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Evaluation of Pollution Abatement Policies in the Marmara Sea with Water Quality Monitoring

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Istanbul Metropolitan area has been subjected to heavy population influx since 1950's and the non-existence of urban planning has aggravated the infrastructure problems by postponing effective measures. Rapid population growth on the one hand and industrialization on the other, have led to a soaring volume of domestic and industrial waste being discharged directly into the Marmara Sea and Istanbul Strait (Bosphorus). The assimilation capacity of the receiving waters, whose adverse hydrodynamic conditions are an important constraint, has been exceeded and pollution has damaged the natural ecological balance, eroding the range of beneficial uses for these waters. Consequently, the decline of the Marmara Sea reached an alarming level in the late 1970's. As a remedial action, comprehensive sewerage infrastructure investments have been initiated for Istanbul. This study discusses the achievement of the wastewater management program and obstacles encountered in the course of efforts to protect the marine environment of Istanbul based on representative results of the water quality monitoring study being carried out over the last ten years.

Key Words: Hot-spots, Istanbul Metropolitan area, Land-based pollution, Marmara Sea, Nutrient, Water quality monitoring.

INTRODUCTION

Istanbul metropolitan area (hereafter called Istanbul) exhibits a striking example of population increase by ten-fold in 50 years due to mainly immigration and natural growth. The sharp slope between 1985 and 1997 reflects high immigration waves as the consequence of socio-political issues. The uncontrolled expansion of the city coupled with inadequate urban planning has caused a chronic delay in infrastructure facilities. For long years, mainly sewerage investment has been inadequate and this negligence has significant impact on the receiving waters of Istanbul causing the degradation of both fresh and marine waters. As a consequence, the

marine environment of the Marmara Sea has become increasingly vulnerable; whose oceanographic features do not help much its self-purification capacity. This inland sea is a semi-enclosed water body of 11111 km^2 with an average depth of 260 m connecting the Mediterranean and the Black Sea *via* the Çanakkale and Istanbul Straits[1]. Istanbul is located on both sides of the Istanbul Strait and the Marmara Sea Northern sides.

The most important feature of this system is the formation of a two-layer current due to the salinity gradient between the more saline (38 psu) and dense waters of the Mediterranean flowing towards the Black Sea *via* the lower layer and the less saline (18 psu) Black Sea waters *via* the upper layer in the opposite direction[2]. A strong and permanent stratification occurs as the result of mainly salinity, density and temperature gradient along the Istanbul strait and at the junction of the Marmara Sea and Istanbul strait. 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 the Istanbul strait[3]. The ecological characteristics of the Marmara Sea are closely related to the Black Sea due to the direct communication between these two water bodies through the Istanbul strait[4-6]. In various studies, it is stipulated that the Black Sea determines the quality and ecology of the upper layer of the Marmara Sea whose volume and surface area are fairly small compared to the Black Sea with an average depth of 1300 m and 460000 km^2 surface area[7].

The first 10 to 15 m width upper layer of the Marmara Sea is well oxygenated with dissolved oxygen values reaching nearly saturation levels. The lower layer of the Marmara Sea below 30 to 40 m depths is chronically deficient representing on the average 25 % of the dissolved oxygen saturation value. The average oxygen concentration[8] at the lower layer in the Marmara Sea decreases to 2 mg/L.

Mixing between the two layers at the junction and along the Bosphorus and turnover of the lower layer current when blockage of the latter by the upper layer current occurs during unfavourable meteorological conditions are two scientific data that are of crucial importance for the decision-making process with regard to wastewater treatment and disposal[9-12]. Using the Marmara Sea as the recipient of the Marmara Basin together with the influence of the nutrient-rich Black Sea waters brings a high risk of eutrophication. This risk increasingly threatens the Marmara Sea, especially its semi-enclosed polluted bays *e.g.*, Izmit, Gemlik and its heavily populated shorelines where coastal discharges occur. The pollution generated in the Marmara Sea is due to three major sources: domestic and industrial wastewater discharges from Istanbul and its surroundings, point source and diffuse pollution in the Southern Marmara Basin and nutrient load transported *via* the upper layer Black Sea current[13].

This paper evaluates the pollution abatement efforts for Istanbul carried out by Istanbul Water and Sewerage Administration (ISKI) in the light of the historical evolution of the wastewater management program and the outcome of a 10 year monitoring study.

Background

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 to the Marmara Sea. Additionally visible sewage pollution on the shoreline is frequent where streams discharge, causing human-health and aesthetic concerns.

In accordance with the first Master Plan finalized in the 1970's and subsequent projects revised to accommodate changing circumstances, a comprehensive wastewater management program has been launched for Istanbul envisaging treatment of an average daily wastewater discharge of 3.2-4.8 million m^3 for the year 2020 equivalent to a population of 20 million. Two other features of this comprehensive program were set as the rehabilitation of streams-effectively open sewers-carrying high domestic and industrial pollution load into the Marmara Sea and the control of industrial pollution at source. Under the stream rehabilitation program, the wastewater discharged into the streams, which serve as receiving media, is planned to be channeled into collectors and conveyed to urban scale sewage plants. Where industrial effluent is concerned, pretreatment prior to discharge into the municipal sewer network has been made compulsory.

A few receiving media studies were carried out intermittently to understand the physical oceanographic features and ecology in the receiving waters of Istanbul before 1993.

The ongoing monitoring study started in 1993 with a Mediterranean Environmental Technical Assistance Program (METAP) grant has since then been financed by ISKI, started with the joint initiative of Istanbul University-Institute of Marine Sciences and Management, Navigation and Oceanography Department of the Navy and Istanbul Technical University with the technical assistance of the Scientific & Technological Research Council of Turkey (TUBITAK) and ISKI laboratories. Previous studies were carried out by the Middle East Technical University, Erdemli Institute of Marine Sciences before 1993.

The main objective of the ongoing monitoring study is to inventory the oceanographic features of the Marmara Sea, Istanbul Strait and adjacent seas impact with real time series data and to follow-up the commissioning of the wastewater schemes. The study also includes; (i) Presentation of data aiming to provide a comparison between the impacts of the planned

discharge systems and estimated impacts after their commissioning, (ii) Production of oceanographic hydraulic, physical, chemical and biological data for the calibration and verification of the ecological model to be developed for the Istanbul Water and Sewerage Administration, (iii) Presentation of appropriate data to carry out multi-purpose risk analyses, (iv) Carry out simultaneous measurements to identify the conditions for the blockage of the Marmara Sea and the collection of data to estimate the adverse effects on water quality conditions, (v) Detailed observations of the Black Sea contamination sources and presentation of suitable data to discuss in international platforms, (vi) Establishment of a data bank for the assessment of data on a systematic basis, for the evaluation of the sea currents data and for the evaluation of coliform data, (vii) Determination of the dispersion pathways of the discharged wastewater plume, (viii) Risk analysis of the vertical movement of wastewater discharges to the sea surface, (ix) Determination of the impact of available wastewater discharges.

The water quality monitoring study sampling frequency is designed to monitor the Istanbul strait sea water quality monitoring stations on monthly basis, whereas the Marmara Sea and Black Sea stations are followed on seasonal basis for a comprehensive set of parameters enabling the identification of the physical, chemical, biological state of the marine environment for all the stations amounting to a figure of 49 altogether[14].

Soon after the establishment of ISKI in 1981, the wastewater collection and disposal strategies as proposed in the Master plan and feasibility report for water supply and sewerage for the Istanbul region (DAMOC) finalized in 1971 and regarding the Istanbul Strait lower layer current as a sewage discharge and conveyance channel to the Black Sea, started to be implemented[15]. This disposal strategy after primary treatment and deep sea outfall formulated with limited available oceanographic data was based on the hypothesis that the lower more saline Mediterranean current was reaching the Black Sea without significant infiltration to the upper layer less saline Black Sea current. This meant that pollution was assumed to be captured in the lower layer and no significant detrimental effect was foreseen on the water quality of the Marmara Sea. The Yenikapi primary treatment plant was commissioned as the first result of the DAMOC Plan in 1988. In 1986, a few years after the construction of the Yenikapi plant started, visible signs of pollution alerted the ISKI management to take effective pollution prevention measures and it was decided to follow the fate of sewage discharges into the lower layer. Physical oceanography measures carried out between 1986 and 1989 proved evidence of mixing between the two layers[3].

After the local municipal election of 1989 in Istanbul, the environmental policy was revised and new concepts have been adopted regarding waste-

water treatment and disposal facilities. The DAMOC Master Plan projections were not applicable since the expansion trend of Istanbul had changed and it was no longer in line with projections in the previous plan. Therefore, it was decided to draw up a new plan for Istanbul. Following the review of the environmental policy, the disposal strategy of discharging sewage into the Istanbul Strait after only primary treatment was abandoned. The revised environmental concepts were based on more stringent standards in order to protect the receiving water bodies heavily polluted by domestic and industrial pollutants. As part of this revised concept, diversion of the generated wastewater of the Asian side to the Black Sea and discharge into the lower layer current after primary treatment (at Riva) was the adopted alternative[16]. This alternative also resulted in the cancellation of the construction of three primary treatment plants with sea outfalls in addition to the elimination of discharging raw sewage in the Istanbul surroundings.

But again after the municipal election of 1994, the concept of conveyance of sewage to the Black Sea entrance was canceled due to technical and financial reasons. A second revision for re-siting the treatment plants took place. The construction of primary treatment plants with deep-sea outfalls started in 1995 for a second time.

In the early 1990's, the lack of a comprehensive receiving media studies with long-term time series data and reliable numerical modeling study led to biased technical viewpoints and this resulted in frequent changes regarding disposal strategies. This fact coupled with changes in the ISKI management (three times in 13 years) resulted in delay due to interruptions in the decision-making process.

Since the Black Sea determines the quality and ecology of the Marmara Sea waters, we must conclude that: the Marmara Sea cannot be rehabilitated unless the Black Sea is rehabilitated; which calls for effective nutrient pollution control in the five other riparian countries with those of the Danube Basin focusing mainly on the diffuse pollution aspect generated by agricultural drainage, the most important activity generating nutrient pollution in the Black Sea.

Land-based pollution profile in Istanbul: The need of the above mentioned monitoring programs are due to high amount land based discharges of pollutants to the marine environment. The metropolitan area of Istanbul has a total area of 5712 km^2 and is bounded by the Marmara Sea, Istanbul Strait, Golden Horn and Black Sea. The proportion of agricultural land in this area is minimal; therefore land-based pollution derives mainly from residential areas, industry and storm water.

Daily domestic pollutant loads were computed based on the wastewater characterization study that was carried out with experimental data in Istanbul to indicate the unit emission rate for domestic sewage within the scope of

the Istanbul Master Plan study[17]. Since no substantial changes have occurred in household customs, the same emission rates have been taken for, BOD_5: 40 (g/capita/d), SS: 45 (g/capita/d), TOT-N: 6.7 (g/capita/d), TOT-P: 1.3(g/capita/d), respectively. The domestic pollution load discharged in the marine environment is given in Table-1, the details of the plants in Table-2 and their location[18].

TABLE-1
DOMESTIC POLLUTION LOAD DISCHARGED IN THE MARINE ENVIRONMENT

Sea Outfalls after primary treatment	Domestic pollution loads ($tonxday^{-1}$)			
	BOD_5	SS	Total-N	Total-P
Yenikapi	100.00	112.50	16.75	3.25
Baltalimani	60.00	67.50	10.05	1.95
Büyükçekmece	18.00	20.25	3.02	0.59
Küçükçekmece	24.00	27.00	4.02	0.78
Üsküdar	8.00	9.00	1.34	0.26
Kadiköy	89.20	100.35	14.94	2.90
Küçüksu	55.08	61.96	9.23	1.79
Tuzla*	5.20	5.85	4.36	0.85
Total	359.48	404.41	63.71	12.37

*The wastewater at the Tuzla plant is discharged after biological treatment, the BOD_5 load is computed on the assumption of 80 % removal rate.

The corresponding yearly load is in ton/year 131210, 147610, 23254 and 4515 for BOD5, SS, total-N and total-P, respectively.

The pollution load estimated by the Istanbul Master Plan study for 2040 predicts a daily figure of more than 112 metric tons of N and 28 metric tons of P load input from the Istanbul discharges[19]. In 1993, the domestic organic load generated by the settlements in terms of BOD_5 for the entire Marmara basin was computed as approximately 565 tons/d, of which 395 tons/d corresponds to the entire Istanbul load.

Bacteriological contamination: Controlling storm water flow is not only difficult but also there are no adequate and reliable figures for the amount of pollution, which it generates. More than 50 streams, effectively open sewers, carry high domestic and industrial pollution loads. Although an extensive rehabilitation program started in the early 1990's, there are still several creeks of various sizes with a total length of 500 km that need to be rehabilitated with a corresponding cost of nearly US$ 3×10^9. The water quality monitoring study results prove experimental evidence of bacteriological pollution at the discharge location of these streams as shown in Fig. 1, a representative case.

TABLE-2
SOME DETAILS OF TREATMENT PLANTS LOCATED IN ISTANBUL [Ref. 18]

Name of the plant	Commissioning year	Cost (Million$)	Capacity (m/d)	Population connected	Discharge location	Discharge depth
Yenikapi primary treatment plant	1988	27.00	864000	250.000	Istanbul Strait-B.limani	-60 m
Baltalimani primary treatment plant	1997	38.20	625000	1500000	Istanbul Strait-B.limani	-70 m
Büyükçekmece primary treatment plant	1998	14.00	155520	450000	Marmara -Bababurnu	-40 m
Küçükçekmece primary treatment plant	2003	4.50	130000	600000	Marmara-Kcekmece	-27 m
Ataköy biological treatment plant	1996	11.00	7650	45000	Ayamama	Stream
Terkos Advanced biological treatment plant	2000	1.64	1700	10000	Terkos Lake	Terkos
European side total		**96.34**	**1783870**	**4505000**		
Uskudar primary treatment plant	1992	7.16	108000	200000	Ist. Strait-	-47 m
Kadikoy primary treatment plant	2003	66.60	622000	2230000	Marmara-Kad?köy	-51.5 m
Küçüksu primary treatment plant	2004	18.00	640000	1377000	Ist. Strait-Küçüksu	-67 m
Tuzla biological treatment plant	1998	92.74	150000	650000	Marmara	-46 m
Pasakoy advanced biological treatment plant	2000	31.07	125000	250000	Riva	Stream
Asian side total		**215.57**	**1645000**	**4707000**		
Istanbul total		**311.91**	**3428870**	**9212000**		

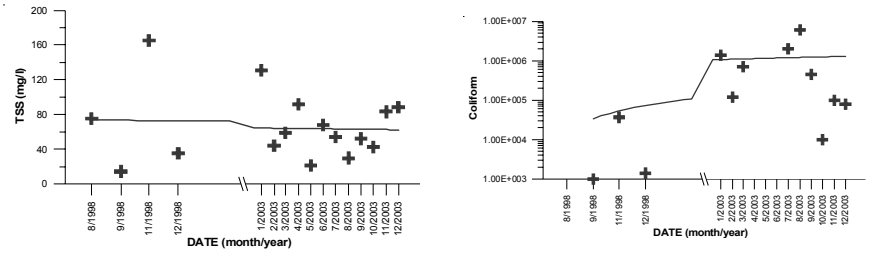


Fig. 1. TSS and Coliform variations at the discharge area of Küçüksu creek between 1998 and 2003

The increase in coliform data after 2000 is due to the developing residential area whose sewerage is not completed yet, discharging partially to the creek whose rehabilitation construction has recently started.

Hot-spots in the Marmara Sea: Based on various field studies, the land-based pollution load for the Marmara Sea generated by major hot-spots was calculated during the compilation of the Istanbul Master Plan study by DHI found out that the major hot-spots is Istanbul (almost 65% of the total input to The Sea of Marmara)[20]. The Marmara region is the most developed in terms of industrialization, with a wide variety of industries concentrated in the Gulf of Izmit, Gemlik and around Istanbul. The build-up effect of pollution has started to spread over the continental shelf, giving rise to a widespread deterioration of the natural balance in the marine ecosystem.

Hydraulic properties of Bosphorus: The Istanbul strait has a stratified structure due to the high salinity gradient between the Black Sea and Marmara Sea. While the brackish Black Sea originated water mass forms the upper layer current towards the Marmara Sea. The lower layer current flows in the opposite direction which is formed by the Mediterranean originated saline water. Some diverse atmospheric conditions may change this structure. Strong southerly winds blowing more than couple of days causes rising up of the high saline Mediterranean waters and increases the surface salinity of the strait (this is known as orkoz event) and blocks the upper layer flow towards the Black Sea[21]. The ADCP transect shown in Fig. 2 supports the view that the lower layer water mass blocks the upper layer flow.

Under these diverse hydrodynamic conditions, mixing up with the upper layer water, the sewage discharged into the lower layer current converges to the surface. This fact is contradictory to the wastewater disposal policy that was based on the conveyance of the domestic pollution to the anoxic zone of the Black Sea.

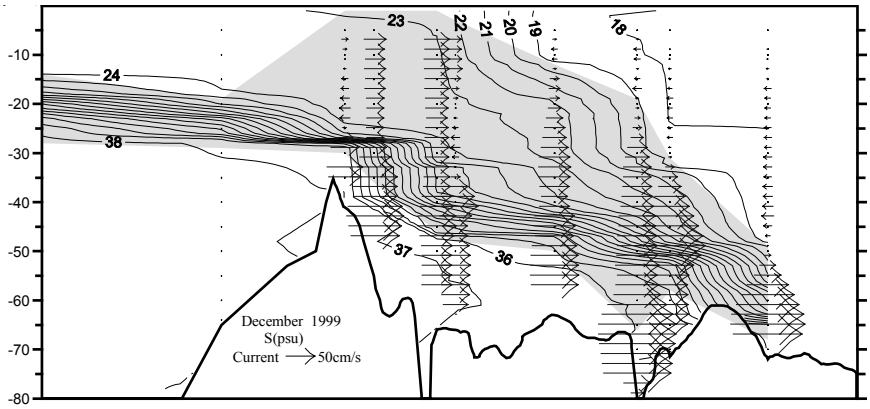
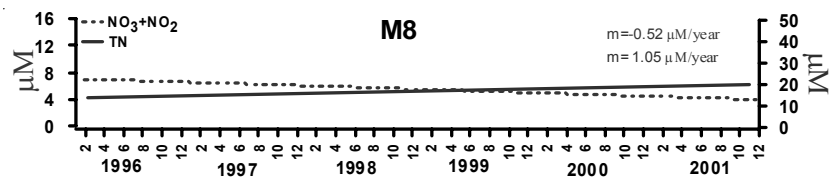


Fig. 2. Salinity contours across the longitudinal transect of the Istanbul strait illustrated with current vectors

RESULTS AND DISCUSSION

The experimental results of a ten year of monitoring, study from the year 1996 to the year 2005, indicates an improvement with regard to nutrient load in the surface waters of the Marmara Sea after the commissioning of the deep-sea outfalls[22]. But there is still incremental and point source pollution in the Marmara Sea with high phytoplanktonic activity. Therefore, pollution is still a concern for the receiving waters of Istanbul and in the Marmara Sea basin in general despite a large investment figure allocated for Istanbul[18,22].

At the two stations M8 and K0 an increasing trend in total nitrogen ~4 μM to 20 μM is observed between the period 1996 and 2001 (Fig. 3). The significant changes in total nitrogen figures after 1999, especially at K0 reflects the commissioning of most of the deep-sea outfall discharges rich in organic forms of nitrogen, nitrite and ammonia and the decrease in NO_x compounds are in line with this trend. The upper layer PO_4 and $NO_3 + NO_2$ concentrations displayed a decreasing trend at station M8, supporting the improvement effect of substantial elimination of surface discharge[23] as shown in Fig .4.



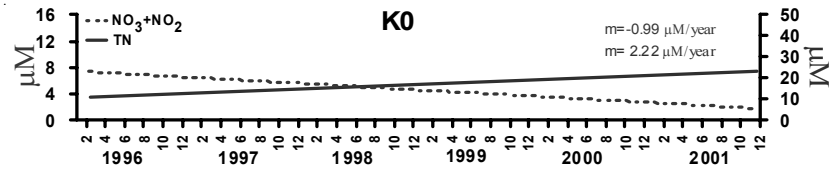


Fig. 3. Lower layer chronological nutrient ($NO_2 + NO_3$ and total nitrogen) trends between 1996-2001 at the stations K0 and M8 located at the Black Sea and Marmara exits of the Istanbul strait, respectively [Ref. 23]

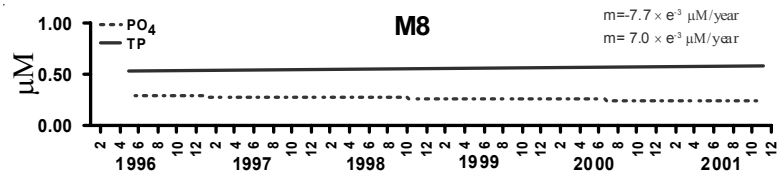


Fig. 4. Lower layer chronological nutrient trends (PO_4 and total phosphate) between 1996-2001 at the station M8 [Ref. 23]

Conclusion

It can be deduced that the obstacles encountered and the delay in the rehabilitation program are due to the difficulties of managing a metropolis over 10 million inhabitants and frequent strategical changes in wastewater management policies. The lack of reliable modeling studies based on long-term time series data can be encountered as another factor. These delays are also costly.

Bearing in mind that Istanbul is under demographic high pressure, is continually expanding, which causes an increase in the amount of waste discharges. Further, the receiving waters of the city exhibit a very complex hydrodynamic feature under the effect of adjacent seas. Thus the main points of an overall appraisal encompassing the wastewater management and monitoring studies of a metropolitan area should take into account:

(a) To ensure a target-oriented comprehensive receiving media rehabilitation program, the entire sewerage network including branch sewers and house connections and stream rehabilitation should be given prime importance and all industrial premises must be strictly controlled to ensure the installment and proper operation of treatment plants fulfilling the criteria of regulations concerning discharge into any municipal sewers, (b) The reassessment of the treatment level at each drainage areas and upgrading the treatment plants in a phased approach guided by a comprehensive and reliable modeling, (c) In accordance with the rehabilitation program of the

receiving waters of the Istanbul Metropolitan area, an extensive pollution abatement program for the Marmara Sea basin is required, (d) Specific for Istanbul, in parallel to the national programs, the impact of the Black Sea impact on the Marmara Sea should be brought to the attention of regional seas programs highlighting the efforts of Turkey.

The Marmara Sea is an inland sea within the Turkish jurisdictions. This has a controversial aspect with regard to the sovereignty of Turkey and regional commitments with respect to transboundary pollution. In other words pollution abatement programs may not be compulsory as a clause of binding documents for the Marmara Sea but only be initiated as a result of environmental awareness. Therefore the fact that it is an inland sea may not attract sufficient international attention, but if it is seen as an inland sea belonging to the adjacent sea basins, the transboundary pollution of the Black Sea affecting the Marmara Sea would attract more interest regionally and internationally.

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