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THE REPUBLIC OF TURKEY

THE STUDY ON ANKARA AIR POLLUTION CONTROL PROJECT

FINAL REPORT

JANUARY 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request of the Government of the Republic of Turkey, the Government of Japan decided to conduct a Feasibility Study on Ankara Air Pollution Control Project and entrusted the Study to the Japan International Cooperation Agency (JICA).

The JICA sent to Ankara a preliminary survey team, headed by Mr. Masaaki Sakurai in March and July in 1983. The team had a series of discussions on the Study with the officials concerned of the Government of Turkey and agreed on the Scope of Work (S/W), which was signed in August 1984 between JICA and the General Directorate of Environment (GDE) of Turkey.

Based on the S/W, JICA dispatched to Ankara a survey team, led by Dr. Shigeru Ikai, which made a full-scaled survey, in consultation with the Turkish side from November 1984 to January 1986, and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of Turkey for their close cooperation extended to the team.

January, 1986

Keisuke ARITA
President
Japan International Cooperation Agency

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CHAPTER 1 INTRODUCTION

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The City of Ankara became the capital of the Republic of Turkey in 1923. Since then, the City has been undergoing a continual development as the administrative center of the Republic. The population of the City has grown from 120,000 in 1935 to about 2 million at the present. The remarkable development of the City, however, has been accompanied by the growth of air pollution. The extent of the pollution in winter has been pronounced especially since the late 1960's. Causes of the air pollution in Ankara can be summarized into the following three factors:

(1) Lignite containing high levels of sulfur and ash is used as a major fuel for domestic heating.

(2) Consumption of the lignite has been increasing corresponding to the increase in the city population.

(3) Under the topographic and the meteorological conditions of Ankara which is situated in a basin on the Anatolian Plateau, a ground level inversion or a low-level inversion lid is apt to form in winter, that prevents a sufficient degree of dispersion of air pollutants over the upper atmosphere.

Public and private sectors in Turkey have been working in cooperation in order to abate the air pollution of Ankara as well as other environmental problems. In August 1978, the Undersecretariat of Environment (UE) was established under the Prime Minister's Office with the mandate of developing necessary regulations and policies for promoting rational use, protection, and improvement of air and water resources and for taking necessary measures for abatement of environmental pollution. In August 1983, Environment Law was enacted providing the legal basis to govern the arrangements to be made and the measures to be taken in order to protect and improve the environment; to protect and make optional use of land and natural resources in rural and urban areas; to prevent water, soil and air pollution; and to develop and guarantee the standard of health, civilization, and living of the present and future generations by preserving the nation's plant and animal life and its natural and historical wealth. In June 1984, the UE was reorganized as the General Directorate of Environment (GDE) again under the Prime Minister's Office. As its mandate indicates, to develop and to implement necessary measures to abate air pollution in cooperation with the various governmental and non-governmental agencies and institutions is one of the major tasks of the GDE.

Combatting against the air pollution of Ankara, Turkey has been devoting itself to studying, developing, and implementing various control measures, at times accomodated with loans from abroad. However, the quality of ambient air in Ankara has not been improved yet to a satisfactory level, and the abatement efforts are being continued.

Under these circumstances, the Turkish Government requested a technical cooperation for the abatement of the air pollution in Ankara to the Government of Japan where great degrees of improvement were realized in the qualities of air that were once degraded to critical levels in some areas.

Accepting the request, Japan International Cooperation Agency (JICA), which is the official body to execute the overseas technical cooperation programs, dispatched a contact mission to Ankara in March 1983. JICA dispatched the second mission in July 1983 to discuss the content of the draft of "Scope of Work for the Study on Ankara Air Pollution Control Project in Turkey" (S/W) with the Turkish authorities coordinated by the UE. Since then, Turkish and Japanese governments fostered better understanding on the execution of this study through the diplomatic channel, and the S/W was formally signed between JICA and GDE in August 1984. JICA promptly organized an advisory committee and a study team (JICA team, collectively) to conduct the Study on Ankara Air Pollution Control Project (hereinafter called as "the Study"). The Turkish Government also set up the Turkish Technical Committee (TTC) mainly constituted by the staff of the GDE. In November 1984, the TTC and the JICA team discussed in Ankara on the content of the Inception Report prepared by the JICA team. The Study was started immediately following the agreement between both parties on the details of methodologies of the Study.

1.2 OUTLINE OF THE STUDY

1.2.1 Scope of the Study

The main purpose of the Study is to present a medium-term abatement plan against the air pollution problem in Ankara. To reach this goal, the following investigations and analyses were conducted:

(1) Field observation and analysis of ambient air quality, meteorology, and related matters to evaluate the present state of air pollution

(2) Investigation of sources and quantities of air pollutants

(3) Study of the present state of air pollution control measures adopted in Ankara

(4) Study of the present socio-economic conditions related to the air pollution in Ankara, and their future projection

(5) Technical and economic study of various air pollution control measures that can be employed in Ankara

(6) Selection of reasonable combinations of source control measures to constitute a mid-term and a temporary plans and an emergency plan considering the socio-economic conditions in Ankara

(7) Evaluation of the effects of the control plans by air quality simulation models

(8) Study and proposal of air quality monitoring system and organization

Air quality indicators considered in the Study are sulfur dioxide (SO_2) and particulate matter (PM).

The study area covered Ankara Metropolitan Municipality boundary placing emphasis on the central part of the City.

1.2.2 Study Work Flow and Time Schedule

The Study was conducted in three phases, i.e., Phase I (November 1984 -March 1985), Interim Phase (April - May 1985), and Phase II (June - December 1985). The study work flow and the time schedule are shown in Figure 1.2.1 and Figure 1.2.2, respectively.

1.2.3 Study Organization

The Study was carried out in close cooperation between JICA and GDE. JICA organized the Advisory Committee and the Study Team, and GDE organized the Turkish Technical Committee (TTC). Members of these teams are listed below.

(1) JICA Advisory Committee

Name	Field in Charge	Present Post
Mr. Tamotsu Tsuyuki	Chairman	Assistant to Director General of Air Quality Bureau, Environment Agency
Mr. Osamu Ikeda	Air Quality Monitoring and Analysis	Deputy Director of Planning Division, Air Quality Bureau, Environment Agency
Mr. Shozo Shibata	Air Pollution Control	Director of Pollution Control Division, Dept. of Living Environment, Hokkaido Government
Mr. Makoto Okazaki	Air Pollution Control Administration	Director of Pollution Control Division, Dept. of Environment and Health, Niigata Prefectural Government
Mr. Mitsuo Kinjo	Planning and Coordination	Senior Project Officer, Japan International Cooperation Agency

Note: Mr. Tokuhisa Yoshida was in charge of air quality monitoring and analysis until February 1985.

(2) JICA Study Team

Name	Field in Charge	Firm
Dr. Shigeru Ikai	Team Leader/Heating System	JEAC
Mr. Hideo Ohmori	Sub-Leader/Regional Planning	PCI
Mr. Masao Kanekiyo	Sub-Leader/Source Control	JEAC
Dr. Akira Uchida	Air Pollution Control Planning	PCI
Mr. Kihachiro Urushibata	Energy Utilization Planning	PCI
Mr. Hiroshi Ueno	Combustion Facility Planning	JEAC
Mr. Motoji Katsuta	Measurement/Monitoring System	JEAC
Mr. Kazuyuki Yamakawa	Atmospheric Measurement	JEAC
Mr. Takamitsu Maida	Atmospheric Measurement	JEAC
Mr. Atsushi Aoki	Atmospheric Measurement	JEAC
Mr. Kunio Takeuchi	Measurement for Stationary Sources	JEAC
Mr. Kunitaka Nonaka	Economic Analysis & Evaluation	PCI
Mr. Shinji Wake	Air Quality Simulation Analysis	PCI
Mr. Eizo Ichikawa	Forecast System	JEAC
Mr. Minoru Hirao	Combustion Test	JEAC
Mr. Tsuyoshi Matsumoto	Socio-Economic Analysis	JEAC
Mr. Koichi Kitamura	Energy Development Analysis	JEAC
Mr. Reiji Niira	Lignite Quality Improvement	JEAC
Mr. Shozo Yatabe	Lignite Quality Improvement	JEAC

Note: PCI = Pacific Consultants International, Ltd.
JEAC = Japan Environmental Assessment Center, Ltd.

(3) Turkish Technical Committee (TTC)

Name	Field in Charge
Dr. Muzaffer EVIRGEN	Leader of TTC (Director General of GDE)
Dr. Ali Riza YILMAZ	Sub-leader of TTC (Head of the Department of Environmental Standards, GDE)
Dr. Kazim CEYLAN	Member of TTC (Head of the Department of Organization and Finance, GDE)
Dr. Tansu GURPINAR	Member of TTC (Expert of the Department of Research, Planning, and Coordination, GDE)
Miss A. Oznur OZER	Member of TTC (City Planner of GDE)
Miss Serpil GUNAY	Member of TTC (Physicist of GDE)
Mr. Mustafa YILDIRIM	Member of TTC (Mechanical Engineer of GDE)
Mrs. Canan YESILYURT	Member of TTC (the member from the Public Health Institute)
Mrs. Solmaz UTKU	Member of TTC (the member from the Ankara Metropolitan Municipality)
Mr. Alpaslan ERTUNA	Member of TTC (the member from the State Meteorological Works)
Mr. Mahmut AKKAS	Member of TTC (the member from the State Meteorological Works)
Mr. Yekta KARABIYIK	Member of TTC (Biologist of GDE)
Mrs. Sema ACAR	Member of TTC (Chemist of GDE)
Mrs. Nevin PAMUKCU	Member of TTC (Pharmacist of GDE)
Miss Bilgi YUCEL	Member of TTC (Environmental Enginner of GDE)

Note: Mr. Mehmet OZGUN was the leader of the TTC until February 1985.

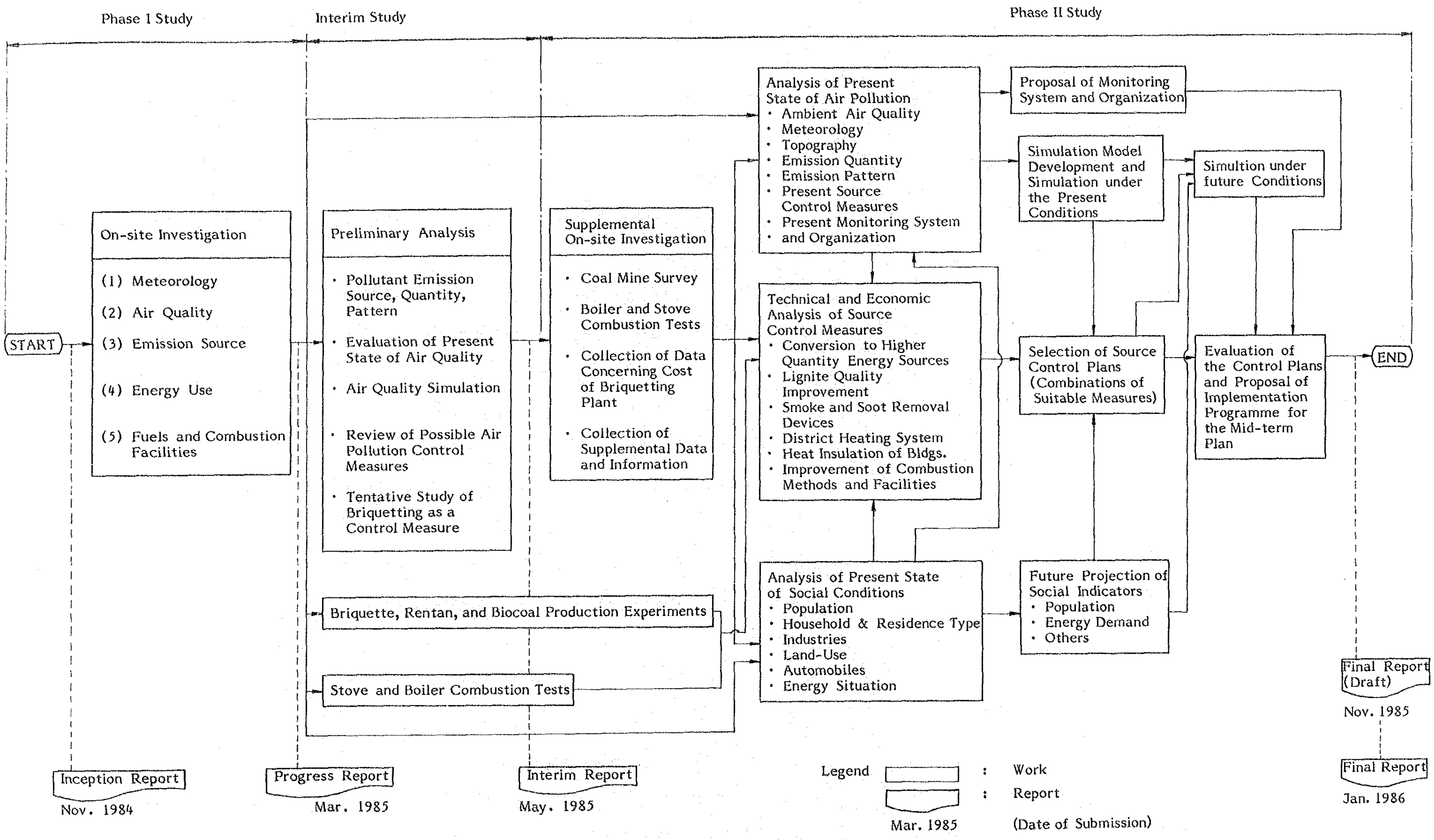
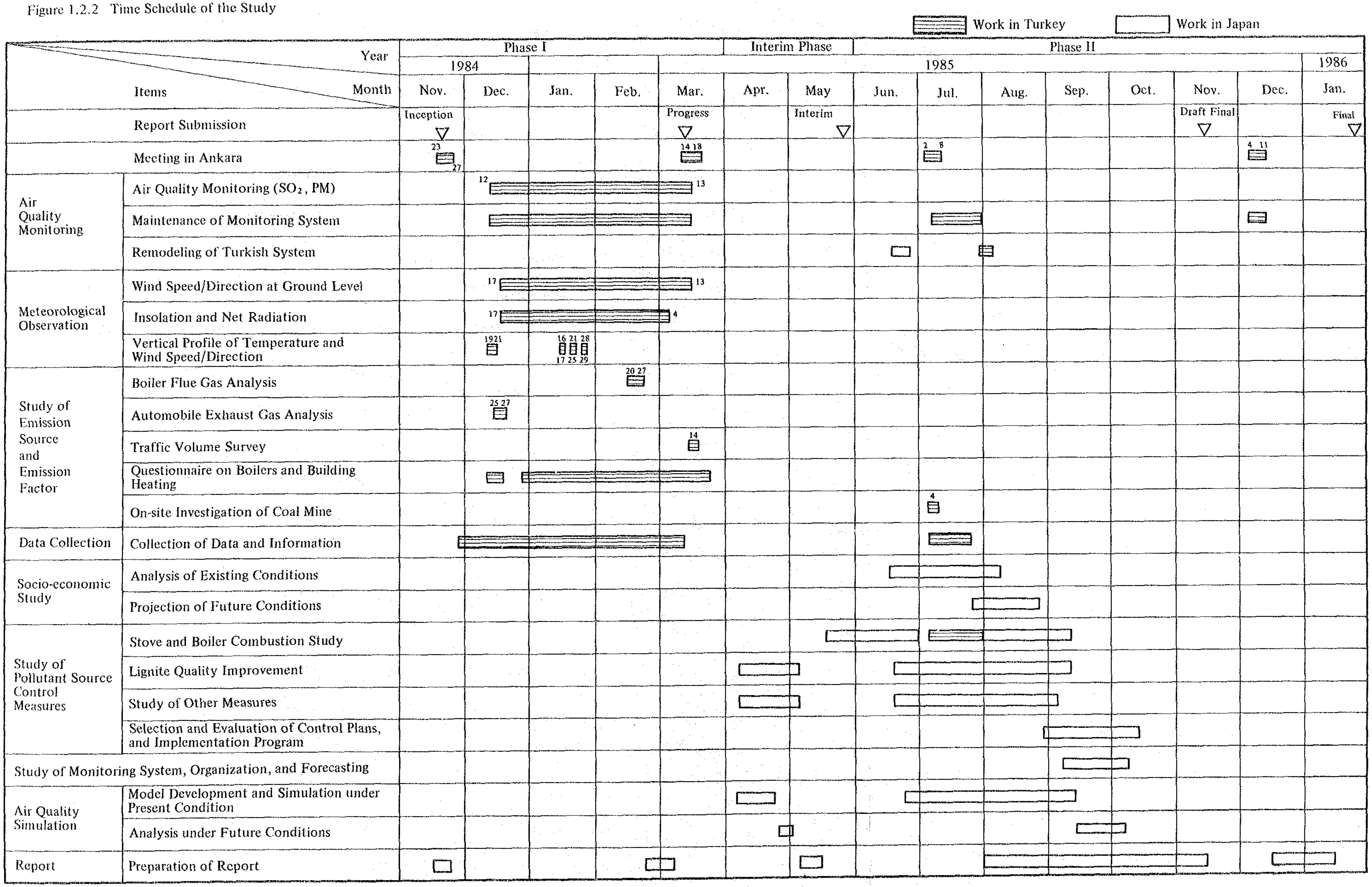


Figure 1.2.1 Study Work Flow

Figure 1.2.2 Time Schedule of the Study



1.3 GENERAL DESCRIPTION OF THE STUDY AREA

1.3.1 Geography

The City of Ankara is situated in lat. 40°N. and long. 33°E. occupying a central area of the Province of Ankara which holds a north-western part of the Central Anatolian Region (see Figure 1.3.1).

The City lies in a basin surrounded by the highlands over 1000m above the sea level. Average altitude of the basin is about 900m and that at the lowest part is about 750m. The City is expanding largely toward the west along the basin (see Figure 1.3.2).

1.3.2 Climate

Ankara's climate is characterized by hot and dry summers, cold and medium-wet winters. Annual precipitation is relatively small being about 370mm. However, spring and fall rains may cause floods. Temperature variation is large during a day and a year. The highest and the lowest temperatures in record are 40°C and -25°C, respectively. (See Table 1.3.1)

Among monthly average temperatures in Ankara, the highest is 23.2°C in July, and the lowest is -0.2°C in January. Mean number of days with minimum temperature being -10°C or less is 10 in a year, and mean number of days with maximum temperature being 0°C or less is 15 in a year.

Annual frequencies of major wind directions in order of high frequency are NE(23.0 %), N(17.0 %), NNE(12.8 %), SW(11.5 %) and W(6.0 %). The directions between N and NE dominate during a year with the total frequency of 54%. Mean wind speeds in various directions are around 3m/sec.

As to humidity, annual mean relative humidity of 60 % and the winter average of about 75 % are rather high considering the relatively small quantity of precipitation. Foggs are prone to set in during winters with appearance on 5 days per month.

Legend

Central Anatolian Region

Ankara Provionce

Ankara City

Figure 1.3.1 Location of Ankara

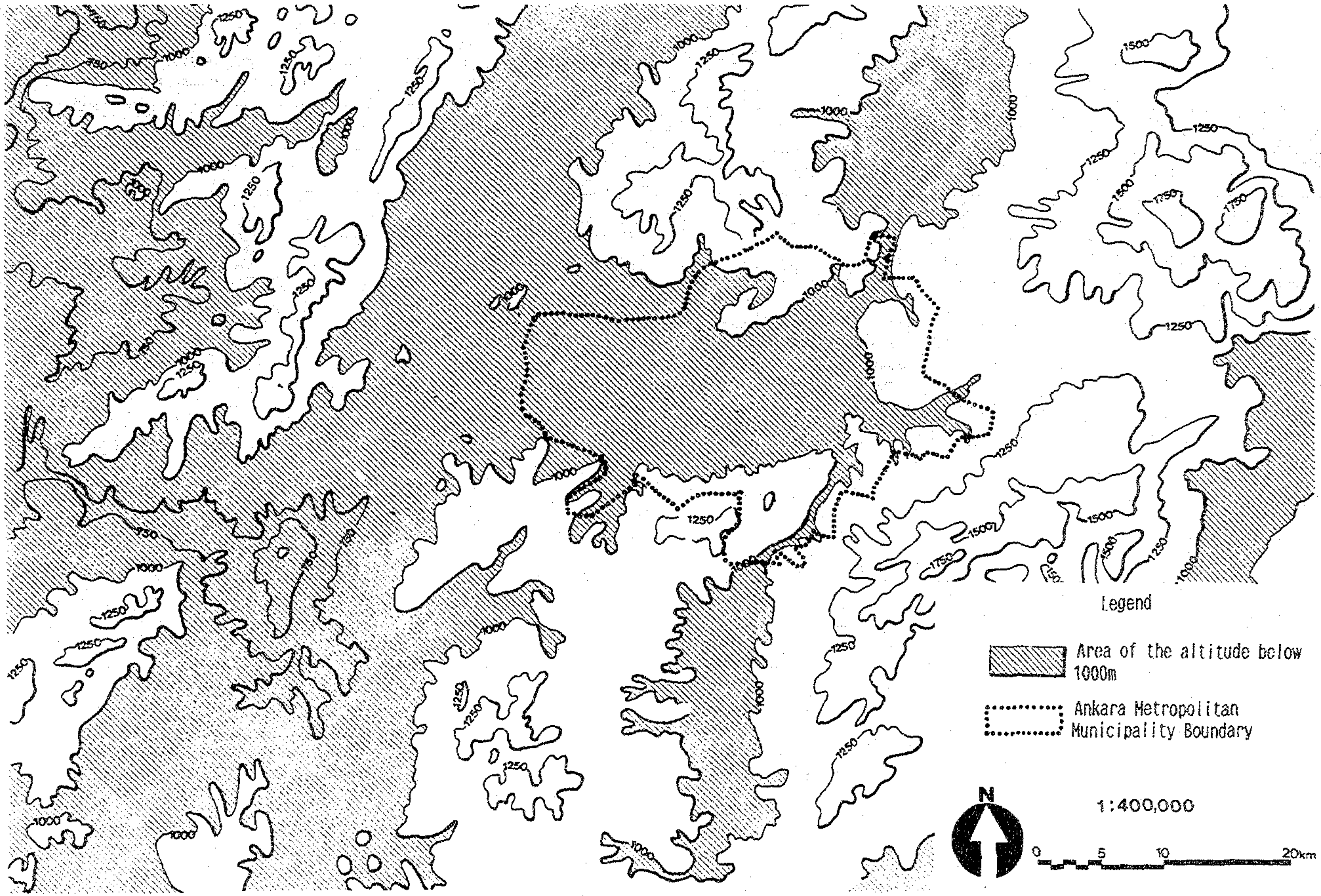


Figure 1.3.2 Topographical Sketch Around Ankara

Table 1.3.1 Monthly Averaged Meteorological Data in Ankara

Altitude: 894m
Latitude: 39° 57'N.
Longitude: 32° 53'E.

Item	Observation Period (yrs)	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean Temperature (°C)	55	-0.2	1.2	5.3	11.1	16.0	19.9	23.2	23.1	18.3	12.9	7.5	2.3	11.7 (mean)
Extreme Maximum Temperature (°C)	57	16.4	20.4	28.5	31.6	34.4	36.4	38.8	40.0	35.7	33.3	25.3	20.4	40.0 (max)
Extreme minimum temperature (°C)	57	-24.9	-24.4	-16.3	-7.2	-1.6	3.8	4.5	5.5	-1.5	-5.3	-17.5	-24.2	-24.9 (min)
Mean number of days with max. temp. 30°C or more	45	-	-	-	0.2	1.2	5.7	16.1	17.4	5.0	0.3	-	-	45.9 (total)
Mean number of days with min. temp. -0.1°C or less	45	6.0	4.7	0.7	-	-	-	-	-	-	-	0.2	0.3	14.7 (total)
Mean number of days with min. temp. -10°C or less	45	3.9	3.1	1.0	-	-	-	-	-	-	-	0.2	1.5	9.7 (total)
Mean relative humidity (%)	55	78	74	65	58	57	50	43	41	47	57	70	78	60 (mean)
Mean precipitation (m)	55	39.7	35.5	35.6	38.4	52.1	31.7	12.6	9.0	18.5	23.1	28.7	46.5	371.6 (total)
Mean number of days with precipitation	55	12.8	11.6	10.9	10.6	12.2	8.1	3.4	2.1	4.2	6.4	7.8	12.4	102.4 (total)
Mean number of days with snow	55	9.2	6.8	1.8	0.2	-	-	-	-	-	-	0.4	3.9	22.3 (total)
Average hours of sunshine (hr.min)	53	3.10	4.04	5.31	6.59	9.04	11.04	12.25	11.43	9.37	7.14	5.15	2.55	7.25 (mean)
Mean number of days with fog	45	5.6	3.7	2.9	1.8	0.4	0.3	0.2	0.1	0.4	1.4	3.9	5.1	25.7 (total)
Mean wind speed (m/s)	42	3.2	3.4	3.6	3.6	3.1	3.2	3.6	3.6	3.1	2.8	2.7	2.9	3.2 (mean)
Wind direction with highest frequency	22	NE	N	NE	NE	NE	N	NE	NE	NE	NE	NE	NE	NE

Source: 1). Statistical Yearbook of Turkey 1983.
2). General Directorate of State Meteorological Works.

1.3.3 Population

Population of Ankara City, Ankara Province and the whole Turkey in the past census years are shown in Table 1.3.2. Population of the City had been increasing with accelerated rates until 1975. However, the rate of increase dropped after that through 1980. Present population of the City is considered to be about 2.1 million.

Table 1.3.2 Population (1935 - 1980)

Year	Ankara City (persons)	Ankara Province (persons)	Turkey (persons)
1935	122,270	534,025	16,158,018
1940	157,242	602,965	17,820,950
1945	226,712	695,526	18,790,174
1950	288,536	819,693	20,947,188
1955	451,241	1,120,864	24,064,763
1960	650,067	1,321,380	27,754,820
1965	905,660	1,644,302	31,391,421
1970	1,236,152	2,041,685	35,605,176
1975	1,701,004	2,585,293	40,347,719
1980	1,877,755	2,854,689	44,736,957

Source: (1) Population and Employment Projection for Ankara, 1976
(2) Census of Population - Social and Economic Characteristics of Population, Province: 06-ANKARA, 1970, 1975, 1980
(3) Census of Population - Social and Economic Characteristics, 12.10.1980

1.3.4 Industry

Industrial characteristics of Ankara can be inferred from the sectoral distribution of employment shown in Table 1.3.3.

Table 1.3.3 Sectoral Distribution of Employment in Ankara in 1970

Sector	Employment	Percent
Agriculture	17,800	4.51
Manufacture	53,597	13.52
Construction	27,487	6.93
Communications	26,048	6.57
Trade	33,364	8.41
Services, etc.	238,112	60.05
Total	396,508	100.00

Sixty percent of total jobs in 1970 were in the sector of service and others, and about a half of them were in the government and related activities.

Major factories existing in Ankara includes a cement plant, a sugar factory, an agricultural tractor factory, a gunpowder factory, and two city-gas plants.

CHAPTER 2 ANALYSIS OF THE PRESENT STATE OF AIR POLLUTION

CHAPTER 2 ANALYSIS OF THE PRESENT STATE OF AIR POLLUTION

2.1 OUTLINE OF THE FIELD INVESTIGATION STUDY

In order to understand, on the quantitative basis, the degree of air pollution in Ankara in the winter season and to clarify the primary causes of the pollution, field investigation study was carried out. Outline of the study is described below.

2.1.1 Items and Periods of the Field Investigation

Items and time periods of the investigation are shown in Table 2.1.1. The time schedule of the investigation was shown in Figure 1.2.2 in Chapter 1 as a bar-chart.

Table 2.1.1 Items and Periods of the Field Investigation

Gategory	Investigation Item	Time Period	Remarks
Ambient Air Quality Monitoring	sulfur dioxide (SO_2)	Dec.12, 1984 - Mar.13, 1985	7 stations
	particulate matter (PM)	same as abobe	3 stations
Meteorological Observation	wind speed/direction at ground level	Dec.17, 1984 - Mar.13, 1985	2 stations
	insolation and net radiation	Dec.19 - 21, 1984	1 station
	vertical profiles of air temperature and wind speed/direction (upper layer meteorological observation)	Dec.19 - 21, 1984 Jan.16 - 17, 1985 Jan.21 - 25, 1985 Jan.28 - 29, 1985	1 station 4 times
Emission Source Survey	boiler flue gas analysis	Feb.20 - 27, 1985	10 heating boilers
	automobile exhaust gas analysis	Jan.25 - 27, 985	4 types 10 automobiles

(to be continued)

Table 2.1.1 (continued)

Gategory	Investigation Item	Time Period	Remarks
Emission Source Survey	traffic volume survey	Mar.14, 1985 (16 hours)	5 stations 3 types 2 ways
	on-site questionnaire at boiler rooms	Dec.12 - 20, 1984	100 samples
	questionnaire on residential heating	Dec.24, 1984 - Mar.18, 1985	737 samples

2.1.2 Location and Characteristics of the Investigation Sites

(1) Location of the Investigation Sites

Locations for the ambient air quality monitoring, meteorological observation, and traffic volume survey were determined as shown in Figure 2.1.1 after consultation with GDE. Names of the stations and observation items are shown in Table 2.1.2.

Table 2.1.2 Station Names and Investigation Items

Station Name	Investigation Items
Yenimahalle	SO_2
Tandogan	SO_2, WD/WS
Cebeci	SO_2
Bahcelievler	SO_2, PM
Sihhiye	SO_2, PM
Kavaklidere	SO_2, PM, WD/WS
Cankaya	SO_2
Meteorological Agency	Insolation, Net radiation, Vertical profiles of air temperature and WD/WS (upper-layer meteorological observation)
① Dormitory	Trafic Volume Survey • 16 continuous hours • classified into three types of cars • two-way traffic count
② EGO	
③ MENR	
④ Opera House	
⑤ GDE	

Note: WD/WS = wind direction and wind speed

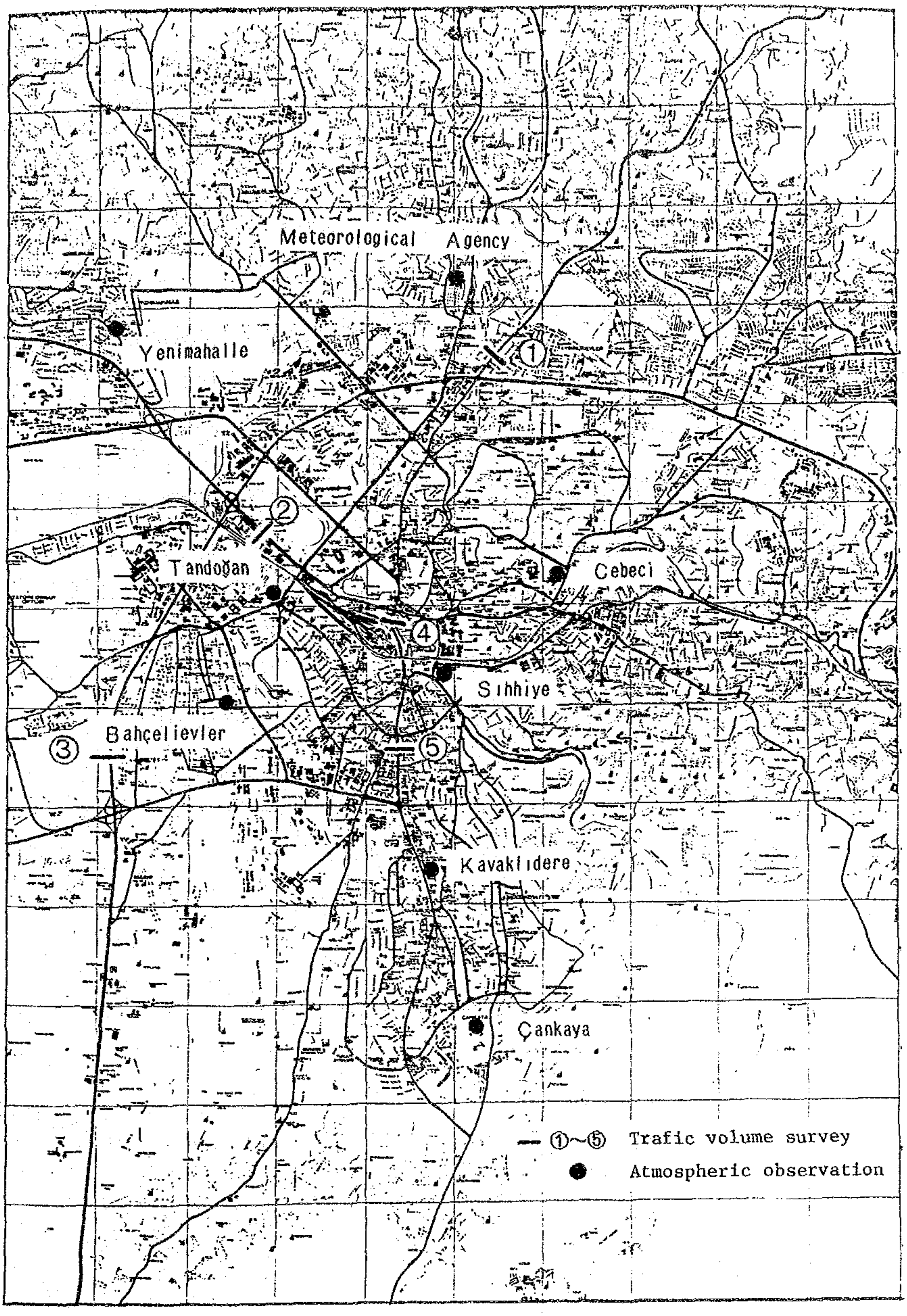


Figure 2.1.1 Location of Field Investigation

(2) Characteristics of Air Quality Monitoring Stations

Characteristics of seven stations for air quality monitoring selected from existing 15 stations within the City are as follows.

Cankaya station is situated in the southern part of the City at about 1000 m above the sea level.

Stations of Kavaklidere, Bahcelievler, Tandogan, and Sihhiye are located in the central part of the City along the bottom line of the basin. Altitudes of these stations are between 850 m and 950 m.

Yenimahalle station is situated in the residential area of about 6 km away in the north-east direction from the center of the City. There are no large stationary sources of pollutant emission except those of residential heating.

Cebeci station is located within the residential area at the western part of the City.

2.2 CHARACTERISTICS OF CONCENTRATION VARIATION AND FREQUENCY OF OCCURRENCE

2.2.1 Variation of Daily Mean Concentration

(1) Mean Concentration During the Monitoring Period

Arithmetic mean values of daily mean concentration of SO_2 and PM for the monitoring period are shown in Table 2.2.1. Daily mean concentration was computed averaging every one-hour value from 1 o'clock through 24 o'clock. When data were not obtained for more than 8 hours in a day, that day was excluded from the computation.

Table 2.2.1 Mean Concentration during the Monitoring Period

(unit: ppb)

Item	Station	Mean value	Standard deviation	Maximum	Minimum	Effective days
SO_2	YENIMAHALLE	176.8	102.9	431	42	85
	TANDOGAN	137.4	63.6	324	28	87
	CEBECI	146.3	91.6	458	18	87
	BAHCELIEVLER	355.4	139.4	757	103	87
	SIHHIYE	182.0	68.9	378	57	80
	KAVAKLIDERE	339.1	185.9	817	86	87
	CANKAYA	150.3	140.6	844	7	85
PM	BCHCELIEVLER	227.6	103.9	552	70	87
	SIHHIYE	159.4	84.4	488	60	76
	KAVAKLIDERE	175.0	109.5	535	43	79

Among the seven stations, Bahcelievler showed the highest mean concentration of SO_2 being 0.355 ppm, followed by Kavaklidere being 0.339 ppm. It was lower at Cankaya being 0.150 ppm, i.e., less than a half of those at the highest 2 stations. However, the overall maximum daily mean concentration of SO_2 occurred at Cankaya the value being 0.844 ppm. It is considered that the particular topographic characteristics of Cankaya station is responsible for the phenomenon.

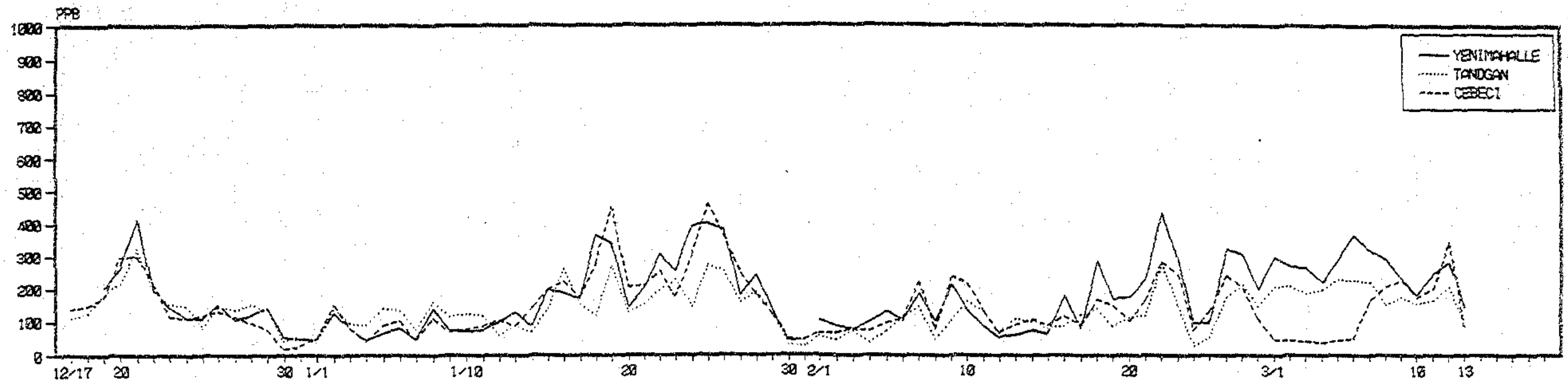
(2) Variation of Daily Mean Concentration

Time variation of daily mean concentration of SO_2 by stations is shown in Figure 2.2.1, and that of PM is shown in Figure 2.2.2.

High levels of SO_2 were observed at all the stations during the period around December 20, the period from the middle to the end of January, and the period from the end of February to the beginning of March. In Cankaya, especially high levels were observed in the beginning of March. Since high levels were also observed in this period at Kavaklidere located at the southern part of the central area of the City, it is considered that the pollutants detained in the bottom of the basin were blown up by the northern winds to the Cankaya area where the altitude is higher.

Daily variation of PM shows the same pattern as that of SO_2.

Figure 2.2.3 shows the daily variation of the ground-level air temperature observed at the Meteorological Agency, and indicates the occurrence of high SO_2 levels corresponding to the air temperature below $0^{o}C$.



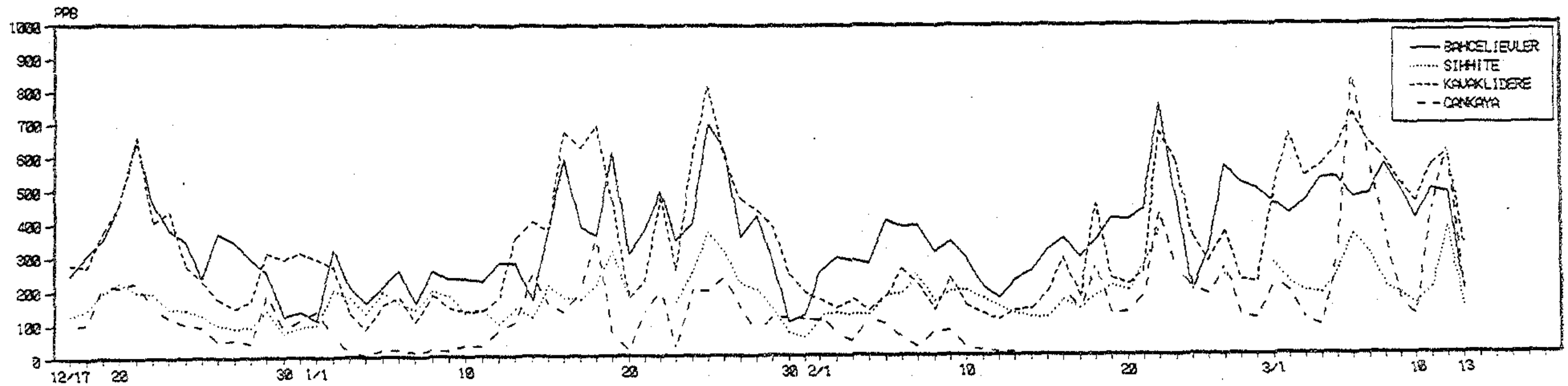


Figure 2.2.1 Time Variation of Daily Mean Concentration of SO_2

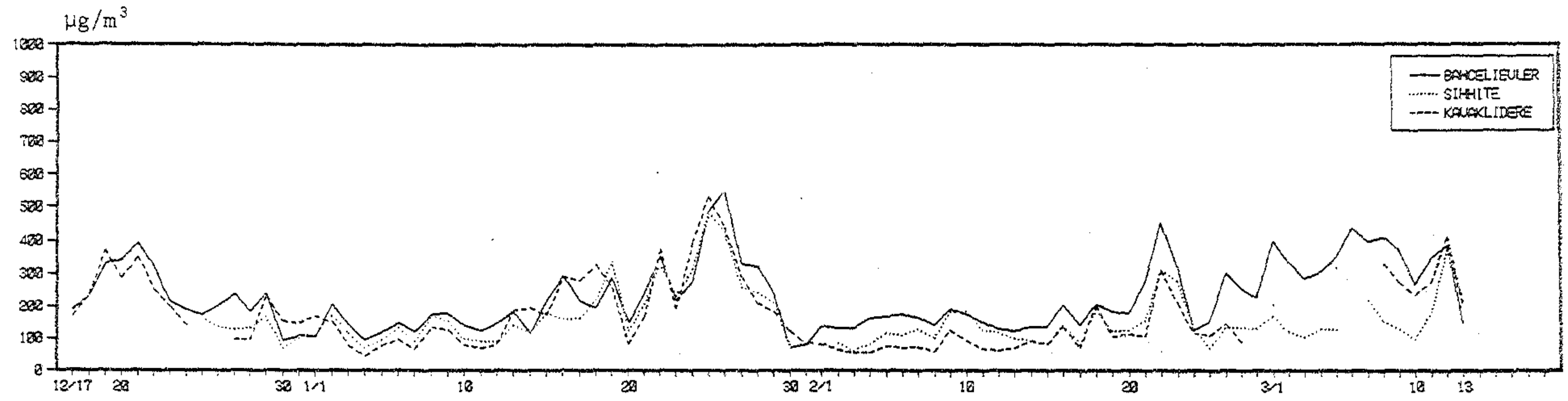


Figure 2.2.2 Time Variation of Daily Mean Concentration of PM

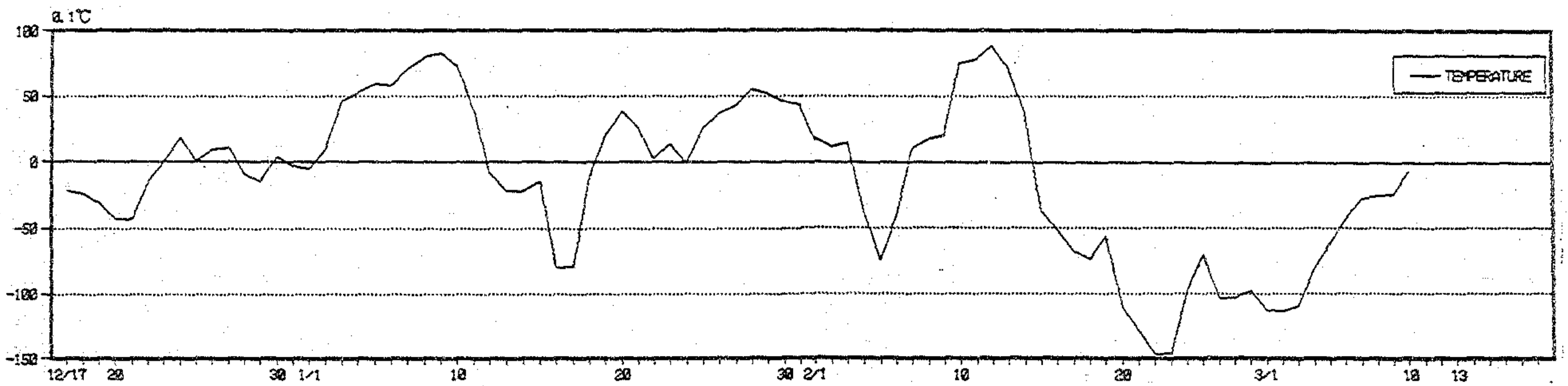


Figure 2.2.3 Time Variation of Daily Mean Air Temperature at the Ground Level

2.2.2 Hourly Variation Pattern

Hourly concentration of SO_2 averaged on each time of the day over the entire period of monitoring is shown in Figure 2.2.4, and that of PM is shown in Figure 2.2.5. The hourly variation patterns for both pollutants are similar having two peaks. This pattern corresponds well to that of time zones of combustion of boilers and stoves for heating indicating that exhaust gas emissions from these small-height sources are major causes of the air pollution. When primary sources of SO_2 emission are heigh stacks of factories as is the case in Japan, such a clear two-peak mode is not usually observed.

2.2.3 Distribution of Frequency of Occurrence of Daily Mean and Hourly Mean Values

In order to assess the degree and impact of air pollution it is necessary to know the frequency of occurrence of high pollutant levels which may affect human health even under the short-term exposure, as well as to know annual and seasonal average pollutant levels that may affect the health through the long-term exposure.

Figure 2.2.6 shows the cumulative frequency distribution curves (on logarithmic-normal probability paper) for daily mean values of SO_2 by stations, and Figure 2.2.7 shows the curves for hourly mean values of SO_2. Figure 2.2.8 shows those curves for PM. These curves are also called as P-C curves. If a P-C curve approximates to a straight line, distribution of occurrence of concentration is assumed to be logarithmic-normal distribution.

These Figures show that distributions of both daily mean and hourly mean values are approximately in logarithmic-normal at all the stations. In general, for the area where there are many small-height emission sources and few large factories the distribution of concentration levels corresponds relatively well to the logarithmic-normal, whereas the normal distribution or Weibull distribution conforms relatively well in the area where there are many large factories. From the fact that the monitoring results are in conformity with the logarithmic-normal distribution as seen above, it is obvious that the major cause of the air pollution in the winter in Ankara is a large number of small-height emissions from heating boilers and stoves.

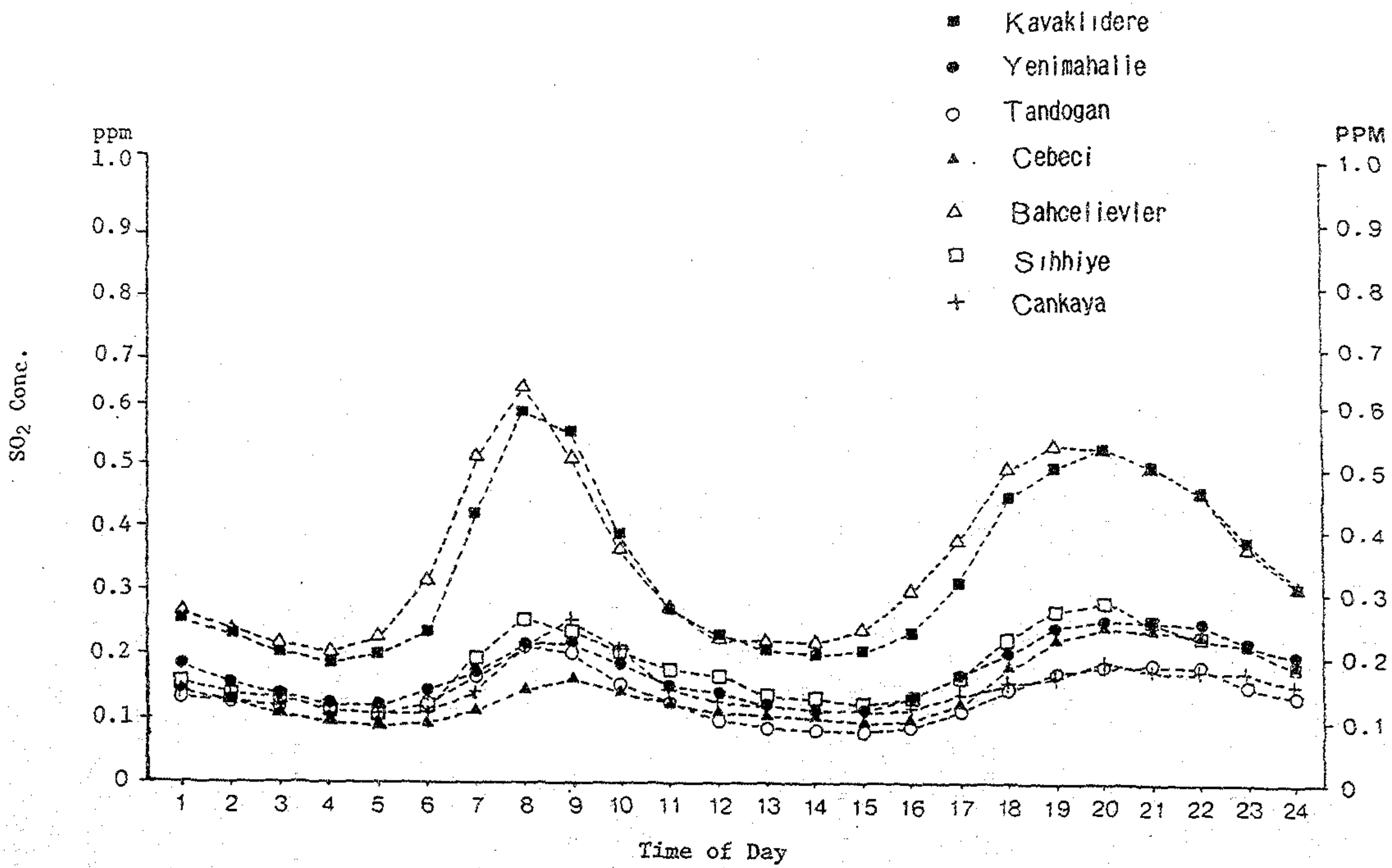


Figure 2.2.4 Daily Time-Variation Pattern of SO_2 Concentration

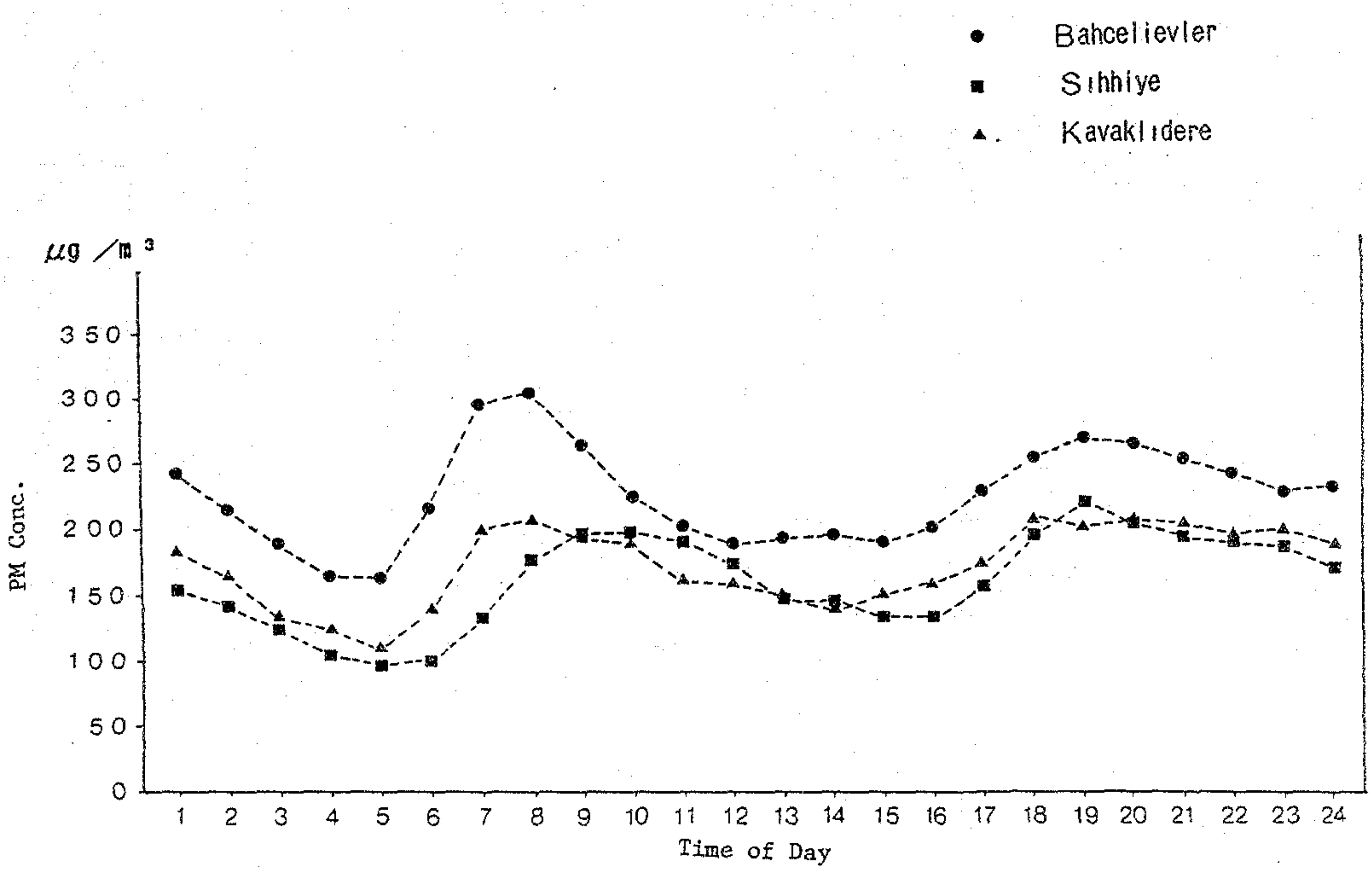


Figure 2.2.5 Daily Time-Variation Pattern of PM Concentration

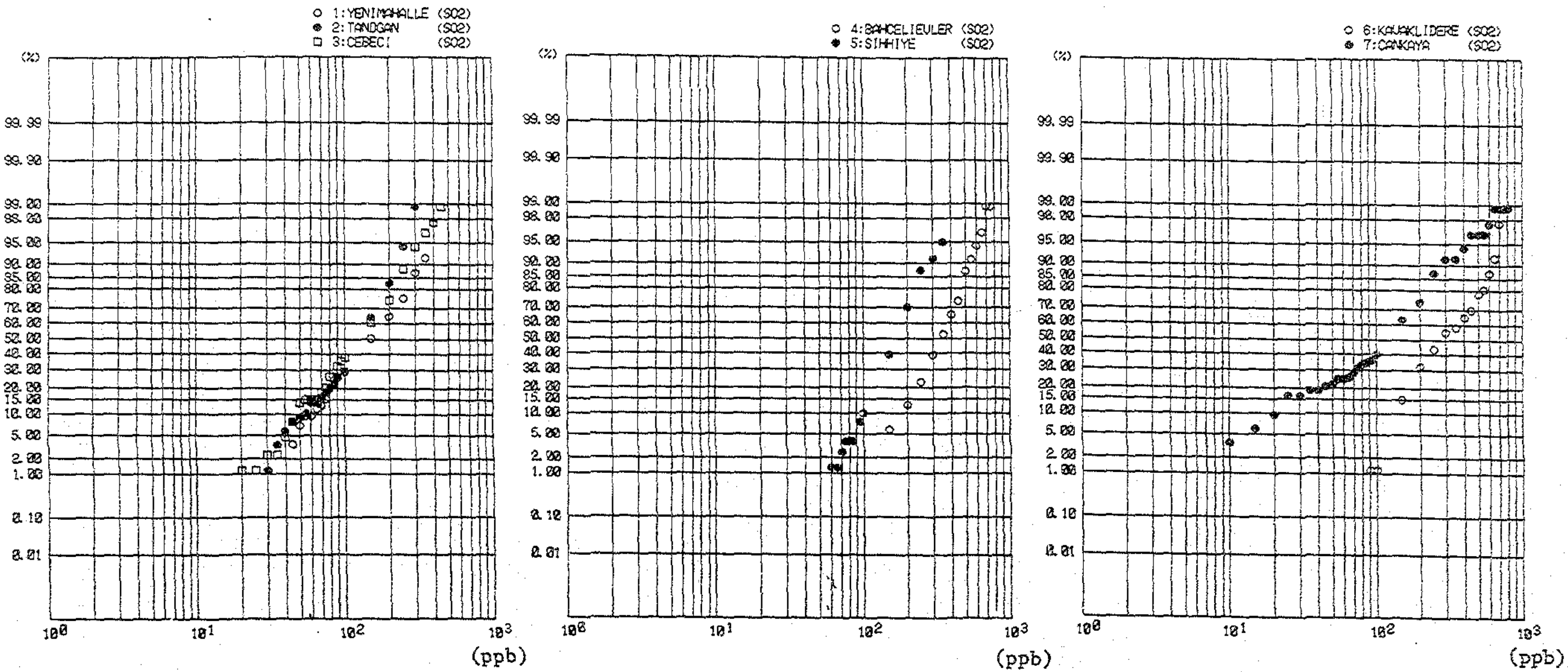


Figure 2.2.6 Cumulative Frequency Distribution Curve for Daily Mean Concentration of SO_2

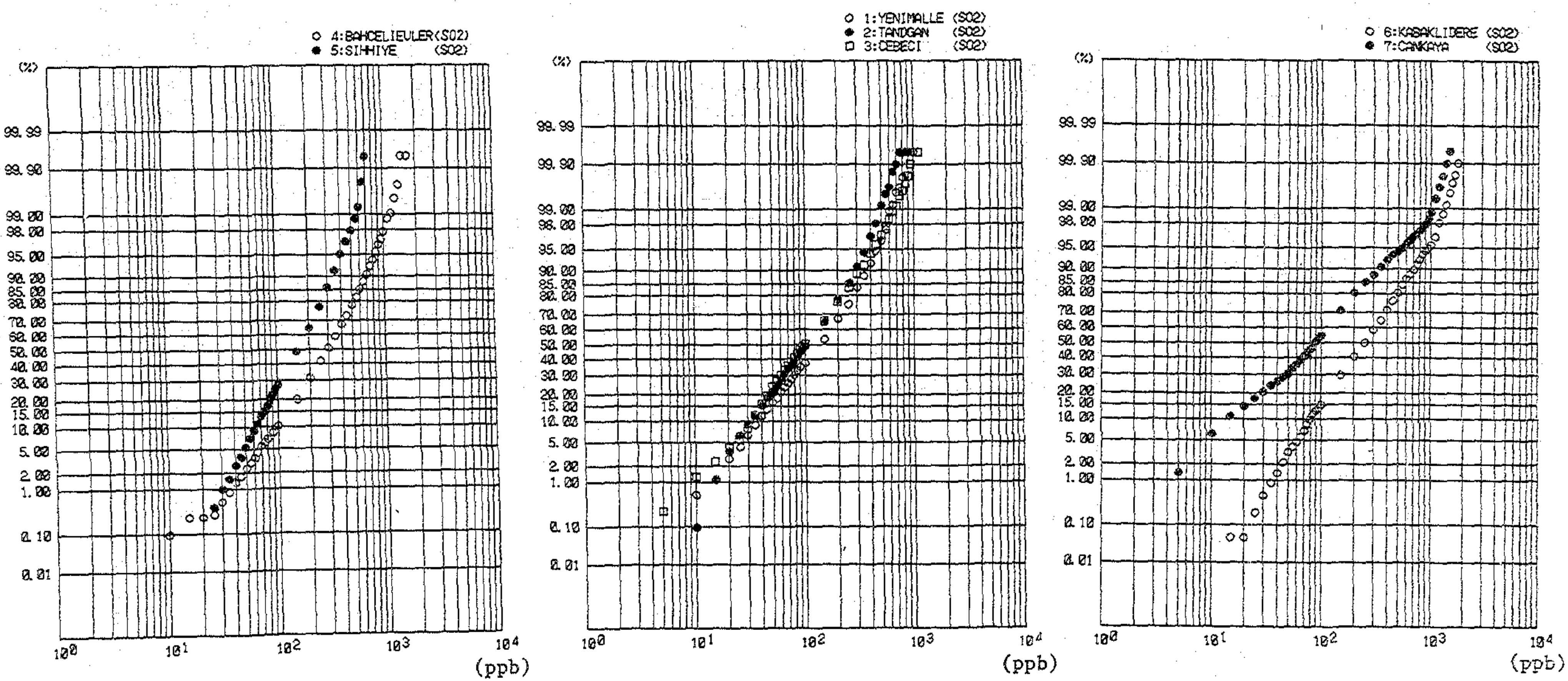
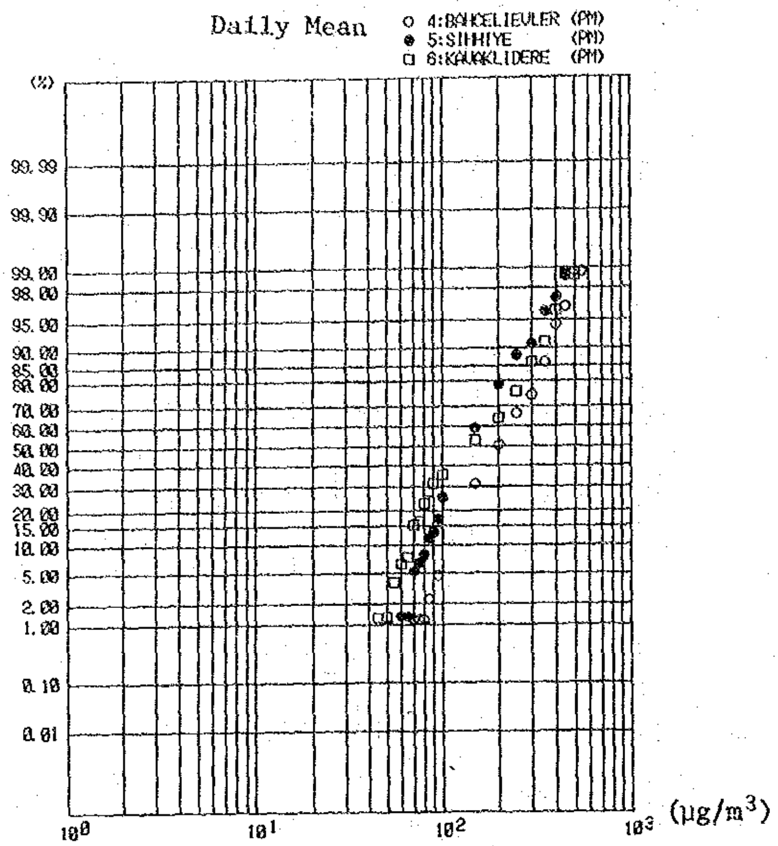


Figure 2.2.7 Cumulative Frequency Distribution Curve for Hourly Mean Concentration of SO_2



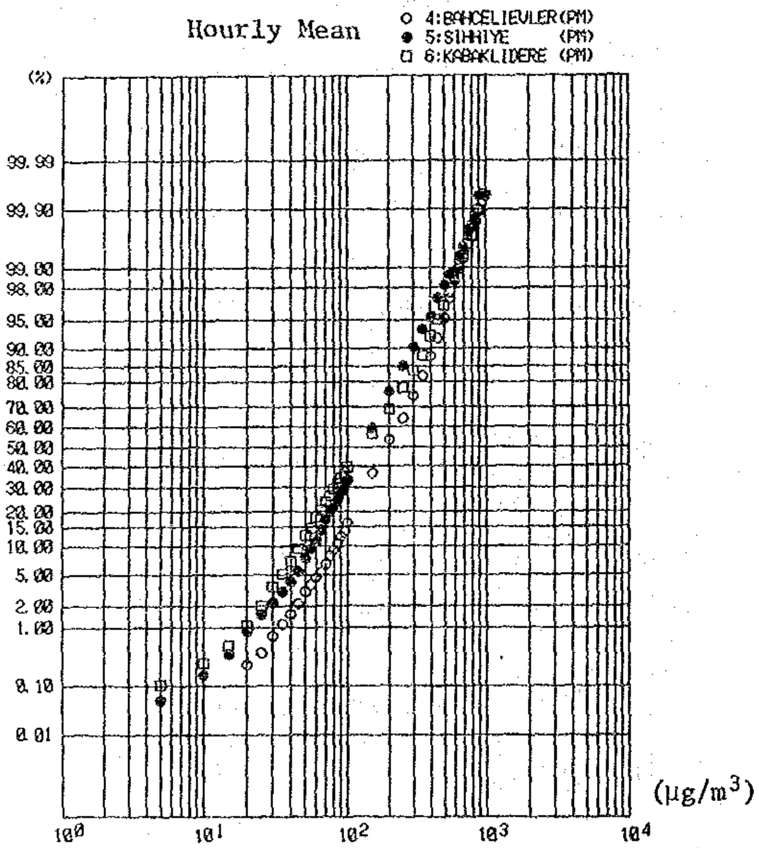


Figure 2.2.8 Cumulative Frequency Distribution Curve for PM

Slope of the P-C curve indicates the degree of scattering of concentration values. On the logarithmic-normal probability paper, the value obtained by deviding the 84% value by the 50% value corresponds to one geometric standard deviation. The station where this standard deviation is particularly large (slope of the straight line is small) is likely to be under influence of a particular emission source. Among the seven stations, the standard deviation is the largest at Cankaya. It may be caused by the convection of pollutants from the central part of the City at the time of particular wind direction.

2.3 CONCENTRATION VARIATION BY METEOROLOGICAL CONDITION

2.3.1 Meteorological Condition

Wind direction and wind speed were measured every hour at 2 stations, i.e., Tandogan and Kavaklidere. Data at Meteorological Agency in Ankara for the same period were also obtained. Wind roses at these three stations are shown in Figure 2.3.1.

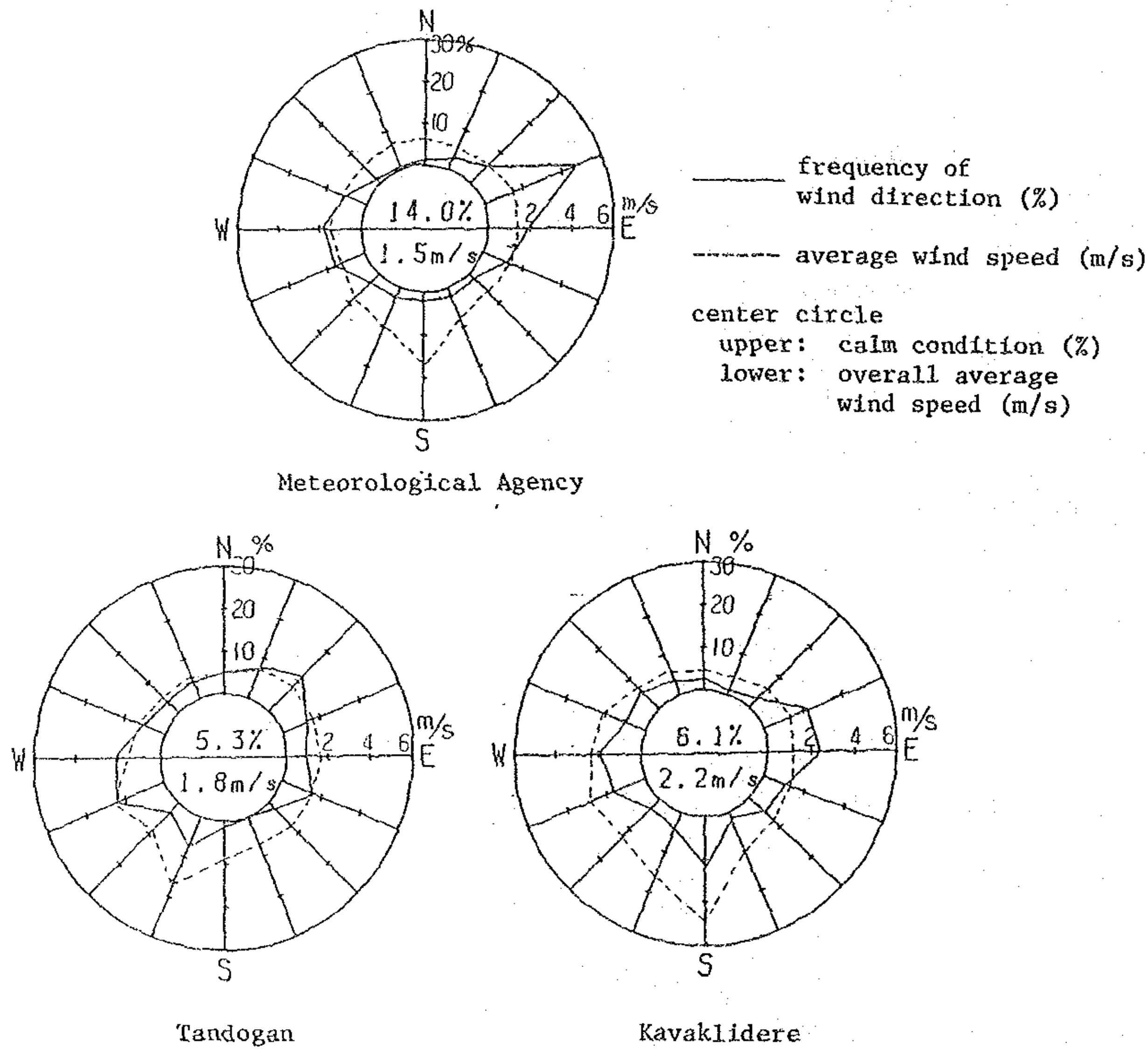


Figure 2.3.1 Wind Rose (Dec. 17, 1984 - Mar. 13, 1985)

Dominating wind direction is NE at Tandogan, E at Kavaklidere, and ENE at the Meteorological Agency. On the whole, eastern winds are dominating.

Average wind speed is relatively low in general. The speed tends to increase when S or SSW winds blow.

Based on the results of measurement of insolation and net radiation at the Meteorological Agency, atmospheric stability which indicates the dispersiveness of air pollutants in the atmosphere was classified according to the classification by Pasquill as shown in Table 2.3.1. The stability class A represents the extremely unstable condition of the atmosphere under which air pollutants can be dispersed extensively. Conversely, the stability class G represents the extremely stable condition under which air pollutants are not dispersed well.

Table 2.3.1. Pasquill's Classification of Atmospheric Stability

Wind Speed (m/s)	Insolation (T) $cal/cm^2 \cdot h$				Net Radiation(Q) $cal/cm^2 \cdot h$		
	$T \geq 50$	$50 > T \geq 25$	$25 > T \geq 12.5$	$12.5 > T$	$Q > -1.8$	$-1.8 \geq Q > -3.6$	$-3.6 \geq Q$
< 2	A	A-B	B	D	D	G	G
2 - 3	A-B	B	C	D	D	E	F
3 - 4	B	B-C	C	D	D	D	E
4 - 6	C	C-D	D	D	D	D	D
6 <	C	D	D	D	D	D	D

Note: 1) Net radiation is positive when its direction is upward from the ground. Although it is usually negative during the night, it occasionally becomes positive.

2) Average values for 10 minutes before the designated time are to be taken for both insolation and net radiation.

3) Insolation is used for daytime and net radiation is used for night-time in the classification.

4) Unit of $cal/cm^2 \cdot h$ is used for insolation and net radiation.

Generally, stability classes A - D prevail during daytime and the classes D - G prevail during night. The class A appears when insolation is large and wind speed is low, and the class G appears when a ground-level inversion is formed under the clear sky at night in winter.

Figure 2.3.2 shows the frequency of appearance of the stability classes. The class D (neutral) appeared most frequently at all the stations. Of other classes, frequency of appearance of B is high during the daytime and G is during the night.

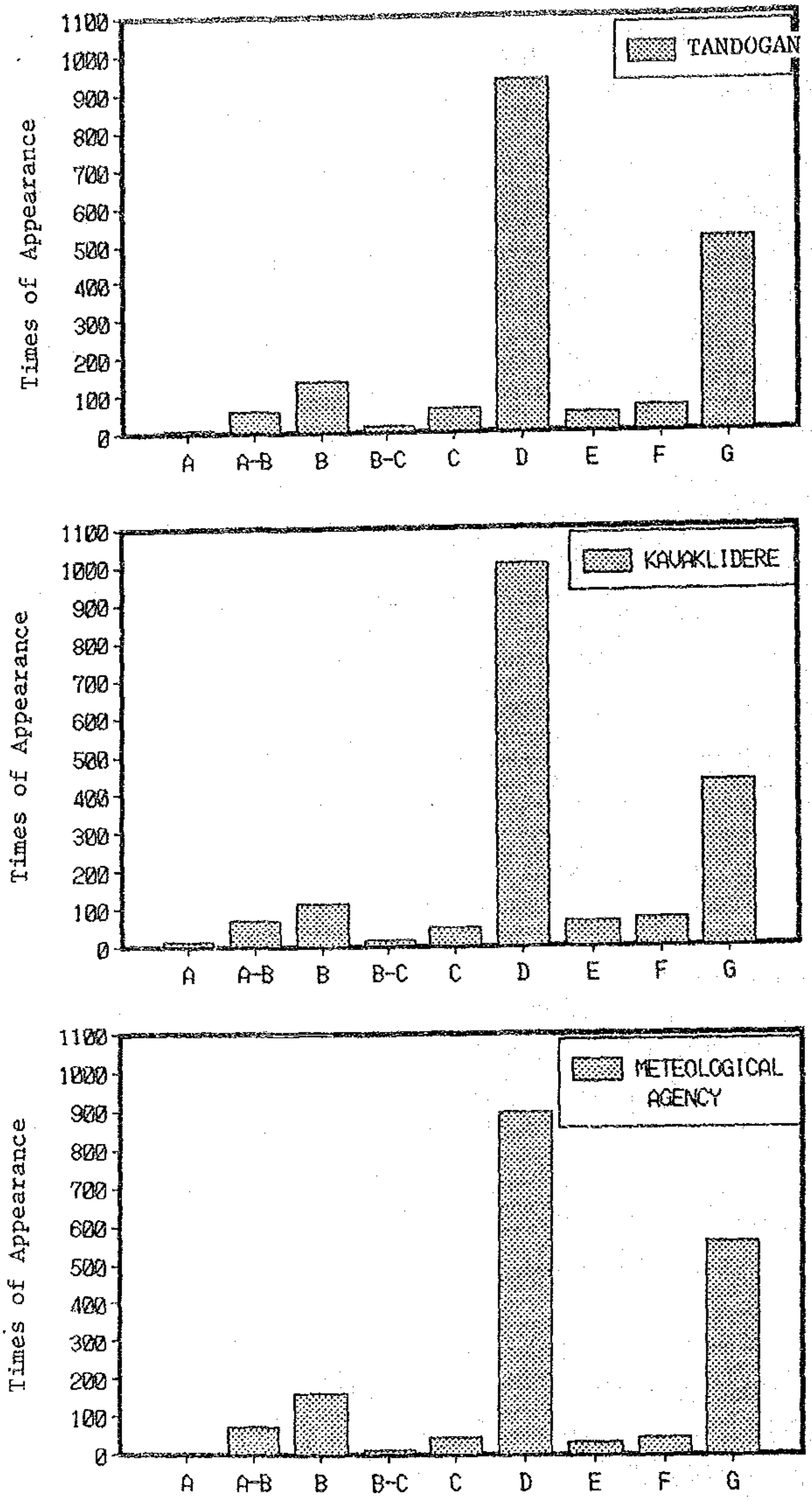


Figure 2.3.2 Frequency of Appearance of Stability Classes

Frequent appearance of G (extremely stable) suggests that the ground level or low-level inversions were often formed under the low or no wind condition due to the topographic characteristics as basin.

2.3.2 Variation by Wind Direction and Speed

Through the analysis of concentration characteristics at a station in relation to wind directions and wind speeds, locations of emission sources that affect the concentration at that station can be detected. Concentration values of SO_2 at the seven stations and PM at the three stations were cross-checked against wind direction and wind speed. The meteorological stations whose wind data were used for the cross-check of pollutant concentration are shown in Table 2.3.2.

Variation in average concentration of SO_2 by wind directions at each monitoring station is shown in Figures 2.3.3 (1) and 2.3.3 (2). And that of PM is shown in Figure 2.3.4.

Table 2.3.2 Combination of Meteorological Station and Air Quality Monitoring Station for Analysis

Air quality monitoring station	Meteorological station	Monitoring item
Yenimahalle	Meteorological Agency	SO_2
Tandogan	Tandogan	SO_2
Cebeci	Tandogan	SO_2
Bahcelievler	Tandogan	SO_2, PM
Sihhiye	Tandogan	SO_2, PM
Kavaklidere	Kavaklidere	SO_2, PM
Cankaya	Kavaklidere	SO_2

At the stations Yenimahalle, Bahcelievler, and Tandogan which are located to the northwest or west of the City center, high concentrations are observed when wind directions are between ESE and SSE. At Kavaklidere and Cankaya which are situated in the southern part of the City, high concentrations are observed when wind directions are between N and E. High concentrations appear at all the stations when winds blow from the direction of the City center. At Cebeci situated in the eastern part of the City, high concentration occurred also at the time of northwest wind. This is considered to be the influence of a large number of low-storied houses in Altindag located in the north-west of the station. At

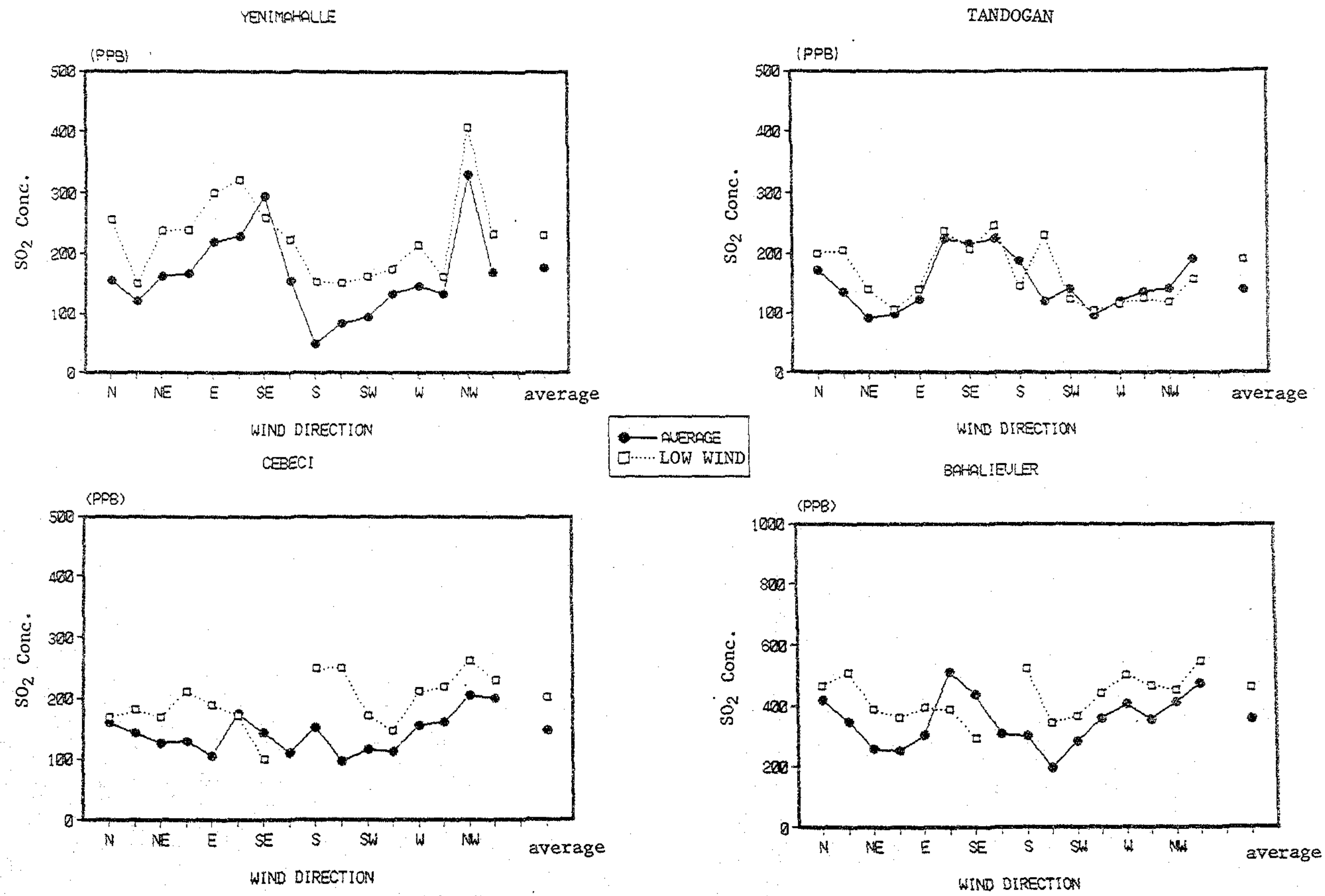


Figure 2.3.3(1) Concentration Variation of SO_2 by Wind Direction

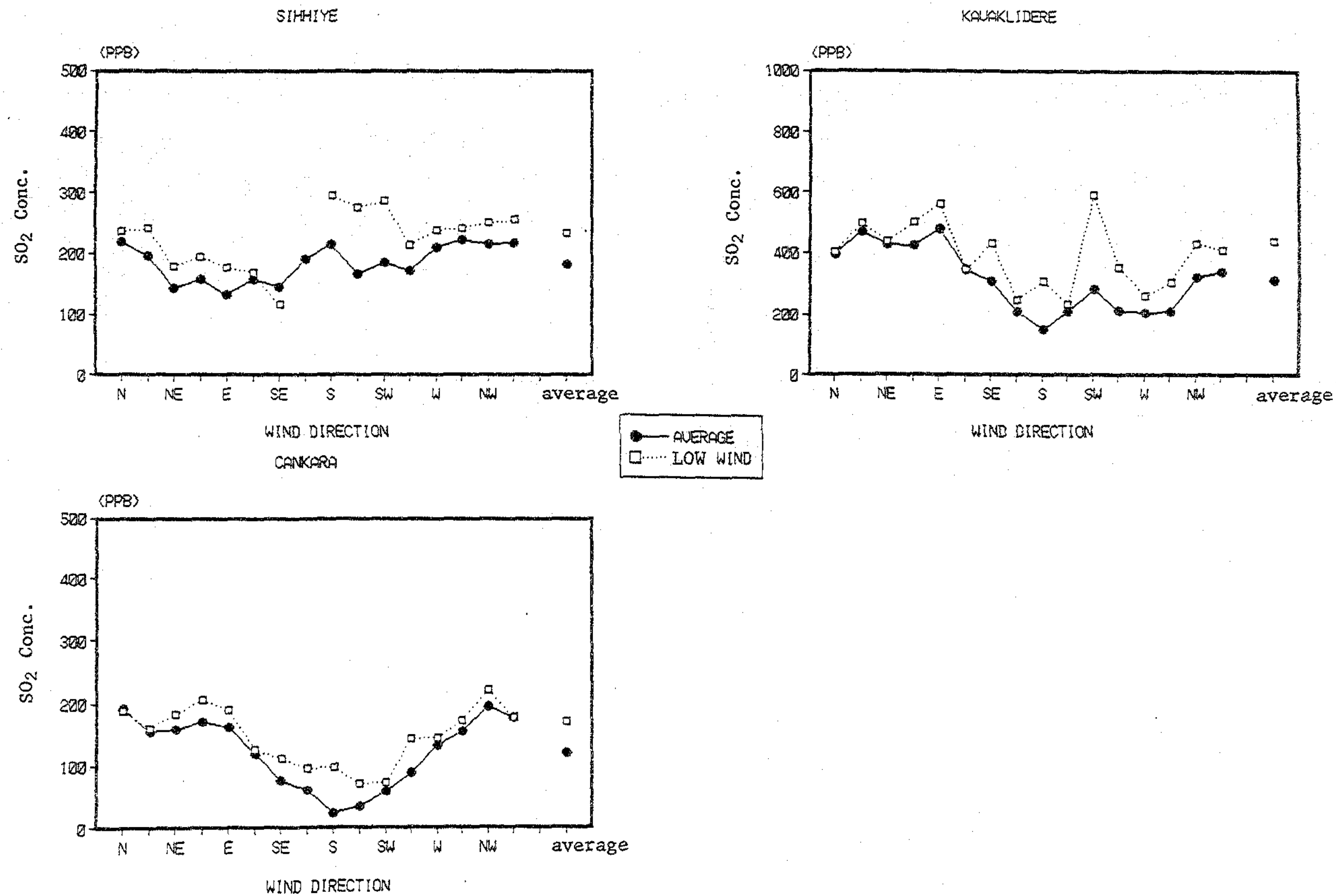


Figure 2.3.3(2) Concentration Variation of SO_2 by Wind Direction

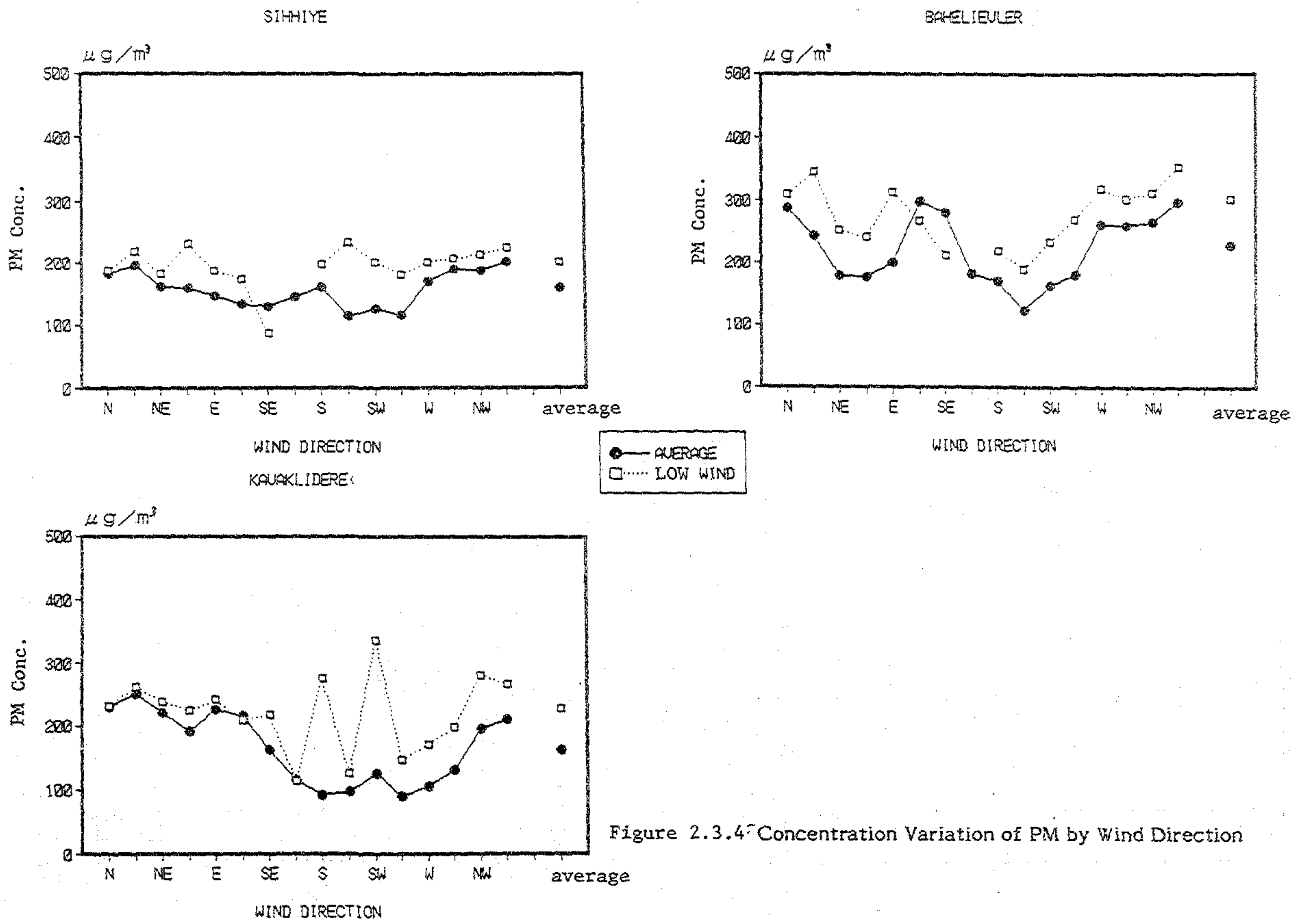


Figure 2.3.4 Concentration Variation of PM by Wind Direction

Sihhiye, in the center of the City, no significant change in pollutant concentration by wind direction is observed.

These Figures also show concentrations by wind directions at the time of low-speed winds (0.5 - 0.9 m/s). It is recognized that the relation between wind direction and high concentration is not altered significantly by the speeds of wind.

The concentration of PM is observed to occur in the same tendency with SO_2.

Figure 2.3.5 shows concentration variation by different wind speeds. At the Bahcelievler and Kavaklidere stations, high concentrations of SO_2 occur especially at the times of no wind and low wind, indicating the influence of emission sources in their immediate vicinity. At Cankaya and Sihhiye, concentrations are higher at the times of low winds (0.5 - 0.9 m/s) than that of no wind (0 - 0.4 m/s) indicating the convective transport of pollutants from surrounding areas.

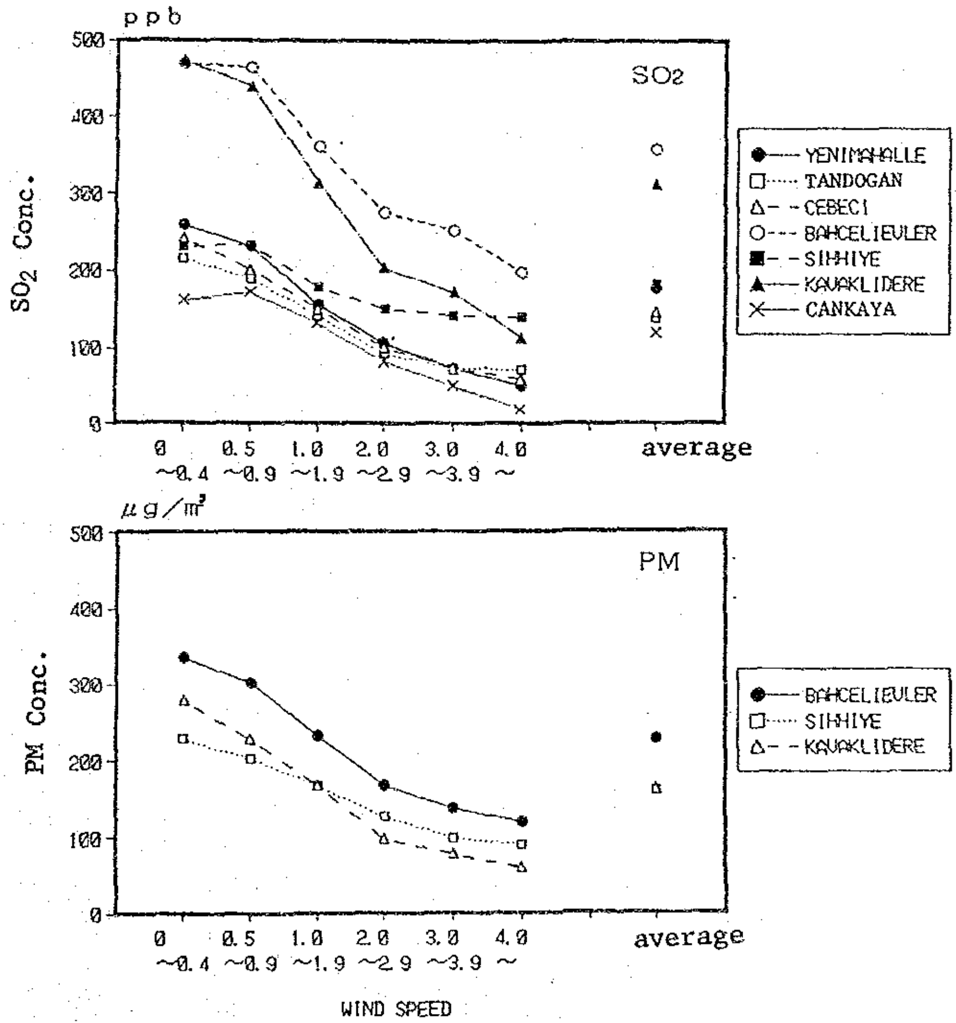


Figure 2.3.5 Concentration Variation by Wind Speed

2.3.3 Variation by Atmospheric Stability

As described before, the atmospheric stability classes represent the atmospheric dispersiveness of air pollutants. They are classified into 10 cases of A (extremely unstable) through G (extremely stable).

Frequency of occurrence of each stability class depends on the time zones of a day. As an example, average hourly concentrations of SO_2 corresponding to each class of the stability at Kavaklidere are shown in Table 2.3.3.

For the whole observation period, the class G in the stable cases and the classes A-B and B in the unstable cases coincide with occurrence of high concentrations. The high concentrations under the stability G occurred during the night time between 18:00 o'clock and 23:00 o'clock when emission of SO_2 is high. It is inferred also that since height of emission sources is low, pollutants are not dispersed upward and sustained near the ground level as a mass of smoke.

In general, the class G appears within a stable layer of inversion reaching the ground level. In case height of emission sources is above this layer, pollutant concentration at the ground level becomes low because the downward dispersion of pollutants is prevented.

Table 2.3.3 Concentration of SO_2 by Time and Atmospheric Stability at Kavaklidere

unit: ppb

Time		Concentration by Stability										Average
		A	A-B	B	B-C	C	C-D	D	E	F	G	
Time of day	1	0	0	0	0	0	0	190	104	145	328	234
	2	0	0	0	0	0	0	144	167	89	293	206
	3	0	0	0	0	0	0	121	63	74	235	175
	4	0	0	0	0	0	0	99	68	95	220	146
	5	0	0	0	0	0	0	94	68	89	201	130
	6	0	0	0	0	0	0	114	106	174	278	179
	7	0	0	0	0	0	0	360	216	244	508	382
	8	0	0	841	0	0	0	534	0	0	0	546
	9	0	797	836	0	296	0	464	0	0	0	531
	10	0	700	466	217	284	0	320	0	0	0	385
	11	424	393	307	164	186	0	220	0	0	0	273
	12	358	316	262	88	122	0	197	0	0	0	235
	13	281	241	246	192	124	0	179	0	0	0	208
	14	0	245	229	92	146	0	178	0	0	0	197
	15	184	253	240	156	139	0	202	0	0	0	201
	16	0	178	375	0	148	0	218	0	0	0	218
	17	0	0	256	0	0	0	269	197	299	424	301
	18	0	0	0	0	0	0	326	324	536	526	429
	19	0	0	0	0	0	0	375	421	428	569	466
	20	0	0	0	0	0	0	377	294	377	639	483
	21	0	0	0	0	0	0	353	349	432	637	471
	22	0	0	0	0	0	0	253	245	373	658	432
	23	0	0	0	0	0	0	264	295	250	525	359
	24	0	0	0	0	0	0	218	164	290	385	277
Whole period		340	380	360	173	170	0	267	215	315	424	311
mid-night		0	0	0	0	0	0	157	111	151	286	207
early morning		0	0	0	0	0	0	211	117	135	294	230
morning		0	715	686	217	287	0	458	0	0	0	488
daytime		355	307	255	150	144	0	194	0	0	0	228
evening		184	238	272	156	143	0	230	197	299	424	241
night		0	0	0	0	0	0	322	322	408	592	440
December		132	489	383	366	203	0	300	243	339	418	324
January		328	424	380	144	146	0	256	258	322	475	336
February		184	162	213	143	179	0	238	182	296	310	247
March		383	461	617	0	0	0	603	0	394	565	539

High concentrations under the stability classes A-B and B occurred in the time zone of 8:00 - 11:00 a.m. with a few hours delay from the morning peak of the emission. It is considered that the occurrences of high concentration were due to the formation of trap-type inversion layers that usually appear in the process of collapse of ground-level inversion layers developed during previous nights. This process is illustrated in Figure 2.3.6.

When a trap-type inversion is formed, the lower layer becomes unstable and promotes mixing of pollutants. The pollutants are trapped, however, within the layer because of the presence of the elevated inversion to result in high pollutant concentration, if a large number of low-height pollutant sources exist.

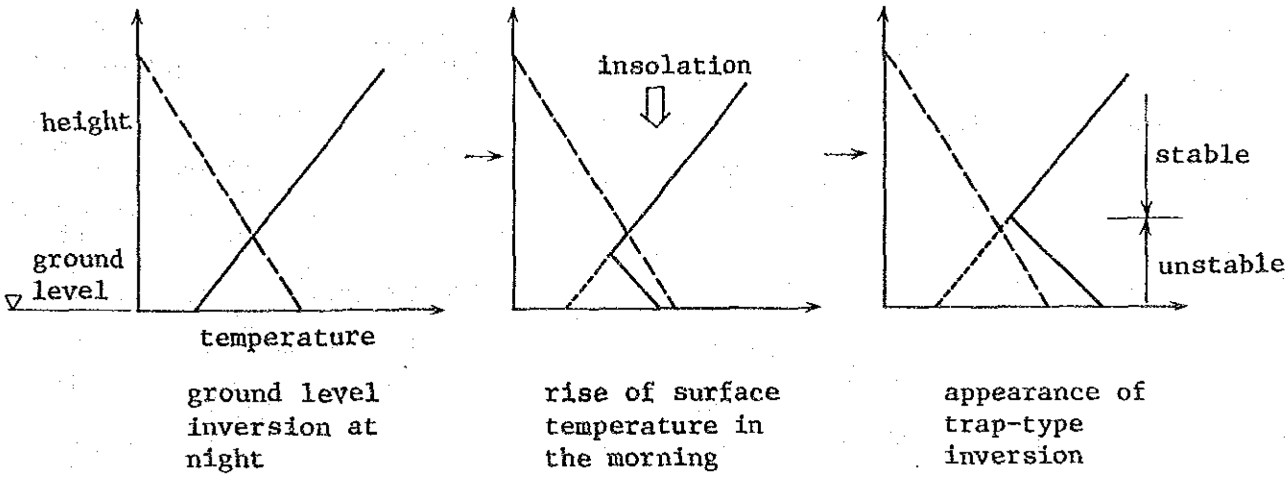


Figure 2.3.6 Formation of Trap-Type Inversion

It is considered also that because of the basined topography of Ankara City, the elevated inversion formed in the late morning functions as a lid thus causing high pollutant concentration in the lower layer even under the atmospheric stability of the classes A, A-B, and B.

2.4 STATISTICAL ANALYSIS OF THE OBSERVATION RESULTS

2.4.1 Correlation Between Observed Items

Table 2.4.1 shows correlation between the sixteen items of meteorology and air quality observed, such as daily average insolation, wind speed, air temperature, and SO_2 and PM concentration at each station.

Regional similarity or difference in wind condition can be judged by examining correlation coefficients between daily mean wind speeds measured at the 3 stations.

The coefficient is largest between Tandogan (P2) and Kavaklider (P6) followed by between Tandogan (P2) and Meteorological Agency (ME). It is small between Meteorological Agency and Kavaklidere. Therefore, the analysis of air pollution in Ankara City in terms of wind condition requires separate treatment of the northern part represented by Meteorological Agency and the southern part represented by Kavaklidere.

As to the pollutant concentration in relation to meteorological parameters, there is a strong correlation with daily mean wind speed. Correlations with insolation, net ratiation, and daily mean temperature are weak. As an example, a scatter diagram of daily mean SO_2 concentration and wind speed at Kavaklidere is shown in Figure 2.4.1.

Correlation in pollutant concentration between stations is generally high. The correlation coefficients of SO_2 concentration show greater than 0.8 between the following pairs of stations, namely Yenimahalle and Bahcelievler, Yenimahalle and Sihhiye, Yenimahalle and Kavaklidere, and Tandogan and Bahcelievler. As an example of high correlation, a scatter diagram of SO_2 concentration at Yenimahalle and Bahcelievler is shown in Figure 2.4.2.

Between the following pairs of stations, the correlation coefficients of SO_2 concentration are less than 0.6; Cankaya and Tandogan, Cankaya and Cebeci, Cankaya and Bahcelievler, and Cebeci and Kavaklidere.

As shown above, correlation in SO_2 concentration between Cankaya and the central area of the City is low. It indicates that Cankaya area has different characteristics in meteorology and pollutant emission from those of the central area of the City. However, relatively high correlatin in SO_2 is found between

Table 2.4.1 Coefficients of Correlation Between Meteorological and Air Quality Parameters (Daily Mean Values)

- significant positive correlation
- significant negative correlation
- insignificant correlation

SUN : insolation
RD : net radiation
P2WS: wind speed at Tandogan
P6WS: wind speed at Kavaklidere
MEWS: wind speed at Meteorological Agency
METM: air temperature at Meteorological Agency

P1 : YENIMAHALLE
P2 : TANDOGAN
P3 : CEBECI
P4 : BAHCELIEVLER
P5 : SIHHIYE
P6 : KAVAKLIDERE
P7 : CANKAYA
SO_2: sulfur dioxide conc.
PM : PM conc.

	SUN	RD	P2WS	P6WS	MEWS	METM	P1SO2	P2SO2	P3SO2	P4SO2	P5SO2	P6SO2	P7SO2	P4PM	P5PM	P6PM
SUN	1.000															
RD	-0.209	1.000														
P2WS	-0.079	0.119	1.000													
P6WS	-0.177	0.139	0.800	1.000												
MEWS	0.068	0.093	0.795	0.572	1.000											
METM	-0.326	0.610	0.232	0.473	0.145	1.000										
P1SO2	0.150	-0.258	-0.625	-0.556	-0.590	-0.452	1.000									
P2SO2	0.150	-0.243	-0.559	-0.386	-0.491	-0.232	0.798	1.000								
P3SO2	-0.100	-0.090	-0.483	-0.365	-0.466	-0.055	0.702	0.624	1.000							
P4SO2	0.208	-0.436	-0.544	-0.477	-0.518	-0.514	0.864	0.826	0.673	1.000						
P5SO2	0.063	-0.296	-0.426	-0.254	-0.511	-0.323	0.811	0.718	0.644	0.761	1.000					
P6SO2	0.224	-0.286	-0.555	-0.666	-0.357	-0.452	0.805	0.673	0.521	0.707	0.648	1.000				
P7SO2	0.110	-0.309	-0.442	-0.529	-0.362	-0.475	0.618	0.373	0.274	0.466	0.610	0.709	1.000			
P4PM	0.164	-0.252	-0.641	-0.555	-0.545	-0.369	0.867	0.828	0.611	0.865	0.782	0.805	0.626	1.000		
P5PM	-0.077	0.035	-0.576	-0.469	-0.519	0.010	0.745	0.657	0.828	0.595	0.764	0.627	0.454	0.727	1.000	
P6PM	0.038	-0.104	-0.597	-0.638	-0.429	-0.202	0.777	0.680	0.716	0.656	0.621	0.906	0.675	0.825	0.821	1.000

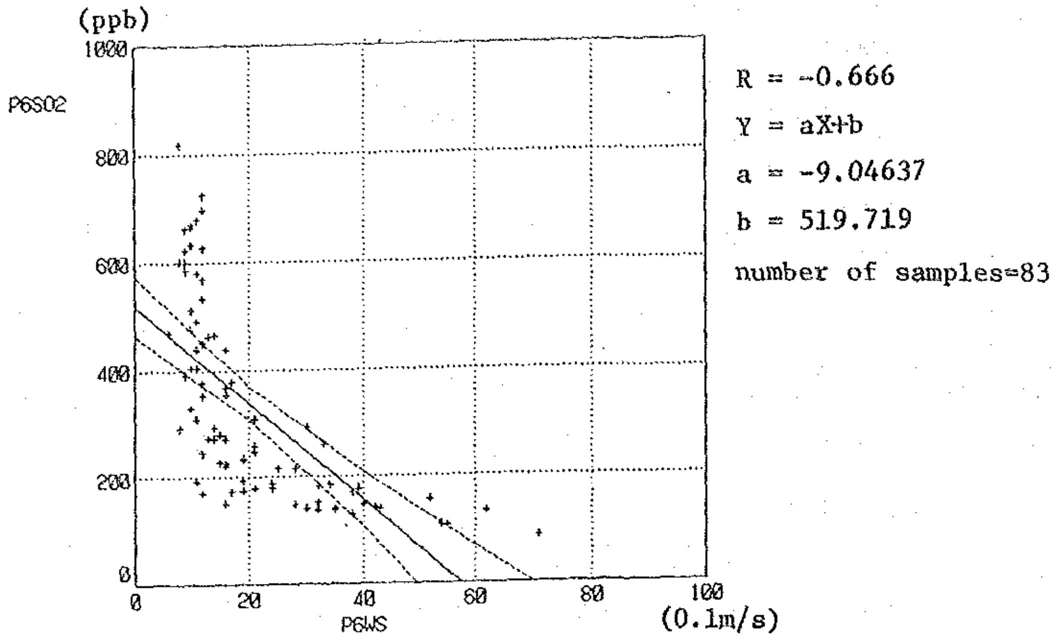


Figure 2.4.1 Relation between Wind Speed (WS) and SO_2 Concentration (SO2) at Kavaklidere (Daily Mean Values)

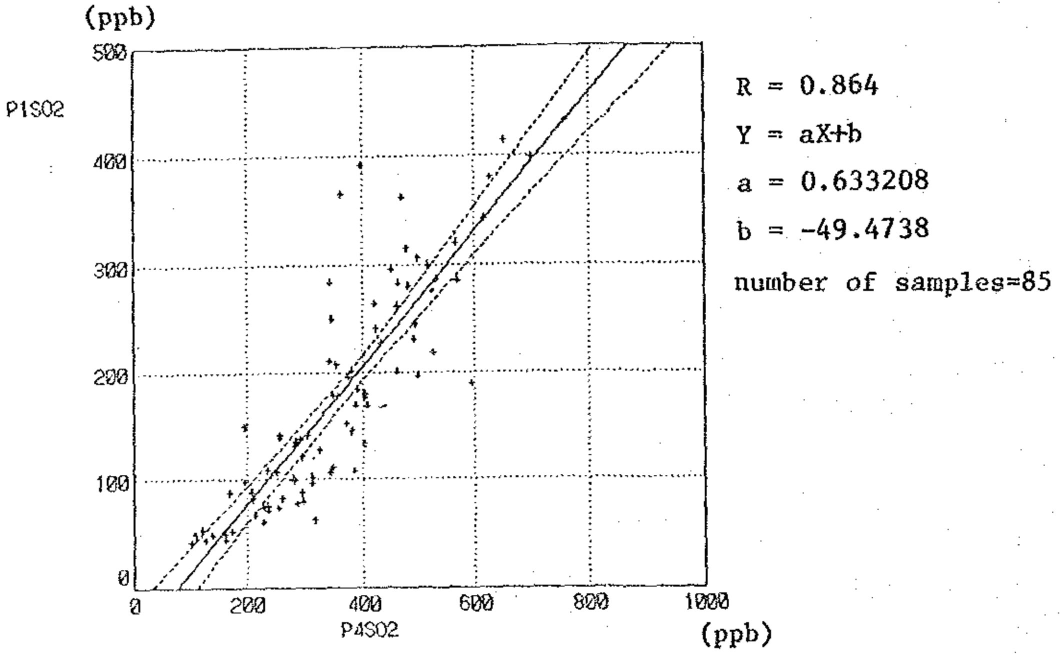


Figure 2.4.2 Relation between Yenimahalle (P1) and Bahcelievler (P4) in SO_2 (Daily Mean Values)

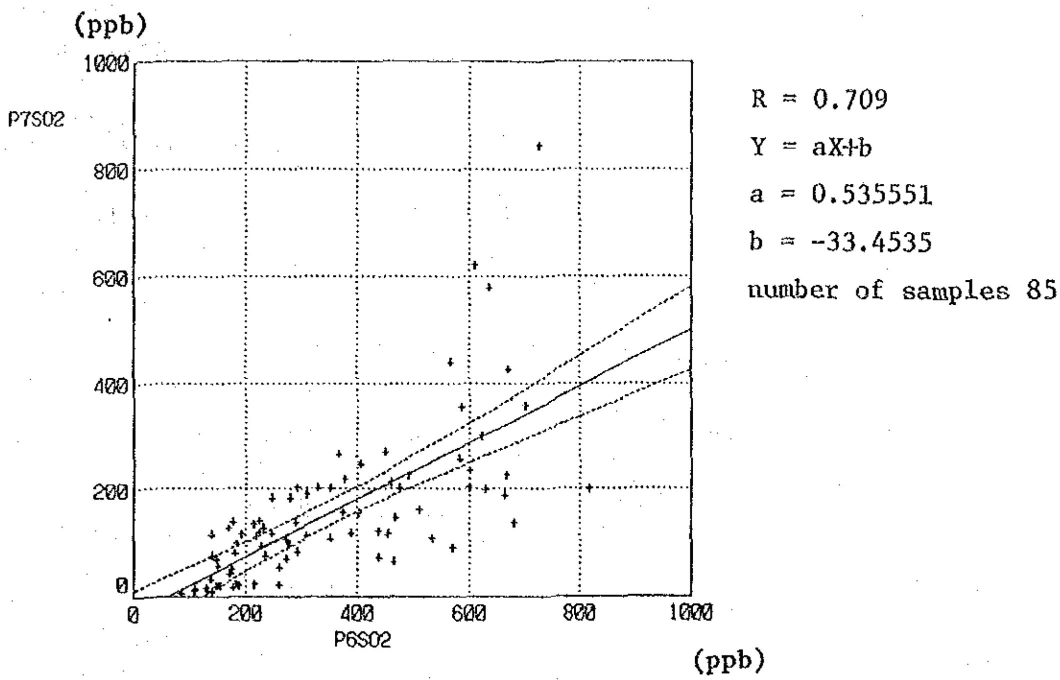


Figure 2.4.3 Relation between Cankaya (P7) and Kavaklidere (P6) in SO_2 (Daily Mean Values)

Cankaya and Kavaklidere the latter is situated adjacent to Cankaya in the north. A scatter diagram of SO_2 concentration at these two stations is shown in Figure 2.4.3.

Correlations are generally weak between Cebeci Station and the others. Cebeci is situated to the east of the City center, and the area is also considered to have different characteristics from the central areas in meteorology and pollutant emission.

From the correlation analysis described above, the City area can be broadly divided into three blocks in terms of meteorology and air quality. They are; (1) central and north-western block (Yenimahalle, Tandogan, Bahcelievler, and Sihhiye), (2) southern block (Kavaklidere and Cankaya), and (3) eastern block (Cebeci).

Correlations in PM concentration between the three monitoring stations are high.

Correlation between the concentration of SO_2 and PM is very high at each station. Scatter diagrams showing these correlations are shown in Figure 2.4.4. These high correlations indicate that SO_2 and PM are emitted from the same

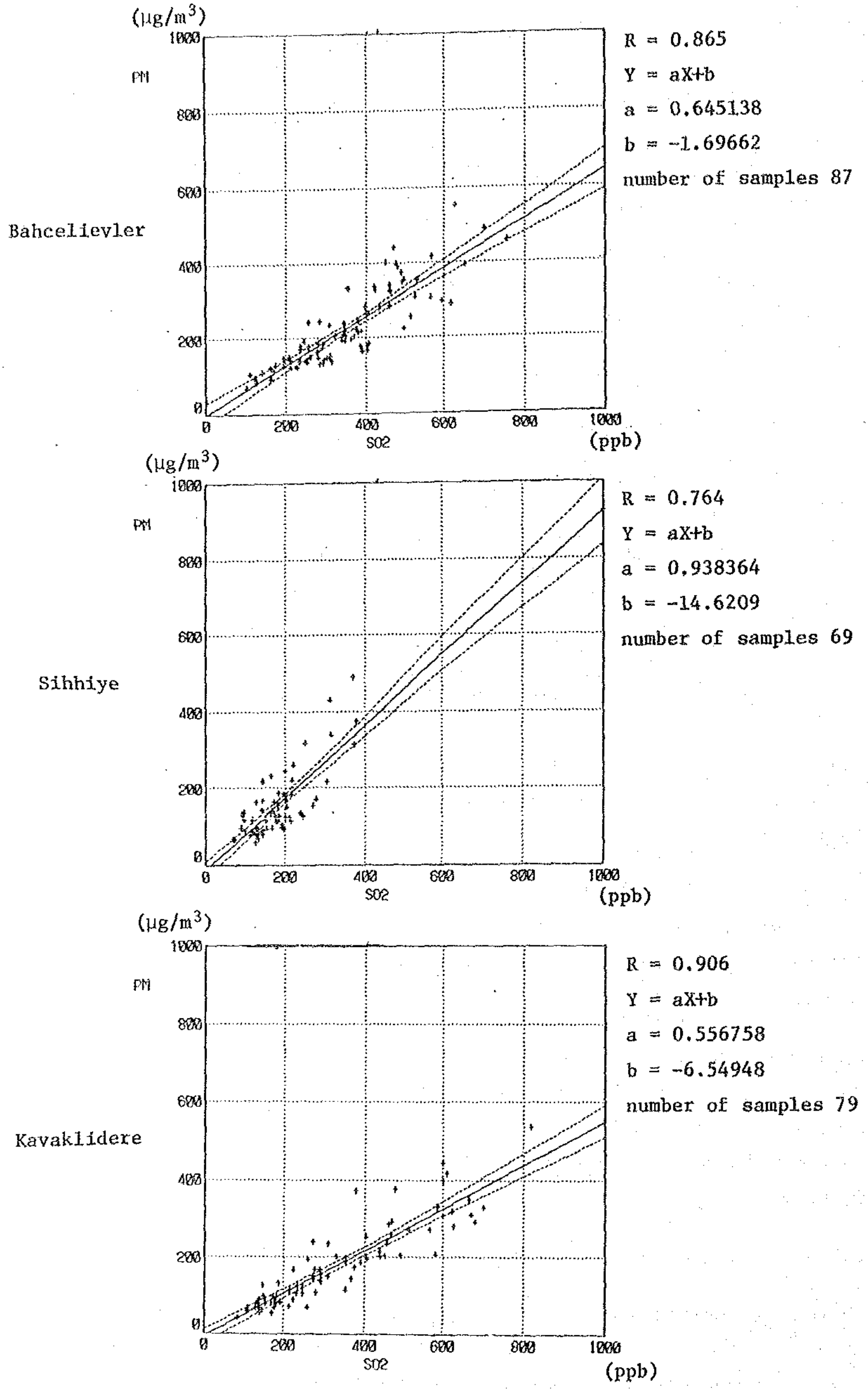


Figure 2.4.4 Relation between SO_2 and PM at Each Station (Daily Mean Values)

sources, i.e., particulate matters also are discharged from the small-height emission sources such as stacks of stoves and heating boilers.

Gradients of regression equations for SO_2 and PM differ from station to station. The SO_2 levels at Sihhiye are low and their variation is limited within a relatively narrow range. Therefore, if the general relationship between the daily mean concentrations of SO_2 and PM in Ankara is to be drawn, the following expression based on the regression equations at Bahcelievler and Kavaklidere may be used:

$$Y = (0.56 - 0.65)\,X$$

where,

X = daily mean concentration of SO_2 (ppb)

Y = daily mean concentration of PM ($\mu g/m^3$)

2.4.2 Concentration During the Periods of Upper-Layer Meteorological Observation and Influential Factors

The upper-layer meteorological observation was made for 13 days or 80 hours in total measuring the vertical profiles of wind direction, wind speed, and air temperature using a pilot balloon and a radiosonde. From these results mixing depth was also estimated.

Table 2.4.2 shows the correlation coefficients between one-hour mean values of meteorological and air quality parameters.

Looking into mixing depth and pollutant concentration, there exists negative correlation in general (smaller mixing depth corresponds to higher concentration), but correlation coefficient values are small. As an example, scatter diagram of these two parameters at Kavaklidere is shown in Figure 2.4.5.

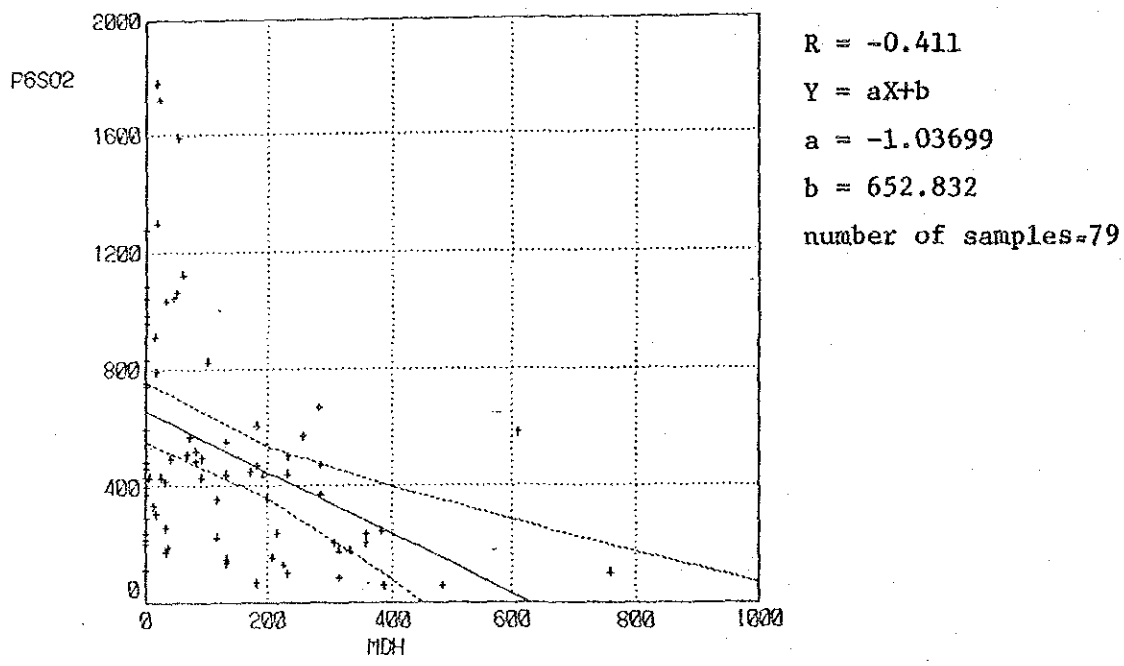


Figure 2.4.5 Relation between Mixing Depth and SO_2 Concentration at Kavaklidere (One-hour values)

Table 2.4.2 Coefficients of Correlation Between Meteorological and Air Quality Parameters (One-hour Values)

- ▩ significant positive correlation
- ▥ significant negative correlation
- ☐ insignificant correlation

ME : Meteorological Agency
P1 : Yenimahalle
P2 : Tandogan
P3 : Cabeci
P4 : Bahcelievler
P5 : Sihhiye
P6 : Kavaklidere
P7 : Cankaya

RD : net radiation
WS : wind speed
TM : air temperature
SFT : ground level temperature
MDH : mixing depth
MDT : upper layer temperature
SFWS : ground level wind speed
SO_2 : concentration of SO_2
PM : concentration of PM

	RD	P2WS	P6WS	P1SO2	P2SO2	P3SO2	P4SO2	P5SO2	P6SO2	P7SO2	P4PM	P5PM	P6PM	METM	MEWS	SFT	MDH	MDT	SFWS
RD	1.000																		
P2WS	0.126	1.000																	
P6WS	0.370	0.291	1.000																
P1SO2	-0.294	-0.130	-0.325	1.000															
P2SO2	-0.249	-0.135	-0.137	0.574	1.000														
P3SO2	-0.329	-0.218	-0.277	0.712	0.560	1.000													
P4SO2	-0.415	-0.025	-0.298	0.662	0.634	0.698	1.000												
P5SO2	-0.082	-0.218	-0.155	0.670	0.558	0.821	0.690	1.000											
P6SO2	-0.216	0.108	-0.283	0.758	0.594	0.584	0.730	0.640	1.000										
P7SO2	0.110	-0.084	-0.178	0.273	0.187	0.124	0.209	0.263	0.432	1.000									
P4PM	-0.247	-0.255	-0.314	0.537	0.499	0.670	0.699	0.681	0.520	0.206	1.000								
P5PM	-0.049	-0.303	-0.354	0.586	0.378	0.809	0.611	0.816	0.504	0.113	0.715	1.000							
P6PM	-0.133	-0.122	-0.234	0.590	0.433	0.551	0.507	0.550	0.656	0.326	0.556	0.611	1.000						
METM	0.433	-0.208	0.205	-0.153	-0.319	-0.076	-0.261	0.101	-0.248	-0.124	-0.128	0.280	-0.153	1.000					
MEWS	0.168	0.432	0.130	-0.171	-0.094	-0.277	-0.166	-0.307	0.055	-0.030	-0.270	-0.390	-0.077	-0.427	1.000				
SFT	0.475	-0.215	0.180	-0.168	-0.331	-0.109	-0.281	0.087	-0.255	-0.097	-0.139	0.270	-0.171	0.992	-0.419	1.000			
MDH	0.351	0.029	0.327	-0.435	-0.331	-0.330	-0.261	-0.194	-0.411	-0.139	-0.222	-0.104	-0.316	0.373	-0.069	0.372	1.000		
MDT	0.336	-0.263	0.049	-0.038	-0.226	0.043	-0.167	0.171	-0.137	-0.077	-0.050	0.396	-0.074	0.933	-0.484	0.932	0.089	1.000	
SFWS	0.235	0.440	0.102	-0.198	-0.152	-0.301	-0.187	-0.272	0.069	-0.002	-0.295	-0.346	-0.125	-0.255	0.995	-0.232	-0.008	-0.282	1.000

An attention must be paid to the mixing depth when a trap-type inversion is formed and pollutants are prevented from dispersing into the upper layer, which tends to appear in the morning. From the measurement data at the Kavaklidere station, the data during the time zone of 9:00 - 11:00 a.m. are extracted for the regression analysis. Result is shown in Figure 2.4.6. Correlation coefficient for mixing depth and SO_2 concentration being -0.645 indicates a significant degree of relation.

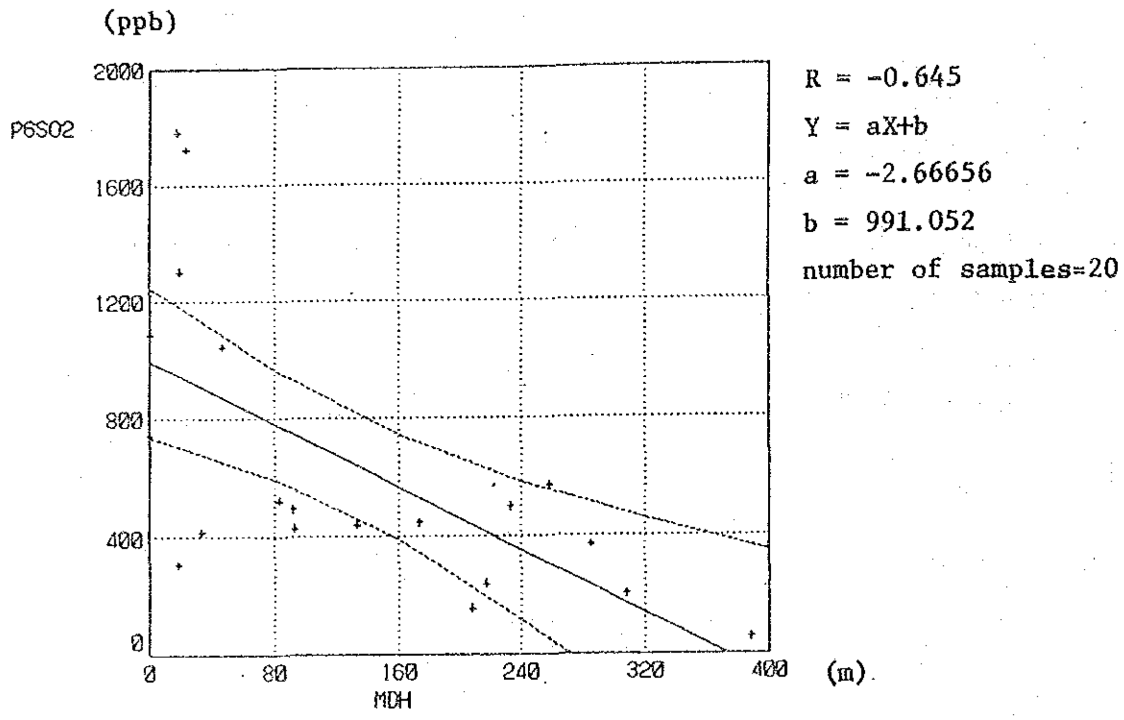
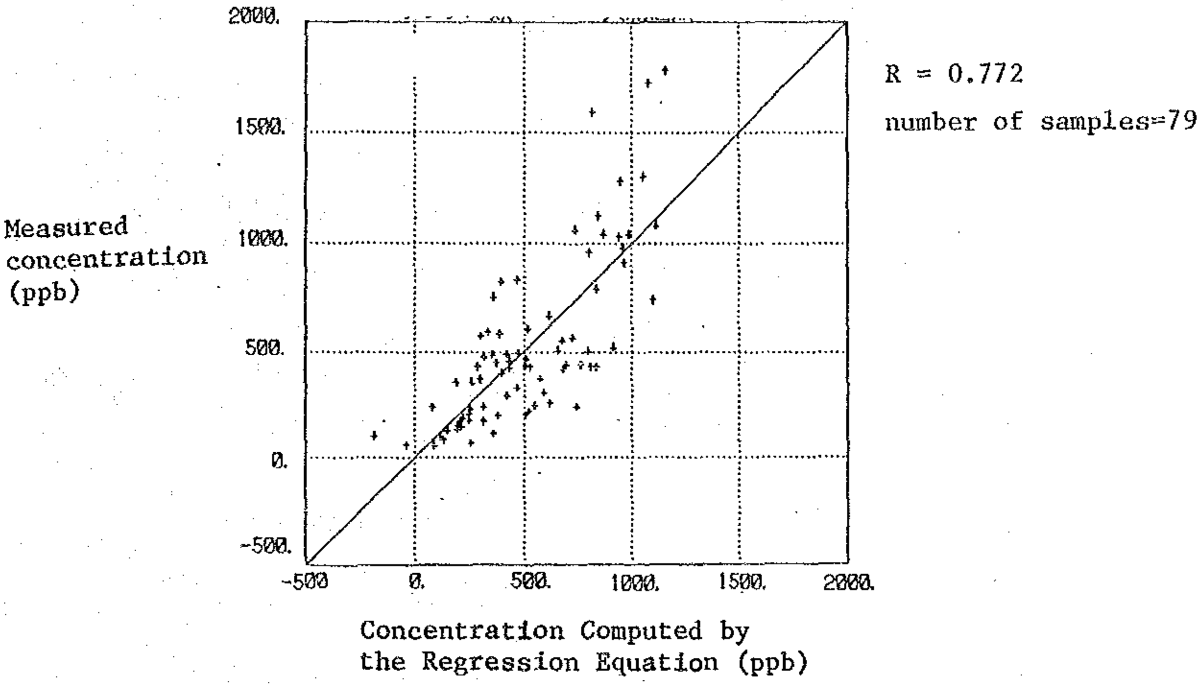


Figure 2.4.6 Correlation Between Mixing Depth and SO_2 Concentration at Kavaklidere (One-hour values)

Among factors affecting ambient concentration of SO_2, source strength (represented here by time-zone), wind direction, wind speed, atmospheric stability, and mixing depth are considered to be important. In order to evaluate the degree of influence of these factors, a multiple regression analysis was made using the data at Kavaklidere during the period of the upper layer meteorological observation. The results are shown in Figure 2.4.7. It reveals that time zone (source strength) is the most influential factor on the concentration of SO_2, followed by mixing depth. It is shown that mixing depth is more influential than wind direction, wind speed, and atmospheric stability.



No.	Factor	Degree of influence of factor	Coefficient value	Co-factors	Degree of influence of co-factors
1	Time zone		-2.572E+02	mid-night & early morning	
			3.813E+02	morning	
			-8.035E+01	afternoon	
			2.364E+02	night	
2	Wind direction		-4.242E+01	eastern	
			4.578E+01	western	
			4.683E+01	northern	
			2.534E+01	southern	
			6.072E+01	calm	
3	Atmospheric stability		4.984E+01	neutral	
			-3.199E+01	stable	
			-7.002E+00	unstable	
4	Wind speed		-8.896E+00		
5	Mixing depth		-1.053E+00		
6	Constant		7.590E+02		

Figure 2.4.7 Results of Multiple Regression Analysis on the Concentration of SO_2 at Kavaklidere (One-hour values)

2.5 ANALYSIS OF THE OCCURRENCE OF HIGH CONCENTRATION

2.5.1 State of High Concentration Occurrence

Daily mean concentration values of SO_2 and PM during the whole monitoring period are shown in order of high concentration with the dates of their occurrence in Table 2.5.2.

Emergency levels of SO_2 and PM specified by the Turkish Government are shown in Table 2.5.1 (1), and WHO's guideline values for SO_2 and SPM (suspended particulate matter) are shown in Table 2.5.1 (2).

Table 2.5.1 (1) Emergency Levels of SO_2 and PM in Ankara

Warning level	SO_2		PM
	(μg/m^3)	(ppb)	(μg/m^3)
1st	700	272	400
2nd	1,000	389	600
3rd	1,500	583	800
4th	2,000	777	1,000

Note: SO_2 values in the ppb unit are converted from those in the unit of g/m^3 under the condition of 0°C and 0.9 atmospheric pressure.

Table 2.5.1 (2) WHO's Guideline (1979)

Category	SO_2		SPM
	(μg/m^3)	(ppb)	(μg/m^3)
24-hour mean	100 - 150	39 - 58	100 - 150
Annual mean	40 - 60	16 - 23	40 - 60

Note: Same conversion was applied as with Table 2.5.1 (1) for SO_2.

Table 2.5.2 (1) Daily Mean Concentration of SO_2 and PM in Order of High Value (1st - 50th)

	SO2																					PM								
	YENIMAHALLE			TANDGAN			CEBECI			BAHCELIEVLER			SIHHIE			KAVAKLIDERE			CANKAYA			BAHCELIEVLER			SIHHIE			KAVAKLIDERE		
RANK	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO
1	2	22	431	12	21	324	1	25	458	2	22	757	3	12	378	④ 1	25	817	④ 3	6	844	1	26	552	1	25	488	1	25	535
2	12	21	414	2	22	275	② 1	19	449	1	25	699	2	22	373	3	6	725	③ 3	12	619	1	25	488	① 1	26	429	1	26	444
3	1	25	398	① 1	25	273	1	26	363	12	21	652	1	25	370	1	18	698	3	7	579	2	22	456	3	12	374	① 3	12	416
4	② 1	24	392	1	19	269	3	12	342	1	26	626	3	6	358	1	16	680	3	11	439	3	6	440	1	19	339	1	24	399
5	1	26	380	1	16	259	1	24	302	1	19	616	1	19	316	2	22	670	② 2	22	425	3	8	414	1	22	331	1	22	377
6	1	18	365	1	26	250	12	21	298	③ 1	16	594	1	26	314	12	21	665	1	18	358	① 3	1	400	1	24	318	12	19	372
7	3	6	362	1	23	227	12	20	297	3	8	569	3	7	305	3	2	662	3	8	356	3	7	397	2	22	314	12	21	351
8	1	19	342	3	5	226	2	22	279	2	26	567	① 3	1	278	3	7	633	① 3	5	300	12	21	391	2	23	277	3	8	332
9	2	26	320	3	6	222	① 1	18	278	3	5	531	2	21	270	1	17	627	2	18	270	3	12	390	1	27	260	1	18	330
10	3	7	315	12	20	217	1	22	254	3	4	527	1	24	251	3	5	622	2	26	265	3	9	374	1	28	246	3	5	320
11	1	22	306	3	7	216	1	27	246	2	27	516	3	5	247	3	12	609	2	23	257	1	22	355	1	23	232	2	22	312
12	2	27	300	2	27	208	2	23	242	1	22	498	2	7	241	1	24	600	1	14	247	3	5	353	1	18	220	1	27	294
13	3	1	296	3	1	206	2	26	240	2	28	498	2	26	241	1	26	600	1	26	235	3	11	350	3	13	219	1	16	293
14	3	5	287	3	2	204	2	9	236	3	11	494	12	20	225	③ 3	8	585	12	21	227	12	20	340	3	7	216	12	20	287
15	3	8	285	3	12	204	1	16	223	3	9	492	1	27	222	2	23	581	3	1	227	3	2	338	1	29	215	1	17	282
16	2	18	284	3	4	196	3	9	223	3	12	481	1	18	219	3	4	569	12	19	219	12	19	333	1	21	210	3	11	274
17	2	23	283	12	22	194	2	7	221	3	7	478	3	2	216	3	11	557	12	20	213	1	27	331	2	18	187	3	9	273
18	① 3	12	280	1	22	194	12	22	219	3	6	471	1	15	215	3	3	533	1	24	203	1	28	327	2	9	185	1	19	261
19	3	2	264	1	28	187	2	10	213	2	23	463	2	19	210	3	9	511	2	16	203	2	23	324	2	10	185	12	22	255
20	12	20	262	3	3	185	1	21	208	12	20	462	3	8	206	3	1	491	1	22	202	12	22	323	1	15	183	12	18	240
21	3	3	261	12	19	184	3	8	205	12	22	461	1	2	202	1	22	476	2	24	202	3	4	307	3	11	182	3	10	236
22	1	23	250	3	9	176	1	20	204	3	3	461	1	28	202	1	27	470	3	13	202	2	26	305	1	8	171	12	29	234
23	3	11	245	2	26	174	3	11	200	3	1	452	3	11	202	1	19	465	1	25	200	1	16	296	1	2	170	1	28	213
24	1	28	241	3	11	165	1	15	198	2	21	433	12	21	201	12	20	462	1	17	199	1	19	289	3	1	170	2	23	207
25	3	9	230	2	10	161	2	27	198	1	28	424	1	8	200	3	10	455	12	29	190	3	3	285	12	29	167	3	1	205
26	2	21	227	1	8	160	1	28	181	3	2	420	2	20	200	2	18	451	3	2	189	1	24	282	12	25	163	2	18	203
27	3	4	218	1	27	157	12	19	177	2	19	408	2	10	199	1	28	439	2	21	183	2	21	278	1	17	163	12	23	201
28	2	9	210	3	10	156	1	17	174	3	10	404	1	5	198	12	23	438	2	25	183	3	10	267	1	16	161	3	13	201
29	12	19	207	12	23	153	3	10	174	2	5	403	12	19	196	1	14	405	3	9	161	2	27	256	1	9	155	1	14	197
30	1	21	201	1	17	152	1	23	171	2	20	403	2	9	196	12	22	404	1	15	156	1	21	245	2	21	154	1	23	194
31	12	22	200	3	8	152	2	18	167	1	24	399	3	3	194	② 1	29	390	12	22	155	1	29	245	3	8	152	1	13	190
32	1	15	196	12	28	150	2	21	167	2	7	390	12	22	193	12	19	378	1	27	146	12	29	242	1	13	142	1	29	186
33	2	28	196	1	21	150	3	7	165	② 1	17	389	2	6	193	1	15	377	1	21	140	12	27	240	2	16	141	1	15	174
34	1	16	189	12	24	147	1	2	152	2	6	385	3	4	186	2	26	368	1	1	139	12	18	235	12	26	136	12	17	169
35	2	7	184	2	23	147	2	19	150	12	23	382	1	9	184	1	13	354	2	17	139	2	28	225	1	6	134	1	1	169
36	3	10	180	2	28	147	12	18	147	1	21	380	2	5	184	2	24	353	1	16	137	1	15	221	2	26	134	1	21	168
37	1	27	178	12	26	146	1	14	142	1	15	377	3	9	184	3	13	330	2	20	134	1	23	220	2	27	133	12	30	155
38	2	16	178	1	24	144	12	17	139	12	26	371	2	18	183	12	29	310	2	19	128	1	17	217	12	28	132	1	2	150
39	2	20	175	2	7	144	2	11	134	1	18	363	1	16	180	12	31	310	2	1	127	12	23	214	2	7	130	12	31	149
40	1	17	168	1	5	142	2	25	133	1	27	355	1	3	178	12	30	293	12	23	121	2	18	209	2	28	129	2	26	145
41	2	19	168	1	2	141	12	26	129	12	19	354	1	20	176	2	16	293	2	27	119	1	2	205	2	24	128	12	24	143
42	12	26	152	2	18	140	1	29	120	2	16	349	2	11	176	1	1	292	1	29	117	2	16	205	3	5	128	2	16	137
43	3	13	149	1	15	138	12	25	118	12	24	348	1	17	174	2	25	281	1	30	117	12	26	203	12	27	127	1	8	132
44	12	23	145	12	29	137	2	16	118	1	23	346	2	8	169	12	17	279	3	10	117	1	18	197	2	11	127	1	9	126
45	12	29	141	12	27	135	12	23	114	12	27	344	2	16	168	12	24	275	1	31	116	2	9	193	3	4	127	2	9	126
46	1	20	141	1	6	132	12	27	114	2	18	344	1	23	167	12	18	273	2	4	115	12	17	191	3	9	127	1	30	123
47	1	8	139	2	11	131	12	24	112	2	9	341	1	6	163	① 1	2	273	12	31	114	12	24	191	1	20	124	2	24	115
48	2	10	137	1	20	128	1	8	112	1	2	323	3	10	154	2	6	262	2	28	112	12	28	185	2	19	124	2	20	113
49	1	29	135	1	29	127	2	28	112	2	15	315	2	12	152	1	23	260	3	3	108	2	19	185	2	20	124	2	25	108
50	2	5	133	12	18	126	2	6	111	2	25	312	12	23	149	2	21	249	1	13	107	1	13	184	1	1	120	2	19	105

Note: ①, ②, ③ = 1st, 2nd, and 3rd warning levels

M D = month and day

Co = concentration in ppb for SO_2 and $\mu g/m^3$ for PM

Table 2.5.2 (2) Daily Mean Concentration of SO_2 and PM in Order of High Value (51st - 87th)

	SO2																				
	YENIMAHALLE			TANDGAN			CEBECI			BAHCELIEVLER			SIHHIE			KAVAKLIDERE			CANKAYA		
RANK	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO	M	D	CO
51	1	13	131	1	10	124	2	14	109	2	8	310	12	18	147	1	30	248	12	18	105
52	1	2	128	2	17	124	1	12	107	12	18	308	12	24	146	2	9	236	12	24	100
53	12	28	121	1	11	119	2	20	104	1	20	304	1	7	146	2	19	233	2	5	98
54	12	24	111	2	21	119	1	6	103	2	17	296	2	17	146	12	25	229	12	17	96
55	12	25	108	1	18	118	12	28	98	2	2	294	1	29	145	1	21	227	12	25	93
56	2	1	107	2	20	116	2	5	96	12	28	293	1	13	144	2	27	227	3	4	89
57	2	6	107	1	9	114	2	13	92	2	10	291	12	29	143	2	28	222	12	30	83
58	12	27	106	12	17	112	2	17	92	2	3	287	3	13	143	2	7	216	1	12	80
59	2	8	102	2	6	112	1	5	91	1	29	284	1	11	141	2	20	216	2	8	75
60	2	4	101	2	13	110	1	11	89	1	13	282	1	4	134	1	31	194	2	9	75
61	1	12	99	2	9	104	2	15	89	1	12	280	1	10	134	2	15	193	1	28	73
62	2	24	98	2	14	102	1	13	87	① 2	4	278	2	2	133	1	8	189	1	2	70
63	2	25	97	3	13	100	3	13	86	1	6	260	12	17	131	2	5	184	2	2	70
64	2	11	89	1	3	96	1	3	81	1	8	256	2	13	129	1	6	183	Ⓦ 1	19	65
65	1	14	88	1	4	90	1	10	80	12	29	255	12	25	128	1	12	180	12	27	55
66	2	2	88	2	16	89	12	29	78	2	14	254	2	1	128	2	17	179	2	6	54
67	1	3	83	1	13	88	2	3	77	2	1	251	2	4	127	1	20	178	12	26	50
68	1	6	83	2	19	87	2	8	77	12	17	247	2	3	126	12	26	175	12	28	43
69	2	17	80	12	25	83	2	24	76	1	9	237	2	14	119	12	28	174	2	3	43
70	2	3	78	1	7	79	2	4	72	1	10	237	1	14	117	2	1	172	1	10	33
71	1	9	76	2	15	79	1	9	71	12	25	235	2	15	114	2	3	171	1	11	32
72	1	11	76	2	3	72	2	12	67	1	11	228	1	12	101	1	5	157	1	6	23
73	2	14	74	2	5	71	2	1	66	2	13	228	12	26	99	2	10	153	2	7	23
74	1	10	72	1	14	70	Ⓦ 2	2	66	1	5	213	1	1	99	12	27	152	1	23	22
75	1	5	68	2	12	67	1	1	53	1	3	212	12	28	94	1	9	149	2	10	22
76	2	15	63	Ⓦ 1	12	60	3	6	50	2	11	208	12	27	92	2	2	149	1	5	21
77	Ⓦ 2	13	61	12	31	57	1	30	48	2	24	195	12	31	91	2	8	142	1	8	21
78	12	30	55	2	1	57	1	31	47	3	13	195	12	30	74	2	14	141	1	9	20
79	2	12	53	2	25	54	3	1	47	2	12	176	Ⓦ 1	30	70	2	4	140	1	20	17
80	1	1	50	2	8	49	1	7	46	1	14	170	1	31	57	2	13	140	2	11	16
81	1	7	50	2	2	45	3	5	45	1	4	164	1	21	*	1	11	139	1	7	13
82	12	31	49	12	30	43	3	2	44	1	7	163	1	22	*	1	10	138	1	3	12
83	1	4	45	1	1	39	3	3	42	12	31	140	2	23	*	1	3	133	2	12	10
84	1	31	45	2	4	36	1	4	40	1	31	127	2	24	*	2	11	131	2	13	9
85	1	30	42	1	30	31	3	4	40	12	30	124	2	25	*	1	7	110	1	4	7
86	12	17	*	2	24	31	12	31	29	1	1	111	2	27	*	2	12	109	2	14	0
87	12	18	*	1	31	28	12	30	18	Ⓦ 1	30	103	2	28	*	Ⓦ 1	4	86	2	15	0
		AVE	177		AVE	137		AVE	146		AVE	355		AVE	182		AVE	339		AVE	147
		N	85		N	87		N	87		N	87		N	80		N	87		N	87

	PM								
	BAHCELIEVLER			SIHHIE			KAVAKLIDERE		
RANK	M	D	CO	M	D	CO	M	D	CO
51	1	9	180	1	14	118	2	21	105
52	2	20	179	2	12	118	12	27	97
53	1	8	176	2	5	117	12	28	97
54	2	6	176	3	2	117	1	6	96
55	2	10	175	1	3	115	2	10	90
56	12	25	172	2	6	109	2	14	90
57	2	5	168	3	3	102	2	27	89
58	2	7	165	12	31	99	1	20	83
59	2	4	163	2	8	99	1	31	83
60	2	25	152	2	13	99	1	12	81
61	2	11	150	1	10	98	2	1	81
62	1	6	149	1	5	97	1	3	80
63	1	12	148	3	10	96	1	10	80
64	3	13	148	1	7	92	2	15	80
65	1	20	147	1	12	92	1	5	79
66	1	3	143	2	14	91	2	5	76
67	2	8	143	1	11	90	2	7	72
68	2	17	142	2	2	85	1	11	69
69	1	10	140	2	4	81	2	6	69
70	2	1	139	2	17	81	2	17	69
71	2	15	137	2	15	80	2	13	68
72	2	14	135	1	4	71	1	7	67
73	2	2	134	12	30	69	2	11	67
74	2	3	132	2	25	68	2	2	63
75	2	12	131	1	30	67	2	12	60
76	2	24	125	2	3	60	2	8	58
77	1	11	124	12	17	*	2	3	55
78	2	13	123	12	18	*	2	4	55
79	1	5	122	12	19	*	1	4	43
80	1	7	121	12	20	*	12	25	*
81	1	14	114	12	21	*	12	26	*
82	12	31	110	12	22	*	2	28	*
83	1	1	106	12	23	*	3	2	*
84	12	30	94	12	24	*	3	3	*
85	1	4	94	1	31	*	3	4	*
86	1	31	82	2	1	*	3	6	*
87	1	30	70	3	6	*	3	7	*
		AVE	228		AVE	159		AVE	175
		N	87		N	76		N	79

Note: ① = 1st warning level, Ⓦ = WHO's guideline

M D = month and day

Co = concentration in ppb for SO_2 and $\mu g/m^3$ for PM

Numbers of days are shown in Table 2.5.3 when the pollutant concentration exceeded the emergency levels for Ankara and the upper limit of the 24-hour mean in the WHO's guideline.

Table 2.5.3 Number of Days Exceeding Emergency Levels and WHO's Guideline

Item	Station	Emergency levels in Ankara				WHO GUIDE-LINE	Effec-tive day
		4	3	2	1		
SO_2	Specified conc. (μg/m^3)	2000	1500	1000	700	150	
	YENIMAHALLE	0	0	4	18	77	85
	TANDOGAN	0	0	0	3	76	87
	CEBECI	0	0	2	9	74	87
	BAHCELIEVLER	0	6	33	62	87	87
	SIHHIYE	0	0	0	8	79	80
	KAVAKLIDERE	1	14	31	47	87	87
	CANKAYA	1	2	5	8	64	85
PM	Specified conc. (μg/m^3)	1000	800	600	400	-	
	BAHCELIEVLER	0	0	0	6		87
	SIHHIYE	0	0	0	3		76
	KAVAKLIDERE	0	0	0	3		79

The situation of occurrence of high concentration is summarized as follows.

i) Number of days on which concentration of SO_2 exceeded the first emergency level was largest at Bahcelievler being 62 days or 71% of the observation period of 87 days, followed by Kavaklidere being 47 days (54%).

ii) Number of days exceeding the 4th emergency level for SO_2 appeared once at Kavaklidere and Cankaya. Those exceeding the third level were 6 at Bahcelievler, 14 at Kavaklidere, and 2 at Cankaya. Occurrence of high concentration was more frequent in the western and southern zones than in others.