrological cycle for their vital and economic needs, and the water used returns back to the cycle. In this cycle, substances that enter the water cause the pollution by changing the physical, chemical and biological properties of the water. The main factors that accelerate water pollution are population growth and rapid industrialization (Liyanage and Yamada, 2017). Water is a vital source of infections that can be transmitted through the digestive system. Pathogenic bacteria and other microorganisms mix with water in feces and similar ways depending on many factors such as the geographical location of the region, infrastructure facilities, sewage processes, the socio-economic structure of the community. Viruses, pathogenic bacteria, and parasites can be found in the water as harmful biological agents for human health (Griffin et al., 2003).

The increasing use of water due to population increase and developing industrialization is a crucial factor accelerating water pollution. Pollutants discharged from the point sources such as domestic and industrial sea outfalls or discharged from the distributed sources also pollute the water resources and prevent other uses of receiving waters. Protection of water resources, development, prevention of deterioration in quality and sustainable use of water for long-term conservation of water resources is necessary.

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Fecal coliforms and fecal streptococci are dangerous indicators of health associated with fecal contamination (Barcina et al., 1991). The main entranceway of enteric bacteria and viruses such as *Escherichia coli* to coastal areas is by urban and agricultural wastes (Rees et al., 2010). Enteric bacteria exposed to the marine environment simultaneously, different to their natural habitat, encounter a variety of abiotic and biotic challenges that is marked (Rozen and Belkin, 2001). Biotic stress arises from natural seawater microbiota, which are better scavengers for limited nutrients available and may also prey and graze on the enteric newcomers. Abiotic stress faced by enteric bacteria in seawater include sunlight temperature, pH, lack of nutrients, salinity, current and turbulence and (possibly) hydrostatic pressure (Troussellier et al., 1998; Barcina et al., 1991; Rozen and Belkin, 2001). Lack of water quality management of coastal waters can lead to both health and income losses at shellfish trade centers and fishing places (Rees et al., 2010). Continuous water quality management at coastal waters are vital for human health. In this study, measurements and evaluations of physical, microbiological quality parameters and plankton abundance were performed for Fethiye Inner Bay. The monthly variations of microbiological quality parameters were investigated through the site measurements conducted in between March 2016 and February 2017.

The Fethiye Bay is located in the Eastern Mediterranean coast of Turkey. It is a sheltered area against currents and waves approaching from north, west and southeast directions. Fethiye Inner Bay is an enclosed water body having limited water exchange from the openings on both sides of the Şövalye (Zeytin) Island located in the Fethiye Bay (Cebe, 2016) and it is surrounded by the town of Fethiye. The primary economic activity in the town is tourism. Besides the tourism, its economy is mainly based on agriculture and animal husbandry (Cebe, 2016). Due to the compatibility of climate and physical conditions, irrigated agriculture is mostly performed in the town. The drainage waters of agricultural lands flow to the waters of Fethiye Bay via Murt (Mersinli) and other channels. Low flushing rate of the enclosed Inner Bay waters increases the sensitivity to pollutants.

The wastewater of the Fethiye Town is transferred to the treatment plant and then discharged to the Inner Bay from the eastern part of the Şövalye (Zeytin) Island (*Fig. 1*). The treated wastewater is rich in nitrogen and phosphorus, and it has been discharged into Fethiye Inner Bay together with the agricultural drainage waters that are also rich in nitrogen and phosphorus salts carried by the Murt River. The pollution in Murt River alone has a potential to affect the inner bay of Fethiye. Also, seven channels discharge the agricultural drainage waters directly into Fethiye Inner Bay without any treatment or sedimentation (*Fig. 2*). Likewise, settlements located in the Şövalye (Zeytin) Island and in the west of the bay constitute one of the primary sources of pollution because they are not connected to the wastewater system, and are not subject to the treatment. Other sources of pollution are Fethiye Marina and wastewaters emptied from the boats (Yılmaz et al., 2017). In this study, it is aimed to determine the coastal pollution level in Fethiye Inner Bay, to analyze the temporal and areal changes of water quality parameters and establish a database for evaluations.

Measurements and analysis

The field study has been conducted monthly between March 2016 and February 2017, in the Fethiye Inner Bay coastal waters in Turkey shown in *Figure 2*. Fourteen

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(14) measurement points were located at the site, and their names, water depths, and coordinates are listed in *Table 1*. Measurements of physical parameters were performed at every 2 meters throughout the water column. The total number of measurements at the site is 1164 for the water temperature, salinity, pH, and 168 for the turbidity, each repeated at least three times. Measurement devices used are listed in *Table 2*.

Figure 1. *Location of Fethiye Inner Bay and Fethiye Town in Turkey (Google Earth, 2018)*

Table 1. *Coordinates of the measurement points at the site*

Point name	Coordinate (degree-minute)	Water depth (m)	Point name	Coordinate (degree-minute)	Water depth (m)
F1	36°38.657'K- 29°5.787'D	25.3	F8	36°38.581'K- 29°6.997'D	4.5
F2	36°38.384'K- 29°5.820'D	17.1	F9	36°38.707'K- 29°6.499'D	15.4
F3	36°38.176'K- 29°6.120'D	15.4	F10	36°38.944'K -29°6.266'D	16.2
F4	36°37.448'K- 29°5.690'D	14.7	F11	36°38.905'K- 29°6.843'D	4.6
F5	36°37.680'K- 29°6.153'D	15.3	F12	36°39.184'K- 29°6.528'D	16.3
F6	36°38.057'K- 29°7.076'D	5.3	F13	36°39.666'K- 29°6.367'D	15.2
F7	36°38.270'K- 29°6.621'D	15.2	F14	36°39.098'K- 29°5.060'D	46

Table 2. *Measurement devices*

Measurement device	Measurement	Sensitivity range
YSI Pro Plus Model Quatro (20 m cable)	pH (mV, pH)	± 0.2
	Temperature (°C, °F, K)	± 0.2 °C
	Salinity (ppt, psu)	± 1.0%; ± 0.1 ppt
	DO (mg/L, ppm) (-5 to 50 °C)	0 to 20 mg/L ± 2% 20 – 50 mg/L; ± 6%
HF MicroTPI field portable turbidimeter	Turbidity (0.01–1100 ntu/ftu)	± 2% of reading or 0.01 ntu (0-500 ntu) ± 3% of reading (500-1100 ntu)

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Figure 2. *Fethiye Inner Bay measurement points (Google Earth, 2018)*

Total coliform, fecal coliform, fecal streptococci, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Salmonella* analysis have been performed in 168 water samples taken for the temporal and spatial analysis of the changes of the bacteriological water quality parameters in the coastal waters. Phytoplankton and zooplankton abundance analyzes have been carried out in the laboratory for water samples taken from the surface and the bottom layer at depths exceeding 8 m using plankton nets. Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) requirements were determined by the relevant Turkish Standards Institution (TSE) standards for comparison with the changes in bacteriological parameters.

Microbiological laboratory test-methods are given in *Table 3* (TS EN ISO 9308-1, 2014; TS EN ISO 16266, 2009; TS EN ISO 7899-2, 2000), BOD and DO test-methods are listed in *Table 4* (TS EN ISO 5814, 2012; TS EN ISO 10707, 2005). BOD and DO were detected in 168 and 1164 samples, respectively.

55-micron Hydro-Bios plankton nets were used through the water column vertically to collect phytoplankton and zooplankton samples during the study. Then, both phytoplankton and zooplankton samples were fixed with 4% formaldehyde buffer solution until counting and identification activities.

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Table 3. *Microbiological test-methods*

Microbiological analysis	Used standards
Enumeration of coliform bacteria	TS EN ISO 9308-1 Water quality- Detection and enumeration of *Escherichia coli* and coliform bacteria Part-1 Membrane filtration method
Enumeration of *Escherichia coli*	TS EN ISO 9308-1 Water quality- Detection and enumeration of *Escherichia coli* and coliform bacteria Part-1 Membrane filtration method
Enumeration of *Pseudomonas aeruginosa*	TS EN ISO 16266 Water quality - Detection and enumeration of *Pseudomonas aeruginosa* -- Method by membrane filtration
Enumeration of intestinal enterococci	TS EN ISO 7899-2 Water quality - Detection and enumeration of intestinal enterococci - Part 2: Membrane filtration method

Table 4. *Chemical test-methods*

Chemical analysis	Used standards
DO	TS EN ISO 5814 Water quality-determination of dissolved oxygen electrochemical probe method
BOD	TS EN ISO 10707 Water quality - Evaluation in an aqueous medium of the "ultimate" aerobic biodegradability of organic compounds - Method by analysis of biochemical oxygen demand (closed bottle test)

APHA Standard Methods (1995) were used during the counting of phytoplankton and zooplankton samples with Leica DM500 binocular microscope, and Sedgewick-Rafter Counting Chamber was employed as the counting chamber unit. The Sedgewick Rafter Counting Cells are designed primarily for the quantitative measurement of the exact number of particles in a precise volume of a fluid. This chamber itself is 50 mm in length, 20 mm in width and 1 mm in depth. The base part of the chamber is also grid marked with 100 x1 mm squares. Before transferring to the counting chamber, each sample was shaken at least 1 min, and 1 ml of sample were placed in the chamber. During the counting and identification, the number phytoplankton and zooplankton on each counting cell were recorded under the light microscope. Countings were repeated on 8 subsamples (Harris et al., 2000).

Physical parameters

Physical parameters were measured every 2 m from the surface to the bottom at each of the 14 stations. Salinity and temperature recorded at all measurement points are given in *Figure 3*. As a result of 12-month measurements carried out between March 2016 and February 2017, it was observed that the seawater salinity in Fethiye Inner Bay changed between 30.37 ppt (at F06) and 39.43 ppt (at F14) at the surface and the lowest salinity value was recorded in September, and the highest value was recorded in August. The salinity of surface waters is lower in all seasons than in the bottom layers. Towards the sea bottom from the surface, the average salinity increase is 4.35 ppt in the spring, 1.49 ppt in summer, 2.89 ppt in autumn, and 2.85 ppt in winter. Similarly, seawater temperatures were ranging in between 12.7 and 30.8 °C. The seasonal temperature averages decreased from the surface to the bottom of the water column from 20.7 to 18.6 °C in the spring, from 29.2 to 25.1 °C in summer, and they remained almost unchanged along the water column with a slight increase from 22.5 to 22.8 °C in the autumn and 16.8 to 16.8 °C in winter. Measured pH values ranged from 7.55 to 8.38.

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The surface layer pH and turbidities measured at all points are given in *Figure 4*. Turbidity recorded at point F14 (water depth is 46 m.) changed in between 0.54 and 3.2 ntu, whereas at all other points ranged in between 1.02 and 4.81 ntu. The lowest values were recorded in autumn. All turbidity values were less than 5 ntu that is the acceptable limit for recreational purposes in coastal waters.

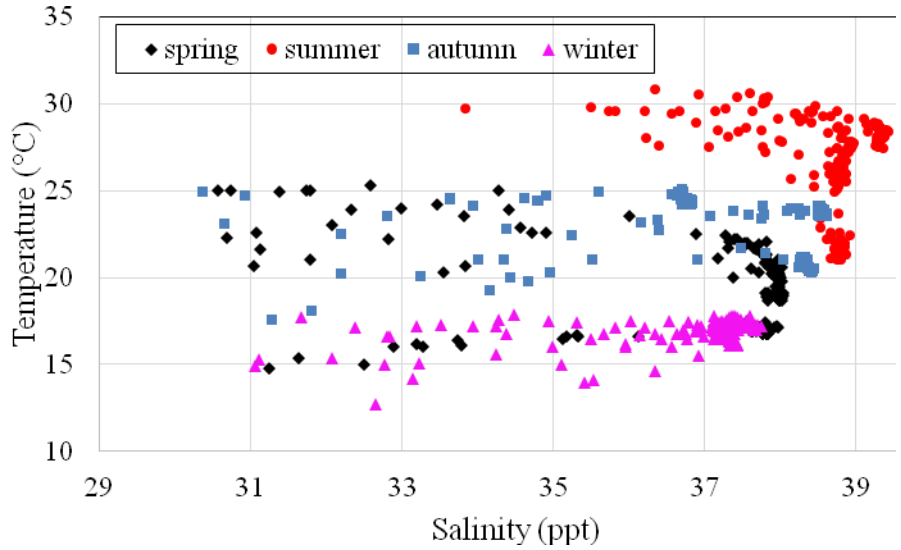

Figure 3. *Salinity and temperature recorded at all measurement points*

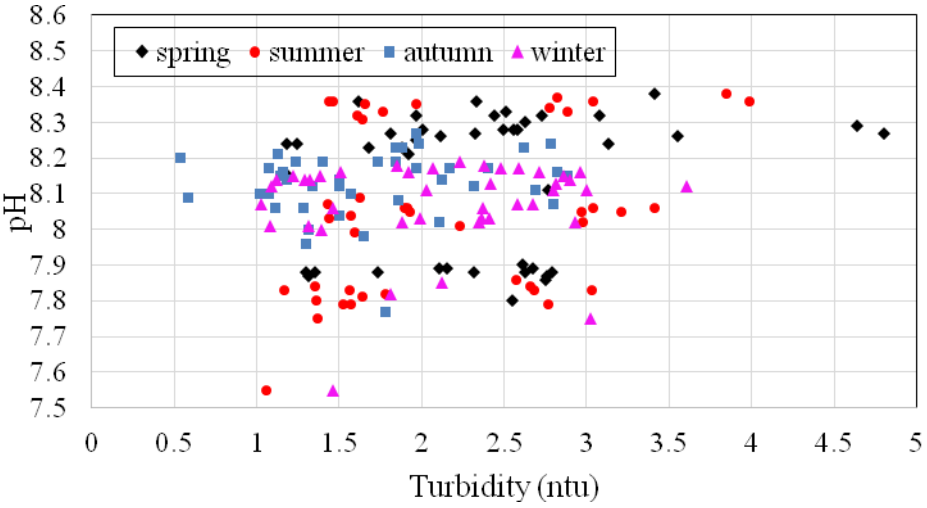

Figure 4. *Surface turbidity (ntu) and pH recorded at all measurement points*

Microbiological parameters

Coliform bacteria are bacteria that show the contamination of coastal waters. These bacteria are found in soil and plants as well as in the feces of warm-blooded animals. Such bacteria are fast-breeding species, and their presence indicates that disease-causing organisms (pathogens) from the feces of humans or animals could be existent in the coastal waters. Coliform bacteria are grouped as total coliform or fecal coliform

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according to general characteristics. Total coliforms (TC) are common in soil or vegetation and do not show that water is contaminated by feces (Gao et al., 2015).

According to the 12-month measurements made between March 2016 and February 2017, the temporal changes in total coliform values at all measurement points are given in *Table 5*.

Table 5. *Temporal variations in TC (cfu/100 ml) at all measurement points*

		F01	**F02**	**F03**	**F04**	**F05**	**F06**	**F07**	**F08**	**F09**	**F10**	**F11**	**F12**	**F13**	**F14**
2016	Mar	57	300	30	55	200	300	230	102	30	45	650	120	48	46
	Apr	414	704	40	160	100	60	240	60	60	40	840	180	160	240
	May	1050	600	130	170	430	360	100	40	40	60	900	850	648	260
	Jun	300	100	100	120	40	60	20	120	180	40	50	12	13	10
	Jul	50	50	30	30	20	22	12	30	60	120	1040	180	20	0
	Aug	410	525	40	100	60	43	70	1040	70	30	140	120	15	6090
	Sep	779	413	50	20	20	320	70	40	220	170	450	254	140	0
	Oct	650	0	0	420	20	0	10	0	0	0	0	1440	0	1680
	Nov	1160	2	10	26	130	100	520	50	130	120	26	3650	460	100
	Dec	650	4	43	52	128	58	378	60	192	417	30	2850	682	192
2017	Jan	90	7	70	80	150	50	240	280	250	750	400	2150	900	390
	Feb	140	170	0	0	420	600	260	130	0	50	0	200	50	140

Measured coliform bacteria values provide guidance value (500 cfu/100 ml) of the Quality Criteria Table to be provided by Bathing Water Quality for Swimming and Recreation purposes, Annex-1 of Regulation for the Quality of Bathing Water (2006). The 15.5% of samples were above the guide standard however they were all less than the mandatory standard (10000 cfu/100 ml). In 91.7% of the samples TC was recorded. According to measured values, it is seen that the total coliform bacteria density is low in Fethiye Inner Bay coastal waters. However, coliform contamination was found at the mouth of Murt River (F11), along with the Çalış Beach (F12, F13), and in holiday village swimming bay (F01, F02) during the rainy spring and winter months. While this pollution is lower than the mandatory standard, its presence suggests that there may also be pathogens from the feces of humans or animals in the water.

Coliform bacteria originate as organisms in soil or vegetation and the intestinal tract of warm-blooded animals (fecal coliform). Fecal coliform (FC) bacteria are indicators of fecal contamination and the potential presence of pathogens associated with wastewater or sewage sludge. The total group includes FC bacteria such as *Escherichia coli*, as well as other types of coliform bacteria that are naturally found in the soil. The presence of fecal coliform in water may indicate recent contamination of the water by sewage or feces which could contain other bacteria, viruses, or disease-causing organisms. This is why coliform bacteria are considered "indicator organisms"; their presence warns of the potential presence of disease-causing organisms and should alert the person responsible for the water to take precautionary action (Gao et al., 2015).

The temporal variations in fecal coliform values at all measurement points according to the 12-month measurements made between March 2016 and February 2017 are shown in *Table 6*.

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Table 6. *Temporal variations in FC (cfu/100 ml) at all measurement points*

		F01	**F02**	**F03**	**F04**	**F05**	**F06**	**F07**	**F08**	**F09**	**F10**	**F11**	**F12**	**F13**	**F14**
2016	Mar	15	100	5	32	15	200	18	55	18	12	211	60	34	33
	Apr	252	448	20	160	20	60	60	60	40	20	380	100	60	20
	May	150	130	20	50	50	60	20	30	40	20	900	850	136	170
	Jun	200	80	20	110	20	20	50	40	160	20	12	12	13	0
	Jul	50	58	43	30	24	18	12	10	15	20	220	50	100	0
	Aug	130	147	110	40	32	10	70	1040	30	5	20	100	10	6090
	Sep	201	82	54	32	20	120	10	10	220	100	50	166	40	0
	Oct	130	0	0	150	10	0	10	0	0	0	0	360	0	1680
	Nov	60	1	0	0	50	40	28	1	5	12	22	1120	30	4
	Dec	22	0	23	28	28	23	22	0	23	13	2	760	82	11
2017	Jan	20	30	500	150	5	9	20	50	40	14	8	460	150	19
	Feb	0	0	0	0	128	10	40	0	0	0	0	40	0	20

Measured FC bacteria values satisfy the guide standard (100 cfu/100 ml) of the Regulation for the Quality of Bathing Water (2006), Annex-1: Quality Criteria Required for Swimming and Recreation Waters, only at F07 in all of the measurements. In 85.7% of the samples FC was recorded. The 21.4% of samples were above the guide standard. At F14, the FC count was almost three times higher than the mandatory level (2000 cfu/100 ml) in August. Measurements indicate that there is substantial fecal pollution in Fethiye Inner Bay coastal waters. The source might be wastewater, sludge, septage, or animal excreta, resulted from the intensive anthropogenic facilities.

Escherichia coli is a member of the fecal coliform group and a more specific indicator of fecal pollution and commonly used to identify the presence of pathogenic microorganisms (Feng et al., 2012). It can be found in the digestive system of humans and warm-blooded animals. They cause digestive system infection. It is most commonly transmitted to humans by swimming in or swallowing the polluted water. Its presence in seawater indicates the entrance of sewage (Craig et al., 2004). There is a strong correlation between the increased *E. coli* levels in recreational waters, and the gastrointestinal disease even though the vast majority of them are not pathogenic (Blaustein et al., 2013). The temporal variations in *E. coli* values at all measurement points according to the 12-month measurements made between March 2016 and February 2017 are given in *Table 7*.

No limit value is defined for *E. coli* in the Regulation for the Quality of Bathing Water (2006). According to the bathing water quality standards for coastal and transitional waters in Directive 2006/7/EC of The European Parliament and the Council, Annex I, excellent quality and sufficient values of *E. coli* are stated as 250 and 500 cfu/100 ml, respectively. Similarly, in "Standard Values Required for Coastal and Transitional Waters Used for Recreational Use" (Regulation for the Surface Water Quality, 2016, Annex-5, *Table 6*) provides a guide standard of 250 cfu/100 ml and the mandatory standard of 500 cfu/100 ml. Measurements indicate that in rainy spring and autumn, *E. coli* significantly increases. Along the beach (Çalış Beach, F12 and F13 Points), *E. coli* values have doubled to the mandatory standard. In 38.1% of the samples *E. coli* was recorded. The 3.6% and 1.8% of samples were above the guide standard and the mandatory standard, respectively.

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Table 7. *Temporal variations in E. coli (cfu/100 ml) at all measurement points*

		F01	F02	F03	F04	F05	F06	F07	F08	F09	F10	F11	F12	F13	F14
2016	Mar	0	0	0	0	0	0	8	0	0	0	42	22	0	0
	Apr	224	392	0	0	20	40	40	40	20	20	63	40	60	0
	May	0	0	0	0	0	40	0	0	0	0	51	94	850	119
	Jun	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Jul	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	Aug	87	147	0	0	0	0	10	0	0	0	0	0	0	0
	Sep	201	0	0	0	0	0	0	0	110	0	0	71	20	0
	Oct	43	0	0	0	0	0	0	0	0	0	0	0	0	0
	Nov	36	1	0	0	38	40	28	1	2	0	20	933	25	2
	Dec	5	0	13	12	22	6	18	0	20	7	16	678	43	9
2017	Jan	0	0	500	150	5	9	10	0	40	14	8	460	75	19
	Feb	0	0	0	0	0	0	13	0	0	0	0	0	0	10

Fecal streptococci (FS) are also known as enterococci and of intestinal origin. They are a more resistant group of bacteria to be used as fecal pollutant indicators (Sinton et al., 1993). Especially they live in sea waters longer. The temporal variations in FS at all measurement points according to the 12-month measurements made between March 2016 and February 2017 are presented in *Table 8.*

Table 8. *Temporal variations in FS (cfu/100 ml) at all measurement points*

		F01	F02	F03	F04	F05	F06	F07	F08	F09	F10	F11	F12	F13	F14
2016	Mar	12	39	0	0	0	0	0	1	0	2	12	2	10	3
	Apr	69	137	0	1	0	1	15	2	1	5	235	3	11	39
	May	16	6	0	5	59	4	3	2	0	0	800	147	40	3
	Jun	0	0	0	0	1	0	0	0	1	0	2	1	1	0
	Jul	0	0	0	0	1	0	0	0	1	0	2	1	1	0
	Aug	27	86	0	1	0	0	0	0	1	0	4	1	3	1
	Sep	82	23	0	0	0	0	0	1	5	17	105	56	28	2
	Oct	25	9	0	0	0	1	9	2	4	34	11	17	4	0
	Nov	11	21	5	0	2	2	11	9	5	13	15	18	16	0
	Dec	8	11	35	60	16	47	17	83	102	14	52	65	228	18
2017	Jan	10	0	63	125	25	95	24	155	205	14	100	115	469	38
	Feb	0	12	0	0	10	0	0	0	0	0	0	20	10	0

Measured FS values at F01, F03, F05, F06, F07, F10, and F14, all satisfy the guide standard (100 cfu/100 ml) of the Regulation for the Quality of Bathing Water (2006), Annex-1: Table of Quality Criteria Required for Swimming and Recreation Waters. However, they exceed the guide standard at F02 in April, at F04 and F08 in January, at F09 and F13 in December and January, at F11 in April, May, September, and January, at F12 in May and January. All the measured values are less than the mandatory standard (1000 cfu/100 ml). In 66.1% of the samples FS was recorded. The 7.7% samples were above the guide standard.

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Microbial degradation of waters used for drinking, irrigation or recreational purposes is monitored using concentration levels of fecal indicator bacteria (the United States Environmental Protection Agency, 2002). However, other bacteria, including gram-negative opportunistic pathogens of humans, *Pseudomonas aeruginosa*, and HPC bacteria, may also be useful in characterizing the quality of seawater (Carter et al., 2000). *P. aeruginosa* especially exists in coastal and transitional waters that interact with land (Kimata et al., 2004; Mena and Gerba, 2009). The increase in indicator bacteria in seawater and sediment has been associated with the risk of pathogenic microorganism-induced disease in humans (Donovan et al., 2008). Gastrointestinal diseases, skin infections, and risk of acute respiratory tract infections are increasing in people exposed through the recreational use of coastal waters intensified by indicator bacteria (Karbasdehi et al., 2017). Although not yet in Turkey, many regulations define measures to control *P. aeruginosa* pollution in recreational waters foreseeing such risks (Centers for Diseases Control and Prevention, 2014). The temporal variations in *P. aeruginosa* values at all measurement points according to the 12-month measurements made between March 2016 and February 2017 are summarized in *Table 9*.

Table 9. *Temporal variations in P. aeruginosa (cfu/100 ml) at all measurement points*

		F01	**F02**	**F03**	**F04**	**F05**	**F06**	**F07**	**F08**	**F09**	**F10**	**F11**	**F12**	**F13**	**F14**
2016	Mar	163	4	2	2	4	89	120	56	52	11	78	825	93	163
	Apr	223	242	8	4	9	13	10	5	2	1	18	77	23	172
	May	9	13	3	19	84	20	10	0	0	0	0	9	106	9
	Jun	0	0	16	1	1	0	0	0	0	0	0	2	7	0
	Jul	0	0	30	0	12	0	5	0	0	89	0	240	200	123
	Aug	336	1500	0	0	0	0	0	21	40	60	71	250	200	150
	Sep	920	800	0	0	0	0	0	16	25	40	500	230	35	0
	Oct	60	0	0	0	1	4	10	6	10	122	29	40	3	2
	Nov	320	60	50	0	0	16	0	10	70	0	30	1520	184	2
	Dec	210	20	221	115	123	348	45	33	56	145	138	2400	520	45
2017	Jan	0	0	410	250	270	720	90	60	40	320	285	3350	870	80
	Feb	270	920	240	80	820	1150	740	300	100	20	120	1750	100	240

The highest values of *P. aeruginosa* as a pathogenic bacteria was measured at F12 in winter time. No limit value is defined in the regulations for this bacteria in coastal waters. In Italian regulations, it is defined as 1 cfu/100 ml (Guida et al., 2016) in swimming pool waters. *P. aeruginosa* was detected as well in the absence of the TC, FC and FS. In 76.2% of the samples *P. aeruginosa* was recorded.

Salmonella is a pathogenic bacterial species, and it is dangerous for human health. They may enter to coastal waters by land-based anthropological sources, wastewaters, surface flows and ballast waters of marine vessels (Altuğ, 2012). The temporal variations in *Salmonella* values at all measurement points according to the 12-month measurements made between March 2016 and February 2017 are given in *Table 10*.

Measured *Salmonella* values are generally at high levels. They exceed the limit value (0 cfu/100 ml) of the Regulation for the Quality of Bathing Water (2006), Annex-1: Table of Quality Criteria Required for Swimming and Recreation Waters. The highest values have been reached at F11, F14 and F02 in August. *Salmonella* was detected as

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well in the absence of the TC, FC and FS. In 93% of the samples *Salmonella* was recorded.

Table 10. *Temporal variations in Salmonella (cfu/100 ml) values at all measurement points*

		F01	F02	F03	F04	F05	F06	F07	F08	F09	F10	F11	F12	F13	F14
2016	Mar	18	22	42	0	12	82	8	15	6	0	3	52	14	9
	Apr	12	180	26	12	3	98	320	280	850	25	5	28	26	125
	May	150	340	0	0	0	240	700	700	800	0	0	460	100	530
	Jun	410	1230	1780	820	700	2560	450	660	640	9580	2650	1750	2310	200
	Jul	128	37	58	146	437	56	22	48	23	33	35	487	126	95
	Aug	4050	10800	250	1450	650	5150	580	2400	1240	3260	18550	600	5250	17500
	Sep	6350	3450	350	100	150	300	40	850	900	650	2650	550	300	100
	Oct	0	5500	2600	400	150	550	600	350	150	500	350	0	500	0
	Nov	1560	900	100	300	980	2200	2260	740	860	200	540	2210	500	720
	Dec	654	330	95	178	501	1100	1120	323	540	95	252	1120	260	347
2017	Jan	11	30	100	100	50	50	50	21	200	50	18	250	50	23
	Feb	30	30	60	0	20	150	20	40	10	0	10	60	20	20

Plankton abundance

The temporal changes in the phytoplankton and zooplankton abundance values as number per ml (#/ml) at the surface layer of the water and at the depth of -8 m from the surface in Fethiye Inner bay are shown in *Tables 11–14* according to the monthly measurements between March 2016 and February 2017.

Table 11. *Temporal change of surface layer phytoplankton abundance (number per ml) at all measurement points*

	2016										2017	
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
F01	55833	11641	221839	38089	8299	6963	2820	5368	16287	45965	81752	27166
F02	46527	9086	219607	76055	10443	8091	13261	31080	61605	46987	31857	45398
F03	32843	7179	101325	89226	5729	6921	11706	7582	18469	34742	55280	70518
F04	112444	20161	69361	315769	8741	4047	11088	17608	54267	70721	93718	63724
F05	8031	14671	76132	39142	16929	10448	13725	11834	84207	54321	19369	81138
F06	8934	16641	114803	88872	7882	6966	9317	21008	29176	62391	99364	91007
F07	86218	18043	293864	51258	18763	5168	7362	7881	24748	25098	25754	35920
F08	70297	17760	67343	268413	9602	4993	8827	27911	23648	61238	109721	28246
F09	55096	7815	81279	34553	8247	7168	7769	38407	18604	57432	94822	43181
F10	115702	16923	109821	87645	6378	6882	5862	12567	28379	51867	79752	38131
F11	123704	10123	387105	99421	7122	10963	8487	28095	18737	19746	20281	48803
F12	117518	10964	123619	156963	11967	4569	3768	27960	34183	30545	26635	25279
F13	93821	15567	125742	77363	8043	5802	6668	33986	21864	25143	29183	21149
F14	97404	7439	121095	153750	4861	4089	3347	4158	31268	33613	37006	20869

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Table 12. *Temporal change of phytoplankton abundance (number per ml) at -8 m from the surface at all measurement points*

	2016										2017	
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
F01	71508	4729	80751	81796	5567	6043	3101	6287	40233	30245	20917	20133
F02	135865	9361	89611	52609	10439	8922	5327	16933	30173	27158	25363	23704
F03	142303	13684	246129	59803	8954	5963	7669	9611	8386	27149	46375	57352
F04	153108	31528	258198	172448	8086	3247	15179	9843	91279	86954	83106	87611
F05	165708	32642	117305	181249	11097	6019	9043	18052	38719	35732	34118	58792
F06	131038	11569	204311	112679	7083	8687	4783	28155	49811	44498	40247	76619
F07	34917	14048	121374	100826	15929	9281	7463	11743	23823	50139	82415	82193
F08	64923	13926	205103	81339	8051	7246	3569	7027	19403	45436	77369	47351
F09	92309	13466	71233	61287	16122	12844	3241	38406	44611	41213	38261	23769
F10	104627	14079	37581	270811	23901	12847	7746	5827	15332	24157	32669	18351
F11	119062	14602	73427	80643	8125	5521	6781	4427	14482	25941	40137	61837
F12	71508	4729	80751	81796	5567	6043	3101	6287	40233	30245	20917	20133
F13	135865	9361	89611	52609	10439	8922	5327	16933	30173	27158	25363	23704
F14	142303	13684	246129	59803	8954	5963	7669	9611	8386	27149	46375	57352

Table 13. *Temporal change of surface layer zooplankton abundance (number per ml) at all measurement points*

	2016										2017	
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
F01	113	327	194	194	457	1308	301	171	73	84	93	201
F02	98	244	143	146	568	749	458	396	44	75	117	184
F03	85	138	179	337	640	725	745	179	88	98	109	189
F04	76	290	143	284	498	378	201	85	83	89	93	218
F05	101	402	163	225	884	540	626	208	62	98	143	139
F06	99	347	129	211	766	1211	436	288	93	120	149	129
F07	103	325	165	218	726	2684	377	201	58	89	123	152
F08	108	284	346	127	523	1812	781	379	137	142	158	121
F09	197	315	303	78	735	1359	801	601	147	125	102	117
F10	176	344	276	126	342	832	409	248	81	89	95	217
F11	133	322	101	66	504	761	609	463	99	118	138	189
F12	210	205	165	261	542	747	222	284	105	123	147	163
F13	218	228	663	461	478	1244	377	492	150	120	86	153
F14	298	456	104	237	264	564	323	163	115	98	81	161

Samples from F01 and F02 were dominated by Copepod and copepod nauplii individuals during March 2016. A few numbers of Cladocerans were also observed from the same sample. The dominance of Copepod and copepod nauplii groups were also observed between April and August 2016. Diatoms were the abundant phytoplankton group for the same period. While filamentous and green algae were dominated the April sample for F01 and F02, the system was shifted to filamentous

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algae dominance during May 2016. However, diatoms were the most abundant group in the August sample.

Table 14. *Temporal change of zooplankton abundance (number per ml) at -8 m from the surface at all measurement points*

	2016										2017	
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
F01	178	347	92	213	544	642	299	198	127	132	120	114
F02	162	298	179	145	551	901	468	164	114	105	128	145
F03	106	209	126	266	566	477	369	189	97	61	136	109
F04	89	372	118	249	431	359	371	156	104	71	148	150
F05	76	375	376	115	610	699	384	79	137	124	152	158
F06	68	417	106	185	969	2548	627	315	147	129	172	163
F07	43	283	141	37	1059	1904	1104	503	114	101	129	194
F08	46	399	90	259	472	745	209	237	152	165	144	195
F09	57	361	225	258	583	1026	265	415	221	279	161	134
F10	149	403	153	159	549	1014	463	317	92	77	109	109
F11	339	395	136	342	439	638	456	207	98	81	113	187
F12	178	347	92	213	544	642	299	198	127	132	120	114
F13	162	298	179	145	551	901	468	164	114	105	128	145
F14	106	209	126	266	566	477	369	189	97	61	136	109

Samples from stations F03 and F04 were Copepod and copepod nauplii dominated during March 2016. Moreover, few Cladoceran individuals were spotted at samples from 4 m depth. Copepod and copepod nauplii were both the abundant groups at the same stations between April and August. Phytoplankton samples for the same stations were dominated with diatoms between March and August. Therefore, filamentous and green algae domination was observed during April and May 2016. While Copepod nauplii and Rotifera groups were dominant at F05 during March, Copepod, Copepod nauplii, and Cladocera groups were observed in April from the same spot. Moreover, Copepod and copepod nauplii abundance was observed between May and September. Diatoms were the dominant phytoplankton group in March for F05. Both filamentous algae and diatom were the observed during April as well. However, the system was shifted to filamentous algae dominance during May. Diatoms were the dominant group at August sampling.

Rotifer and Copepod nauplii were dominant at F06 during March sampling. However, Cladocera, Copepod and Copepod nauplii were found to be the dominant groups in April (2016). Afterward, the abundance of Copepod and Copepod nauplii groups were reached to their highest number from May to the end of August. Diatoms were the dominant phytoplankton group in March among all phytoplankton. Both filamentous and green algae were the most dominant groups together with diatoms in April 2016 samples. While the system was shifted to filamentous algae dominance at May, diatom abundance was observed in August samples.

Copepod and Copepod nauplii group were dominant at F07, F08 and F09 from April to the end of August. Cladocera individuals were also observed at F07 and F09 during the investigation of 8 m samples in April. Filamentous algae dominance was observed

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between April and May for both stations, and a few individuals of green algae and diatoms were also observed in the same samples. Followingly, diatoms dominated the system during August. The abundant groups were Copepod and Copepod nauplii for F10, F11, F12 and F13 from April until the end of August. Additionally, Cladocera individuals were observed at F11 during April.

Diatoms, filamentous and green algae were found to be the dominant groups for the same stations in April. After that the system was first shifted to filamentous algae dominance during May, then diatom dominance was observed during August. Copepod and Copepod nauplii groups were dominant at F14 between March and August. Additionally, Cladocera individuals were observed in March and April samples. While the diatoms were dominant in March, the system was shifted to diatom, filamentous and green algae dominance in April. Filamentous algae abundance was observed in May, and diatom dominance was found during August.

Copepod and Copepod nauplii were the dominant zooplankton group at F02, F05, F06, F07, F08, F09, F10, F12, F13 and F14 during June. Moreover, some Cladoceran individuals were observed at F01 and F03. Copepod nauplii were the only zooplankton group that was observed at F11. If we summarize phytoplankton distribution, filamentous algae dominance was observed for all stations.

Copepod and Copepod nauplii were dominant zooplankton groups at F01 and F02 during September 2016 sampling. Additionally, Appendicularia individuals were observed in October at both stations for the same period. Copepod and Copepod nauplii were dominant zooplankton groups together with Cladoceran individuals for November 2016 and January 2017 samples. Copepod and Copepod nauplii were the abundant zooplankton groups as well as in March 2017 sampling. Henceforth, members of Rotifera, Cladocera and Appendicularia were observed in the sample. During the investigation of phytoplankton distribution of the stations, diatom dominance was observed for September and October 2016. Small amounts of diatoms and filamentous algae were dominated the November 2016 sample while January 2017 samples were full of green algae and a few diatom species. Diatom dominance was observed at all samples in March 2017.

Copepod and Copepod nauplii dominance was observed between September and November 2016 for F03 and F04. Additionally, a few Appendicularia class individuals were found in 4 m samples. The abundant groups were Copepod and Copepod nauplii for F03 and F04, and a small number of Cladocera individuals were found in January 2017 samples. Copepod, Copepod nauplii, Cladocera and Appendicularia individuals were observed in March for both stations as well. The phytoplankton samples of F03 and F04 were dominated by diatoms and a few dinoflagellates during September and November 2016. However, filamentous algae dominance were observed in November 2016 for the same spots. January 2017 samples were abundant with green algae and a few diatoms. Diatom dominance was observed at all samples in March 2017.

Copepod and Copepod nauplii were dominant between September and November 2016 for F05, F06, F07, and F08 together with a few Appendicularia class individuals. On the other hand, Copepod, Copepod nauplii, and Rotifera groups were mostly found in January 2017 samples with a small amount of Cladoceran and Appendicularia individuals. The same phytoplankton distribution pattern was observed for F05, F06, F07, and F08. While Diatoms and dinoflagellates were dominated the system during September and October 2016, filamentous algae abundance was found in November 2016 samples. Green algae were dominant in November 2016, and a few diatom species

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were observed in January 2017. The system was shifted to diatom dominance during March 2017.

Copepod and Copepod nauplii were the dominant zooplankton groups for F09, F10, and F11 between September and November 2016. Also, Cladoceran and Appendicularia individuals were found in samples. Sampling points were dominated by Copepod and Copepod nauplii zooplankton groups during January 2017. However, Rotifera abundance was observed together with a few Cladoceran and Appendicularia individuals for March 2017. Phytoplankton distributions of the points showed the same pattern as F05, F06, F07, and F08.

Copepod and Copepod nauplii were the abundant zooplankton groups for F12, F13, F14, and F15 between September and November 2016. Additionally, Cladoceran and Rotifera individuals were observed in October 2016. Copepod and Copepod nauplii were found to be the dominant zooplankton groups in January 2017. Moreover, few Rotifera and Cladoceran individuals were observed in January 2017. Copepod and Copepod nauplii were the dominant zooplankton group in March 2017 together with a small number of Rotifera, Cladocera, and Appendicularia individuals. Phytoplankton distribution of the same stations showed diatom dominance with a few individuals of dinoflagellate for September and October 2016. Filamentous algae were dominant in November 2016. Green algae have dominated the samples during January 2017, and a few diatom species were found in the sample. Diatom abundance was observed in the system in March 2017 samples.

Dissolved oxygen and biochemical oxygen demand

Dissolved Oxygen (DO) level is one of the most critical parameters in monitoring water quality and is an essential indicator of water mass's ability to support healthy ecosystems (Manivanan et al., 2013). DO is the amount of oxygen present in molecular form to provide life in seawater. The DO can enter the marine environment, directly through mixing and diffusion, or as a by-product of photosynthesis. Therefore, the level of DO in the water may increase due to strong wind and wave motions and the presence of plants and algae. On the other hand, it decreases by respiration and decay. When the plant population is very intense, oxygen consumption increases. Organisms such as bacteria, phytoplankton, and zooplankton need oxygen and consume dissolved oxygen in large quantities. Degradation of organic matter is the most significant oxygen consumer in the system. In general, a dissolved oxygen level of at least 4 mg/L is required to support live life. In marine environments, chronic oxygen deficiency occurs when the DO amount is between 2.0 and 6.0 mg/l, and hypoxic conditions (acute oxygen deficiency) threaten livelihood occur when DO is lowered than 2.0 mg/l. When the DO level drops below 0.2 mg/l, anoxic or oxygen-free conditions occur (O'Boyle et al., 2009). As temperature and salinity increase, the oxygen concentration in the seawater decreases.

The 12-month measurements between March 2016 and February 2017 were made at every 2 m from the surface to the sea bottom. The temporal changes of DO measurements at the water surface and at -14 m below the surface are presented in *Tables 15* and *16*, respectively. The seasonal and annual averages of DO (mg/l) at all measurement points are summarized in *Table 17*. The measured dissolved oxygen values are in between 3.83 and 9.12 mg/l, and the values are decreasing in the summer when the temperature is the warmest. In summer, mean DO values are below 6 mg/l,

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and chronic oxygen deficiency condition is seen. All of the measurements were higher than 2 mg/l higher and hypoxic or anoxic condition was not observed.

Table 15. *Temporal change of surface dissolved oxygen (mg/l) at all measurement points*

	2016										2017	
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
F01	9.12	6.47	7.95	6.2	5.58	5.6	6.08	5.91	6.78	6.78	6.78	7.52
F02	8.96	6.76	7.46	6.47	5.52	5.29	5.77	5.97	6.94	6.51	6.23	7.26
F03	8.97	6.93	8.01	6.14	5.01	5.34	6.79	6.13	6.79	6.32	7.51	7.56
F04	7.77	7.57	7.26	5.97	5.56	5.27	6.35	6.01	7.96	6.81	7.28	7.35
F05	7.96	7.66	8.18	6.42	5.32	5.96	6	6.16	8.48	6.73	6.87	6.73
F06	8.21	7.2	8.57	6.41	5.41	5.37	6.26	6.62	5.68	6.8	7.55	6.95
F07	8.18	8.16	8.32	6.95	5.07	5.91	6.7	6.09	6.72	6.3	6.02	7.69
F08	7.89	8.66	6.79	7.26	5.23	5.99	6.01	6.81	6.43	7.1	7.55	7.32
F09	8.8	7.6	7.57	6.9	5.53	5.3	6.23	6.52	7.25	6.74	7.64	7.1
F10	8.55	6.55	8.34	6.05	5.33	5.38	5.9	6.17	6.53	6.95	7.23	7.8
F11	8.25	7.69	8.48	6.98	5.15	5.38	5.46	6.48	6.35	7.12	7.64	7.64
F12	8.55	7.25	7.37	6.32	5.15	5.89	5.79	6.41	5.31	6.28	6.94	6.48
F13	9.03	7.33	7.33	6.41	5.37	5.64	6.53	5.99	5.43	6.27	6.84	6.76
F14	9.03	6.64	7.07	6.34	5.56	5.43	6.44	5.92	6.26	6.49	6.62	7.98

Table 16. *Temporal change of dissolved oxygen (mg/l) at -14 m below the surface at all measurement points*

	2016										2017	
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
F01	7.57	7.46	7.09	6.72	6.06	5.39	5.99	5.85	6.24	6.08	5.98	6.31
F02	7.15	7.29	6.89	6.89	6.06	5.28	5.71	5.66	6.23	6.08	5.98	6.25
F03	7.07	6.95	6.95	6.75	5.3	4.65	6.08	5.8	6.33	5.97	5.74	6.33
F04	7.04	7.26	6.86	6.41	3.83	4.89	5.93	5.81	6.36	6.24	6.17	6.32
F05	7.11	7.19	6.95	6.65	5.35	4.88	5.86	5.77	6.25	6.16	6.1	6.1
F07	7.01	7.26	6.91	6.75	5.55	5.63	5.99	5.82	6.22	6.02	5.9	6.37
F09	7.51	7.22	6.79	6.42	5.73	5	5.93	5.71	6.11	6.11	5.97	6.28
F10	7.18	6.73	6.99	6.84	5.9	5.36	5.48	5.36	6.06	5.63	6	6.41
F12	7.28	7.38	7.01	6.78	6.09	4.17	5.94	5.87	6.11	5.66	5.36	5.64
F13	7.36	7.22	7.06	6.09	4.21	5.58	5.33	5.08	5.56	5.47	5.42	5.43
F14	8.1	7.85	7.29	7.02	6.2	5.68	5.88	5.8	6.38	6.33	6.3	6.56

Table 17. *Dissolved oxygen (mg/l) seasonal and annual averages*

	Spring	**Summer**	**Autumn**	**Winter**	**Annual**
Surface	7.87	5.79	6.34	7.00	6.75
-4 m	7.56	5.78	5.99	6.44	6.44
-8 m	7.55	5.87	5.99	6.22	6.41
-12 m	7.28	5.85	5.98	6.07	6.29
-14 m	7.18	5.76	5.89	6.02	6.21

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Biochemical Oxygen Demand (BOD) is a measure of the amount of oxygen that is consumed by microorganisms to break down organic substances. As the water temperature values increase, the BOD values also increase. When the water temperature rises, photosynthesis rate of plants increases, plants grow faster and die. Decay the dead plants by the bacteria requires oxygen, and as a result, the BOD values rise. For this reason, the BOD values in the summer months are higher than the winter months values. The increase in nitrate and phosphate increases the rate of plant growth and death, and thus the organic pollutant load that will be broken down by bacteria in the marine environment. For this reason, the increase in nitrate and phosphate values is also effective in increasing BOD levels. As the BOD level rises, the dissolved oxygen (DO) values used by bacteria are reduced. In the months of intense rainfall, there is an increase in the mixing of the organic materials found in the soil with the sea water. Generally, in the uncontaminated waters, the BOD level is less than 4 mg/l, while it can reach 8-150 mg/l in the wastewater (Regulation of Surface Water Quality, 2016).

According to the 12-month measurements between March 2016 and February 2017, the temporal changes of the BOD values at the surface of Fethiye Inner Bay are presented in *Table 18*. All measured BOD values range from 2.3-6.8 mg/l.

Table 18. *Temporal change of biological oxygen demand (mg/l) at the surface layer for all measurement points*

	2016										2017	
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**
F01	2.41	5.03	3.66	4.92	3.98	5.26	5.51	5.45	3.89	3.64	3.42	3.58
F02	3.21	5.48	4.52	4.74	4.16	5.40	5.20	3.76	3.55	3.66	3.93	3.53
F03	2.32	3.09	3.43	4.82	5.34	4.97	4.54	3.86	3.69	3.76	4.13	3.43
F04	2.70	4.90	3.21	5.04	5.37	5.43	4.79	5.87	4.37	3.43	3.82	3.75
F05	3.03	3.15	4.06	4.82	5.24	5.03	4.59	4.08	4.52	4.36	3.99	4.24
F06	3.20	3.53	3.71	4.96	5.35	4.98	5.13	3.92	4.57	4.00	3.89	4.36
F07	3.11	3.26	3.18	4.54	4.97	4.71	4.46	4.10	4.63	4.13	4.32	3.64
F08	2.65	2.50	2.85	4.60	4.55	6.22	5.16	4.36	4.65	3.40	3.25	3.43
F09	2.40	2.82	2.72	4.36	4.54	4.85	4.16	4.16	3.94	3.81	3.77	3.20
F10	2.43	3.21	3.43	4.55	5.31	5.09	4.77	3.64	3.40	3.71	3.42	3.10
F11	4.39	5.98	6.85	5.46	5.60	4.96	5.52	5.13	4.85	4.80	4.75	4.57
F12	2.92	3.43	4.91	4.00	5.52	4.60	4.63	4.80	6.72	5.97	5.18	4.53
F13	2.94	3.10	4.37	4.13	4.82	4.64	3.47	4.08	4.53	4.25	3.87	3.42
F14	2.37	3.28	3.47	3.36	3.53	5.12	3.37	4.10	3.40	3.01	3.31	2.81

In this study, a three-dimensional coastal waters hydrodynamic (Balas and Özhan, 2003), wave propagation, transport and water quality (Cebe and Balas, 2016) numerical model HYDROTAM-3D, was used and a water quality monitoring and evaluation database system based on geographical information system (GIS) was established. The database system is available at www.hydrotam3d.com/fethiye by username: fb and user password: fb. Coordinated and temporal access is provided to all data.

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Results and discussion

The monthly variations of water quality parameters were investigated through the site measurements conducted in between March 2016 and February 2017. Once at every month, at selected 14 locations, water samples were collected, and total coliform, fecal coliform, fecal streptococci, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella* detection, phytoplankton and zooplankton abundance analyses were performed in the laboratory. By using the related TSE standards, biochemical oxygen demand (BOD) and dissolved oxygen (DO) levels were determined, and water samples were collected from surface and -8 meters below if possible. The physical parameters measured throughout the water column were water temperature, salinity, pH, and turbidity. Changes in parameters measured between March 2016 and February 2017 were summarized in *Table 19*.

Table 19. *The measured ranges of physical and chemical parameters suitable to water samples in Fethiye Inner Bay*

Number of samples	Parameters	Mean	Minimum	Maximum
14	Water Depth (m)	16.2	4.5	46
1164	Salinity (S, ppt),	37.5	30.4	39.4
1164	Temperature (T,°C)	21.4	12.7	30.8
1164	pH	8.09	7.55	8.38
168	Turbidity (Turb.,ntu)	2.08	0.54	4.81
168	Total coliform (TC, cfu/100 ml)	298	0	6090
168	Fecal coliform (FC, cfu/100 ml)	131	0	6090
168	Fecal streptococci (FS, cfu/100 ml)	28	0	800
168	*E. coli* (cfu/100 ml)	37	0	933
168	*P. aeruginosa* (cfu/100 ml)	174	0	3350
168	*Salmonella* (cfu/100 ml)	930	0	18550
1164	DO (mg/l)	6.4	3.83	9.12
168	BOD (mg/l)	4.2	2.3	6.8

Pearson correlation matrix and related p-values were carried out on all the data set of water samples to describe the relations between measured parameters. In *Table 20*, coefficient of correlations (r) were listed, and significant correlations at $p < 0.05$ were indicated. After examination of several scatter plots, it is decided to refer the correlation as a weak correlation if $0.1 < r < 0.3$, a moderate correlation if $0.3 < r < 0.5$ and a strong correlation if $0.5 < r < 1.0$.

According to the correlation analysis, it is seen that temperature shows a weak positive significant correlation with the salinity ($r = 0.28$), pH ($r = 0.15$) and turbidity ($r = 0.25$). In line with a moderate positive correlation ($r = 0.3$), as water temperature increases, zooplankton counts increases as well. pH values show a weak negative correlation with DO ($r = -0.17$) and phytoplankton counts ($r = -0.15$) and a weak and moderate positive correlations with turbidity ($r = 0.19$) and zooplankton counts ($r = 0.32$) respectively. Zooplankton shows a reduction in numbers at the lower pH levels.

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Table 20. *Correlation (r) matrix between all parameters analyzed in Fethiye Inner Bay coastal waters*

	T	S	pH	DO	BOD	Turb.	TC	FC	FS	Phyto	Zoo
T	1.00										
S	**0.28***	1.00									
pH	**0.15***	-0.08	1.00								
DO	0.04	**-0.15***	**-0.17***	1.00							
BOD	0.06	**0.33***	0.14	**-0.61***	1.00						
Turb.	**0.25***	**-0.29***	**0.19***	0.12	0.09	1.00					
TC	0.03	0.02	0.03	-0.12	**0.34***	-0.03	1.00				
FC	0.10	0.01	0.02	-0.12	**0.24***	-0.06	**0.85***	1.00			
FS	0.13	-0.08	0.12	0.15	**0.24***	**0.20***	**0.17***	0.12	1.00		
Phyto	-0.02	**-0.27***	**-0.15***	**0.43***	-0.10	0.14	-0.01	-0.01	**0.33***	1.00	
Zoo	**0.30***	0.10	**0.32***	**-0.45***	**0.35***	0.08	-0.02	0.07	**-0.13***	**-0.30***	1.00

*significant at $p < 0.05$

As the salinity of coastal waters decreases in rainy seasons, DO (r = -0.15) and phytoplankton counts (r = -0.27) increase and BOD decreases (r = 0.33). The measured DO decreases in the summer, as the water temperature increases. In 32% of the measurements, DO values are below 6 mg/l, and chronic oxygen deficiency condition is seen. DO and BOD values show a strong inverse relation (r = -0.61) as shown in *Figure 5*. DO values reach the highest values in the spring, while BOD values are the lowest. It is seen that, as phytoplankton counts (r = 0.43) increase and zooplankton counts (r = -0.45) decrease, DO increases in coastal waters of Fethiye Inner Bay. Whereas zooplankton counts show a positive moderate correlation with BOD (r = 0.35).

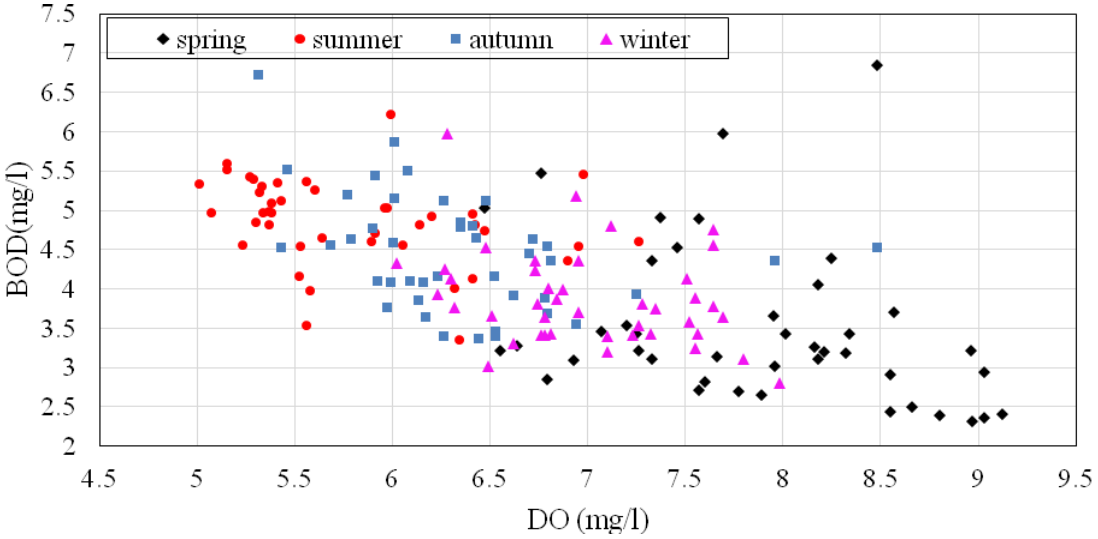

Figure 5. *Seasonal change of dissolved oxygen and biological oxygen demand*

BOD tends to increase in summer and autumn. This is due to the increase in microorganisms that requires dissolved oxygen to oxidize organic matter. BOD values

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are higher than 4 mg/L in 55% of measured samples. It is seen that BOD values have a positive relation with TC (r = 0.34), FC (r = 0.24) and FS (r = 0.24). BOD increases as the concentration values of organic pollutants increase. As an example of this positive relation, timewise changes in BOD, total coliform, fecal coliform and fecal streptococci values at selected measuring points F06 and F12 are presented in *Figure 6*.

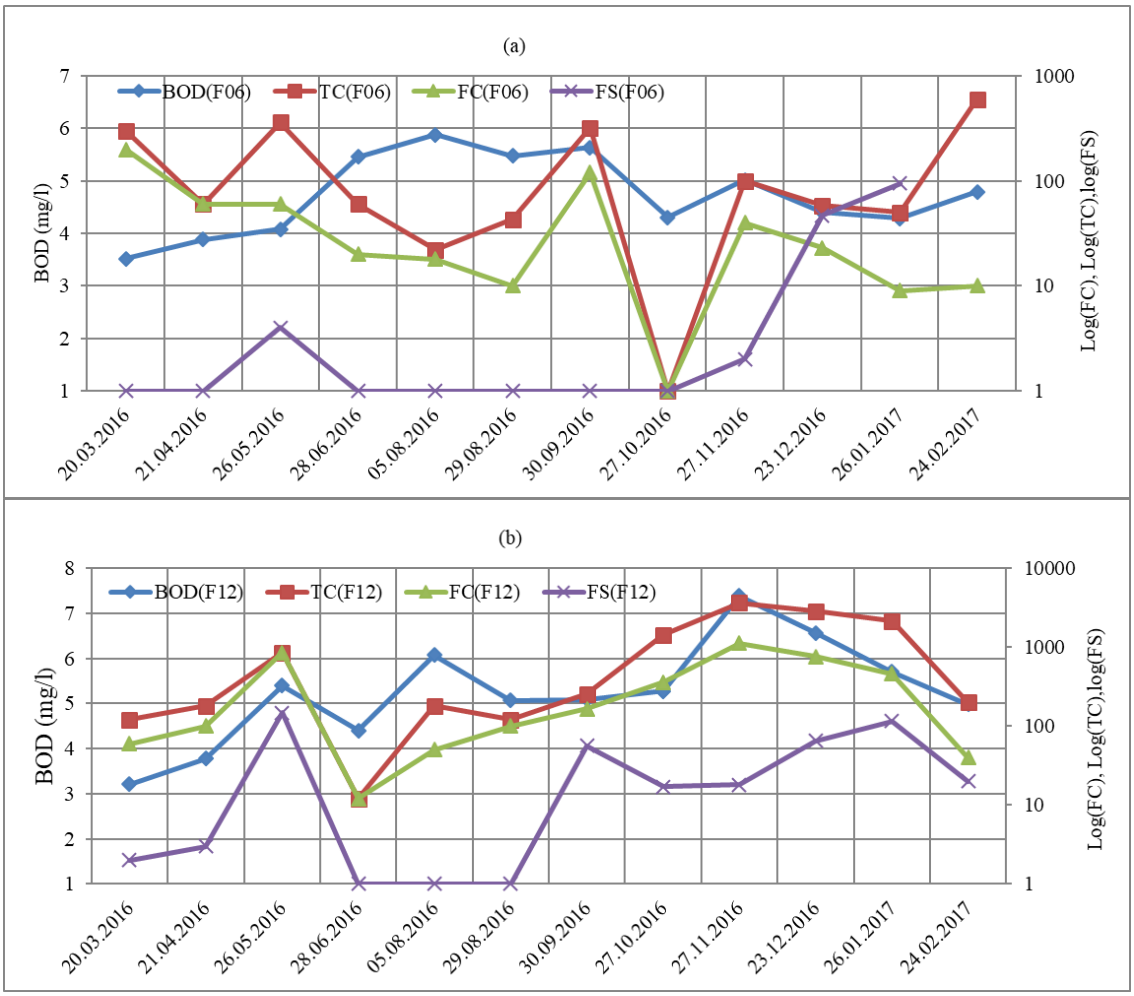

Figure 6. *Temporal changes in BOD, total coliform, fecal coliform and fecal streptococci values a) at point F06 b) at point F12*

It is seen that as TC amount increases, FC (r = 0.85) strongly increases and also FS (r = 0.17) shows an increase. In 91.7%, 85.7% and 66.1% of the samples TC, FC and FS were recorded respectively. In 15.5%, 21.4% and 7.7% of them were above the TC, FC and FS guide standards respectively. In 38.1% of the samples *E. coli* was recorded, and 3.6% and 1.8% were above the guide standard and the mandatory standard, respectively. It is seen that, FS amount has positive moderate correlation with phytoplankton count (r = 0.33).

In this study, "Spring Bloom" were observed between May and July which corresponds with the highest level phytoplankton abundance in the sampling points and the results are in line with Sverdrup's (1953) study (Colebrook, 1982; Martinez et al., 2011). During the "Spring Bloom", the amount of phytoplankton in aquatic

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environments increase significantly due to less stratification, more stable dispersion of temperature and higher availability of surface nutrients.

After the spring bloom season, there was a decrease in phytoplankton and increase in zooplankton in all samples. Measurements show that there is an inverse correlation between zooplankton and phytoplankton counts (r = -0.3). Zooplankton numbers were reached to their maximum between August and September, then started to decrease in October. Moreover, a few phytoplankton peaks were also observed in the end of the fall bloom. This pattern corresponded with an event called "Fall Bloom". According to literature, the stratified water column started to mix due to an increase in the atmospheric events that cause an increase in nutrient levels as well in the aquatic ecosystem which results with a bloom in phytoplankton levels for a short period (Sverdrup, 1953). In this study, fall bloom was spotted starting from October, and it lasted for three months.

According to the results of the study performed, the number of total coliform bacteria had a significant increase during May and September. All measured microbiological parameters frequently increase in spring and winter, often exceeding guide standards. In a study by Kim et al. (2000), it was shown that increase in bacterial populations tended to be seasonal, which was in line with results of this study. The observations in the current study showed that zooplankton samples were mostly dominated by copepods which had a low grazing control of bacteria. Correspondingly, it is thought that the bacterial growth is not controlled by zooplankton in this study.

In conclusion, land-based pollutants transported with increasing surface runoff are thought to cause an increase in microorganism concentrations. Swimming in Çalış Beach coastal waters (F12 and F13) might be dangerous for human health. Seasonal averages and high BOD values indicate that the Fethiye Inner Bay is under considerable threat of continuous pollutant loadings. Measurements all indicate that immediate measures should be taken to reduce the land-based pollution causing degradation of coastal water quality in Fethiye Inner Bay.

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