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Comparison of fecal coliform bacteria before and after wastewater treatment plant in the Izmir Bay (Eastern Aegean Sea)

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Abstract The distribution of fecal coliforms was investigated and determined in Izmir Bay from 1996 to 2005. Izmir Bay severely was polluted from industrial and domestic discharges during decades. In early 2000, a wastewater treatment plant began to treat domestic and industrial wastes. This plant treats the wastes about 80% capacity after 2001. The sampling periods cover before and after treatment plant. Assessment method for determining the number of fecal coliform has evolved membrane filtrations. Maximum surface fecal coliform concentration was 4.9×10^5 cfu 100 ml^{-1} in 1996–2000 period. Following the opening treatment system, fecal coliform density decreased 2.1×10^4 cfu 100 ml^{-1} during 2001–2005. A continuous improvement can be sustained in the water quality if direct inflow of untreated wastewater is prevented.

Keywords Indicator bacteria · Fecal coliform · Wastewater · Izmir Bay · Eastern Aegean Sea

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Introduction

Bacterial contamination in surface waters of coastal areas is a problem affecting recreational and commercial uses of bays, inlets, estuaries, and rivers. Water quality degradation from fecal contamination may result in increased health hazards to recreational users (Gersberg et al. 1995; ISSC 1997). The current standard for detection of fecal pollution in surface waters is the determination of fecal coliform (FC) bacteria density (Kelsey et al. 2003). Fecal coliforms are used as indicators of enteric pathogenic organisms in aquatic environments (Noble and Fuhrman 2001). They are regularly monitored to ensure that water bodies meet established sanitary standards use in recreational activities (Chigbu et al. 2005). Of the fecal coliform group, one species, *Escherichia coli*, is most closely associated with feces from warm-blooded animals (Kelsey et al. 2003). Wildlife, sewage effluents, failing septic systems, and runoff from farm animal feedlots and agricultural lands are important sources of fecal coliform bacteria in water bodies (Hunter et al. 1999; Crowther et al. 2002).

Fecal coliforms in surface waters peak after a rain event (Ferguson et al. 1996; Mallin et al. 2001). Thereafter, they decrease or disappear from the water column with time, through death and sedimentation processes, and can concentrate in sediments at high densities (Stevenson and Rychert 1982; Bergstein-Ben Dan and Stone 1991). Following sedimentation, coliform bacteria can be resuspended in shallow waters by tidal movements and winds (Bordalo 2003), dredging (Grimes 1980), storm surge (Field and Pitt 1990), increased stream flow, and recreational activities such as boating (Crabill et al. 1999). Fecal coliform dynamics in coastal waters is a functi on of bacterial loading from streams and rivers, mass transport, and bacterial losses due to death and sedimentation. Their disappearance rates from surface waters depend on a number of factors such as the availability of nutrients, temperature, salinity, turbidity, degree of water mixing, solar radiation, predation, and competition (Hood and Ness 1982; Flint 1987; Auer and Niehaus 1993). However, temperature and solar radiation are considered to be the most important abiotic factors (Esham and Sizemore 1998; Kagalou et al. 2002; Xu et al. 2002; Chigbu et al. 2005).

Izmir Bay (western Turkey) is one of the great natural bays of the Mediterranean. The main urban conurbation around the bay is the Izmir Metropolitan Municipality, covering 88,000 ha. Izmir is an important industrial and commercial center and a cultural focal point (Kucuksezgin et al. 2006). The bay has a total surface area of over 500 km^2, water capacity of 11.5 billion m^3, a total length of 64 km, and opens in the Aegean Sea. The bay has been divided into three sections (outer, middle, and inner) according to the physical characteristics of the different water masses middle and inner sections extend in an east–west direction and are collectively 24 km long and 6 km wide (Sayin 2003). The inner section is small (57 km^2) and shallow (maximum depth 15 m). The middle bay is separated from the inner bay by a 13-m deep sill, the Yenikale Strait. The depth of water in the outer bay is about 70 m and decreases toward to the inner bay. The Gediz River, which flows to the northern part of the bay, is the second biggest river along the eastern Aegean coast. The Gediz River is densely populated and includes extensive agricultural lands and numerous manufacturing, food and chemical industries. The streams and hundreds of small domestic discharge outlets flow to the bay (Kontas et al. 2004).

Domestic and industrial sewage discharge points of the city of Izmir are concentrated at the inner bay. Furthermore, several streams and creeks, which collect the wastewaters of industrial complexes and urbanization centers on the way, also increase the organic–inorganic matter input and concentration of pollution. One of the most important factors of water pollution is microbial pollution, especially the pathogenic organisms (Karaboz et al. 2003). In this study, amounts of fecal coliform were measured from cruises of the R/V Koca Piri Reis in the Izmir Bay (Eastern Aegean). The main aim of this study was to assess

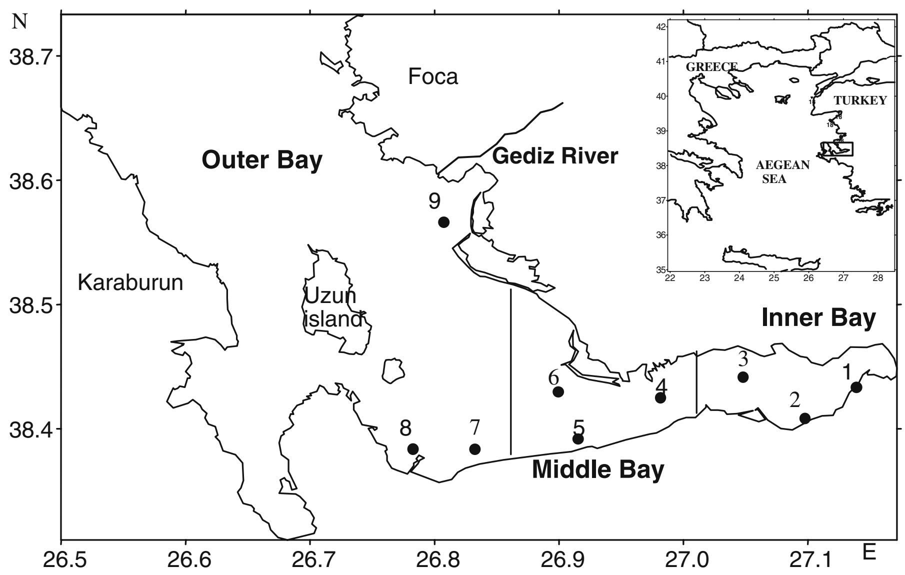

Fig. 1 Location of sampling stations in Izmir Bay

Table 1 Ranges and mean ± standard error values of physical parameters recorded during 1996–2005 in the Izmir Bay

Period	Temperature (°C)			Salinity (psu)			Density (kg^{-3})		
	Min	Max	Mean ± SE	Min	Max	Mean ± SE	Min	Max	Mean ± SE
01/97	13.19	15.71	14.08 ± 0.29	37.87	38.99	38.49 ± 0.13	28.58	29.05	28.87 ± 0.05
01/98	13.89	15.35	14.76 ± 0.20	38.59	38.94	38.76 ± 0.05	28.79	28.99	28.92 ± 0.02
01/01	13.80	15.73	14.98 ± 0.24	38.32	38.91	38.63 ± 0.08	28.41	28.87	28.78 ± 0.06
02/97	13.78	14.91	14.04 ± 0.17	38.75	39.04	38.96 ± 0.04	29.11	29.32	29.24 ± 0.04
02/02	12.77	14.77	14.23 ± 0.02	37.76	39.03	38.59 ± 0.02	28.15	29.21	28.91 ± 0.01
02/05	8.48	13.22	11.24 ± 0.05	36.95	38.91	37.98 ± 0.02	28.19	29.68	29.04 ± 0.01
03/00	11.36	13.89	12.41 ± 0.34	37.69	39.61	38.72 ± 0.24	28.81	30.01	29.39 ± 0.16
03/03	9.33	9.33	9.33 ± 0.00	37.84	38.79	38.26 ± 0.01	29.10	29.50	29.37 ± 0.44
03/04	10.58	13.54	12.62 ± 0.03	38.01	38.98	38.68 ± 0.01	29.24	29.45	29.38 ± 0.02
04/97	12.56	13.58	13.06 ± 0.11	37.64	39.06	38.57 ± 0.16	28.50	29.51	29.16 ± 0.11
04/98	16.74	18.15	17.19 ± 0.21	38.07	38.95	38.68 ± 0.15	27.80	28.61	28.30 ± 0.15
04/00	14.80	16.31	15.62 ± 0.14	36.77	38.75	38.10 ± 0.23	27.03	28.91	28.22 ± 0.20
04/01	16.09	16.86	16.40 ± 0.11	38.71	39.72	39.07 ± 0.13	28.40	29.36	28.78 ± 0.12
04/05	14.78	16.77	11.24 ± 0.05	36.95	38.91	37.98 ± 0.02	28.19	29.68	29.04 ± 0.01
05/00	18.08	20.17	19.23 ± 0.31	38.13	39.33	38.64 ± 0.13	27.19	28.18	27.74 ± 0.13
05/03	20.49	22.75	22.19 ± 0.02	37.31	38.88	37.85 ± 0.02	25.76	27.59	26.33 ± 0.02
06/96	21.26	23.22	22.46 ± 0.29	38.57	39.38	39.17 ± 0.12	26.58	27.71	27.26 ± 0.15
06/02	21.10	23.20	22.65 ± 0.03	38.55	39.32	39.00 ± 0.01	26.62	27.54	27.07 ± 0.01
06/05	21.45	25.85	24.23 ± 0.04	38.56	39.17	38.89 ± 0.008	25.79	27.54	26.51 ± 0.01
07/97	21.16	26.97	25.39 ± 0.86	38.86	39.43	39.26 ± 0.08	25.64	27.67	26.43 ± 0.27
07/00	23.76	26.85	25.59 ± 0.42	38.96	39.54	39.29 ± 0.07	25.96	26.98	26.40 ± 0.14
08/97	23.99	26.30	25.08 ± 0.38	38.65	40.54	39.63 ± 0.25	25.70	27.62	26.82 ± 0.24
08/01	25.46	28.46	26.97 ± 0.42	39.58	39.73	39.67 ± 0.01	25.77	26.67	26.24 ± 0.12
08/04	24.40	27.78	26.68 ± 0.03	38.96	39.85	39.48 ± 0.009	25.53	26.89	26.19 ± 0.01
09/97	19.88	22.70	21.16 ± 0.41	39.55	39.76	39.67 ± 0.03	27.47	28.37	28.00 ± 0.12
09/98	23.52	25.94	25.04 ± 0.34	39.25	39.49	39.40 ± 0.04	26.29	27.01	26.65 ± 0.09
10/96	18.95	20.13	19.69 ± 0.11	38.76	39.29	39.13 ± 0.06	27.72	28.28	28.01 ± 0.06
10/98	21.91	22.21	22.10 ± 0.05	38.24	38.40	38.33 ± 0.03	26.63	26.80	26.72 ± 0.03
11/96	15.88	16.71	16.43 ± 0.11	37.73	39.14	38.79 ± 0.22	27.87	28.79	28.57 ± 0.14
11/97	16.53	17.14	16.89 ± 0.08	38.35	39.14	38.99 ± 0.09	28.17	28.79	28.62 ± 0.07
11/00	17.44	18.03	17.89 ± 0.07	38.36	38.89	38.70 ± 0.07	27.93	28.25	28.14 ± 0.04
11/02	17.65	17.65	17.65 ± 0.00	37.16	38.64	38.14 ± 0.01	26.68	28.09	27.54 ± 0.01
11/04	20.04	20.56	20.20 ± 0.04	38.83	39.54	39.26 ± 0.06	27.63	28.17	27.96 ± 0.05
12/01	12.23	14.05	13.39 ± 0.25	38.37	39.01	38.78 ± 0.12	28.87	29.40	29.24 ± 0.08

the density of fecal coliforms and to evaluate the changes in the marine environment after installation of a treatment plant in the bay.

Materials and methods

Study area

The data were evaluated from seasonally collected surface samples during cruises of R/V Koca Piri Reis from 1996 to 2005 at nine sampling stations, in the framework of the "Izmir Bay Marine Research Project" supported by Izmir Metropolitan Municipality. Nine stations were chosen to represent areas where routine monitoring has shown levels of fecal coliform: three at inner part lower depth, three at middle part, and another three stations at outer part. Izmir wetland wastewater treatment system under investigation was started to functioning in 2000 (Fig. 1).

Seawater analysis

Seawater samples were collected seasonally with General Oceanic Go-Flo Rosette bottles attached to the conductivity–temperature–depth (CTD) system from surface and transferred to 250-ml sterile dark glass bottles. Membrane filtration was carried out for bacteriological examination (APHA 1999). Subsamples were filtered immediately onboard from sterile 0.45-μm membrane filters (Whatman) with sterile metal vacuum filtering set. For FC enumeration, filters were incubated for 24 h at 44.5 ± 0.1°C on m-FC medium (Difco).

The physical parameters of the water column (temperature, salinity, density) were measured with a Sea-bird (Model 9) CTD probe attached to a remote-controlled 12 bottles (10 l capacity) rosette system. Sea-bird CTD sensors were calibrated by the Northwest Regional Calibration Center (operating under contract to National Oceanic and Atmospheric Administration) once a year.

Statistical analysis

The relationship between FC and other environmental parameters was analyzed by Pearson correlation. Analysis of variance (ANOVA) was used to compare the changes in the coastal water quality by means of FC. A two-way ANOVA was used to compare the FC concentrations among seasons, sampling location, and stations (Sokal and Rohlf 1995).

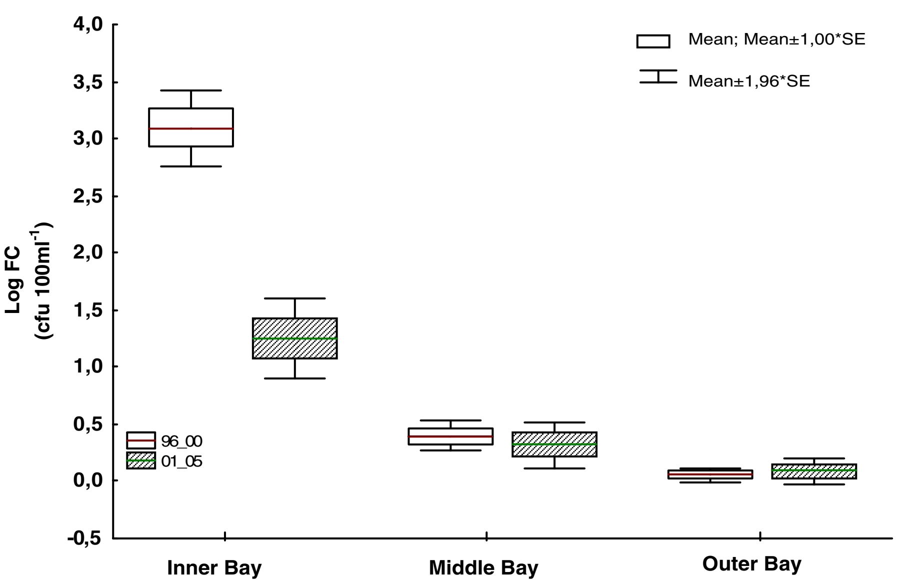

Fig. 2 Distribution of fecal coliform in the different parts of the Izmir Bay

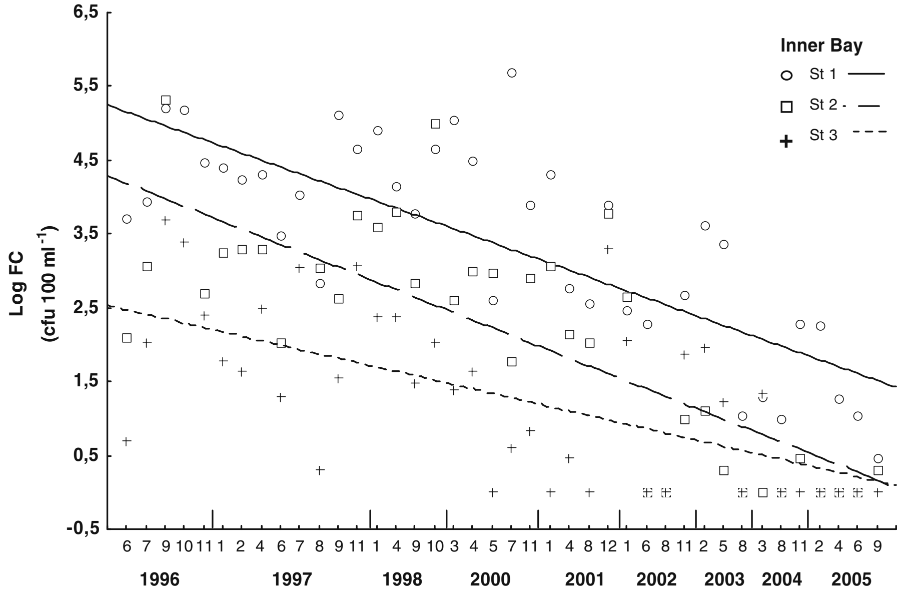

Fig. 3 Fecal coliform distribution in the inner bay from 1996 to 2005

Results and discussion

The seawater physical parameters showed variation during the study period (1996–2005; Table 1). The water quality in the Izmir Bay had been affected by large amounts of domestic discharges and industrial inputs for decades. High concentrations of fecal coliform bacteria had been in the inner bay until established wastewater treatment plant. The main shift in the water quality of the inner bay was observed after 2001 (Fig. 2).

The inner part of the bay displayed higher bacteriological pollution compared to the middle and outer part. In the inner bay, surface values of fecal coliform were between 4.0×10^2 and 4.9×10^5 cfu 100 ml^{-1} at station 1 during 1996–2000 period. However, FC started to decrease after stepped in wastewater treatment systems and FC values were

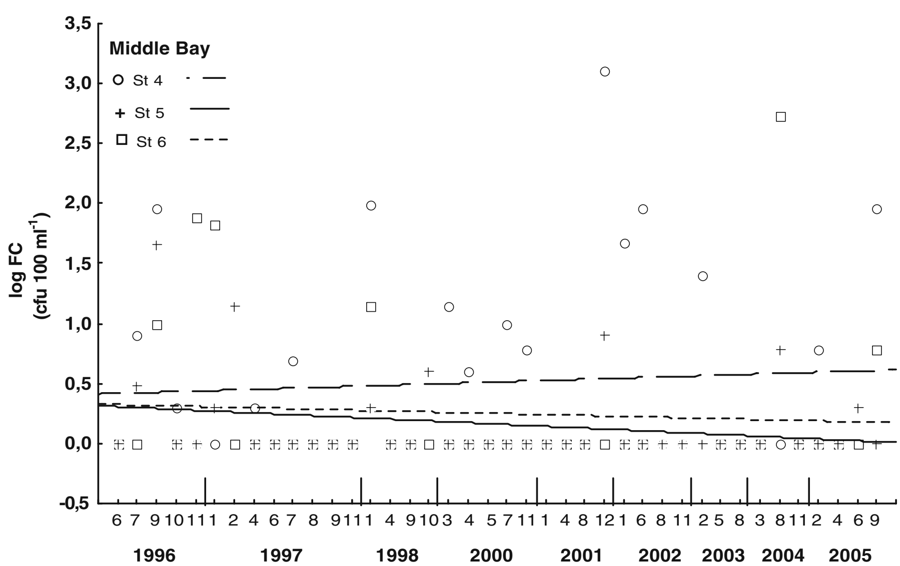

Fig. 4 Fecal coliform distribution in the middle bay from 1996 to 2005

Table 2 Ranges and mean values of fecal bacteria (cfu 100 ml^{-1}) in the surface waters of Izmir Bay

Station	June 1996–November 2000 Min–max Mean	January 2001–September 2005 Min–max Mean
1	4.0×10^2–4.9×10^5	$< 10^0 - 2.1 \times 10^4$
	6.3×10^4 [22]	2.1×10^3 [18]
2	6.0×10^1–2.1×10^5	$< 10^0 - 6.2 \times 10^3$
	1.6×10^4 [20]	4.5×10^2 [18]
3	$< 10^0 - 5.0 \times 10^3$	$< 10^0 - 2.0 \times 10^3$
	5.2×10^2 [22]	1.3×10^2 [18]
4	$< 10^0 - 9.8 \times 10^1$	$< 10^0 - 1.3 \times 10^3$
	1.1×10^1 [22]	8.7×10^1 [18]
5	$< 10^0 - 4.5 \times 10^1$	$< 10^0 - 8.0 \times 10^0$
	3.0×10^0 [22]	$< 10^0$ [18]
6	$< 10^0 - 7.7 \times 10^1$	$< 10^0 - 5.3 \times 10^2$
	7.0×10^0 [22]	3.5×10^1 [15]
7	$< 10^0 - 4.8 \times 10^1$	$< 10^0 - 3.0 \times 10^0$
	2.0×10^0 [22]	$< 10^0$ [14]
8	$< 10^0 - 1.2 \times 10^1$	$< 10^0 - 5.0 \times 10^0$
	$< 10^0$ [22]	$< 10^0$ [17]
9	$< 10^0 - 5.0 \times 10^0$	$< 10^0 - 3.9 \times 10^2$
	$< 10^0$ [22]	2.1×10^1 [18]

$<10^0$–2.1×10^4 cfu 100 ml^{-1} in the 2001–2005 sampling period. The same reductions were observed in fecal coliform, which were significantly reduced, from 6.0×10^1–2.1×10^5 to $<10^0$–6.2×10^3 cfu 100 ml^{-1} at station 2 and from 3.10^0–5.0×10^3 to $<10^0$–2.0×10^3 cfu 100 ml^{-1} at station 3 (Fig. 3). These reductions are similar to the mean reductions reported for different municipal treatment wetlands (Gersberg et al. 1987; Reed et al. 1995; Kadlec and Knight 1996). According to other similar study results of the long-term treatment behavior of a full-scale constructed wetland in China, the highest percentage reductions observed were for total coliform (99.7%) and fecal coliform (99.6%), from 2.4×10^6 and 1.6×10^6 counts 100 ml^{-1} to 8.0×10^3 and 6.0×10^3 cfu 100 ml^{-1}, respectively. Results from the study demonstrated that the constructed wetland system could effectively reduce the output of fecal coliform (99.6%; Song et al. 2006).

On the other hand, in the middle bay, while fecal coliform concentrations were observed below the standard limit (<200 cfu 100 ml^{-1}) during the sampling period (1996–2000) at all the stations (stations 4, 5, and 6), after 2000, FC densities increased particularly at stations 4 and 6. Especially, at station 4, which is on wastewater exhaust line, FC concentrations were increased to $<10^0$–1.3×10^3 cfu 100 ml^{-1}. Similarly, FC density was observed of $<10^0$–5.3×10^2 cfu 100 ml^{-1} at station 6. No significant variation was found at station 5 in terms of FC concentrations (Fig. 4).

During the sampling period (1996–2005), fecal coliform densities were detected very low at stations 7 and 8 in the outer bay. In station 9, which is on influx of Gediz River, the highest FC concentration was observed as 3.9×10^2 cfu 100 ml^{-1} during 2001–2005 (Table 2).

According to ANOVA result, the water quality in Izmir Bay significantly changed in respect to FC density after installation of wastewater treatment plant ($F = 9.79$, $p < 0.05$). The results of two-way ANOVA showed a significant variation in the density of FC with related to the period after stepping in wastewater treatment systems ($F = 11.11$, $p < 0.05$ and $F = 4.57$, $p < 0.05$, for the region and stations of bay, respectively). On the other

Table 3 Correlation results between surface fecal coliform and physical parameters ($p < 0.05$)

Region	Number of sample	Temperature (°C)	Salinity (psu)	Density (kg m^{-3})
Inner	47	0.09	−0.11	−0.13
Middle	95	−0.30	−0.04	0.32
Outer	97	−0.30	−0.13	0.12

hand, the seasonal variations and FC density were not statistically significant in the all region ($p > 0.05$). In the Izmir Bay, according to ANOVA results, FC did not display any seasonal pattern before and after wastewater treatment plant.

The relations between surface FC and other environmental parameters were also evaluated. Studies reveal a negative relation with enteric bacterial survival and temperature (Anderson et al. 1983; Rhodes and Kator 1988; Yilmaz et al. 2004). Anderson et al. (1983) stated that survival duration of *E. coli* depend on the temperature in the absence of eukaryotes in coastal waters; therefore, a significant seasonality was observed in their study. However, surface temperature and fecal coliform displayed low negative relation both middle ($r = -0.30$, $p < 0.05$, $n = 95$) and outer bay ($r = -0.30$, $p < 0.05$, $n = 97$) in our study. In the inner bay, no relation was observed between FC and temperature (Table 3).

A negative correlation between FC and salinity detected by Anderson et al. (1979) proved that decreasing salinity increased the survival capability of *E. coli*. Troussellier et al. (1998) stated that hyperosmotic shock combined with nutrient limitation result in energy charge decrease and membrane transport inactivation of enteric bacteria. In addition, FC was proved to be the most sensitive bacteria to salinity; the survival rate increased approximately 1.5 times in 27 psu when compared to 35 psu (Gabutti et al. 2000; Yilmaz et al. 2004). Nevertheless, salinity and fecal coliform did not display any significant correlation in the surface water for all regions throughout the study period. In density, while displayed poor positive correlation in the middle bay ($r = 0.32$, $p < 0.05$, $n = 95$) with FC, no significant relations were observed in the inner and outer bay (Table 3).

Conclusion

Analysis of the database indicates that domestic constructed wetland systems can greatly improve water quality. In this study, fecal coliform concentrations have been determined during 1996–2005 cruises in the Izmir Bay. By the early 2001, the inner bay especially had become a polluted area with the increasing settlements and industrial facilities. In early 2000, the wastewater treatment plant began to treat domestic and industrial wastes. This plant at present treats approximately 80% of the total wastewater produced by the city. In the inner bay, significant differences were detected in the values of fecal coliform concentrations between the samples collected before and after the wastewater treatment plant. The fecal coliform levels decreased in 5 years. Nevertheless, there are still some problems to solve, such as direct inflow of streams and their runoff material including several uncontrolled domestic and industrial discharges. However, in the middle bay, there is a little increase seen at fecal coliform concentration after wastewater treatment plant established because of wastewater exhaust line. Microbial pollution in the outer bay generally is not significant for all periods. A continuous improvement can be sustained in the water quality if direct inflow of untreated wastewater is prevented.

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