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ORIGINAL ARTICLE

Changes of oceanographic characteristics and the state of pollution in the Izmit bay following the earthquake of 1999

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Abstract The Izmit Bay is an elongated semi-enclosed bay in the Marmara Sea. It is being increasingly polluted by both domestic and industrial waste discharge since 1970's. A monitoring program was conducted between 1999-2000 to document the state of pollution in the bay. This includes the effect of Marmara (Izmit) earthquake (magnitude 7.4) that occurred in August 1999. A stable two-layer ecosystem exists in the bay throughout the year due to continuous inflows of the saltier Mediterranean and brackish Black Sea waters to the Marmara basin. Therefore, the principal biochemical characteristics of the bay are governed by the two-layer flow system over the basin. Dissolved oxygen (DO) is generally at a saturated levels in the surface layer which is 10 to 15 m thick, but it is depleted to 60–70 μM in the lower layer, exhibiting a steep gradient in the sharp halocline. When the earthquake occurred, great loads of industrial wastes were released into the bay surface waters, which enhanced primary production in the upper layer and thus large export of particulate organic matter to lower layer and eventually to the bottom. Accordingly, DO was consumed and anoxic condition was established even in the upper layer/halocline interface, the halocline and bottom waters of the eastern and central bay. In this period, concurrent increases were observed in phosphate and ammonia contents at the halocline and in deep waters whilst the nitrate was almost consumed via denitrification processes in the anoxic water. Recently, the industrial C, N and P loads increased by as much as 8 fold within five years (1995–2000) whilst domestic inputs increased by 50%. Total organic matter discharged to the bay increased more than double within the last 15 years. Besides, most factories in the region release toxic wastes into the bay after only partial treatment.

Keywords Coastal contamination · Water quality · Oceanography

Introduction

Located at the eastern end of the Marmara Sea, Izmit Bay is approximately 45 km long and 1.8–9 km wide (Fig. 1). Its surface area of approximately 261 km^2 is comprised of three regions connected through relatively narrow passages. The eastern bay, the smallest component of the entire system, is about 15 km in length and relatively shallow having a maximum depth of about 35 m. The central bay, being the largest component of the system, is about 20-km long, and the bottom topography varies considerably in the north-southerly direction; its northern part is relatively shallow with an average depth of about 60 m, the depth increases to approximately 180 m in the southern

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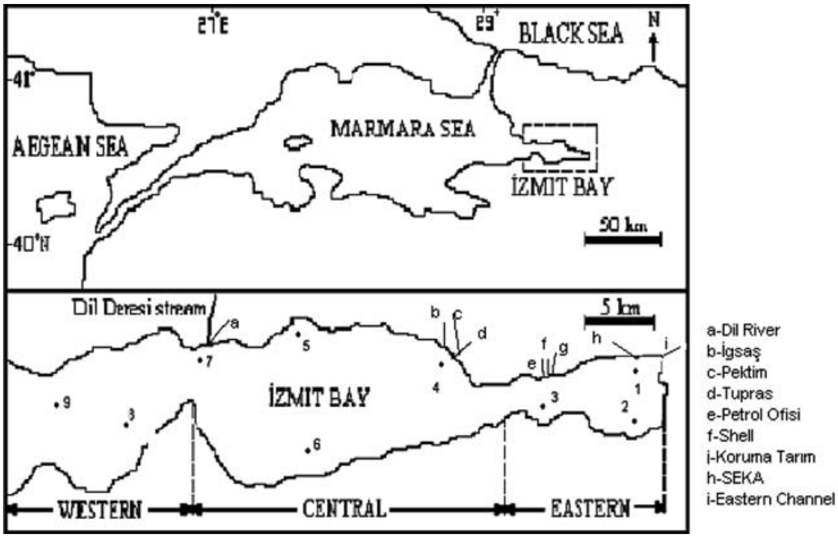


Fig. 1 Location of Izmit Bay and sampling points

section. A narrow, 2-km-wide opening with a 55-m-sill-depth at Dil Burnu, separates it from the deeper western bay. The bottom topography of the western bay slopes downward toward the Marmara Sea increasing to a depth of about 200 m near its mouth where its width is about 16 km (Fig. 1).

Principal oceanographic properties of the Bay are generally the same as those of the Sea of Marmara, basically being a two-layer ecosystem throughout the year. The Marmara Sea is directly connected to the Black Sea and to the Aegean basin of the Mediterranean via the Turkish Straits, the Bosphorus and the Dardanelles. Thus, the surface layer is composed of well oxygenated but nutrient-poor, brackish Black Sea water, below which salty Mediterranean waters extend down to the bottom over the entire basin, including Izmit Bay. The two-layer system of the Marmara Sea, including the coastal waters and bays (with >30 m total depth), is distinguished by a steep halocline located between 10 and 30 m below the surface. This unique ecosystem is partly modified in the shallow eastern part of Izmit Bay due to the large input of waste and the limited exchange of water with the outer bay (Timur et al. 1982). Since there exists a continuous input of particulate organic matter (POM) from the brackish surface waters, the salty lower layer water always suffers hypoxia which ranges between 0.2 and 2.0 mg/L. The lowest values may be found in the inner bay during the July–September period. In the same period, an oxygen minimum may also be established just below the halocline. Not unexpectedly, the lower layer waters of the bay are enriched in nutrients since photosynthetic production is consistently limited to the upper layer (Morkoç et al. 1997, 2001a, b). The nitrate generally varies from 3.0 to 10 μM below the halocline, whereas the phosphate values are between 0.5 and 1.5 μM (Tuğrul et al. 1989).

The large-scale industrialization and the accompanying increase in population around the bay during recent decades have caused serious water quality problems. Izmit Bay has been receiving large input of domestic and industrial wastewaters (Orhon et al. 1984; Tuğrul et al. 1986, 1989). Concentrations of land-based pollutants are significant and the residence-time of the water masses is relatively long, especially in the eastern part of the bay (Tuğrul and Morkoc 1990). Due to the strong thermohaline stratification of both the Bay and the Sea of Marmara throughout the year and the relatively low current in the Bay (Oğuz and Sur 1986), the Bay's ecosystem is highly sensitive to increased production of organic matter. During the last few decades, increased eutrophication appears to have affected the Bay's ecosystem negatively (Morkoç et al. 1997, 2001a, b). The main causes of eutrophication have been the increase of nutrient concentrations and the organic matter load from industrial and municipal effluents along the shoreline (Morkoç et al. 1996, 2001a, b). Increased eutrophication indicates that industrialization; urbanization and fertilizer runoff from agricultural activities raised the level of nutrients and organic matter production well beyond the natural assimilation capacity (Tuğrul et al. 1989). The most affected areas in the Bay ecosystem are the eastern part and the discharge area of the Dil River situated in the northwestern part of the Bay.

Extraordinary episodes may easily alter the Bay's ecosystem. The earthquake with a magnitude of 7.4 occurred on 17 August 1999 and destroyed the eastern Marmara Region. The small city, Gölcük (Fig. 1), was the epicenter of the earthquake, located on the southern coast of Izmit Bay. A refinery fire caused by the earthquake drastically increased the concentration of PAHs in the water and especially in sediments (Okay et al. 2001; Morkoç et al. 2001a, b); it also caused accumulation of sulfide and ammonia in the originally oxygen-depleted bottom waters of the bay (Belkıs 2003). Following the fire, the surface waters of the bay were partly covered by thick petroleum layers and by a film (Ünlü et al. 2000).

The purpose of this paper is to document changes in oceanographic and water quality characteristics of the bay by the earthquake.

Materials and methods

Data were obtained from nine different stations located in the Bay (Fig. 1), visited by a small boat on eight different occasions during the period from September 1999 to September 2000. Water samples were collected from both the upper- and lower-layers of the bay (down to 50 m depth) using Nansen Bottles. An YSI model probe was used to measure the temperature and salinity. Dissolved oxygen (DO) was measured by the Winkler titration technique (Greenberg et al. 1985). Biological oxygen demand (BOD) was determined by the Winkler technique (Greenberg et al. 1985).

Composite samples from industrial discharges were collected either by horizontal water samplers or by using polyethylene bottles. The flow rates in channels were calculated from their cross-sectional areas and velocity of the outflows.

Chlorophyll-a concentrations were determined spectrophotometrically after extraction of the filtered samples by acetone (APHA, AWWA, WPCP, 1985). Samples for the analysis of silicate were stored at 4°C, whereas the other nutrient samples (nitrate + nitrite, ortho-phosphate) were deep-frozen at –20°C and stored for no longer than 2 weeks. A Technicon Autoanalyzer II System was used to carry out nutrient analyses; the method followed is described in Strickland and Parsons (1972) and Grasshoff et al. (1983). The total phosphate (TP) and total nitrogen (TN) were determined by the Technicon autoanalyzer after persulfate digestion (Grasshoff et al. 1983). The organic carbon content of the samples was determined using a Shimadzu 500 Total organic carbon (TOC) analyzer. Total suspended solids (TSS) was analyzed gravimetrically, as described in APHA, AWWA, WPCP (1985). The seawater samples for Total PAH analysis were performed according to the Standard Methods (UNEP 1986). Samples of seawater collected from a 1 m depth in 2.5 L amber glass bottles were immediately extracted with hexane (50–100 ml) and the hexane fraction was separated for subsequent measurement of the total PAHs. The PAH are dissolved and particle bound in the water samples (UNEP 1986).

The short-term toxicity of water samples was assessed by the ^{14}C method (Damgard and Nyholm 1980). Diluted wastewater samples (1, 5, 10, 25, 50 and 75%) and undiluted wastewater sample were incubated with the addition of f/2 medium Guillard and Ryther (1962) and phytoplankton for 4 h under 3,500–4,000 lux illumination for acclimatization. Subsequently radio active $NaH^{14}CO_3$ was added and incubated for two more hours. The ^{14}C uptake was counted by a low level Liquid Scintillation Counter (Packard 1550). Results were compared against the controls. Micro algal cultures of *Phaodactylum tricornutum* were used as an assay organism in the toxicity tests.

Results and discussion

Industrial and domestic waste loads entering the Izmit Bay and the principal biochemical characteristics of water column in the bay were investigated between the years 1999 and 2000. These data have been evaluated to assess pollution levels of the bay waters and the effect of pollutants on water quality. In addition, the toxicity of the discharges into the bay was determined by ^{14}C technique and evaluated.

In order to obtain the regional averages of the measured parameters, the bay was divided into three sub-regions, depending upon its oceanographic characteristics and the degree of pollution at the sites monitored. The western region of the bay is the least-polluted site in the area, since it is under the direct influence of the Marmara Sea through a wide and deep channel. In addition, there is no industry with high polluting potential in that region. The central part is highly influenced by the heavy industries discharging their wastewaters through Dil River into the bay. Dil River has been drastically polluted during the recent years (Morkoç et al. 2001a, b). The eastern part is the most polluted, industrialized and shallowest site of the bay. One of the most-populated cities of Turkey, the Izmit city, is situated on the coast of that part.

Data obtained from these sections were examined separately, regarding their own oceanographic characteristics. Profiles in Table 1 show the vertical distributions of DO and those in Fig. 2 show the changes of nutrients, TOC, suspended solids and chlorophyll-a in the western (Station 8), central (Station 5) and eastern (Station 1) part of the bay, respectively. The 1999–2000

Table 1 Dissolved oxygen (mg/L) concentration at Stations 1, 5 and 8

Depth (m)	February 1999	May 1999	September 1999	December 1999	March 2000	June 2000
Station 1						
0.50	12.60	16.00	8.62	9.70	16.20	13.10
5.00	11.90	15.90	1.94	8.60	16.60	9.90
10.00	11.20	15.10	1.60	8.60	8.80	8.80
20.00	6.10	11.40	0			5.50
Station 5						
0.50	12.80	12.60	7.89	11.10	14.20	10.50
5.00	12.80	12.60	7.94	11.10	14.50	10.80
10.00	12.40	12.00	2.50	11.00	13.40	11.20
20.00	10.90	7.80	0.27	3.90	10.20	5.80
30.00	6.20	5.00	1.04	3.10	3.10	1.10
40.00	5.50	4.10	0.58	3.20	2.80	
50.00	5.40	4.10	0.48	2.40	2.00	
60.00	5.40	4.10		1.50	1.70	
Station 8						
0.50	13.00	11.60	7.86	11.40	13.80	10.40
5.00	12.40	11.60	5.84	11.40	14.20	10.70
10.00	12.60	12.10	3.72	10.60	12.00	10.90
20.00	11.40	8.50	0.87	10.90	5.30	8.30
30.00	5.50	4.90	1.03	3.00	2.90	1.70
40.00	4.90	4.50	2.20	4.50	2.40	1.90
50.00	4.60	4.00	1.83	4.20		1.70

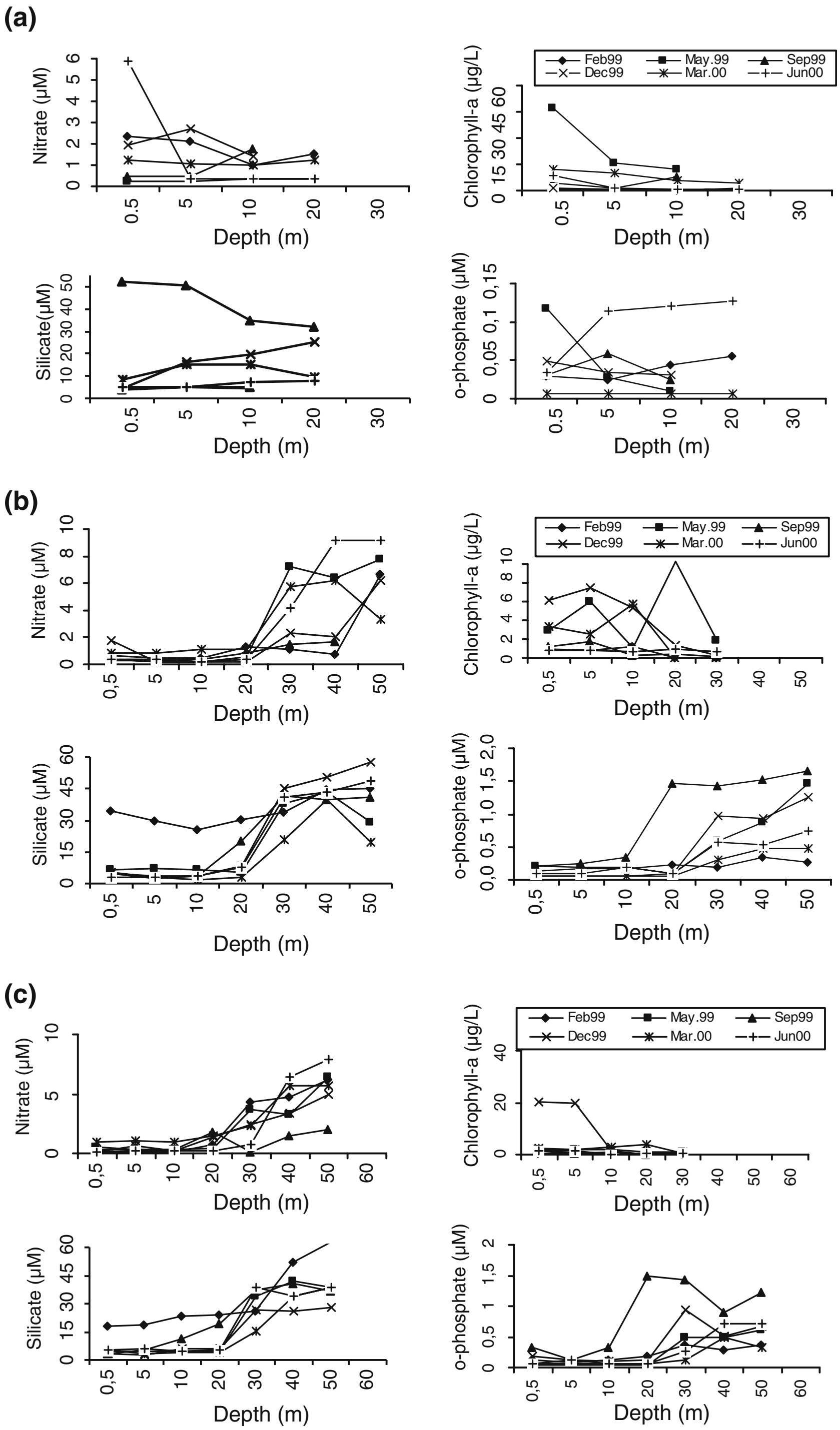
findings reveal that the Bay of Izmit, as being a part of Marmara Sea, has been influenced to a large extend by the water exchanges taking place between the Black Sea and Aegean basin of the Mediterranean (Tuğrul and Morkoc 1990).

Temperature and salinity profiles show that the summer season corresponds to relatively higher temperature (20–24°C) and lower salinity (22–24 ppt), indicating influence of the brackish waters of the Black Sea via the Bosphorus surface flow. During the winter period, the surface layer salinity increases as a consequence of upward movement of the high salinity deep waters via vertical mixing through the relatively thin interface. The bottom waters occupying the bay show little change in its hydrographic properties with a salinity of 38.0–38.5 ppt and temperature values of 14.5–15.0°C throughout the year. A permanent stratification occurs at about 25 m in the Marmara Sea (Beşiktepe et al. 1994). However, it is highly variable in Izmit Bay (Oğuz and Sur 1986), and may be found in the range of 10–25 m.

Dissolved oxygen concentrations show considerable local variations in the eastern part compared to the DO values obtained for the rest of the bay. The vertical DO changes in water column are shown in stations that are representative for the eastern, central and western parts (Table 1). The surface waters of the eastern bay are supersaturated in oxygen (107–194%) due to large nutrient loads of wastes as compared to the limited volume of the upper layer waters with the long residence time in the region (Tuğrul and Morkoc 1990). In the other parts of the bay, the surface waters are also saturated with oxygen (105–170%) but not as much as in the eastern part due to intensive photosynthetic production in the near surface waters. Dissolved oxygen concentrations in the lower layers of the bay decreased steadily from May (3.0 mg/L or 35%) to September (0.2 mg/L or 2.3%) (Table 1). This is most likely caused by the limited ventilation of bottom waters, i.e., restricted vertical circulation and continuous supply of POM from the surface layer.

In the western region, DO concentrations ranged from 7.4 to 13.8 mg/L in the upper layer and from 0.87 to 4.6 mg/L in the lower layer down to 50 m depth during the sampling period from February 1999 to September 2000 (Table 1). These values are consistent with the DO finding of the previous studies by Ünlüata and Özsoy (1986) and by Ünlüata et al. (1990) in the Marmara Sea. The depth profile of DO in Izmit Bay displays a sharp decrease in the halocline at about 20 m below the surface in the western and central parts of the bay, following the water stratification during the late summer and autumn. In February the gradual decrease of DO occurs at a depth of about 30 m in the eastern part due to the weakened stratification compared to the central and western parts. Tuğrul et al. (1989) reported that high DO concentration obtained in the surface waters of the bay is due to the high-productivity. In September 1999, no DO could be detected (<0.2 mg/L) at 10 m depth of Station 2, which is the nearest point studied to the epicenter of 1999 earthquake. Similarly, DO concentration was found to be below 0.2 µg/L (detection limit) at 20 m of the stations 1, 3 and 4 in September 1999 (Fig. 3) after the earthquake as reported previously by Belkıs (2003). The formation of hypoxia and anoxic condition in the bay waters below the surface layer was principally the result of large discharges of organics from land (mainly oil from refinery) and the re-suspension of organic matter accumulated on the sea bottom by the extensive tremble due to the earthquake, determined by the measurement of DO concentration in the lower layers. The distribution of TSS and phosphate concentrations were significantly high, but the nitrate concentration was found to be drastically lower at depth of 20 m of Station 2 (Fig. 4) than previous values measured before the earthquake. This was due to denitrification in the oxygen-depleted waters. The observation of hydrogen sulfide and greater phosphate, ammonia values in the water column indicate that sulphate reduction also took place in water and sediment layer

Fig. 2 **a** Distribution of some parameters at Station 1. **b** Distribution of some parameters at Station 5. **c** Distribution of some parameters at Station 8



as experienced in the Black Sea for thousands of years (Sorokin 1983). Dissolved oxygen concentrations were always found to be higher than the detection limit at the other stations located in the central and western parts of the bay. Dissolved oxygen concentrations in the surface waters of the bay were comparable and lower than that of the rest of the measurements in September 1999. This was most likely due to the discharges of untreated wastewaters into the surface waters of the bay after the earthquake.

The distribution and transport of TSS were evaluated in order to compare with the water-quality criterion. Currently, most of the waters in Izmit bay do not have a TSS concentration in excess of the legal maximum of 30 mg/L. TSS shows remarkable variations with time and area depending on algal productivity

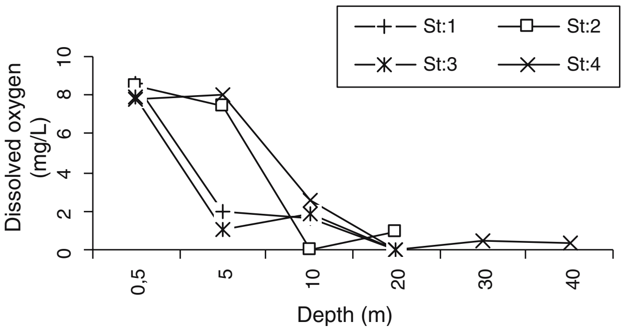


Fig. 3 Vertical variation of dissolved oxygen in September 1999

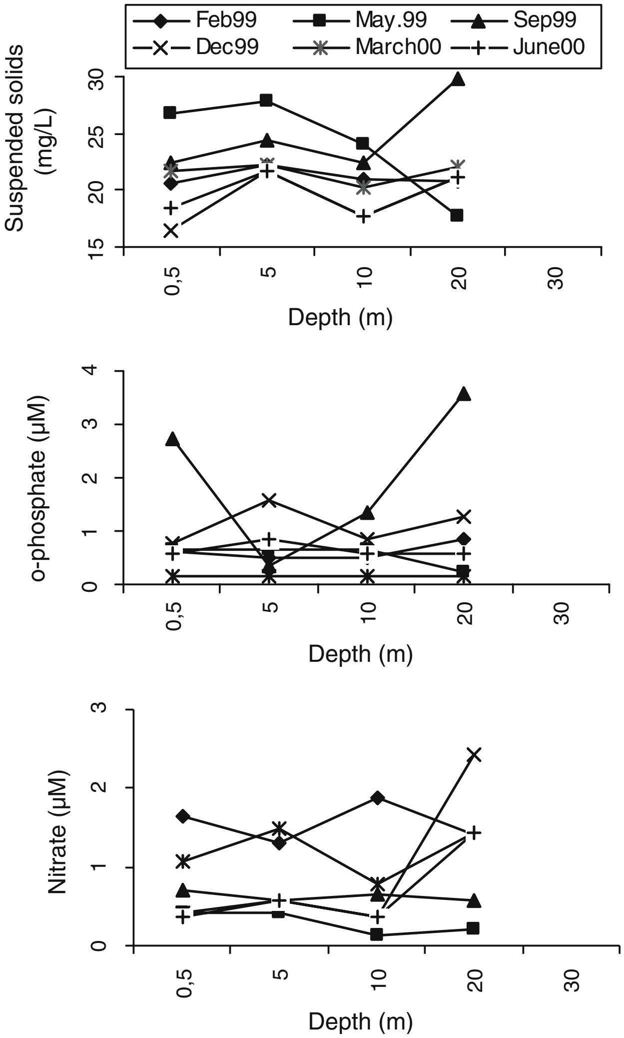


Fig. 4 Distribution of TSS, nitrate and ortho-phosphate and at Station 2

(internal source) in the bay, inputs from land-based sources and the atmosphere. It was measured about over 30 mg/L at Station 1 in the eastern part of the bay. It ranges between 20 and 30 mg/L in the central part with the higher values in the near-shore waters. In the western part of the bay, the TSS concentration was in the range of 20–25 mg/L, which is comparatively lower than the values obtained for the inner bay. There has been a remarkable decrease in the levels of suspended solids compared to the results presented by Legović et al. (1997) who determined relatively higher TSS values (higher than the unpolluted sea water criteria of 30 mg/L). In this study, TSS data exceeded the upper limit in the eastern and the eastern part of the central bay. TSS shows a significantly higher value (30 mg/L) at 20 m of the Station 2, which correlates with the deficiency of DO concentration in September 1999 after the earthquake (Fig. 3).

Previous studies conducted on modeling and simulation show that the majority of the TSS does not originate from the land-based sources but probably represents the phytoplankton. The reason for the reduction of TSS is the removal of excessive quantities of N and P discharged into the eastern and central part of bay (Legović et al. 1997).

Nutrient concentrations in the productive surface waters of the bay were always low during spring and summer periods as previously emphasized (Morkoç et al. 1997, 2001a, b). Nutrient results obtained in the spring–autumn period ranged between 0.21 and 1.07 µM for nitrate, 0.07 and 0.39 µM for phosphate and 0.7 and 10 µM for silicate. This study and previous findings (Tuğrul et al. 1989; Morkoç et al. 1997, 2001a, b) have clearly shown that surface nitrate and phosphorus concentrations increase almost fivefold from summer to winter due to the inputs from both the lower layers, and the industrial and domestic wastes as well as the weakening production due to the limited light intensity. Not unexpectedly, nitrate, phosphate and silicate contents of the surface waters all increase from the western to eastern parts (Fig. 2). The gradients follow the ratio between the lower and upper concentrations so that the highest gradients were found in the silicate and the lowest was in ortho-phosphate concentration as previously described by Morkoç et al. (1997).

Low silicate concentrations in the surface layers (<1.8 µM) from April to July indicate that diatoms dominate in the bay. This result was also confirmed by the recent observations in the Marmara Sea and Izmit Bay (Okuş and Yüksek 1996; Morkoç et al. 1997; Aktan et al. 2005).

Figure 2 shows that the nutrient concentrations are depleted in the productive upper layer, displaying an apparent increasing trend in the halocline and reaching the highest values in the lower layer waters of the bay. This feature is very consistent with the DO profiles displaying an opposite trend from the surface to the bottom. The bottom waters contain 0.3–1.7 μM of phosphate, 1.93–7.86 μM of nitrate and 23–61 μM of silicate. N/P ratios derived from nitrate and phosphate are as low as between 3 and 7 in the bottom water, indicating a net loss of nitrate via denitrification in the oxygen-depleted water column and in the sediment. Nutrient concentrations were expected to show coherent increases in the eastern part and eastern-central part due to the environmental effect of the earthquake. Nitrate was as high as 1.07 μM in the surface waters of Station 1 due presumably to the direct inputs of nutrients from wastewater treatment plants that were broken down. But phosphate concentrations at Station 2 show a significant increase: 1.25 μM in the surface, 0.6 μM at 10 m and 1.56 μM at 20 m, correlating with the high TSS and undetectable DO concentrations at Station 2 at the eastern section of the bay (Fig. 3).

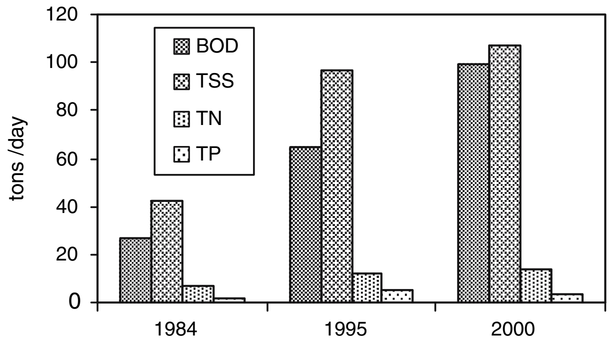
Although most factories discharging wastes into the Izmit bay have wastewater treatment plants, the concentration of TOC, ortho-phosphate and silicate are relatively high in the eastern bay except during the productive seasons. Low N/P ratios in the surface waters are usually taken as an indicator of the nitrogen-limited algal production, candidates for which would be the eastern and central parts of the bay. However, it should be cautioned that N/P Redfield ratio in phytoplankton might not correspond to the same ratio in water (Legović and Cruzado 1997). In fact, in some periods and locations, the results of bioassay studies indicated that ortho-phosphate was the most potential limiting nutrient for algal growth in the bay, particularly in late autumn (Morkoç et al. 1989). Microscopic observations have shown that diatoms using silicate to construct their cell wall have been the dominant group of species of phytoplankton throughout the bay (Morkoç et al. 2001a, b; Aktan et al. 2005)

In the upper layer waters of the bay, TOC appear to increase from the western to the eastern part of the bay, displaying seasonal fluctuations in the range of 2.5–6.0 mg/L. The highest values were obtained, as expected, during high productive seasons in the eastern part. The concentrations of TOC in the lower layer water were considerably smaller because of organic matter decay by bacteria. This causes reduction of DO concentration below the halocline to a critical value from the end of summer to the middle of autumn until the bottom waters are renewed by lateral inflow from the Marmara deep basin.

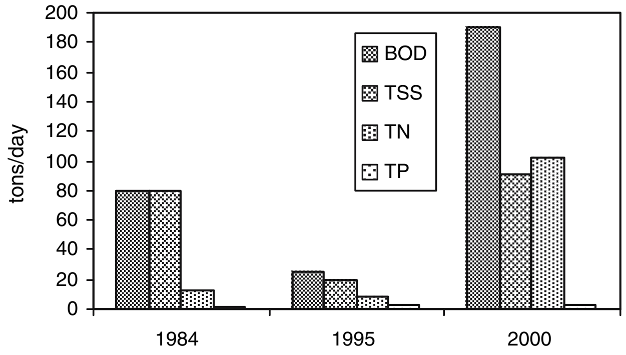
Horizontal distribution of chlorophyll-a demonstrates that phytoplankton biomass increases towards the eastern part of the bay. For example, in May, the chlorophyll-a concentrations range between 23–47, 4.5–32 and 2–3.5 μg/L in the eastern, central and western parts of the bay, respectively. Because of the high productivity during this month, nutrient concentrations declined markedly in the surface waters of the bay.

As the map (Fig. 1) indicates, nine important discharges enter the Bay. Five of these consist virtually entirely of waste from fertilizer, petrochemical, pesticide, chloralkali and pulp/paper industries. Four discharges, the East Channel, the Dil River which is the main source of pollution in the central bay, Petkim and Seka channels, carry mixed domestic and industrial wastes. The results of micro algal (*Phaeodactylum tricornutum*) ^{14}C short-term toxicity tests of discharges show that 5% of the diluted discharges were clearly found to be toxic. Similar results were also found in the previous studies (Okay et al. 1996; Egesel (Tolun) et al. 1996).

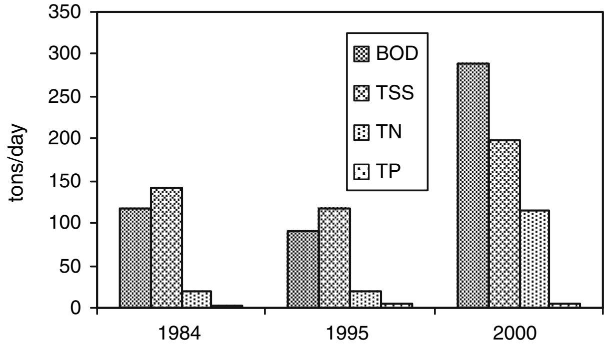
Figure 5 demonstrates results of calculations performed to determine the waste loads originating from nine discharges. To compare the results obtained from this study with the results of previous studies, waste loads representing the years of 1984 and 1995 (Orhon et al. 1984; Morkoç et al. 2001a, b) are also provided in the same graph. The calculations were performed for industrial and domestic waste loads separately according to the procedure described by Orhon et al. (1984). The domestic loads were estimated from the population values. According to Fig. 5, the total waste load has been doubled in 5 years (from 1995 to 2000). The domestic wastes increased in accordance with the mild increase in population. Domestic wastewaters have never been treated prior to 1984 at which time the monitoring studies in Izmit Bay commenced. It was also found that the domestic waste loads contributed more than the industrial waste loads in 1995 (Morkoç et al. 1995). Thus, the significant impact of the domestic wastes on the Izmit Bay ecosystem will most likely continue unabated until the effective treatment plants are established-hopefully- in the near future. In the 10-year period (from 1984 to 1995), the factories, realizing their environmental impact, have been installing waste treatment plants and replacing wasteful operations with new technologies. As a result of those initiations, there has been a significant reduction in the industrial waste loads from 1984 to 1995 despite an increase in industrial activity. Figure 5 shows an alarming increase in the amount of industrial wastes from 1995 to 2000. There was a gradual increase following the major earthquake, which destroyed many of the industrial treatment plants and caused a substantial fire at an oil refinery resulting in a weeklong spillage of oil into the Bay waters. Two months after the earthquake, the waste treatment plants were repaired and



A- Domestic waste loads



B-Industrial waste loads



C- Domestic + industrial waste loads

Fig. 5 Waste loads from land based sources to the surface waters

the ravages of the fire had been ameliorated. Observations suggest that the major reason for the increasing industrial waste is the spread of industries throughout the western and to a lesser extent in the central region of the Bay. For example the discharge of wastes by Dil River has significantly increased (Table 2) due to the increase in the number of nearby factories and the establishment of a large local garbage dump. It is clearly seen that the industries must significantly improve waste management including preventive measures to curb the alarming increase in the industrial load on the bay.

Table 3 expands the seasonal changes of total PAH concentrations sampled from the surface waters at nine stations throughout the bay during the 1999–2000 period.

Table 2 Flow rates and waste loads of Dil River for the years 1995 and 2000

	1995	2000
Flow rates (m^3/day)	60.000	137.000
Total organic carbon (kg/day)	3.200	32.170
Total suspended solids (kg/day)	3.580	27.300
Total nitrogen (kg/day)	2.450	31.000
Total phosphate (kg/day)	70	320

The enormous PAH concentrations observed at all locations in September 1999 underscore the effect of earthquake when industrial treatment plants became damaged, the oil refinery caught fire and large amounts of oil were discharged directly into the Bay. Concentrations of PAHs in the eastern bay increased to abnormally high values of 9.30 μg/L, covering the whole surface layer of the eastern bay and preventing the ventilation of sub-surface waters. One month later, however, the Bay had recovered markedly and PAH concentrations approached acceptable levels of 1.5–2.5 μg/L, non-hazardous values according to the data in the literature (Cossa and Martin 1991). The second feature noticeable in Table 3 is that there is a marked seasonal variation in the surface PAH concentration observed across the Bay. For example, in June 2000, most of the observed results are less than 1 μg/L and are comparable to concentrations observed in unpolluted Antarctic waters (Marti et al. 2001). In September 2000, on the other hand, the observed surface PAH concentrations are markedly high (4.65 μg/L) at Stations 6 (seaward of the Dil River where a significant increase in pollution has already been noted), reaching to the values measured after the 1999 earthquake. The reason for the high PAH concentrations in September 2000 is not clear to us; it may be that the values are a consequence of the inefficient start up of factories and/or domestic waste inflow following closure for the holidays during August. Finally it has to be remarked that the occasionally high values in the PAH concentrations were observed in 2001 and 2002 and the concentrations observed in Septembers emphasize the need for improved and continual control of the pollution discharges. At all stations in Izmit Bay, the PAH concentrations were low (0.006–0.3 μg/l) except TUPRAS channel discharge point, with PAH concentrations ranging between 0.55 and 3.12 μg/L. This shows that effect of earthquake will no longer been seen after 2 years (Tolun et al. 2002). The PAH concentrations observed near coastal stations (near discharge points) showed a wide variation (1.8–18.5 μg/L), whereas the

Table 3 Total PAH concentrations (μg/L) measured in the surface waters

Station number	February 1999	May 1999	June 1999	September 1999	December 1999	March 2000	June 2000	September 2000
1	1.03	1.88	1.17	9.30	1.42	0.64	0.76	3.10
2	3.61	1.63	0.71	8.31	2.01	1.31	0.60	2.26
3	1.76	1.65	0.33	9.30	1.97	1.28	0.42	3.91
4	0.82	1.58	0.03	11.1	2.35	0.59	1.02	2.33
5	0.47	1.92		3.54	1.21	0.38	0.18	2.22
6	1.04	1.49		3.50	1.94	0.41	0.12	4.65
7	0.36	1.83		4.75	2.04	0.88	0.12	0.65
8	0.33	1.36		3.63	1.64	0.42	0.44	0.06
9	2.39	2.24		5.65	1.30	0.38	0.18	0.26

PAH concentrations in mussels were ranging from 1.0 to 21.6 μg/g wet weight (Karakoç et al. 2002). The concentrations of PAH observed in coastal sediments (5.4–146.2 μg/g dry weight) revealed that all sediments were highly polluted, even though the overlying water was comparatively clean (Karakoç et al. 2002).

Conclusion

Starting in 1970, the existing trend of the increase of industrial development and a growth of human population resulted in a dramatic increase of pollution discharge to the Izmit Bay. Treatment plants for both industrial and domestic wastewaters have been established in the region since late 1980s, and significant improvements in water quality of the bay have been observed. Unfortunately, the earthquake on 17 August 1999 caused a vast deterioration of the principal biochemical characteristics of the Izmit Bay due to great input of organics and nutrients to the surface waters. Rapid response of the ecosystem include the depletion of DO and formation of anoxic condition in the halocline and deep waters of the inner bay, increases in phosphate and ammonia but depletion in nitrate in the anoxic waters of the bay and suspended-solid increases in the lower waters of eastern part of the bay. After the earthquake most of the industrial treatment plants had been damaged and the refinery fire caused an increase in the levels of pollutants discharge by Petkim Channel. The results of the long-term monitoring studies have shown that the waste inputs via the Dil River and other sources to the bay drastically affect the inner bay ecosystem. Consequences of the 1999 earthquake in the bay have shown a temporary occurrence of the two-layer ecosystem with very low oxygen content in the lower layer. Such a system has a limited self-purification capacity for organic and nutrient inputs.

In order to minimize toxicity and eutrophication problems, waste loads entering the bay should be reduced further at sources by applying adequate wastewater treatment. However, the degree of waste treatment and the total waste loads that may be assimilated by the bay ecosystem could be estimated by first adopting an adequate water quality criteria, applying an eutrophication model and by conducting a systematic monitoring programme in the bay.

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