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THE IMPACT OF AGRICULTURAL POLLUTANTS IN SIX DRINKING WATER RESERVOIRS

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ABSTRACT

Water is supplied in the Greater Istanbul Metropolitan Area from the surface water of six main reservoirs. The present land use in the catchment areas of the reservoirs indicates that the area devoted to agricultural activities and to forests and meadows varies between 73 and 97% and that only a minor percentage, 1-26%, is devoted to settlements and industries. In contrast to the land use profile, the current environmental evaluation of the catchment areas reveals that point sources dominate over diffuse sources. However, this trend is expected to be reversed in the near future, making diffuse sources and control of fertilizers and pesticides the most significant issue. Pollutant loads regarding pesticides and fertilizers are calculated from unit loads based on area. These pollutants are observed to have a negative impact on water quality in terms of eutrophication and toxicity. In this paper, the status of fertilizers and pesticides are addressed and some protective measures for reducing the impact of agricultural pollutants in the reservoirs are recommended. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Catchment areas; diffuse sources; fertilizers; pesticides; land use; protection zones.

INTRODUCTION

Istanbul is one of the greatest and oldest cities of the world. It is situated around the Bosphorus, joining the two continents of Asia and Europe, and has a total population of over 12 million. Almost 95% of the water supply to Istanbul Metropolis comes from already constructed surface water reservoirs, three of them being on the Asian side and the other three on the European side as shown in Figure 1. Of the city's population, 65% lives on the European side and 35% on the Asian side. This historical city faces infrastructure problems due to rapid population increase with an annual average rate of 4.6%, which is twice the overall rate of Turkey. As approximately 40% of Turkish industry is located in this city, it receives a high amount of migration from other parts of the country. Therefore, the six main drinking water reservoirs of the metropolis are under the threat of pollution. In order to protect the reservoirs from further pollution either in terms of point or diffuse sources of pollutants, a study under the sponsorship of the Ministry of Environment of the Turkish Republic was conducted by a group of scientists working on water quality and management (Gonenc *et al.*, 1995a, b, c, d, e, f). This paper, which forms a part of this study, is mainly devoted to describing the impact of agricultural pollution in the reservoirs following the description of the present status of the reservoirs in terms of pollution.

The total drainage areas and the present land use profiles are shown in Tables 1 and 2, respectively. The present land use of the reservoirs indicates that the area devoted to agricultural activities and to forests and meadows varies between 73 and 97%, and the area devoted to urbanization and industrialization is a minor percentage of 1-26%.

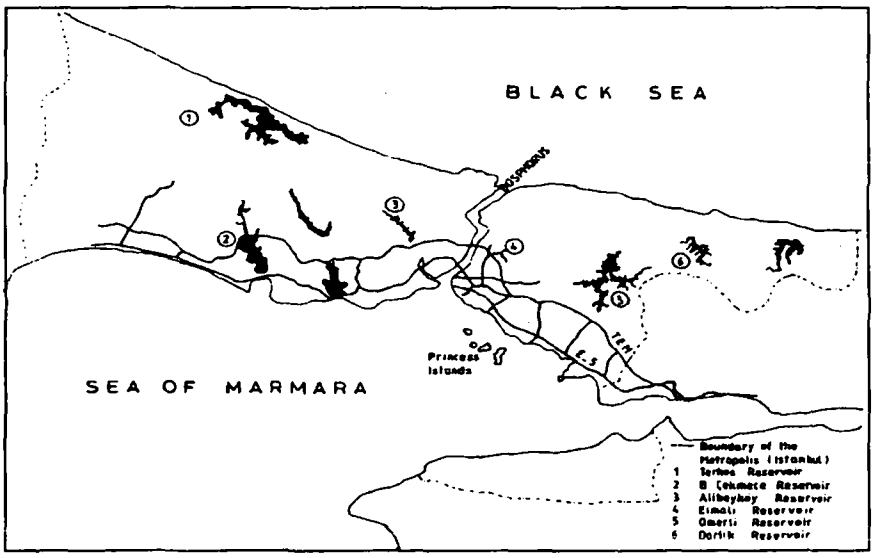

Figure 1. Six main reservoirs of the metropolis

Table 1. The total drainage areas of the reservoirs

Area (km^2)	Terkos	B. Cekmece	Alibeykoy	Omerli	Darlik	Elmali
Total Drainage Area	619	621	160	600	207	76
Reservoir Area	31.8	28.5	3.8	20.0	5.8	12.1

Table 2. The present land use distribution of the six main drinking water reservoirs

Land Use (%)	Terkos	B. Cekmece	Alibeykoy	Omerli	Darlik	Elmali
Forests & Meadows	77	21	68	51	72	42
Agricultural Land	17	65	19	35	25	31
Residential Areas	1	12	3	10	1	26

In contrast to the land use profile, the current environmental evaluation of the catchment areas reveals that point sources, consisting of domestic and industrial wastewater, dominate over diffuse sources originating especially from agricultural activities. That situation is a direct outcome of rapid and uncontrolled population increase in the catchment areas. The distribution of total polluting loads of the drainage areas in terms of the two significant parameters, nitrogen and phosphorus, is shown in Table 3. The amount of polluting loads is calculated according to unit loads that are either derived from literature data or from surveys conducted at the catchment areas (Tanik *et al.*, 1997). It can be observed from Table 3 that in terms of T-P, point sources dominate over diffuse sources. However, for T-N, in half of the cases diffuse sources dominate, largely due to the fact that residential areas occupy a minor percentage.

Table 3. The distribution of total polluting loads of the drainage areas

	Point Sources %		Diffuse Sources %	
Drainage Areas	T- Nitrogen	T- Phosphorus	T- Nitrogen	T- Phosphorus
Terkos	31.5	87.4	68.5	12.6
B. Cekmece	45.4	89.1	54.6	10.9
Alibeykoy	78.0	98.4	22.0	1.6
Omerli	79.5	97.0	20.5	3.0
Darlik	8.0	61.0	92.0	39.0
Elmali	91.9	99.0	8.1	1.0

The present profile reflecting the actual condition of the catchment areas indicated the necessity of proper infrastructure development. The impact of land-based pollution on the water quality of the reservoirs is also clearly observed and can be correlated with the work conducted on the water quality determination studies, based on the German Technical Standards (Beler Baykal *et al.*, 1996; Beler Baykal *et al.*, 1997a; Beler Baykal *et al.*, 1997b). In this classification, Classes 1 and 2 are suitable for drinking water supplies. Class 3 can only be used after a complex treatment scheme, lower quality waters cannot be used for this purpose at all. Table 4 summarizes the evaluation of the current water quality of each of the reservoirs.

Table 4. Water quality of the reservoirs

Source	Quality Class Based on Trophic Criteria	Water Quality Class
Terkos	2 → 3	2
B. Cekmece	2	3
Alibeykoy	2 → 3	3
Omerli	2 → 3	2
Darlik	3 → 4 *	2
Elmali	4 → 5	3

* based on very limited data, not included in calculations for general Water Quality Class

It is clearly seen that the reservoirs of the metropolis show the significance of eutrophication control. B. Cekmece is presently of mesotrophic character, whereas Alibeykoy and Terkos tend towards eutrophic stage from mesotrophic stage. Elmali has already exceeded the eutrophic stage. Therefore, if no strict precautions are taken, there will be no possibility of obtaining drinking water from them in the near future. Therefore, the authorities are now on the way to improve new land use plans for the predefined protection zones. The management strategy developed for point sources will reverse the distribution profile of the land-based sources. Both domestic and industrial sources will be collected, treated and discharged outside the catchment areas. However, this strategy will have no provision for diffuse sources, thus the significance of diffuse sources for the abatement of further deterioration of the water quality then becomes the key issue to be emphasized.

Table 5 reflects the probable distribution of diffuse sources of pollutants in the future following the realization of the management strategy for point sources. It demonstrates the significance of pollutants arising from agricultural activities in terms of fertilizers and pesticides which are determined on the basis of parameters such as nitrogen, phosphorus and toxic pollutants. The N and P loads from agricultural activities constitute 40-82% and 30-58% of the total diffuse sources respectively, whereas toxic loads from pesticides will be 100%.

The impact of diffuse sources, of which pesticides are of great significance due to their toxic and carcinogenic properties, in the reservoirs will be given after briefly mentioning the trends of pesticide consumption in Istanbul and the methods used in their determination based on their toxicity classification. Finally, a management strategy covering the fundamentals of agricultural pollution control will be proposed on the basis of protection zones. Apart from the listed types of pollutants, leachate originating from unregulated dumps of solid wastes is also another type of diffuse source of pollutants, however, there exists no such landfill areas within the boundaries of the catchment areas.

Table 5. The probable distribution of diffuse pollutants in the future following the management strategy for point sources

Catchment Areas	Forests & Meadows (%)		Agricultural Activities (%)		Urban Runoff (%)		Atmospheric Deposition (%)	
	T-N	T-P	T-N	T-P	T-N	T-P	T-N	T-P
Terkos	65.5	56	34	39	0.5	5.0	-	-
B. Cekmece	11	18	81.5	56	6.5	26	1.0	-
Alibeykoy	59	39	38.5	45	2.5	16	-	-
Omerli	35	17	56	46.5	6.0	31.4	3.0	5.1
Darlik	55.5	42	44.5	58	-	-	-	-
Elmali	25.7	10	44	29	16	61	14.3	-

DETERMINATION OF AGRICULTURAL POLLUTANTS IN THE CATCHMENT AREAS OF THE RESERVOIRS

The main sources of agricultural pollutants originate from the use of fertilizers and pesticides in areas spared for agricultural activities. The loads of pollutants arising due to use of fertilizers on agricultural land and in forests and meadows are calculated based on unit loads determined. Unit loads basically vary according to the soil type and structure and on the climatic conditions of Istanbul. The unit loads used in calculations and the corresponding total loads for each of the reservoirs are given in Tables 6 and 7 respectively.

The use of pesticides in the catchment areas is investigated in detail by conducting surveys. The types of pesticides, their percent distribution, solubility, annual consumption, and toxicity levels are determined. Although certain characteristics of pesticides are well known, their final characteristics after they reach a waterbody are extremely difficult to estimate. Typical pesticide classification according to "toxicological effects" is used in this work. The classification includes four classes each of increasing acute LD_{50} values in male mice (lethal dose in 50% of the test animals), (Turkish Toxicological Classification of Pesticides, 1983).

Table 6. Unit polluting loads for non-residential areas (Dahl & Kurtar, 1993)

Areas	Total- N kg / ha. year	Total- P Kg / ha. year
Forests	2	0.05
Greenland	5	0.10
Agricultural Areas	10	0.30

Table 7. Total loads for non-residential areas of the reservoirs

Reservoirs	Forests and meadows		Agricultural activities	
	T-N (kg / year)	T-P (kg / year)	T-N (kg / year	T-P (kg / year)
Terkos	171833	3537	88676	2534
B. Cekmece	39480	658	285915	8169
Alibeykoy	32684	545	21543	616
Omerli	96000	1600	153300	4380
Darlik	44700	745	35700	1020
Elmali	10500	175	18200	520

Pesticides of Class 1 (highly toxic, LD_{50} < 20 mg/kg) and Class 2 (toxic, LD_{50} = 20-200 mg/kg), are considered to be more significant than Classes 3 (slightly toxic, LD_{50} = 200-2000 mg/kg) and 4 (sparingly toxic, LD_{50} > 2000 mg/kg) in terms of toxicity. The application of Class 1 pesticides is strictly forbidden, and this ban is seen to be effective in the six main drinking water reservoirs of the metropolis as shown in Table 8 which gives the percent distribution of pesticides used in the catchment areas according to toxicological classification.

Table 8. Percent distribution of pesticides among the reservoirs according to toxicological classification

Catchment Areas	Class 1 %	Class 2 %	Class 3 %	Class 4 %
Terkos	-	7.20	55.60	37.20
B. Cekmece	-	10.54	37.62	51.84
Alibeykoy	-	2.90	38.10	59.00
Omerli	-	34.00	33.60	32.40
Darlik	-	37.40	13.30	49.30
Elmali	-	39.50	24.50	36.00

Consequently, loads of Class 2 pesticides are determined as 'toxic loads' and are calculated by the unit annual pesticide application in Istanbul. The rest of the pesticides are assumed not to exert any toxic effect in the water body. Table 9 indicates the trends of pesticide consumption in the Metropolis between the years 1990-1996. Slight decreases as years go by are partly due to increased prices of pesticides. The annual consumption values are much higher than the overall average consumption of Turkey, which was 1.25 kg-litre/ha in 1993 (Tanik *et al.*, 1998). Table 10 gives the pesticide loads estimated to reach the reservoirs based on the unit loads. The consumption values are higher than those in developed countries (Ozturk, 1997). Even though minor amounts are consumed in the catchment areas in Turkey, their impact is seen in the reservoirs, so strict precautions should be taken to save the drinking water supplies from the toxic effects of pesticides.

Table 9. Trends of pesticide consumption in Istanbul

Years	1990	1991	1992	1993	1994	1995	1996
Land (ha)	121 216	121 550	116 435	116 435	118 863	109 627	110 189
Pesticide Consumption (kg - litre/ ha)	4. 167	3. 667	3. 510	3.880	2. 780	3.046	2.260

Table 10. Estimated pesticide loads reaching the reservoirs

	Average of years 1990 - 1996 (3.32 kg / year. ha)	Year 1996 (2.26 kg / year. ha)
Reservoirs	kg / year	kg / year
Terkos	3028	2061
B. Cekmece	14293	9729
Alibeykoy	296	202
Omerli	24721	16328
Darlik	6333	4311
Elmali	3410	2321

PROTECTIVE MEASURES TO BE RECOMMENDED FOR REDUCING THE IMPACT OF AGRICULTURAL POLLUTANTS IN THE RESERVOIRS

Agricultural pollutants will be of primary importance after the operation of treatment plants in the future. Thus, diffuse source controls should be implemented as soon as possible, before the distribution profile of pollutants is reversed following the actualization of treatment plants. The basic principle in the abatement of pollution in a catchment area is control at the source (Gonenc *et al.*, 1997). The control of pollution should be carried out in two stages: urgent / short-term control and medium / long-term control. In the urgent / short-term control, unauthorized agricultural land use (not stated in the Basin Protection Plans) should be stopped and the consumption of fertilizers and pesticides should be monitored and controlled under an authorized agency.

In the medium / long-term control, the goal is to maintain the sustainability of the water quality of the reservoirs, at least at the second class of European Community Standards. In order to accomplish this, the catchment areas are proposed to be divided into three main protection zones, which is significantly different from the classical zoning for drinking water protection in various countries. The first protection zone covers the state forests and the areas that have to be afforested. In this zone, no activities except the afforestation and revival activities are to be allowed, and the supervision of forests is to be under the control of the Ministry of Forestry. The second protection zone is to be a restricted zone in terms of activities allowed. The subzones of this zone at the shore of the reservoir are to be no-activity zones. Others are to be kept as greenbelts with limited military activities, limited recreational activities, and agriculture using only natural techniques without fertilizers and pesticides. The third zone is the controlled utilization zone, where agriculture without or with controlled consumption of fertilizers and pesticides is to be allowed.

Controlled consumption of fertilizers and pesticides is to be dictated by pertinent experts. Optimum application dosages are to be advised along with on-site training for farmers together with the prescription of the right application time and duration. Farmers are to be alerted for a possible incidence of pests depending on the occasion of the same in neighbouring locations and weather forecasts. None of the banned pesticides are to be used and the responsibility of such control and management is to be given to a local institution. This local institution responsible for the management of the catchment areas will be named as the Basin Protection and Management Institution. Agricultural activities concerned with protection and management of the basins are to be carried out and supervised by this institution. Participation in the association is to be widespread and include local municipalities, pertinent governmental offices, military authorities of the areas, universities located near the area, representatives of the related ministries, and nongovernmental organizations, and it has to be based on the principle of sharing responsibilities. It has to have financial autonomy and it has to be capable of undertaking investments and management of the basins. Related to water quality, limited recreational activities are also to be under the supervision of the institution. The six main reservoirs are to be governed by similar but different institutions, as each face different types of environmental problems according to their location and to their local characteristics.

CONCLUSIONS

Presently, the point sources of pollutants constitute the major part of the pollution load in the six main drinking water reservoirs of the Greater Istanbul Metropolitan Area. This trend is expected to be reversed by the operation of treatment plants to be constructed for point sources of pollutants. Control of diffuse sources for the abatement of further deterioration of water quality will then become the key issue to be emphasized in the catchment areas. Use of pesticides and fertilizers on agricultural land is to be controlled and only the most appropriate chemicals and application rates are to be used. Urgent / short-term and medium / long-term control objectives are to be given with the aim of protecting and maintaining the water quality of the reservoirs. The control strategy proposed for each of the three major protection zones aims to reduce diffuse pollution. An institution is to be responsible for all activities within the catchment areas and to be in charge of the reservoirs and reservoir management in terms of water quality.

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