Asian Journal of Chemistry Vol. 21, No. 4 (2009), 3166-3174

Environmental Stress Created by Chemical Pollution in the Marmara Sea (Turkey)

SELMIN BURAK*, SELMA UNLU† and CEM GAZIOGLU‡
Department of Marine Environment, Institute of Marine Science and Management
Istanbul University, 34116 Istanbul, Turkey
E-mail: sburak@gmail.com

The ecological consequences of chemical pollution experienced as evidence of significant environmental stress in the Marmara sea which is a semi-enclosed internal basin with a stratified structure. The stratification is due to the Mediterranean sea originated lower layer current and Black sea originated upper layer current that hinders the water circulation. Rapid urbanization on the coastal zone of the Marmara sea has attracted population since the 1970's. This has been one of the main reasons for the pollution that has affected primarily the estuaries and bays of the Marmara sea and has ultimately spread along the shoreline and continental shelf that constitutes 50 % of its total area. The Marmara sea coastal zone is at risk of severe industrial and domestic pollution where hot-spots comprise Izmit, Gemlik, Bandirma bays and Greater Istanbul Metropolitan area. Chemical pollution accumulated in the bays, in particular, has created significant ecological damage resulting in the decrease or extinction of marine species. In this paper, the oceanographic features of the receiving media, the sources of industrial and domestic pollution based on field data and monitoring are presented. Previous studies and the present one carried out so far reveal that a good understanding of the oceanographic and ecological processes is essential for the Marmara sea as a whole. In the light of the findings, the means and tools for an integrated wastewater management plan in the Marmara region are discussed.

Key Words: Marmara sea, Hot-spots, Chemical pollution, Integrated wastewater management.

INTRODUCTION

Marmara sea is under severe environmental stress due to land-based pollution and ship originated oil pollution since the 1970's onward. The present paper remains within the scope of land-based pollution, the latter being the topic of a separate study[1].

†Department of Physical Oceanography and Marine Biology, Institute of Marine Science and Management, Istanbul University, 34116 Istanbul, Turkey.

‡Berkarda Remote Sensing and GIS Laboratory, Institute of Marine Science and Management, Istanbul University, 34116 Istanbul, Turkey.

One of the major outcomes of overall population growth, rapid urbanization and industrialization has been the increase of water use for residential, industrial and agricultural areas during the last decades in the Marmara Sea Basin. As a result, uncontrolled pollution generated by large water consumption has caused the degradation of inland as well as coastal waters. Domestic pollution load generated mainly by the Istanbul Metropolis and its surroundings where 1/5 of Turkey's population live and large industrial facilities amounting to 60 % of the total, located on the bays and coastal areas constitute the most significant portion of local land-based input. Visible sewage pollution is frequent where the polluting sources are directly discharged without adequate treatment facilities. As a consequence the most affected marine environment has been the Marmara sea whose oceanographic features do not much help its self-purification capacity.

Marmara sea is also under the pressure of pollution loads from run-offs and rivers discharging into the Black sea that subsequently flow into the Marmara sea *via* the upper layer current through the Istanbul Strait. The rather complex hydrodynamic structure of the Turkish Straits System (TSS) dependent on meteorological conditions affects the water quality of the Marmara sea.

Oceanographic features of Marmara sea: Marmara sea is an inland, semi-enclosed water body of 11111 km^2 with an average depth of 260 m connecting Mediterranean sea and Black sea *via* Çanakkale and Istanbul Straits[2]. This rather complex hydrodynamic structure composed of Marmara sea and two straits namely Istanbul (Bosphorus) and Çanakkale (Dardanelles) straits, is called the Turkish Straits System (Fig. 1). Çanakkale Strait is a 70 km long and 1370 m wide channel at the narrowest point whereas the Istanbul Strait is 31 km long and 698 m wide[3].

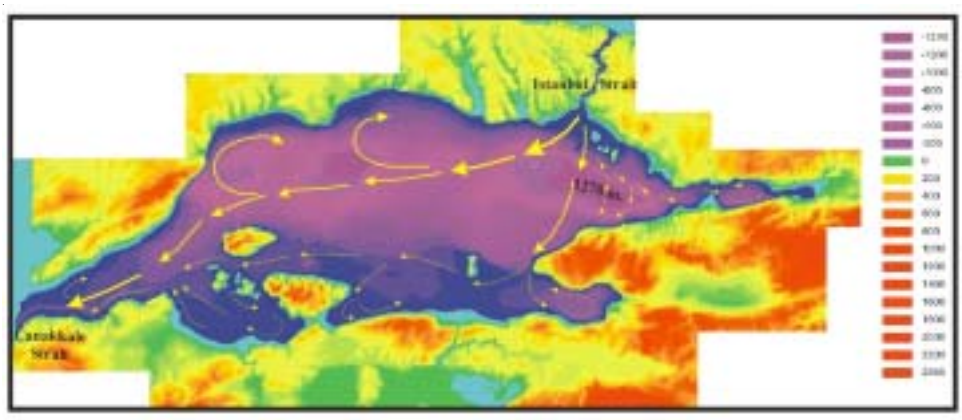

Fig. 1. Bathymetry of Marmara sea and major currents

The most important feature of this system is the formation of a two-layer current due to salinity gradient between the more saline (38 psu) and dense waters of Mediterranean sea flowing towards Black sea *via* the lower layer and the less saline (18 psu)

Black sea waters *via* the upper layer in the opposite direction. A strong and permanent stratification occurs as the result of mainly salinity, density and temperature gradient. An intermediate layer is also formed between these two layers at *ca.* 10 to 15 m depth at the southern sill and 40 to 45 m deep at the northern sill of Istanbul Strait. The characteristics of Marmara sea are closely related to Black sea due to the direct communication between these two water bodies through Istanbul Strait[4]. In various studies, it is stipulated that Black sea determines the quality and ecology of the upper layer of Marmara sea whose volume and surface area are fairly small compared to Black sea with an average depth of 1300 m and 460 000 km^2 surface area[5,6].

The first 10 to 15 m width upper layer of Marmara sea is well oxygenated with dissolved oxygen values reaching nearly saturation levels. The lower layer of Marmara sea below 30 to 40 m depth is chronically deficient representing on the average 25 % of the dissolved oxygen saturation value. The average oxygen concentration at the lower layer[7] in the sea of Marmara is 2 mg/L.

Land-based pollution in Marmara sea basin and its ecological consequences: Pollution is generally most severe in semi-enclosed marginal seas and coastal waters bordering highly polluted and industrialized zones[8]. This statement is justified by the case of Marmara sea, where large industries and cities are located on the coast of the elongated semi-enclosed Izmit Bay, Gemlik and Bandirma bays which receive untreated or partially treated domestic and industrial wastewater (Fig. 2).

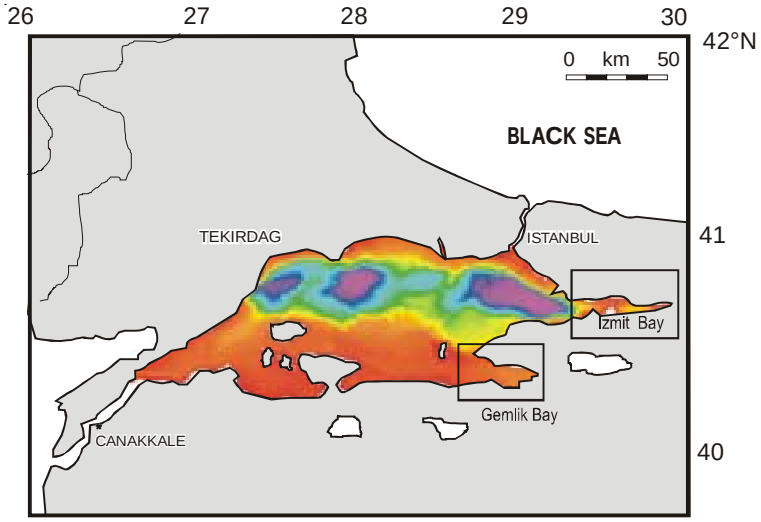

Fig. 2. Study areas (Izmit and Gemlik Bays)

Izmit Bay: Marmara sea coastal zone is at risk of severe industrial and domestic pollution where hot-spots comprise Izmit, Gemlik, Bandirma bays and Greater Istanbul metropolitan area (Fig. 2). Izmit Bay receives waste load from Turkey's most important industrial area as well as the domestic waste of the city of Izmit and

its seaports, oil terminals, urban centers and industries located along the shoreline. The intensive anthropogenic activities cause the pollution of the bay due to the intrusion of contaminants into the receiving media *i.e.* diffuse and point source inputs from coasts, rivers, atmosphere, oil refineries and shipping activities. Another common anthropogenic source of polycyclic aromatic hydrocarbons (PAHs) is generated by spillage of fossil fuels including unrefined (crude oil) and refined products[9]. PAHs, a group of nonionic hydrophobic organic contaminants, are ubiquitously present in coastal areas and arise from numerous anthropogenic activities such as fossil fuel burning, release of uncombusted petroleum products and creosote wood treatment[10].

Ünlü and Alpar[9] reported that significant levels of hydrocarbons exist in the sediments of Izmit Bay and the need for improvements in loading and transport conditions, reduction of ballast and bilge waste discharges and minimization of fuel spills is indispensable. Accidental fuel spill into the sea during loading-unloading operations might be the cause of petrogenic contamination. High PAH concentrations in the adjacent areas originate mainly from municipal effluents, discharges from the local refinery, spillage from vessels, port operations and also from loading and transport activities as well (Fig. 3).

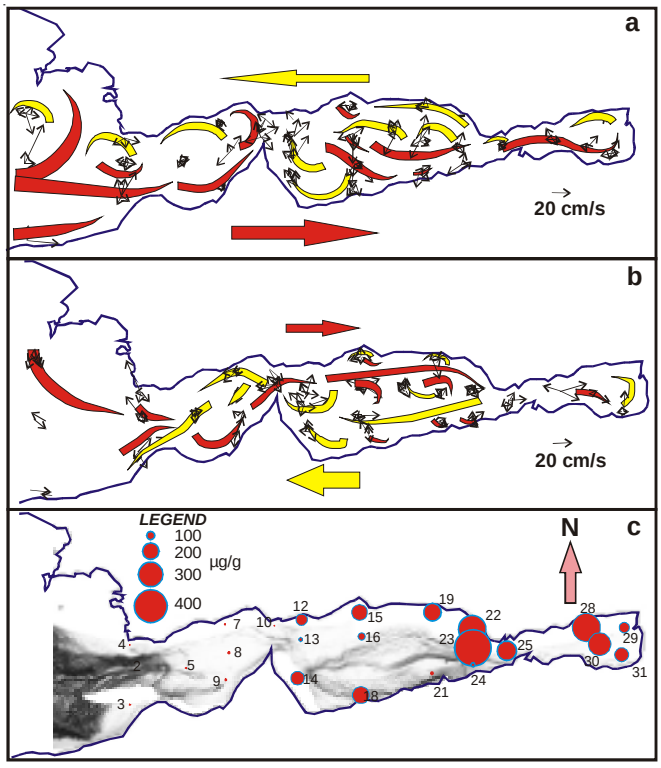

Fig. 3. Surface (a) and bottom currents (b) are effective on the sediment transportation and sediment pollution (c) in the Izmit bay [Ref. 9]

The presence of anoxic conditions in the sediment will cause the decay of aerobic bacteria and benthic organisms. Even the marine environment is rehabilitated and upgraded to its initial oxic state, anoxic conditions will still be prevailing in the sediment.

Gemlik bay: Another critical area in Marmara sea is Gemlik bay. The main anthropogenic sources of pollutants are likely to have their origin in shipping, sewage treatment discharges, urban run-off and industrial activities (Table-1) in Gemlik bay.

TABLE-1
INDUSTRIAL INPUTS IN GEMLIK BAY [Ref. 11]

Industrial formations	Wastewater discharges		Oil grease
	(m^3/day)	(m^3/year)	(ton/year)
Food	3000	1095000	22
	5000	1825000	37
Metal	350	127750	5
	1500	547500	22
Non-metal	200	73000	0.5
	400	146000	1
Textile	20000	7300000	–
	30000	10950000	–
Oil	50	18250	0.37
Chemistry	14000	5110000	1
	16000	5840000	2
Total	37600	13724000	28.87
	52950	19326750	60.37

Intensive industrialization has a severe adverse impact on the coastal area of Gemlik which results in heavy environmental and marine pollution[12]. Additionally, domestic land-based load input plays a significant role in the pollution of the bay (Table-1). Discharge of untreated sewage due to inappropriate and inadequate sewerage infrastructure constitutes the basic pollution problem in the receiving waters. Faecal contamination threatens public health in the recreational areas as a consequence of inadequate sea outfall structure (insufficient length and depth). Alkan *et al.*[13] reported that total coliform concentration varies between 2900-11350 CFU/100 mL and feacal coliform between 2000-9300 CFU/100 mL on the Northern coast of the bay. These test results that remained within the same range until present prove that untreated sewage discharge is the reason for heavy antropogenic pollution in the region. The test results of sediment analyses reveal that large amount of bacteria settle down with particles to the sea bed and accumulate in the medium[13]. Bacteria intruded in the sediment that remain active are liable to be released into the water column as a consequence of hydrodynamic processes and increase pollution level.

The distribution of industrial premises at Gemlik bay, one of the hot-spots in Marmara sea is given in Fig. 2. The measurement carried out at the discharge location of wastewater in the bay shows a significant input from industries with a flow rate varying between 13 to 20 million m^3/year (Table-2).

TABLE-2
ANNUAL INPUTS FROM MUNICIPAL WASTEWATER AND FROM KARSAK CREEK [Ref. 12]

Towns	2005 Population	Q m^3/year m^3/year	BOI5 (ton/year)	TSM (ton/year)	KOI (ton/year)	Total N (ton/year)	Total P (ton/year)
Gemlike	80876	4,660,000	1260	759	–	233	70
Mudanya	24170	1,393,000	377	227	–	70	21
Armutlu	4598	265,000	72	43	–	13	4
Kursunlu	3857	223,000	61	37	–	11	4
B. Kumla	941	55,000	15	9	–	3	1
K. Kumla	6719	388,000	108	65	–	20	6
Zeytinbagi	3024	175,000	48	29	–	9	3
Kumyaka	1239	72,000	20	12	–	4	2
Narli	578	34,000	9	5	–	2	1
Fistikli	1886	109,000	30	18	–	6	2
Kapakli	1150	67,000	18	11	–	4	1
Total	129038	7441000	2018	1215	–	375	115
Other sources							
Karsak creek		58,562,000	407	7724	2256	114	33

In addition to pollution introduced by point sources, Karsak Creek generating from Iznik lake and flowing into Gemlik bay has a major contribution to pollution load since it collects sewage of the settlements located along the river. Pollution load measured in Karsak Creek and seasonal flow fluctuations are given in Table-2. Total nitrogen and phosphorus load generated by land-based pollution within Marmara sea basin is computed as 0.44×10^5 tons/year and 0.77×10^4 tons/year, respectively[14]. The input of land-based pollution into Istanbul strait and Marmara sea shoreline is computed as 0.20×10^5 tons/year of total nitrogen and 0.33×10^4 tons/year of total phosphorus[15].

The pollution load assessment in Istanbul Master Plan study for 2040 gives a daily estimate of more than 112 tons of nitrogen and 28 tons of phosphorus load input from Istanbul discharges[16]. In 1993, the domestic organic load generated by the settlements in terms of BOD_5 for the entire Marmara basin was computed as *ca.* 565 tons/d, out of which 395 tons/d correspond to Istanbul Metropolis load. At present, this load is estimated to be more than 800 tons/d for Marmara basin in terms of BOD_5.

Additionally, the primary production in the upper layer of Marmara sea computed as 0.02-1.00 gC/m^2-day is influenced by Black sea waters for which this figure is 0.05-2.00 gC/m^2-day entering Marmara sea[5].

According to the field study carried out within a 10 year period in Marmara sea, the land-based and ship-originated solid waste distribution is given as 67.1 kg/km^2 between 20 and 100 m depth[17]. Marmara sea which shelters 11 % of the national aquatic products is rich in demersal and migratory fish species and is classified as the second productive sea after Black sea. Migration takes place in the first 40 m of

Marmara sea due to the shortage of oxygen in the lower layer. Thus, land-based pollution diffusion into the coastal waters has a direct adverse impact on pelagic as well as demersal fish species degrading their natural environment of feeding and spawning area.

Marmara sea is facing dense domestic and industrial pollution that creates acute problems exacerbated by unsuitable meteorological conditions and seasonal variations. In Izmit and Gemlik bays, H_2S release occurred in summer due to excessive phytoplanktonic production controlled by eutrophication. Degraded organic matter sinking to the lower layer as detritus depletes totally the dissolved oxygen with weak concentration, giving rise to H_2S release. This phenomenon has been monitored in several studies[17]. These adverse conditions cause the death of fish in huge numbers when the lower layer current rises suddenly to the upper layer under the pressure of strong winds. Serious ecological hazard was monitored in Izmit bay as a result of the death of benthic organisms and some demersal fish species[18,19].

Phytoplankton bloom especially red tide caused by *Noctiluca scintillans* has been monitored very frequently especially in almost all the bays of Marmara sea (*e.g.* Izmit, Gemlik, Bandirma, Erdek, Eregli, Küçükçekmece, Büyükçekmece, Tekirdag) where occurrence of toxic algal bloom is witnessed more than once a year as a result of eutrophication[18,20].

RESULTS AND DISCUSSION

The ecological consequences of land-based pollution experienced so far prove evidence of significant environmental stress in Marmara sea.

The interaction between Black sea, Mediterranean sea and Marmara sea governs the oceanographic processes of this latter throughout seasonal variations and depends on meteorological conditions. Therefore a good knowledge of these processes is utmost importance for an effective and comprehensive environmental management of Marmara sea basin.

The daily input of nitrogen and phosphorus load from Black sea to Marmara sea *via* the upper layer current is 500 tons and 30 tons, respectively, which creates a significant burden on the marine environment. Although the detention time of Black sea waters in Marmara sea is computed to be 3-4 months, the pollution conveyed from Black sea to Marmara sea and trapped along the shoreline has longer adverse impact on the water quality. The above mentioned field studies have revealed that severe ecological hazard occurs in areas where water circulation is weak. This statement is supported with the water quality monitoring study results[21].

Furthermore ship-originated oil pollution worsens the already polluted shoreline *i.e.* beaches and recreational areas increasing the stress on the natural equilibrium of the receiving waters. The combined effect of chronic and acute pollution generated by land-based pollution and ship-originated oil spill caused the decrease and/or extinction of surface and subsurface fish species and crustaceans.

In the light of the findings, it is obvious that wastewater pollution control including nutrients must be given prime importance in the sensitive waters of Marmara sea, in particular, to avoid further ecological damages. This issue necessitates an in-depth analysis comprising the replenishment period of the sensitive bays before setting-up the means and tools for remedial actions.

Existing studies exhibit that the rehabilitation of Marmara sea necessitates an integrated wastewater management policy coupled with appropriate design criteria based on mandatory water quality requirements of the receiving waters (*i.e.* bathing water, recreational purposes and seafood production in accordance with National and EC directives).

The existing scattered polluting sources should be intercepted and undergo chemical, biological and advanced treatment where required and justified by receiving media monitoring and modeling studies. In the light of various monitoring and experimental studies carried out since the 1980's, it can be stated that improvement is far from being satisfactory for Marmara sea despite the commissioning of major sewerage projects. Improvement is localized and depends on seasonal conditions. Where no appropriate sewage treatment works have been implemented, pollution level at hot-spots has remained unchanged[22,23].

Creeks discharging into Marmara sea upper layer current mainly from Istanbul Metropolitan area (*i.e.* Küçüksu, Göksu, Ayamama, Çirçir, Kanlikavak, Tarabya, Sariyer), Gemlik (Karsak) and Izmit (Dil deresi) contribute to the pollution of coastal waters to a great extent[21].

A long-term comprehensive policy in promoting integrated wastewater management is believed to be a sustainable approach for the abatement of chronic pollution in Marmara sea. The water quality in Marmara sea should be the guiding criteria for identifying the level of treatment; either secondary treatment or tertiary treatment with nutrient removal in the case of municipal discharge into the sensitive bays where no strong currents exist. Rehabilitation of creeks receiving industrial and municipal pollution should be given prime importance in parallel with the identification of appropriate treatment level in order to fully comply with the requirements of integrated wastewater management concept.

ACKNOWLEDGEMENT

This work was supported by the Research Fund of the Istanbul University (Project number: 188/15012004).

REFERENCES

1. E. Dogan and S. Burak, *J. Coast. Res.*, **23**, 388 (2007).
2. C. Gazioglu, E. Gökasan, O. Algan, Z.Y. Yücel, B. Tok and E. Dogan, *Marine Geol.*, **190**, 397 (2001).
3. B. Alpar and H. Yüce, *Estuarine Coast. Shelf Sci.*, **46**, 609 (1998).
4. E. Gönenç, O. Müftüoglu, B.B. Baykal, E. Dogan, E. Yüce and M. Gürel, *Wat. Sci. Tech.*, **32**, 63 (1995).

5. E. Dogan, E Gönenç, C. Ömerci, O. Müftüoglu, H. Yüce and A. Türker, Uzaktan Algilama Yöntemleri ile Tuna Nehri Baglantili Karadeniz Istanbul Bogazi Kirlenme Arastirmasi ISKI Projesi, p. 87 (1996) (In Turkish).
6. S.T. Besiktepe, H.I. Sur, E. Özsoy, M.A. Latif T. Oguz and Ü. Ünlüta, *Progr. Oceanogr.*, **34**, 285 (1994).
7. E. Dogan, E. Gönenç, N. Çagatay, K. Güven, A. Kurter, H.Z. Sarikaya, I. Öztürk and E. Okus, ISKI METAP Sonuç Raporu, (Final Report) (1999) (In Turkish).
8. E. Morkoç, O.S. Okay, L. Tolun, V. Tüfekçi, H. Tüfekçi and T. Legovic, *Environ. Int.*, **26**, 1 (2000).
9. S. Ünlü and B. Alpar, *Bull. Environ. Contam. Toxicol.*, **73**, 85 (2004).
10. P.M. Gscweng and R.A. Hites, *Geochim. Cosm. Acta*, **45**, 2359 (1981).
11. S.K.A. Solmaz, T. Yontar and G.E. Üstün, Gemlik Körfezinde karasal kaynakli kirlilik envanteri. Marmara Denizi 2000 Sempozyumu, 11-12 Kasim 2000, Istanbul (2000) (In Turkish).
12. S. Ünlü and B. Alpar, *Chemosphere*, **64**, 764 (2006).
13. U. Alkan, S. Çaliskan, B. Birden, S.S. Cindoruk, Mudanya kiyilarinda Deniz desarjlari ve Fekal kirlenmenin boyutlari. Marmara Denizi 2000 Sempozyumu, 11-12 Kasim 2000, Istanbul (2000) (In Turkish).
14. S. Tugrul and Ç. Polat, *Wat. Sci. Tech.*, **32**, 115 (1995).
15. D. Orhon, O. Uslu, S. Meriç, I. Salihoglu and A. Filibeli, *Environ. Pollut.*, **84**, 167 (1994).
16. ISKI, IMC Atiksu Altyapisi Sonuç Raporu (Wastewater Infrastructure Final Report) (Istanbul Master Plan Consortium), Gibb Anglian, Nippon Koei, UBM, Sistem Planlama, Camp Dresser&Mc Kee, HR Wallingford, WRc, Vol. 3 Part A (1999).
17. E. Okus, A. Yüksek and A. Uysal, Marmara Denizi 20-100 m, Tabaninda Mevcut Kati Atiklar Üzerine Arastirma, II. Ulusal Ekoloji Kongresi, Ankara (1995) (In Turkish).
18. E. Dogan, K.C. Güven, H.I. Sur, E. Okus, A. Yüksek, A. Uysal, N. Balkis and N. Kiratli, Izmit Körfezi' nin Osinografisi. T.C: Çevre Bakanligi Projesi (2000) (In Turkish).
19. A. Uysal, A. Yüksek, E. Okus, E. and N. Yilmaz, Benthic Community Structure of the Bosphorus and Surrounding Area. Third Black Sea International Conference Environmental Protection Technologies for Coastal Areas, 6-8 June 2001, 109-118, Varna, Bulgaria (2001).
20. N. Balkis, *Marine Pollut. Bull.*, **46**, 865 (2003).
21. H.I. Sur, E. Okus, K.C. Güven, N. Kiratli, A. Yüksek, S. Ünlü, H. Altiok, S. Tas, A. Aslan, N. Yilmaz, A.E. Müftüoglu, K. Çetintürk, S. Övez, Ü. Karhan, I. Öz and N. Demirel, Su Kalitesi Izleme Çalismasi, Yillik Rapor. Destekleyen kurulus: ISKI Genel Müdürlügü. Istanbul Üniversitesi, Deniz Bilimleri ve Isletmeciligi Enstitüsü, Water Quality Monitoring Study, Annual Report, Istanbul Water and Sewerage Administration. Istanbul University Institute of Marine Sciences and Management), (2003, Published in 2004) (In Turkish).
22. H.I. Sur, E. Okus, K.C. Güven, N. Kiratli, A. Yüksek, S. Ünlü, H. Altiok, S. Tas, A. Aslan, N. Yilmaz, A.E. Müftüoglu, K. Çetintürk, S. Övez, Ü. Karhan, I. Öz and N. Demirel, Su Kalitesi Izleme Çalismasi, 4. Gelisme Raporu Destekleyen kurulus: ISKI Genel Müdürlügü. Istanbul Üniversitesi, Deniz Bilimleri ve Isletmeciligi Enstitüsü, (Water Quality Monitoring Study, 4th Progress Report, Istanbul Water and Sewerage Administration. Istanbul University Institute of Marine Sciences and Management), (2003, Published in 2004) (In Turkish).
23. E. Okus, I. Özturk, H.I. Sur, A. Yüksek, S. Tas, A.A. Yilmaz, H. Altiok, N. Balkis, E. Dogan, S. Övez and A.F. Aydin, *Desalination*, **226**, 231 (2008).

(*Received*: 26 August 2008; *Accepted*: 23 January 2009) AJC-7172