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ATMOSPHERIC DEPOSITION AND ITS EFFECTS ON DRINKING WATER RESOURCES OF ISTANBUL

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ABSTRACT : *In this study, wet deposition of air pollutants and its effect on the quality of Ömerli water resource of İstanbul were investigated. According to the most recent data the rate of inorganic nitrogen coming from acid rain is calculated as 9 % (minimum) and 25 (mean) of total load which was considered as 1-3 % in previous studies. Rate of inorganic nitrogen load is supposed to be similar for the other reservoirs of İstanbul. Since the limit value for eutrophication of receiving water is 0.2 mg N/lt inorganic nitrogen coming from wet and dry deposition for drinking water resources of İstanbul will be the sources of eutrophication, without considering another sources of pollution such as domestic, industrial and agricultural sources.*

KEYWORDS: *Acid rain, Eutrophication, İstanbul, Deposition, Water resources*

1. INTRODUCTION

Acid rain, first discovered in 1852 (Smith, 1978), is widely recognized as one of the important global environmental problem. It is formed by the reaction of air emissions of both SO_2 and NO_2 with water, oxygen and other oxidants in the atmosphere. These constituents fall down to the earth by means of precipitation (Gülsoy et al., 1997). Movement of the compound from atmosphere onto the earth generally undergoes through 2 ways of deposition, either transported by means of precipitation (wet deposition) or by gravitational force (dry deposition). In wet deposition, acidic compounds may be transported over long distances by means of the wind. On the other hand, dry deposition is most effective in the vicinity areas.

From the view of acid rain, Scandinavian countries, north and northeast of America are the most affected areas. Of emissions, 90 % of sulfide and 95 % of nitrogen oxide at the northeast of America are originated from anthropogenic sources such as industry, resident, transportation and heating.

Combination of water and carbon dioxide in the atmosphere balance the pH of precipitation on 5.6. Phase concentrations of atmospheric SO_4^{2-} and NO_3^- can decrease the pH of precipitation into 5.0. Any precipitation is defined as acid rain if it has pH degree below the 5.0. Accumulation of ions by acid rain is called as wet accumulation.

Ion concentrations in the composition of acid rain are given in Table 1. It is clear that H^+, NH_4^+, Ca_2^+, SO_4^{2-} and NO_3^- are the descriptive parameters. While H^+, NH_4^+ and SO_4^{2-} consist of acidic compounds; Ca^{2+}, Mg^{2+}, Na^+ and K^+ compose alkaline compounds.

Table 1. Ion concentration in the composition of acid rain (Reis, 2000)

Ions	Concentration, μeq/l		
	Sjoangen, Sweden (1973-1975)	Hubbard Brook, New Hampshire, (1973-1974)	Pasedena, California (1978-1979)
SO_4^{2-}	69	110	39
NO_3^-	31	50	31
Cl^-	18	12	28
NH_4^+	31	22	21
Na^+	15	6	24
K^+	3	2	2
Ca^{2+}	13	10	7
Mg^{2+}	7	32	7
H+	52	114	39
pH	4,3	3,94	4,41

The reactions of SO_2 and NO_2 in homogenous and heterogeneous phases in the atmosphere are shown in Figure 1.

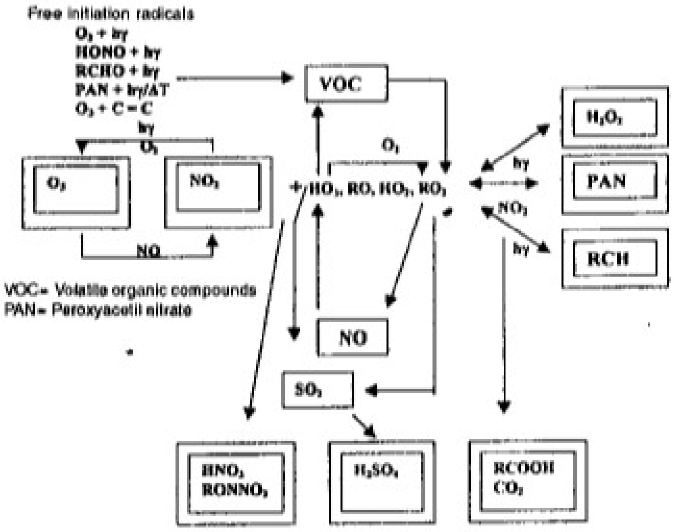

Figure 1. The reactions of SO_2 and NO_2 in homogenous and heterogeneous phases in the atmosphere

Accumulation of ions by means of deposition of HNO_3, SO_4^{2-} and NO_3^- by the effect of gravitational force is called dry deposition. A comparison of the amounts of acidic compounds falling down by dry and wet deposition is given in Table 2. Dry deposition is the more effective and continuous type of deposition according to the Table.

Table 2. Amounts of acidic compounds by dry and wet deposition

Location	Dry deposition (kg/ha-year)	Wet deposition (kg/ha-year)	Rate of dry/wet deposition
Beaver lodge	4,8	5,11	0,94
Calgary	20,7	11,13	1,86
Coronation	18,6	8,61	2,16
Edmonton	21	10,82	1,94
Edison	18,6	9,59	1,94
Fort Mc Murray	21	6,60	3,18
Let bridge	13,8	7,42	1,86
Red Deer	12,3	6,68	1,84
Rocky Mountain House	20,2	10,41	1,94
Suffield	7,2	3,89	1,85
White court	21,9	15,31	1,43
Mean	16,4	8,82	1,86

2. EFFECTS OF ACIDIC ACCUMULATION

Acidic accumulation has some direct adverse effects on plants such as tissue damage, metabolic injuries. Inhibition of plant growth and decreasing the resistance against the pathogens as a result of transformation of soil chemistry are the indirect adverse effects of acid rain.

Acidification of soil is a natural process in humid regions. Acidic accumulation increases the rate of this process by changing the structure of soil. Increasing of acidity of the soil increases the solubility of Al^{3+} and other heavy metals and the inhibition of plant growth. As a result of transportation of Al^{3+} into the water ecosystems some adverse effects arises on fishes such as the irritation and clogging of the gills, formation of mucus layer and the death.

Decreasing of pH by decrease of buffer capacity of natural water resources, decreasing of the number and types of living things in water and increasing of eutrophication risk by means of nutrients ($NO_3^- + NH_4^+$) are the other important adverse effects of acid rain (Wark *et al.*, 1998).

3. PREVIOUS STUDIES ABOUT ACID RAIN IN TURKEY

Due to the lack of studies about acid rain, environmental effects of this process were not sufficiently evaluated in Turkey. In this study, previous studies on wet deposition in various regions of Turkey are summarized (Table 3).

The results of the study (Toros, 1999) were used in this study due to the large number of samples and parameters researched (Table 4).

Annual ionic loads for the precipitation of 500 mm/year for İstanbul are calculated and given in Table 5.

The data about wet and dry deposition of the north and the northeast regions of USA where the most deposition are observed are given in Table 6, Table 7 and Table 8 (Lynch, 1996).

Table 3. Previous studies on water quality on precipitation in Turkey.

Reference	Date	Region	Number of samples	Ion concentrations, mg/l				
				pH	SO_4^{2-}	NO_3^-	Ca_2^+	NH_4^+
Tuncel, 1995	Sep 1989-May 1990	Ankara	27	6.0	7.2	3.78	4.2	0.34
Al Momeni, 1995	Jan 1992-Dec 1992	Antalya	48	5.17	3.17	3.36	2.8	0.90
Okay, 1996	Nov 1993-Nov 1995	Pendik, Kaynarca	78	5.58	14.69	1.98	5.8	0.74
Gülsoy, 1996	Jan 1996-Oct 1996	Bahçelievler	39	6.50	34.18	8.68	3.76	2.05
Gülsoy, 1996	Jan 1996-Oct 1996	Florya	45	6.1	19.06	27.59	3.00	4.10
Gülsoy, 1996	Jan 1996-Oct 1996	Göztepe	25	6.3	13.49	31.68	5.02	1.91
Erüz, 1995	Dec 1991-Oct 1992	Belgrad Forest	-	4.6-7.0	-	-	-	-
Erüz, 1995	Dec 1994-Nov 1995	Vefa	-	4.2-7.8 (6.10)	12.29	4.01	-	-
Erüz, 1995	Dec 1994-Nov 1995	Belgrad Forest	-	4.2-6.8 (mean 5.45)	10.53	1.78	-	-
Erüz, 1995	Dec 1994-Nov 1995	Ömerli Havzası	-	4.0-6.8 (mean 5.45)	10.56	1.57	-	-
Reis, 2000	-	Buca, İzmir	-	5.52	11.0	4.0	31	-
Reis, 2000	-	Bornova, İzmir	-	6.52	37.0	11.0	56	-
Reis, 2000	-	Hatay, İzmir	-	6.64	18.0	9.0	12.0	-
Reis, 2000	-	Antalya	-	5.76	34.0	12.0	8.0	-
Reis, 2000	-	Altınoluk, Balıkesir	-	4.83	11.0	6.0	15.0	-
Reis, 2000	-	Bandırma	-	5.49	31.0	26.0	24.0	-
Reis, 2000	-	Ereğli, Zonguldak	-	4.53	17.0	8.0	17.0	-
Toros, 1999	Oct 1997-Jul 1998	Maslak Campus, İTÜ	153	4.88-7.44 (mean 6.30)	22.42		35.58	3.30
Toros, 1999	Oct 1997-Jul 1998	Belgrad Forest	34	4.99-7.57 (mean 6.24)	23.59		21.94	1.52
Alp, 2000	Feb 2000-Jun 2000	Gültepe	18	4.1-6.53 (mean 5.2)	9.13		-	-
Alp, 2000	Jan 2000-Apr 2000	Maslak Campus, İTÜ	8	4.4-6.2 (mean 5.3)	22.5		-	-

Table 4. Ion concentrations in the precipitation of Istanbul (Toros, 1999)

	SO_4^{-2}	NO_3^-	NH_4^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	H^+
Minimum value	4,59	1,69	0,57	4,91	0,28	1,25	0,24	1,51	0,095
Mean value	23,09	5,79	2,25	28,77	1,24	4,7	0,87	5,2	2,4
Maximum value	59,08	15,14	6,72	86,93	3,49	19,92	2,86	13,5	9,96

Table 5. Ionic loads by wet deposition in Istanbul, kg/ha-year

	SO_4^{-2}	NO_3^-	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	H^+
Minimum	22,95	8,45	2,85	24,55	1,4	6,25	1,2	7,55	0,48
Mean	115,45	28,95	15,15	143,85	6,2	23,5	4,35	26	12

Table 6. Ionic loads by wet deposition, mg/l

Stations	Precipitation, cm	SO_4^{-2}	NO_3^-	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	H^+
İL 63	127,2	1,54	1,11	0,27	0,13	0,02	0,03	0,08	0,14	0,03
İN 20	91,10	2,57	2,15	0,50	0,25	0,05	0,03	0,07	0,15	0,04
İN 34	95,10	2,58	1,99	0,52	0,49	0,09	0,02	0,08	0,19	0,03
İN 41	92,10	2,78	2,17	0,53	0,34	0,05	0,02	0,10	0,18	0,04
MA 08	123,10	1,49	1,51	0,23	0,07	0,03	0,03	0,19	0,36	0,04
Mİ 26	102,60	2,36	2,23	0,57	0,26	0,04	0,02	0,05	0,13	0,04
NY 52	133,30	2,06	2,28	0,42	0,17	0,03	0,04	0,11	0,24	0,04
PA 15	101,90	2,10	1,74	0,29	0,11	0,01	0,02	0,06	0,15	0,05
PA 29	127,80	2,22	1,97	0,30	0,11	0,02	0,03	0,05	0,13	0,05
PA 42	107,50	2,01	1,83	0,26	0,11	0,02	0,02	0,05	0,13	0,05

Table 7. Ionic loads by wet deposition, kg/ha-year (1983-1994)

Stations	SO_4^{-2}	NO_3^-	NH_4^+	H^+	Ca^{2+}	Mg^{2+}
İL 63	19,78	14,12	3,42	0,35	1,71	0,25
İN 20	23,74	19,55	4,51	0,39	2,28	0,46
İN 34	24,86	18,89	4,98	0,25	4,69	0,84
İN 41	25,93	20,03	4,85	0,39	3,09	0,5
MA 08	18,57	18,55	2,87	0,47	0,81	0,36
Mİ 26	24,53	22,89	5,81	0,38	2,65	0,44
NY 52	27,79	30,33	5,54	0,59	2,32	0,4
PA 15	21,69	17,77	2,91	0,49	1,17	0,18
PA 29	28,79	25,13	3,88	0,69	1,39	0,22
PA 42	21,92	19,64	2,8	0,53	1,15	0,18

Table 8. Ionic loads by dry deposition

	Concentration on air, μg/m³				kg/ha-year			
Stations	SO_2	HNO_3	SO_4^{2-}	NO_3^-	SO_4^{2-}	HNO_3	SO_4^{2-}	NO_3^-
West point, NY	7,88	2,11	3,67	0,22	6,43	20,69	1,66	0,11
Huntington Forest, NY	2,5	1,46	2,62	0,099	1,85	11,3	1,24	0,04
Whiteface, NY	2,52	1,55	3,16	0,114	1,92	15,5	1,35	0,05
Argonne, IL	14,97	2,85	4,62	1,06	17,87	23,9	2,12	0,4
Oak Ridge Core, TN	16,54	1,35	5,86	0,17	10,05	7,93	1,06	0,04

4. EFFECTS OF ACIDIC ACCUMULATION ON ÖMERLİ CATCHMENT AREA

In this section, the loading coming from acidic accumulation and those from other sources are compared for Ömerli catchment area, the largest water resource of Istanbul (Table 9).

Ömerli catchment area has a drainage area of 621 km², a reservoir capacity of 357×10^6 m³ and a safe drinking water capacity of 220×10^6 m³/year. Annual precipitation is 797 mm. The catchment area is covered with 59 km² of residential and industrial areas, 219 km^2 of agricultural area, 329 km^2 of forest and 23 km^2 of reservoir area. As a result of high infiltration rate of the soil in the catchment area, the rate of transformation of precipitation into the ground water is high and the water source of Ömerli reservoir is mainly ground water having the velocity of 7,5 m/s.

Table 9. Pollution loading values from various sources in Ömerli catchment area (Gönenç et al., 1995)

Pollution source	BOD_5	Total N	Total P
Domestic wastewater	48 000	4 000	1 040
Industrial wastewater	564	184	127
Non-point sources			
Precipitation	350	90	14
Forest and Agriculture	-	-	16
TOTAL	48 914	4 274	1 197
Tons per year	17 853,6	1560,0	436,9
Portion of the precipitation		% 2,1	% 1,17

Pollution loading from acidic accumulation in Ömerli catchment area is given in Table 10.

Table 10. Pollution loads from acidic accumulation in Ömerli catchment area, tones/year

Minimum loads	SO_4^{2-}	NO_3^-	NH_4^+	Ca^{2+}	Mg^{2+}	H^+
Total catchment area	1425,2	524,7	177,0	1524,6	87,0	29,8
Ömerli reservoir	52,8	19,4	6,6	56,5	3,2	1,1
Mean loads						
Total catchment area	7169,4	1797,8	940,8	8933,1	385,0	745,2
Ömerli reservoir	265,5	66,6	34,8	330,8	14,3	27,6

The pollution loads by dry and wet deposition is about 1-2 % of total load in Table 9. However, as a result of high level of local air pollution since 1980 and pollution transport from Balkan Peninsula and north of Black Sea will bring about serious increase in ion loads especially for inorganic nitrogen (HNO_3 + NO_3^- + NH_4^+) parameter. For wet deposition, an ionic load per hectare is established by accepting the mean precipitation of İstanbul city as 500 mm/year (Table 10). The ionic load of dry deposition is given in Table 11.

Total load of both wet and dry deposition is given in Table 12. Total load is calculated separately for total catchment area and reservoir area. A comparison of loads coming from acidic accumulation and from other sources for the ionic loads is given in Table 13.

Table 11. Pollution loads from dry deposition in Ömerli catchment area, tones/year

Minimum loads	SO_4^{2-}	NO_3^-
Total catchment area	249,3	704,2
Ömerli reservoir	9,2	26,1
Mean loads		
Total catchment area	702,0	1291,7
Ömerli reservoir	26,0	47,8

Table 12. Pollution loading from both dry and wet deposition in Ömerli catchment area, tones/year

Total catchment area	SO_4^{2-}	NO_3^-	NH_4^+	Total N
Minimum	16745,0	1228,9	177,0	277,5+137,7=415,2
Mean	7871,4	3089,5	940,8	697,6+731,7=1429,3

Table 13. Nitrogen loads (NO_3-NH_4^+) in Ömerli catchment area

Source	Load, tones/year	Percent of total	
		Minimum	Mean
Domestic wastewater	4000	(86,97 %)	71,26 %
Industry	184	(4,9 %)	3,28 %
Wet and dry deposition			
Minimum	415,2	9,03 %	
Mean	1429,3		25,46 %
Total			
Minimum	4599,2		
Mean	5613,3		

Total inorganic nitrogen load originating from both wet and dry deposition is between 9 % (min) and 25,5 % (mean) of total load of the catchment area. These data are in good agreement with some data in literature (Table 14).

Table 14. Estimated sources of nitrogen in the Chesapeake Bay (http://www.epa.gov/airs/ag.html)

Water-borne point sources, e.g. industry, sewage treatment plants, etc.	25 %
Runoff from land, e.g., farms, lawns, city streets, golf courses, etc.	50 %
Air sources, e.g., electric power plants; cars, trucks, boats and other mobile sources; municipal waste combustors, etc.	25 %

Some of the estimations about dry and wet deposition in selected estuaries in USA are given in Table 15.

Table 15. Percent of nitrogen entering selected estuaries from air sources (http://www.epa.gov/airs/ag.html)

Tampa Bay	28 %
New York-New Jersey Harbor	38 %
Albermale-Pamlico Sounds	38 %

5. RESULTS

Increasing population of world and changes in climate increase the importance of protection of drinking water resources. Conventional techniques on the protection of water resources are not enough to maintain the existing quality of the reservoirs. Issue of water resource protection is the major environmental problem of especially developed and industrialized countries. Water resources of north and northeastern regions of USA are evident examples of this problem.

In this study, effects of precipitation on the drinking water quality of Ömerli Reservoir, the biggest water resource of İstanbul, is evaluated. In the previous studies about acidic precipitation, the rate of inorganic nitrogen coming from acid rain was considered as 1-3 % of total load. However, according to the most recent data the rate is calculated as 9 % (minimum) and 25 (mean). It is considered that the rate of inorganic nitrogen is similar for the other reservoirs of İstanbul. Since the limit values for eutrophication of receiving water are 0.2 mg N/lt inorganic nitrogen coming from wet and dry deposition for drinking water resources of İstanbul will be the sources of eutrophication, without considering another sources of pollution such as domestic, industrial and agricultural sources.

Although recent developments in the control of ionic loads had successful results in the control of SO_4^{2-}, many studies are conducted for nitrogen control coming from the air sources in the USA. More studies about control of ionic loads from deposition must also be carried out to protect the eutrophication problem in drinking water reservoirs of İstanbul.

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