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ASSESSMENT OF SOIL ACIDIFICATION: A CASE STUDY

SELÇUK SOYUPAK

LABEEB MUKHALLALATI

BAŞAK KILIÇ

COŞKUN YURTERI

Middle East Technical University
Ankara, Turkey

ABSTRACT

The Menemen-Aliağa-Foça region on the northwestern Aegean coast of Turkey near İzmir, is under the influence of air emissions originating from various industrial establishments. In this article, the long-term acidification impacts of these industrial emissions on the agricultural and forest soils of the region were studied by using qualitative and quantitative soil acidification assessment approaches. The relevant characteristics of the regional soils were determined experimentally and the number of years required to reach certain critical soil pH levels were estimated. Predictions were also made regarding the improvements expected in the future when the existing industries comply with the emission standards stipulated by the currently effective legislation.

INTRODUCTION

In general, soil acidification occurs as a consequence of long-term atmospheric deposition of such acidic air pollutants as sulfur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) to soil, and it involves complex chemical changes in soil as well as soil water. The major adverse changes are expected to occur in base saturation, soil pH and molar Al/BC ratio; where Al and BC are defined as the total amounts of aluminum and divalent base cations, respectively. The literature offers several mechanistic approaches to estimate these changes [1-4]. For instance, the so-called SMART (Simulation Model for Acidification's Regional

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Trends) model, developed by De Vries et al., simulates the long-term soil responses to acid deposition in various buffer ranges, and can be utilized to estimate the changes in base saturation, pH and molar Al/BC ratio for agricultural as well as forest soils [3]. Subsequently, by utilizing the mechanisms of SMART, one can predict the number of years required to reach critical soil pH values, if acid deposition rates and soil properties are known in the region of interest.

In estimating the number of years to reach threshold pH values in pivotal soils, an alternative to modeling is experimental determination of the acid-buffering capacity. The acid deposition rates are again the key information for this approach, which has been implemented in previous environmental impact assessment studies [5]. There are also well established qualitative approaches for the assessment of soil susceptibles to acidification. In the past, such methodologies were also utilized in parallel to quantitative approaches [6].

The major objective of this study was to predict the sensitivity of various soils in the Menemen-Aliağa-Foça region to acidification under the influence of the existing air emissions. With this intention, both mechanistic modeling and acid buffering capacity approaches were utilized in parallel. The results of these quantitative approaches were then interpreted in the light of qualitative criteria and guidelines accepted world-wide. Furthermore, future predictions were made regarding the improvements that will be attained when major industrial sources in the region comply with Turkish emission standards stipulated by the current Air Quality Control Regulation [7].

THE STUDY AREA

The study area of interest was the Menemen-Aliağa-Foça region which corresponds to a circle of about 25 km in radius having its center near the town of Aliağa, where two major industrial sources, Tüpraş petroleum refinery and Petkim petrochemical complex, are located. In addition, the coal-fired Soma thermal power plant which is about 70 km northeast of Aliağa, has also a partial impact on the region. The study area is depicted in Figure 1.

Climatology and Air Pollution Meteorology

The air pollution in a region depends on meteorological parameters which can allow accumulation of pollutants in the airshed. In general, meteorological parameters which affect pollution are the duration of light wind speeds, atmospheric stability, and mixing height. More importantly, the amount of precipitation downwind from the point sources determines the deposition rates of pollutants.

Detailed information on the climatology of the study area can be found elsewhere [8]. In terms of precipitation, the Aegean coast receives significant rain fall during the winter months. The precipitation occurs as snow in the inner parts. During the summer months, on the other hand, precipitation is rare due to the

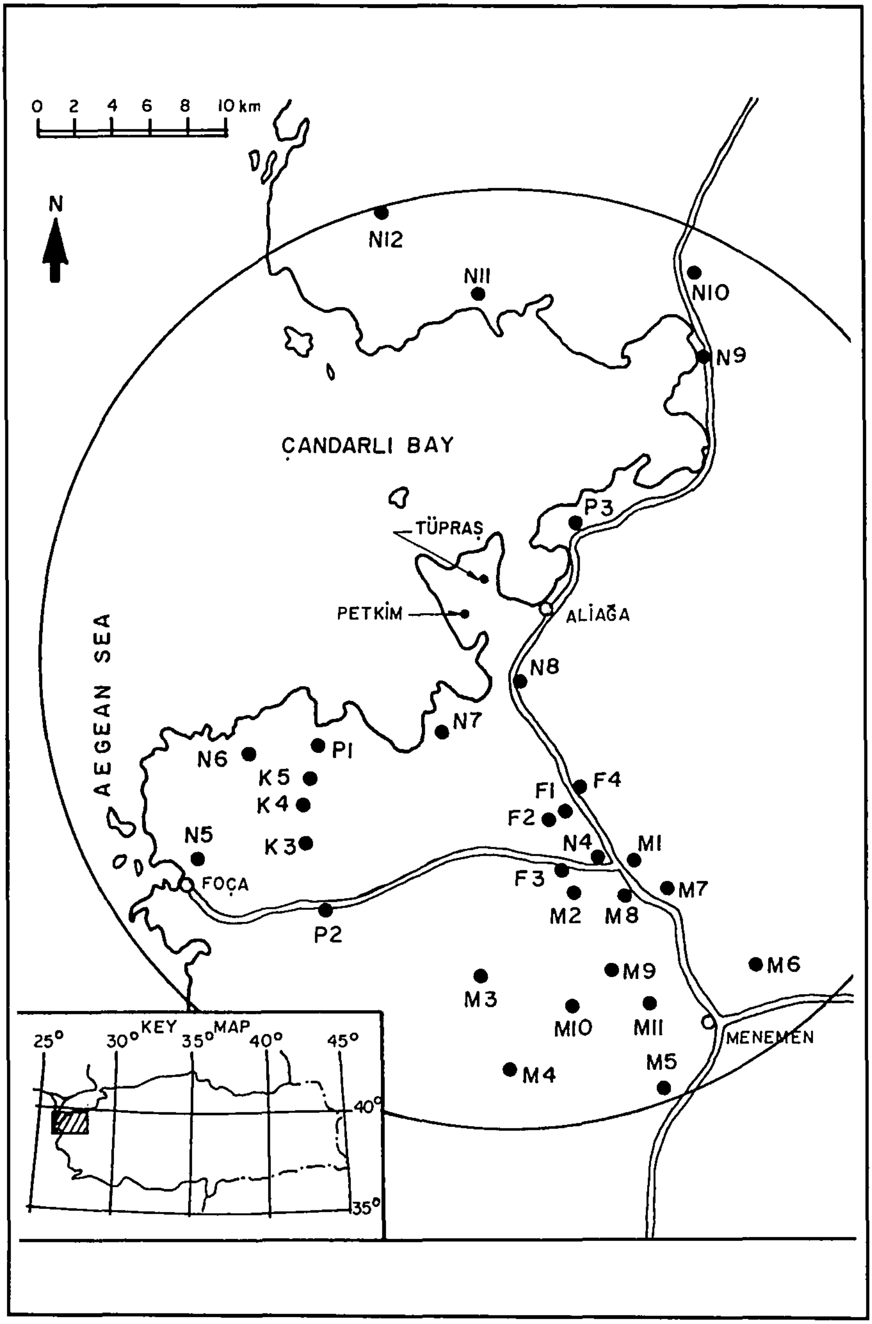


Figure 1. Study area and sampling points.

formation of the frontal systems north of Turkey. In this season, the sky is usually clear and vaporization is high with temperatures reaching up to 40°C. Northeasterly winds dominate the region during the summer. In addition to this, a sea-breeze/land-breeze system sets up near the shoreline.

Topography

There are no high geological formations in the study area and the topography of the region is characterized by low altitude rolling hills. Elevation starts from the sea level and rise to about 100 m at 5 km inland. This rather smooth topography is typical for the Aegean coast. Consequently, a strong effect of topography on local meteorology is not expected.

Sources of Atmospheric Emissions in the Airshed

In particular, the Aliağa region which was a small recreational area in the 60's rapidly industrialized after in the 70's when incentives were given by the Turkish Government to create an industrial zone in the region. Currently, major sources in the region are: a refinery, a petrochemical complex, four major and several small-scale iron and steel works, a paper plant, a fertilizer plant, a chemical plant, and several ship dismantling plants.

Among these, the fertilizer plant, the paper plant, and the chemical manufacturing plant do not have significant emissions due to their small capacities. Other than some fugitive dust, the ship dismantling plants are not important sources of atmospheric emissions. The iron and steel works use electric arc furnaces to melt iron and do not consume significant amounts of fossil fuel in the process. Consequently, the iron works do not have significant SO_2 and NO_2 emissions. However, these plants, that have no stacks, are important sources of particulate emissions as fugitive dust.

The main sources of SO_2 in the region are the Soma thermal power plant, the Tüpraş refinery and the Petkim petrochemical complex. Even though the emissions of the Soma are higher than the combined emissions of Tüpraş and Petkim, the relative contribution of this plant on both ground level concentrations and deposition in the region was found to be marginal due to the long distance separating the plant from the study area. The SO_2 emissions from Petkim and Tüpraş are close to each other. The annual SO_2 and NO_2 emissions of the major industrial sources are listed in Table 1.

The Tüpraş refinery processes 7,000,000 tonnes of crude oil each year. The source of crude oil used by the refinery varies. The refinery has a total of twenty-one stacks and three flares. The annual fuel-oil consumption of the refinery is about 400,000 tonnes. On the average, the fuel oil consumed by Tüpraş contains 5.6 percent sulfur. The Petkim petrochemical complex obtains raw material mostly from the neighboring refinery. The plant has more than one dozen units producing some twenty major products. The Petkim plant has three stacks that are 72 meters high and six flares, of which three are 92 m and three are 45.8 m

Table 1. Emissions of SO_2 and NO_2 in the Study Area

	Location		Annual emissions (tonnes/year)		
Point Sources	Distance (km)	Direction	SO_2 Measured	SO_2 Calc.[a]	NO_2 Calc.[a]
Tüpraş	8.3	NNE	41,172	45,578	2,813
Petkim	8.2	NNE	24,674	32,883	3,033
Soma	72.2	ENE	—	94,024	37,445

[a] Calculation based on U.S. EPA AP42 emission factors, fuel usage, and amount of material processed.

high. However, flares are not operational at all times. The Petkim complex has a total fuel-oil consumption of 370,000 tonnes. The fuel-oil primarily comes from the Tüpraş refinery and contains 4.5 percent sulfur. The coal-fired Soma thermal power plant is located about 70 km NE of Aliağa and was taken into account in the modeling studies due to its high emission rates. The power plant has four 165 MW units, and consumes 3,500,000 tonnes of local lignite with an average sulfur content of 1 percent. The flue gases are emitted via two 150 m stacks.

The total annual NO_2 emissions in the region is 43,291 tonnes. About 86 percent of these emissions are due to the Soma thermal power plant. Tüpraş and Petkim account for 6.5 and 7.0 percent of the total NO_2 emissions, respectively. As in the case of SO_2, NO_2 emissions of the other industries are not significant. Further, NO_2 emissions from motor vehicles are not included in the modeling studies.

Soil Characterization

Soil types within the study area differ considerably with location and agriculture of a wide variety of crop types is being practiced. The Menemen Plain, one of the most fertile agricultural plains of Turkey, is within the study area. Some olive and *Pinus brutia* forests and empty bush land also exist within the boundaries of the study area. Details on the natural and agricultural vegetation of the study can be found in [8, 9].

Soil samples were collected at thirty-one points representing thirty-one distinct soil types as mapped by the former General Directorate of Soil and Water, Ministry of Agriculture and Village Affairs [10]. Soil sampling points are shown in Figure 1. Soil sampling and analyses studies were conducted from February 1991 to January 1992. Soil samples were collected by pick and axe. The sampling depth was 50 cm from the surface for olive yards and forest areas and 25 cm from the top for other soils including the agricultural soils. Various soil types that exist in the area and the types of plants that grow on these soil groups are listed in Table 2.

Table 2. Soil Sampling Points for the Study Area (See Figure 1 for Locations)

Station Number	Soil	Agricultural Practice	Expected pH
M1	Hatundere-Arapdere Sub-Region	Grape yard	6.50 and less
M2	Gediz-Ciflik-Eskiyatak Sub-Region	Grape yard	6.51-7.50
M3	Kozluca-Ulucak Sub-Region	Grape yard	7.51 and more
M4	Süzbeyil-Seyrek-Gürle Sub-Region	Cotton	7.51 and more
M5	Gediz-Ciflik-Eskiyatak Sub-Region	Grape yard	6.51-7.50
M6	Bombay-Asarlik-Koyundere Sub-Region	Grape yard	6.51-7.50
M7	Uplands	Grape yard	6.51-7.50
M8	Hatundere-Arapdere Sub-Region	Grape yard	6.51-7.50
M9	Süzbeyli-Seyrek-Gürle Sub-Region	Cotton	6.51-7.50
M10	Süzbeyli-Seyrek-Gürle Sub-Region	Cotton	7.51 and more
M11	Gediz-Çiflik-Eskiyatak Sub-Region	Grape yard	6.5-7.50
F1	Kozluca-Ulucak Sub-Region	Olive grove	—
F2	Uplands	Olive grove	—
F3	Hatundere-Arapdere Sub-Region	Olive grove	7.51 and more
F4	Bombay-Asarlik-Koyundere Sub-Region	Olive grove	6.51-7.5
P1	Outside of the Menemen Plain	Grape yared	6.50 and less
P2	Outside of the Menemen Plain	Grape yard	6.51-7.50
P3	Outside of the Menemen Plain	Grape yard	6.50 and less
K3	Outside of the Menemen Plain	Cotton	6.50-7.51
K4	Outside of the Menemen Plain	Bush land	6.50-7.51
K5	Outside of the Menemen Plain	Bush land	6.50-7.51
N4	Hatundere-Arapdere Sub-Region	Cotton	6.50 and less
N5	Uplands	Forest	—
N6A	Uplands	Forest	—
NgB	Uplands	Forest	—
N7	Uplands	Forest	—
N8	Uplands	Bush land	—
N9	Outside of the Menemen Plain	Olive	6.50-7.51
N10	Outside of the Menemen Plain	Cotton	6.50-7.51
N11	Uplands	Forest	—
N12	Uplands	Olive	—

The collected soil samples were analyzed for pH (1:2.5 in water, 1:1 in 0.01M $CaCl_2$ and saturation); $CaCO_3$ content; total, soluble and exchangeable base cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+), cation exchange capacity (CEC); base saturation; sodium adsorption ratio (SAR); potassium adsorption ratio (PAR); aluminum content (total, $Al(OH)_3$ and Al_2O_3); percent saturation; and bulk density. Common analytical techniques cited in conventional soil sampling and analysis texts were adapted for the measurements [11-13].

Acid Deposition Rates

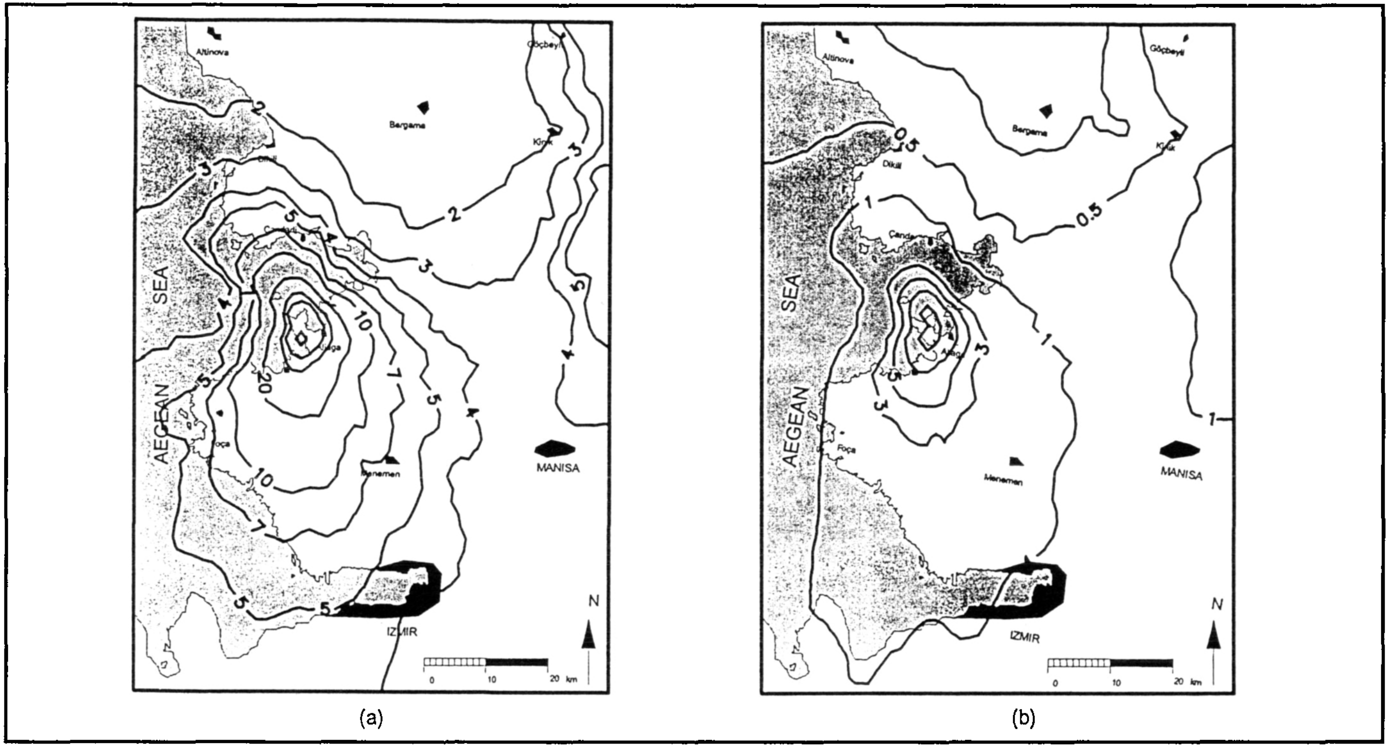
At the present time, the major sources of air pollution for the study area include the Soma thermal power plant, Tüpraş and Petkim facilities and the long-range transport of various pollutants from Europe [14, 15].

In terms of acid deposition, the most important pollutant is SO_2. The contribution of the other acid precursors, namely NO_x and NH_3, to wet and dry deposition can be estimated if SO_2 deposition rates are known. The annual average total (wet + dry) SO_2 deposition rates to the study area due to the existing industries (Tüpraş, Petkim and Soma) were predicted using the well-known Alberta Deposition Model With Terrain (ADEPT) [8, 14, 16]. ADEPT, which is widely used for regulatory purposes, can predict seasonal and annual ground-level SO_2 concentrations as well as wet and dry sulfur depositions for up to ten single point source emissions within a radius of 100 km of complex terrain.

In this study, the meteorological data required by ADEPT were prepared by processing the hourly surface measurements obtained from the Ciğli Airport meteorological station, with the REG-308 preprocessor of the Ontario Ministry of Environment [14]. In addition to meteorological data, ADEPT also needs relevant inputs for stack sources and deposition data such as rain pH and dry deposition velocities. Furthermore, ADEPT uses a grid system of maximum 30 × 30 resolution, with terrain elevations input at each grid point. Also, the surface roughness of the region is required for dispersion calculations. At each grid point, the sulfur deposition due to the long-range transport, as estimated by a recent study [15], was added to the wet and dry depositions calculated by ADEPT to obtain the total sulfur deposition. In Figure 2(a), the estimated annual average total sulfur deposition rates due to the existing industries are presented as equal-deposition contours. Figure 2(b) presents the sulfur depositions for the same area when the existing industries comply with the currently effective Turkish air quality control legislation [7].

SOIL ACIDIFICATION PREDICTION METHODS

As noted, quantitative soil acidification predictions can be made by mechanistic modeling or by estimating experimental acid buffering capacity. There are also well established qualitative approaches for the assessment of soil susceptibilities to acidification.



(a)

(b)

Figure 2. Annual average calculated total sulphur deposition from Tüpraş, Petkim and Soma. (a) Under existing conditions. Maximum deposition: 2149 kg/ha. Contour intervals: 2, 3, 4, 5, 7, 10, 20, 50, 100, 1000 kg/ha. (b) In compliance with standards. Maximum deposition: 387 kg/ha. Contour intervals: 0.3, 0.5, 1, 3, 5, 10, 50 kg/ha.

Soil pH is an important parameter, especially in terms of agricultural production. In general, it is agreed that there will be no significant limitation for the production of most crops if pH lies between 6.0 and 7.0. However, if pH is lower than 5.5, one should expect limitations that may restrict the range of crops that can be grown on such soils. In the following sections, the time periods required to reach critical pH levels are predicted by means of different assessment approaches.

Mechanistic Modeling Approach

In this study, the dynamic soil acidification model SMART was adapted to predict the expected changes in soil properties due to acid deposition. By acknowledging soil properties, acid deposition rates and other local factors such as meteorology and agricultural practices, the SMART model solves a set of differential equations describing various soil mechanisms, and outputs pH values as a function of time. The total list of mechanisms incorporated in SMART are summarized in Table 3.

In addition to the mechanisms listed in Table 3, the effects of the current irrigation practices within the study area and the quality of irrigation water were taken into account for agricultural soils.

Graphical representations of the long-term behavior of the regional soils as predicted by the SMART model are given in [17]. The predictions were performed for each soil type under present acid deposition conditions and for deposition rates if existing industries comply with air quality regulations.

Table 3. Mechanisms for Calculating Expected Changes in Soil [3, 4]

Process	H^+	Al^{3+}	BC^{2+}	NH_4^+	NO_3^-	SO_4^{2-}	HCO_3^-
Atmospheric Deposition	+	–	+	+	+	+	–
Growth Uptake	+	–	+	+	+	–	–
Nitrogen Immobilization	+	–	–	+	+	–	–
Nitrification	+	–	–	+	+	–	–
Denitrification	+	–	–	–	+	–	–
Dissociation/Association	+	–	–	–	–	–	+
Carbonate Weathering	+	–	+	–	–	–	–
Silicate Weathering	+	+	+	–	–	–	–
Al Hydroxide Weathering	+	+	–	–	–	–	–
Cation Exchange	+	+	+	–	–	–	–
Sulphate Adsorption	+	–	–	–	–	+	–

Note: + = ion included in the respective process, – = ion not included in the respective process.

Acid Neutralizing Capacity Approach

The number of years to reach preset pH levels can be estimated by means of acid buffering curves. With this intention, different increments of H^+ were added to soil samples of 100 g and, after allowing to equilibrate for ten days, pH measurements were taken and acid neutralizing capacity curves were drawn for each soil type. The results were then plotted as pH versus meq H^+ added per 100 g of soil. For a given soil type, using the acid buffering curve, the moles of acid required to reach a preset pH value can be calculated for each hectare of land. In such acid requirement calculations, respective soil depths of 25 and 50 cm have been used for agricultural and forest soils. The number of moles of acid required to reach a preset pH value is divided by the predicted acid deposition rate, yielding the number of years it would take to reach that value. The procedure was repeated for each soil type under existing emission and future compliance scenarios.

Qualitative Approach to Evaluate Sensitivity to Acidification

The sensitivity of soils to H^+ addition and the ensuing acidification can also be evaluated using a qualitative approach suggested by Holowaychuck and Fessenden [6]. This evaluation for rating the sensitivity of soils to acidic inputs is based on the criteria presented in Table 4. The key factors in this analysis are CEC and pH levels of the soil before any cation is taken.

RESULTS AND CONCLUSIONS

Soil Characteristics and Qualitative Evaluation

Table 5 presents the important properties of the soils within the study area. The pH of the regional soils were between 5.0 and 8.1. Fifteen soils (out of 31) were acidic. All olive forest soils were alkaline. The $CaCO_3$ content, which primarily determines the acid neutralization capacity, was high for most of the agricultural soils of the Menemen Plain (labelled with the letter M).

Soil characteristics criteria given in Table 4 have been used to assess the sensitivity of regional soils to acidification. In this approach, CEC and pH are used to assess soil sensitivity to base loss, acidification and aluminum solubilization. These sensitivity indicators have been integrated to the overall sensitivity rating given in Table 6.

The results summarized in Table 6 indicates that the sensitivities of the vital Menemen soils (M1 through M11) are low to base loss, acidification, Al solubilization. Consequently their overall sensitivity rating was also low, except M1. The relatively high sensitivity of M1 was primarily due to a comparatively low pH and the lack of free carbonates in the soil solution.

On the other hand, agricultural soils (P1 and P3) collected from outside the Menemen Plain had high sensitivities to base loss and acidification; their overall sensitivities were high. This was mainly due to the absence of $CaCO_3$, and

Table 4. Criteria for Sensitivity of Soils to Acid Additions [6]

CEC (cmol/kg)	pH	Sensitivity to Base Cation Loss	Sensitivity to Acidification	Sensitivity to Al Dissolution	Overall Sensitivity
<6	<4.6	H	L	H	H
	4.6-5.0	H	L	H	H
	5.1-5.5	H	M	H	H
	5.6-6.0	H	H	M	H
	6.1-6.5	H	H	L	H
	>6.5	L	L	L	L
6-15	<4.6	H	L	H	H
	4.6-5.0	M	L	H	M
	5.1-5.5	M	L to M	M	M
	5.6-6.0	M	L to M	L to M	M
	>6.0	L	L	L	L
>15	<4.6	H	L	H	H
	4.6-5.0	M	L	H	M
	5.1-5.5	M	L	M	M
	5.6-6.0	L	L to M	L to M	L
	>6.0	L	L	L	L

Note: H = high sensitivity, M = medium sensitivity, L = low sensitivity.

comparatively low pH values. Conversely, the agricultural soil P2 had low sensitivities to base loss, acidification and aluminium solubilization; thus its overall sensitivity was also low.

The soils of olive forests have exhibited low overall sensitivities except F4. The low overall sensitivity of F1, F2 and F3 was primarily due to high $CaCO_3$ content in the soil solution and relatively high pH values (pH > 7.9). Moreover, their total exchangeable cation contents were also high compared to other soils. The remaining soils, that have relatively lower agricultural value, exhibited high overall sensitivity. These soils were labelled as K and N series. Only N7 and N10 exhibited low overall sensitivity.

Results of Quantitative Approaches

In this section, the results obtained from the mechanistic modeling and experimental acid buffering capacity approaches are presented in terms of long-term acidification potentials of the Menemen-Aliağa-Foça soils. For present and allowable future acid deposition conditions, the pH curves for each soil type were

Table 5. The Results of Soil Characterization Study

Sampling Points	pH (in $CaCl_2$)	pH (Sat.)	CEC (meq/100 g)	% $CaCO_3$	% Base Saturation
M1	5.45	5.54	4.064	0.292	44.3
M2	7.90	8.08	6.778	4.528	80.1
M3	7.70	8.07	6.349	12.161	79.7
M4	7.51	8.15	2.517	5.259	84.6
M5	7.95	7.87	5.590	4.528	66.2
M6	7.70	8.02	3.139	2.155	69.8
M7	7.79	7.97	3.730	4.189	63.3
M8	7.96	8.16	3.764	0.730	74.7
M9	7.90	8.13	3.859	6.882	62.4
M10	8.10	8.52	2.846	5.462	85.0
M11	7.90	8.13	3.541	5.097	75.1
F1	7.90	7.94	5.713	21.919	49.7
F2	7.90	8.26	4.743	24.031	66.0
F3	7.95	7.77	5.656	13.308	59.1
F4	6.90	6.88	3.761	0.146	63.8
P1	6.50	7.00	3.045	0.000	52.5
P2	7.00	8.20	3.456	5.971	95.2
P3	6.10	6.34	2.594	0.000	53.2
K3	5.00	6.00	2.438	0.000	67.3
K4	5.80	6.10	2.450	0.000	70.6
K5	6.20	6.30	3.149	0.000	61.6
N4	5.50	5.55	2.425	0.288	63.1
N5	5.52	5.70	3.528	0.288	61.5
N6A	5.90	6.00	3.525	0.180	68.9
N6B	5.00	5.30	3.718	0.288	69.9
N7	7.10	7.40	4.472	1.369	93.5
N8	6.00	6.05	2.547	0.000	66.4
N9	6.15	6.70	4.071	0.000	49.4
N10	7.20	7.40	4.726	5.871	79.3
N11	5.55	6.20	5.610	0.000	58.6
N12	5.80	6.00	2.410	0.000	73.0

Table 5. (Cont'd.)

Exchangeable Ca+Mg (meq/100g)	Exchangeable Ca (meq/100g)	Exchangeable Na (meq/100 g)	Exchangeable K (meq/100g)
1.58	1.31	0.04	0.18
4.94	3.21	0.22	0.27
4.39	4.10	0.16	0.51
1.78	1.56	0.10	0.25
3.16	2.67	0.32	0.22
1.91	1.63	0.12	0.16
2.02	1.66	0.13	0.21
2.11	1.45	0.51	0.19
2.08	1.62	0.15	0.18
2.14	1.37	0.15	0.13
1.82	1.32	0.11	0.73
1.98	1.87	0.35	0.51
2.73	2.14	0.21	0.19
2.81	2.77	0.39	0.14
1.12	0.92	0.41	0.87
1.06	0.76	0.25	0.29
2.15	2.07	0.23	0.91
0.27	0.65	0.13	0.98
1.61	1.10	0.01	0.02
1.70	1.51	0.02	0.01
1.89	1.49	0.03	0.02
1.50	1.06	0.02	0.01
0.85	0.50	0.39	0.93
1.58	0.61	0.53	0.32
1.60	1.16	0.56	0.44
3.72	3.54	0.13	0.33
1.45	1.08	0.11	0.13
1.75	1.48	0.14	0.12
3.44	2.41	0.15	0.16
2.92	2.69	0.21	0.16
1.69	1.32	0.04	0.03

Table 6. Soil Properties and Results of Qualitative Evaluation

Sample Points	CEC cmol/kg	pH[b]	% Base Saturation	% $CaCO_3$	TEC	S-1	S-2	S-3	S-4
M1	4.064	5.45	44.3	0.292	3.11	H	M	H	H
M2	6.778	7.90	80.1	4.528	5.43	L	L	L	L
M3	6.349	7.70	79.7	12.161	5.06	L	L	L	L
M4	2.517	7.51	84.6	5.259	2.13	L	L	L	L
M5	5.590	7.95	66.2	4.528	3.70	L	L	L	L
M6	3.139	7.70	69.8	2.155	2.19	L	L	L	L
M7	3.730	7.79	63.3	4.189	2.36	L	L	L	L
M8	3.764	7.96	74.7	0.730	2.81	L	L	L	L
M9	3.859	7.90	62.4	6.882	2.41	L	L	L	L
M10	2.846	8.10	85.0	5.462	2.42	L	L	L	L
M11	3.541	7.90	75.1	5.097	2.66	L	L	L	L
F1	5.713	7.90	49.7	21.910	2.84	L	L	L	L
F2	4.743	7.90	66.0	24.031	3.13	L	L	L	L
F3	5.656	7.95	59.1	13.308	3.34	L	L	L	L
F4	3.761	6.90	63.8	0.146	2.40	H	H	H	H
P1	3.045	6.50	52.5	0.000	1.60	H	H	L	H
P2	3.456	7.00	95.2	5.970	3.29	L	L	L	L
P3	2.594	6.10	53.2	0.000	1.38	H	H	L	H
K3	2.438	5.00	67.3	0.000	1.64	H	M	H	H
K4	2.450	5.80	70.6	0.000	1.73	H	H	M	H
K5	3.149	6.20	61.6	0.000	1.94	H	H	L	H
N4	2.425	5.50	63.1	0.288	1.53	H	M	H	H
N5	3.528	5.52	61.5	0.288	2.17	H	H	M	H
N6A[a]	3.525	5.90	68.9	0.180	2.43	H	H	M	H
N6B[a]	3.718	5.00	69.9	0.288	2.60	H	M	H	H
N7	4.472	7.10	93.5	1.369	4.18	L	L	L	L
N8	2.547	6.00	66.4	0.000	1.69	H	H	M	H
N9	4.071	6.15	49.4	0.000	2.01	H	H	L	H
N10	4.726	7.20	79.3	5.871	3.75	L	L	L	L
N11	5.610	5.55	58.6	0.000	3.29	H	H	M	H
N12	2.410	5.80	73.0	0.000	1.76	H	H	M	H

[a] N6A and N6B were collected at the same location, N6.

[b] (1:1 in 0.01 M $CaCl_2$)

Note: TEC: Total Exchangeable Cations (Ca + Mg + K + Na); S1: Sensitivity to Base Loss; S3: Sensitivity to Aluminium Solubilization; H: High Sensitivity; M: Medium Sensitivity; S2: Sensitivity to Acidification; S4: Overall Sensitivity; L: Low Sensitivity.

obtained using the mechanistic modeling approach described above. The required number of years to reach each of the preset pH levels was read directly from the pH versus time curves. Acid buffering curves for each soil type were obtained experimentally. The required number of years to reach the preset pH levels were calculated using the acid buffering curves and the estimated acid deposition rates.

Figures 3 through 6 present the calculated number of years that must pass to reach preset pH values of 6.0 and 5.5. In these figures, the impacts of the existing emissions are compared with the hypothetical compliance case when the existing industries (Tüpraş, Petkim and Soma) observe the permissible emission standards.

As can be seen from Figures 3 through 6, under the current rate of emissions, some of the sensitive soils will start to become acidic within the next ten years. The insensitive calcareous soils are not expected to be affected for at least another 100 years of more. If industries comply with the emission standards, the acidification of the sensitive regional soils will slow down considerably. The effect of compliance is particularly visible in Figures 4 and 6, where the pH of the sensitive soils is allowed to drop to 5.5.

When the time estimates obtained from the two quantitative approaches are compared, the estimates of the mechanistic modeling are more conservative for calcareous soils which are rather insensitive to acidification. On the other hand, the mechanistic approach is less conservative for sensitive soils. A comparative evaluation of the two techniques is presented in [18].

CONCLUDING REMARKS

For a specific region of interest, the long-term impacts of wet and dry deposition of acidic air pollutants onto soil media were assessed by two methods, for both existing and expected future emission rates. Simulation and experimental results are as follows:

1. Both qualitative and quantitative techniques revealed that some of the regional soil groups (M1, F4, P1, P3, K3, K4, K5, N4, N6A, N6B, N5, N8, N10, N11 and N12) are sensitive to acidification.
2. For calcareous soils, estimates from mechanistic modeling are more conservative than those derived from acid buffering capacity curves. The mechanistic approach is the less conservative one for sensitive soils. Therefore, in areas where different types of soils exist, both approaches should be utilized in tandem for the assessment of the acidification potential. The results of these quantitative approaches can then be judged in light of qualitative information.
3. Especially for sensitive soils, the enforcement of air quality control legislation will markedly decelerate regional acidification.

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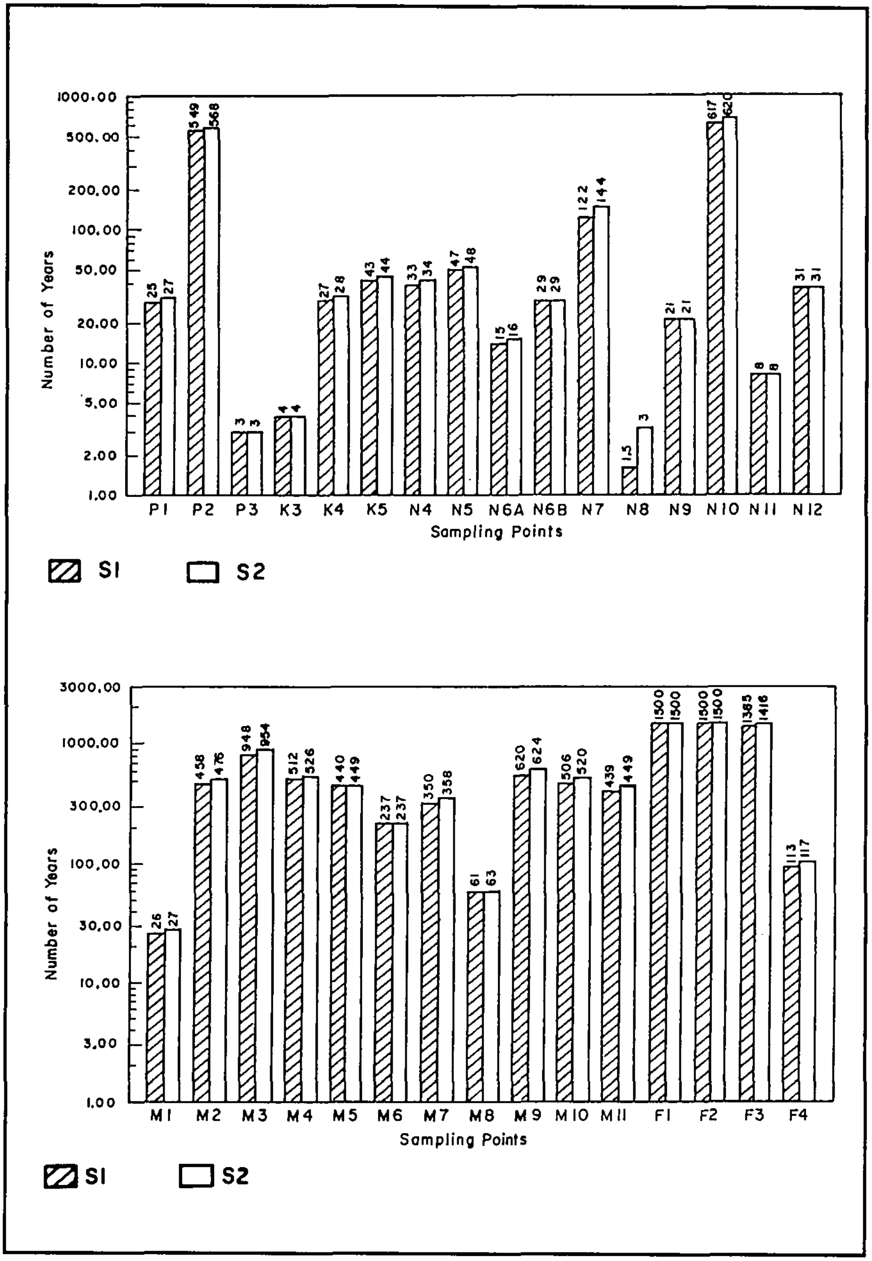

Figure 3. The number of years to reach pH = 6.0 as calculated by mechanistic modeling approach. S1 = Existing conditions, S2 = When the industries comply with the standards.

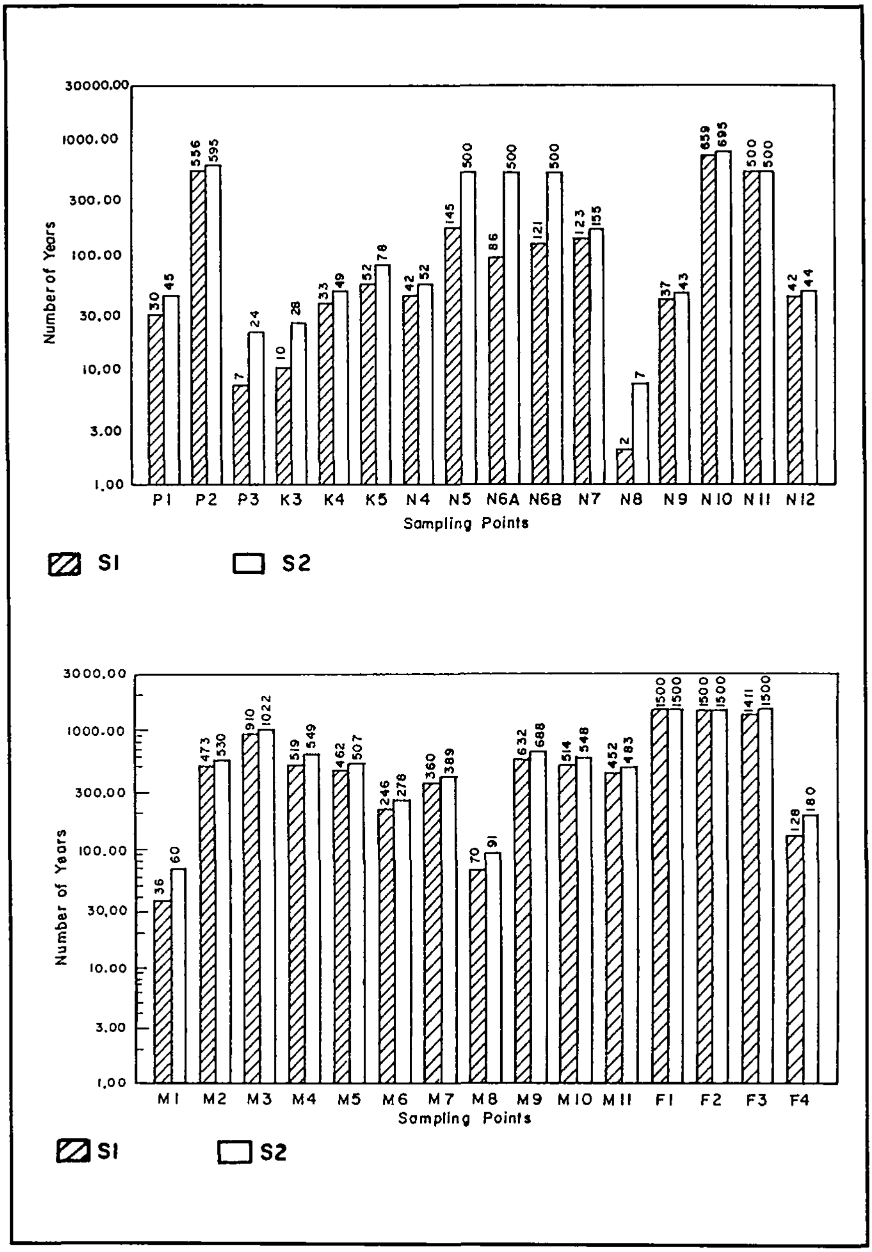

Figure 4. The number of years to reach pH = 5.5 as calculated by mechanistic modeling approach. S1 = Existing conditions, S2 = When the industries comply with the standards.

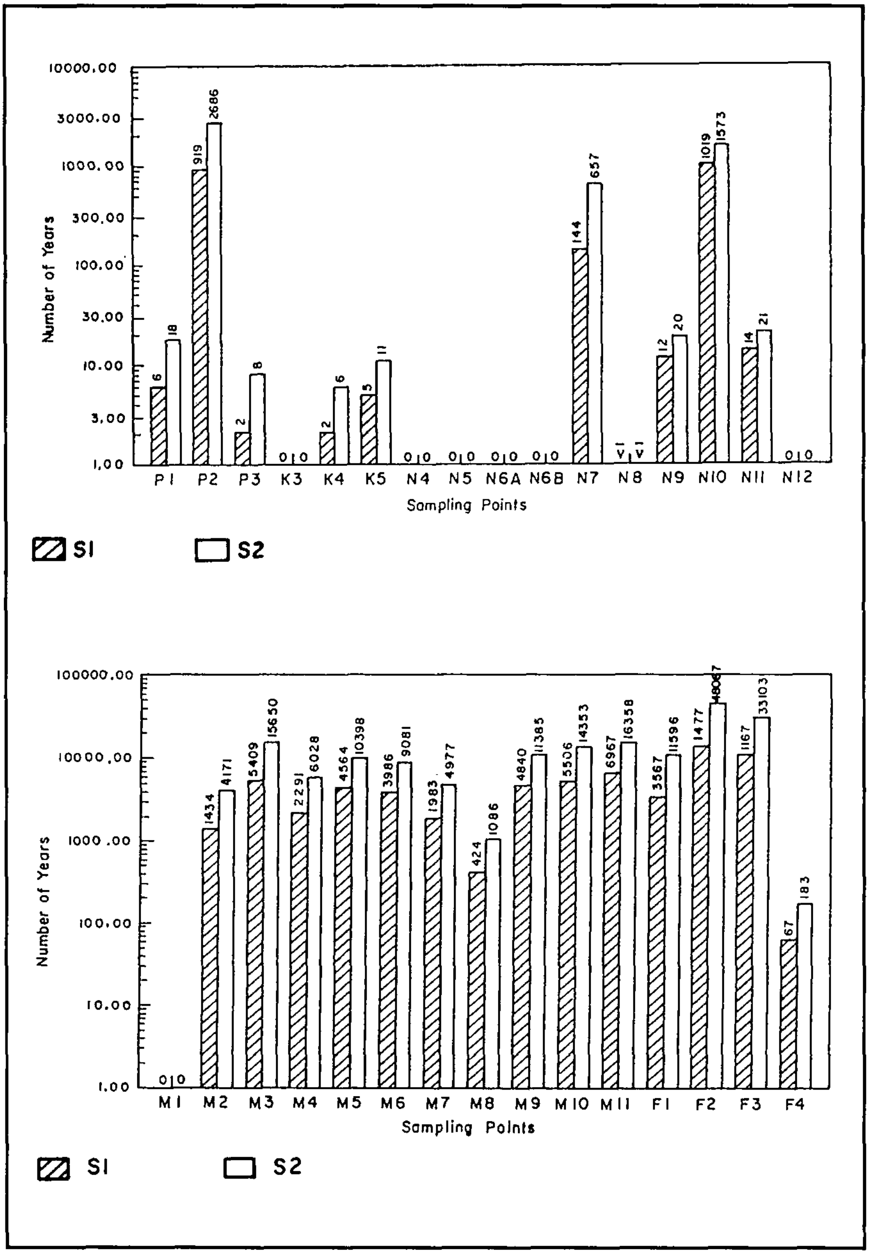

Figure 5. The number of years to reach pH = 6.0 as calculated by acid buffering curves approach. S1 = Existing conditions, S2 = When the industries comply with the standards.

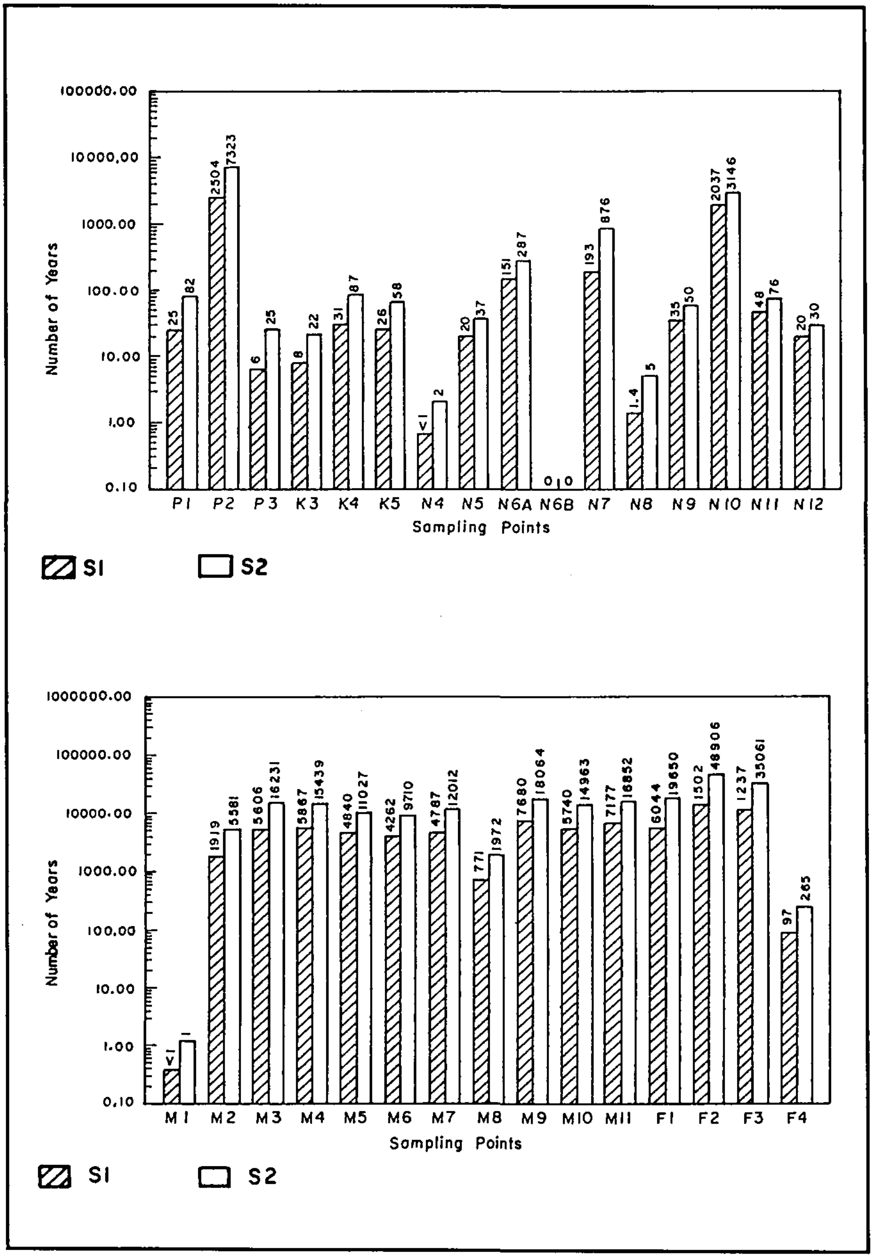

Figure 6. The number of years to reach pH = 5.5 as calculated by acid buffering curves approach. S1 = Existing conditions, S2 = When the industries comply with the standards.

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Direct reprint requests to:

Selçuk Soyupak
Environmental Engineering Department
Middle East Technical University
06531, Ankara, Turkey