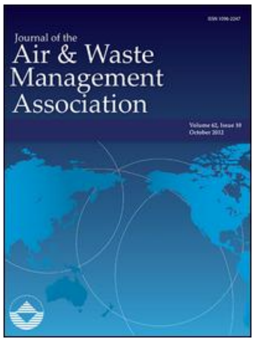

Journal of the Air & Waste Management Association

ISSN: 1096-2247 (Print) 2162-2906 (Online) Journal homepage: https://www.tandfonline.com/loi/uawm20

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To cite this article: Senol Kartal & Ulviye Özer (1998) Determination and Parameterization of Some Air Pollutants as a Function of Meteorological Parameters in Kayseri, Turkey, Journal of the Air & Waste Management Association, 48:9, 853-859, DOI: 10.1080/10473289.1998.10463738

To link to this article: https://doi.org/10.1080/10473289.1998.10463738

TECHNICAL PAPER

ISSN 1047-3289 *J. Air & Waste Manage. Assoc.* **48**:853-859

Determination and Parameterization of Some Air Pollutants as a Function of Meteorological Parameters in Kayseri, Turkey

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ABSTRACT
In this paper, the statistical relations between meteorological parameters and some pollutant ground level concentrations are presented. The daily average sulfur dioxide and smoke values were measured at five stations in Kayseri over 20 months. The model adopted for analysis differed from the power-law form selected by former investigators. Wind speed, degree-day temperature, the percentage of relative humidity, the previous day's pollution concentrations, and the amount of global solar radiation were the variables of multiple regression equations that were derived to calculate pollutant concentrations. The amount of cloud cover, however, had no important effect on the pollutant concentrations. The average variances of these regression equations were found as 84 and 75% for sulfur dioxide and smoke concentrations, respectively. The calculated pollutant concentrations utilizing forecast meteorological parameters reflected that the occurrence of high pollutant concentrations can be predicted.

INTRODUCTION
In the last 20 years there has been a considerable increase in the population of Kayseri and the number of factories. As a result, air pollution has reached alarming levels and has become a hazard to both human life and the very fertile fields of the Kayseri Basin.

As much as 75% of the consumed fossil is lignite with a 1.0–5.5% sulfur content, and a 75% heavy residual oil containing 1–4% sulfur. Unfortunately, up-to-date air pollution source inventories were not available.

In order to understand and predict air pollutant concentrations, numerical models that parameterize meteorological processes were proposed by several former investigators. For a perfect numerical model, a good source inventory is necessary; if the source inventory cannot be supplied, a statistical approach should be performed. Thus, the influence of various meteorological parameters can be investigated.

Most former investigators—for example, Höschele,[1] Marsh and Foster,[2] Bringfelt,[3] and Elsom and Chandler[4]—adopted their models of statistical analysis on a simple power-law expression, each parameter raised to a certain power as a multiplier. On the other hand, Annand and Hudson[5] proposed the nonlinear model to correlate pollutant concentrations and some meteorological parameters.

This research project had two aims: (1) to measure the concentrations of sulfur dioxide and smoke at five stations in Kayseri and (2) to investigate further the influence of meteorological parameters, available from meteorological stations, on sulfur dioxide and smoke levels during the winter periods of 1983 and 1984 by developing empirical regression models that have acceptable correlation coefficients.

IMPLICATIONS

The findings of the present investigation can be of some practical use, especially for local authorities. For example, based on the weather forecasts, the atmospheric pollutant levels can be predicted to take the necessary precautions, or urban plannings can be modified based on a region's climate to minimize air pollution levels in winter months. Also, the air quality data collected a decade ago for this study can be of great value for investigators of current popular atmospheric pollution studies. However, one should also note that the findings are valid for winter months and for a closed basin urban area like Kayseri.

GEOGRAPHY AND CLIMATE OF THE KAYSERI BASIN
Kayseri is located 1,100 m above sea level at a distance of 500 km from the Mediterranean Coast on the high plateau of Asia Minor. The Kayseri Basin, with an estimated population of 750,000 in 1983, covers 100 km^2 in surface area and is surrounded with high mountains—3,916 m on the south, 1,890 m on the east, and 1,630 m on the west. The

basin is oblong with a northwest-southeast major axis about 11-km long and a north-south axis 6-km wide.

The Kayseri Basin has a typical highland climate in that it is generally cold in winter and hot in summer and there are considerable temperature differences between day and night. Data collected over the past 40 years indicate an average daily winter temperature of 0.5 °C (the lowest recorded temperature of -32.5 °C) and an average daily summer temperature of 21.2 °C (a maximum recorded temperature of 40.7 °C). This basin has an annual rainfall of ~400 mm, especially in the winter and spring months. Severe local thunderstorms in spring and fall produce precipitation and rarely exceed 100 km/hr. The average pressure is approximately 893 mb, but is generally higher in October and November. The average annual level of relative humidity is 64%, but this level reaches 75% in the winter. The prevailing wind directions are from the south in winter and from the northwest in summer. The insolation is strong: Average global solar radiation on a horizontal surface is 500 cal cm^{-2} day^{-1} in the summer and 150 cal cm^{-2} day^{-1} in the winter.

AIR POLLUTION AND METEOROLOGICAL DATA

Air Pollution Data

Two air pollutants were measured and analyzed: sulfur dioxide and smoke. Their concentrations were obtained at five stations from January 1983 to August 1984. The stations were installed with volumetric instruments to measure 24-hr average concentrations. The samples were taken twice daily in the fall, winter, and spring, and once a day in the summer. In order to achieve reasonable accuracy a certain quantity of polluted air has to be collected. This requirement determines the time intervals during which certain amounts of sulfur dioxide and smoke concentrations were reached. In our case every sampling duration lasted for 8 hr at the rate of 0.2–0.6 l min^{-1}. Air was collected at a height of 2.5 m above the ground and away from unrepresentative air currents.

The Modified West-Gaeke Method,[6] in which air is absorbed in a solution of potassium tetrachloromercurate by drawing a known volume of air through a Whatman No. 1 filter of known weight, was applied to measure sulfur dioxide concentrations.

Smoke concentrations were measured by a smoke stain reflectometer using the method modified by the Organization for Economic Cooperation and Development.[7]

The measurements were made at five stations in and around the circle of a 4-km radius. A radius of 4-km measuring equipment was installed in schools and other public buildings. Of the five stations, the base station was located at the faculty near the industrial zone (station 1); the first was in the center of the business area of Kayseri (station 3); two were in urban residential areas (stations 2 and 5); and the last was near the industrial zone (station 4).

Meteorological Data

As far as possible, some of the meteorological measurements were made at the base station (station 1), but the data that were supplemented by information provided from the State Meteorology Station were 500 m away from station 3 and about 4 km from the farthest station. The meteorological measurements included wind speed and direction, percentage of relative humidity, outside air temperature, rainfall, amount of cloud cover, and the average global solar radiation.

Figure 1(a) shows a schematic map of the valley and the surrounding mountains and Figure 1(b) shows the meteorological station (M) and the sampling stations. The wind speed in winter was rather low, around 1.6 m sec^{-1}, and also strong enough winds to clean out the city atmosphere were rather infrequent.

On approximately a quarter of the days in which measurements were carried out, the temperature was lower than 0 °C. The average daily air temperature in the winter periods of this research was 1.6 °C.

Apart from the percentage of relative humidity and cloud cover, all of the daily average values of the meteorological parameters were measured within the period of the

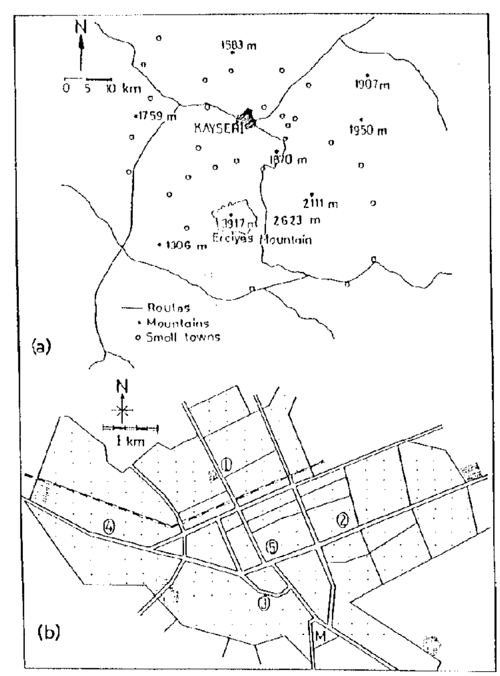

Figure 1. Map of the Kayseri Basin. (a) A schematic map showing the valley and the surrounding mountains. (b) The locations of the observatory stations and the Meteorological Station are marked from 1 to 5 and M, respectively.

sulfur dioxide and smoke sampling (24 hr, from 8:30 a.m. to 8:30 a.m). For the percentage of relative humidity and the amount of cloud cover, the measurements were carried out at three different times: 2:00 p.m., 9:00 p.m., and 7:00 a.m. Rainfall were monthly mean values. The measurements of global solar radiation began in November 1983 (average daily values).

CONCENTRATION LEVELS

The pollutant concentration levels on winter days were higher than the standard values accepted by the World Health Organization (WHO) and the United States. Comparison of sulfur dioxide concentrations between the stations showed the highest pollution occurred at station 5 (the highest value: 1,100 µg m^{-3}) and the lowest pollution occurred at station 4 (the highest value: 300 µg m^{-3}). The ground level concentrations of sulfur dioxide and smoke were rather low on warm and hot days. The observed average concentrations of sulfur dioxide and smoke were 14 µg m^{-3} and 37 µg m^{-3}, respectively, between April and October 1983, and were 18 µg m^{-3} and 27 µg m^{-3}, respectively, from April to August 1984.

The ratios of smoke concentration (C_{SM}) and sulfur dioxide (C_{SO2}) were calculated for the cold and warm days of certain periods. C_{SM}/C_{SO2} ratios were 3.44 for the April–October period and 0.68 for the November–March period. The number of days (episodes) that the sulfur dioxide concentrations higher than 400 µg m^{-3} and their maximum durations are tabulated in Table 1. The number of days with high sulfur dioxide concentrations was related to the number of days with unfavorable circulation types.

RELATIONSHIP BETWEEN POLLUTANT CONCENTRATIONS AND METEOROLOGICAL PARAMETERS

Simple Regression Equations

In this study, first the meteorology-pollution relationships were studied using logarithmic transformations of the meteorological parameters because the pollution data showing a log-normal distribution and dispersion equations suggest that there is a product relationship between pollutant concentrations and meteorological parameters.[4] Table 2 summarizes the results of the correlation analyses between logarithmically transformed pollutant concentrations and meteorological parameters for the two winter periods of the study. The following simple regression equation was used:

$$C=aX^b \quad (1)$$

where C is the average daily pollution concentration, a is a constant, X is the meteorological parameter, and b is the exponent related to the rate of change of the meteorological parameter. Each parameter is discussed below according to its importance in air pollutant concentrations.

Wind speed is one of the most important meteorological parameters controlling pollutant concentrations because the volume and dilution of the polluted air are controlled by wind speed and its directions. By simple regression analyses, the relationship between wind speed and pollution concentrations was investigated for the Kayseri Basin during the winter periods of 1982–1983 and 1983–1984. The exponent b of simple regression equations was found for sulfur dioxide-wind speed correlation as -0.60, and the same exponent b for smoke-wind speed correlation was -0.61. Our exponents agreed well with the published values of -0.5 derived by Meetham,[8] -0.5 by Newall and Eaves,[9] -0.4 by Höschele,[1] -0.5 by Bringfelt,[3] and -0.5 by Elsom and Chandler.[4] The exponents of the two pollutants that we analyzed were not different from each other. The values of the exponents implied that sulfur dioxide and smoke pollution arose from the same emission sources and wind speed had the same influence on sulfur dioxide and smoke pollution in the Kayseri Basin.

Consumption of fuel depends on the air temperature and it is not the primary parameter that affects the diffusion conditions of pollution. Thus, temperature is considered a pollution control parameter.

Marsh and Foster[2] investigated the relationship between temperature and air pollutant concentrations and indicated that above a certain temperature, average daily pollution concentrations were not controlled by average daily temperature (T). But they noticed the existence of a linear or curvilinear relationship below this temperature. The threshold or datum temperature (T_d) was introduced into the degree-day temperature definition (T_d-T). The datum temperature differs for each country; for example, it is 17.0 °C for Sweden, 15.6 °C for the United Kingdom, 15.0 °C for Belgium, and 18.3 °C for the United States.[3,10–12] We applied the same technique[3] and found a datum temperature of 18.0 °C.

Table 1. The number of days with high sulfur dioxide concentrations (≥ 400 µg m^{-3}) and the related values.

Period	Measured Days Number	High SO_2 Concentration Days Number	Their Maximum Durations
January 1983	29	20	6
February 1983	28	5	3
March 1983	31	1	1
November 1983	30	2	2
December 1983	31	11	10
January 1984	31	12	6
Total	180	51	28

Table 2. Summary of the correlation analyses between meteorological parameters and average daily pollutant concentrations in the Kayseri Basin.[a]

Smoke Pollution			Sulfur Dioxide Pollution		
Meteorological Parameter	Correlation Coefficients		Meteorological Parameter	Correlation Coefficients	
	1983 Winter	1984 Winter		1983 Winter	1984 Winter
Wind speed (W, m sec^{-1})	-0.67	-0.55	Wind speed (W, m sec^{-1})	-0.52	-0.46
Degree-day temperature [(T_d-T),°C]	0.58	0.52	Degree-day temperature [(T_d-T),°C]	0.72	0.68
Relative humidity (H,%)	-0.50	-0.52	Relative humidity (H,%)	-0.58	-0.32
Cloud cover amount (B)	-0.02	-0.37	Cloud cover amount (B)	0.07	0.28
Previous day's pollution concentration (C_p,μg m^{-3})	0.69	0.68	Previous day's pollution concentration (C_p,μg m^{-3})	0.83	0.84
Global solar radiation (G,cal cm^{-2} day^{-1})	-	-0.54	Global solar radiation (G,cal cm^{-2} day^{-1})	-	-0.23
Number of cases	74	27	Number of cases	88	152

[a]Level of significance 1% when R = 0.21 or more.

The amount of cloud cover is expected to be inversely related to pollutant concentrations, because it controls the removal and precipitation of the pollutants.[13–15] As predicted, the correlation analyses for Kayseri showed an inverse relationship (Table 2).

Relative humidity should also be inversely related to pollutant concentrations since it controls the rate of absorption of pollutants.[16] Indeed, the simple regression equations for Kayseri showed an inverse relationship (Table 2). The amount of global solar radiation was not included as a meteorological parameter by many investigators. We introduced it into the simple regression for the period of November 1983–March 1984. This parameter has no direct physical influence on diffusion controls as wind speed, but it determines the amount of consumed fuel for space heating. Therefore, it should be inversely proportional to pollutant concentrations (Table 2).

The relationship between the previous day's pollution concentration and the pollutant concentration was also investigated and a fairly good correlation was noted, an average of 0.68 for smoke and 0.83 for sulfur dioxide (Table 2). These values were higher than those of Elsom and Chandler.[4]

Multiple Regression Equations

Bringfelt,[3] Bringfelt et al.,[17] and Elsom and Chandler[4] argued that multiple regression models are a useful step in order to produce emission inventory diffusion models, since important meteorological pollutant concentrations can be readily determined and their relative importance assessed.

The meteorological parameters that had an effect on smoke and sulfur dioxide concentrations were defined by the above-mentioned simple regression equations (Table 2). Thus, in the presence of the other parameters, each parameter is expected to modify each other in the multiple regression equations; as a result, the differences between calculated and experimental values decreased. In order to calculate pollutant concentrations for two winter periods, four important meteorological parameters—wind speed, degree-day temperature, previous day's pollution concentrations, and the percentage of relative humidity—were introduced into the multiple regression equations (Tables 3 and 4). Furthermore, a second set of multiple regression equations were derived by incorporating these four meteorological parameters plus the amount of global solar radiation only for the period of November 1983–March 1984.

The related values of multiple regression equations are tabulated in Tables 3 and 4 in terms of the meteorological parameters, the multiple correlation coefficient (R) and the amount of variance explained (R^2 expressed in percentage) by each equation. The meteorological parameter coefficients derived from multiple regression equations (Table 3) for smoke concentrations are as follows, according to their importance: relative humidity, wind speed, previous day's concentration, and amount of global solar radiation. For sulfur dioxide pollution, the previous day's concentration was the most important control parameter, the second most important parameter was degree-day temperature, and the third was relative humidity (Table 4). It was significant that global solar radiation had no importance in the control of sulfur dioxide, but its related coefficient was -0.52 for the smoke pollution. It is significant also that the previous day's concentration was not a meteorological parameter, but this parameter provides a measure of persistence in air pollution data. It is clear that the pollutant concentrations present in the atmosphere on one day may not be entirely due to the measure of meteorological parameters relative to its 24-hr period. Therefore, the previous day's or the day's meteorological

Table 3. Summary of the multiple regression equations to calculate average daily smoke concentrations in Kayseri.[a]

Smoke Concentrations ($\mu g\ m^{-3}$)								
Winter Periods	**Constant (k)**	**Regression Coefficients of Parameters Logarithmically Transformed**					**Multiple Correlation Coefficients (R)**	**Variance Explained (R^2 %)**
		(T_d-T)	**W**	**H**	**G**	**C_p**		
Jan. 1983–Mar. 1984	1.98	0.49	-0.62	-0.64	-	0.49	0.84	71
Nov. 1983–Mar. 1984	5.88	0.16	-0.70	-2.01	-0.52	0.55	0.88	79

[a]The symbols and units of the parameters were given in Table 2.

Table 4. Summary of the multiple regression equations to calculate average daily sulfur dioxide concentrations in Kayseri.[a]

Winter Periods	**Constant (k)**	**Regression Coefficients of Parameters Logarithmically Transformed**					**Multiple Correlation Coefficients (R)**	**Variance Explained (R^2 %)**
		(T_d-T)	**W**	**H**	**G**	**C_p**		
Jan. 1983–Mar. 1984	1.34	0.58	-0.30	-0.59	-	0.63	0.91	83
Nov. 1983–Mar. 1984	0.53	0.40	-0.28	-0.16	-	0.72	0.92	85
Nov. 1983–Mar. 1984	2.02	0.48	-0.33	-0.75	-0.16	0.68	0.92	86

[a]The symbols and units of the parameters were given in Table 2.

and pollution conditions should account for a proportion of the pollution concentration. A similar approach was employed by Son'kin[18] and Elsom and Chandler[4] for meteorological reasons, since there is always a marked tendency for the meteorological conditions on one day to be preserved in the next. Secondly, the pollution itself was important, although the pollutants can have some influence upon the meteorology.

The presence of other variables modified the values in the multiple regression equations. The following multiple regression eqs 2 and 3 were derived to calculate ground level pollutant concentrations for the 1982–1983 winter period using an average coefficient of four parameters ((18–T), W, C_p, and H) from which logarithmic bases were removed.

$$C_{SO2} = \frac{k(18-T)^{0.49} C_p^{0.68}}{W^{0.29} H^{0.38}} \tag{2}$$

$$C_{SM} = \frac{k(18-T)^{0.45} C_p^{0.49}}{W^{0.62} H^{0.64}} \tag{3}$$

By introducing the amount of global solar radiation as the fifth parameter, the following multiple regression eqs 4 and 5 were derived again for the 1983–1984 winter period in a similar manner.

$$C_{SO2} = \frac{k(18-T)^{0.48} C_p^{0.68}}{W^{0.33} H^{0.75} G^{0.16}} \tag{4}$$

$$C_M = \frac{k(18-T)^{0.16} C_p^{0.55}}{W^{0.70} H^{2.01} G^{0.52}} \tag{5}$$

Our earlier study introduced only three parameters—wind speed, degree-day temperature, and percentage of relative humidity—into the multiple regression equation for the January–March 1983 period in order to calculate only daily sulfur dioxide concentrations.[19] The explained variances of this multiple regression equation on average accounted for 53% (R = 0.73).

The explained variances of the multiple regression eqs 2–5 on average accounted for 83% (R = 0.91) and 71% (R = 0.84) in logarithmic sulfur dioxide and smoke concentrations, respectively (Tables 3 and 4). The addition of global solar radiation as the fifth parameter increased the usefulness of the multiple regression equation regarding the calculations of smoke concentrations. The result was an average 79% (R = 0.88) of the logarithmic smoke concentrations, and this fifth parameter had a small effect on the calculations of the sulfur dioxide concentrations. The new explained variance was 86% (R = 0.92).

Hence, the variance explained in the sulfur dioxide concentrations that were found by eqs 2 and 4 averaged 84 and 86%, respectively. These values compare favorably with the values found by Lalas et al.[20] (52%), Marsh and Foster[2] (58%), Stewart et al.[21] (64%), Höschele[1] (65%), Van Dop and Kruizinga[22] (69%), Bringfelt[3] and Bringfelt et al.[17] (70%), Annand and Hudson[5] (70%, Bolzern and Hudson[23] (72%), Elsom and Chandler[4] (76%), and Steinberger and Balmor[24] (85%). Our regression equations had three equal parameters—wind speed, degree-day temperature, and previous day's sulfur dioxide concentration—and, in addition, the relative humidity and the amount of global solar radiation were introduced into our regression equations. It was clear that these two additional parameters helped to explain the highest variances obtained by this study.

In the case of the calculations of smoke concentrations, variances in our study reached 79% by introducing five parameters that variance was equal to the value found by Elsom and Chandler, and was the highest variance cited in the literature.[5] Elsom and Chandler used four parameters, of which three were identical to our parameters (wind speed, degree-day temperature, and the previous day's smoke concentration). The fourth parameter in their study was mixing height. We did not have an opportunity to determine mixing height, but our study indicated that the relative humidity and global solar radiation could be introduced into the regression equations in order to calculate the concentration of smoke.

In order to compare the calculated and observed air pollutant concentrations common procedures were applied. The calculated pollutant concentrations found by eqs 2, 3, 4, and 5 were plotted against time, then the observed values were plotted on the same scales (Figures 2, 3, 4, and 5). The agreements of the calculated and observed pollutant concentrations were shown by these figures. The correlation coefficient between calculated and observed sulfur dioxide concentrations was 0.89 and level of significance of this coefficient was 0.1% for 241 experimental sulfur dioxide concentrations.

CONCLUSION

This research determined the air pollutant concentrations, then developed a series of multiple regression equations introducing meteorological parameters to calculate the average daily air pollutant ground level concentrations for Kayseri during the winter periods of 1982–1983 and 1983–1984.

Summarizing this first analysis of the sulfur dioxide and smoke pollution in the Kayseri Basin, the following conclusions can be stated.

(1) The pollution concentration levels respond to changes in the meteorological variables in the manner expected from general literature. Thus, previous day's pollution, wind speed, relative hu-

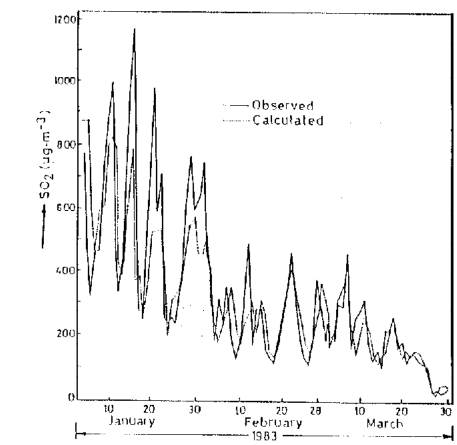

Figure 2. Observed sulfur dioxide concentrations and those calculated from the multiple regression in eq 2 for the January–March 1983 period.

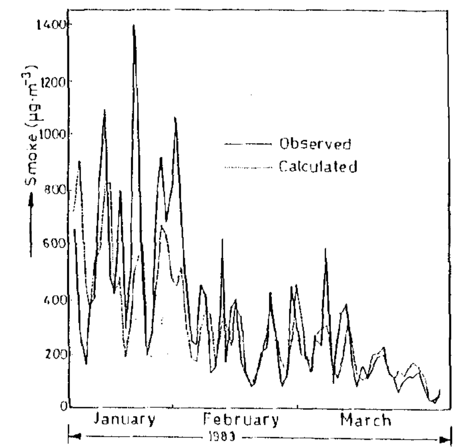

Figure 3. Observed smoke concentrations and those calculated from the multiple regression in eq 3 for the January–March 1983 period.

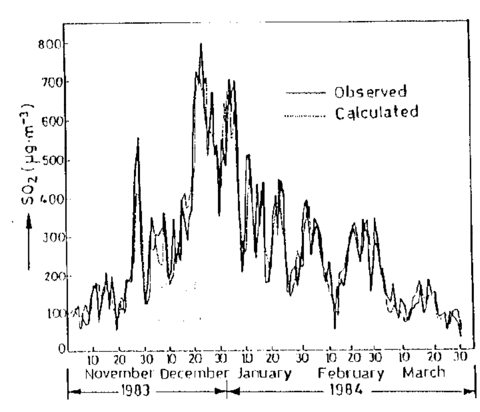

Figure 4. Observed sulfur dioxide concentrations and those calculated from the multiple regression in eq 4 for the November 1983–March 1984 period.

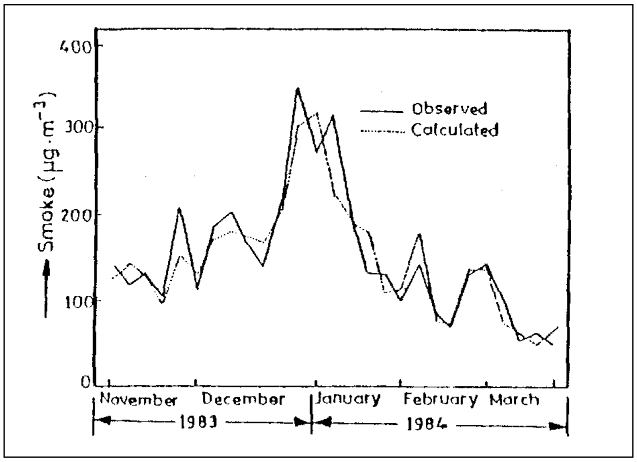

Figure 5. Observed smoke concentrations and those calculated from the multiple regression in eq 5 November 1983–March 1984 period.

midity, degree-day temperature, and amount of global solar radiation were found to be determinant in the cold period of the years. During the summer periods, the effects of meteorological variables on the air pollutants were not investigated, since they were at low levels in the warm periods.

(2) The number of days with high air pollutant concentrations—pollution episodes—was related to the number of days with unfavorable circulation types.

(3) The sulfur dioxide and smoke levels of the five stations in the Kayseri Basin were well correlated with meteorological parameters by the simple regression equations.

(4) Multiple linear regression models presented here explained a substantial part of the data variance (71–86%) and achieved acceptable correlation coefficients.

(5) The agreements of the calculated and observed pollutant concentrations lead us to state that the multiple regression may be used to calculate day-to-day concentrations. Thus, these equations can be employed for a wide variety of purposes, for example, when data were lacking because of instrument failure or other reasons.

(6) By inserting forecasted values of the meteorological parameters into the multiple regression equations, future prediction of air pollution concentrations may be performed in the Kayseri Basin.

(7) The equations should not be applied to summer periods in the Kayseri Basin.

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