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Analysis of effects of meteorological factors on air pollutant concentrations in Ankara, Turkey(*)

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Summary. — In big cities, the air pollution has become an important problem in parallel with the increasing energy use. The sources of the pollutants are the emissions from the industrial facilities, motor vehicles and heating systems. The climatologic factors play important roles on the concentration of the air pollutants. In this study, the relations between air pollutant (SO_2, PM_{10}, NO, NO_2 and CO) concentrations and the meteorological factors (wind speed, temperature and relative humidity) were statistically analyzed for the period of November 2001 and April 2002. The multi-linear regression analysis was applied to quantify the relationship between the air-polluting elements and the climatic factors by using a SPSS program. The results of the analysis show that the concentrations of all the pollutants considered decrease with increasing wind speed. With the increasing temperature, SO_2, PM_{10} and CO concentrations decrease. However, there is not a clear relation between temperature, and NO and NO_2 concentrations. Changes in SO_2, PM_{10}, NO and NO_2 concentrations with the changing relative humidity are insignificant. However, CO concentration increases with increasing relative humidity.

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1. – Introduction

The air pollution in urban areas is closely connected with the energy consumption, geographical and meteorological conditions. The increase in energy consumption with population increase and industrialization has an important role on the air pollution. It is also known that the air pollution concentration is affected by the meteorological factors (wind, precipitation, temperature, etc.)

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In the literature there are studies about the relationship between meteorological factors and the concentration of air pollutants. In a study carried out by Chao [1], the relationship between meteorological factors and air pollutant concentrations in Shanghai was investigated, and some measures were proposed. Escourrou [2] investigated the relation between air pollutant concentration and climatic factors in Paris. In this study it was observed that the concentration of air pollutants is different in different parts of the city due to the effect of the wind. Wind circulation and air pollutant concentration in the coastal city Ravenna was analyzed by Tirabassi *et al.* [3]. They observed a close relationship between wind speed and pollutant ground level concentration. Breeze regime local circulation has important influence on the SO_2 concentration patterns. Miyazaki and Yamaoka [4] investigated the effects of the meteorological factors on dust concentration in Osaka. It was observed that the dust concentration decreases with wind speed and temperature difference. Cuhadaroğlu and Demirci [5] studied the relation between the meteorological factors and pollutant concentration, analyzing the monitored data statistically, in Trabzon (Turkey). The results of this study showed that for some months there is a moderate and weak level of relation between SO_2 concentration and meteorological factors. Mayer [6] studied time series of air pollution data for Stuttgart. It was discussed that emissions from motor traffic are a very important source of pollutants. It is suggested that the developing countries should therefore implement air-quality management. Bouhamra and Abdul-Wahab [7] studied air pollution of Mansouria (Kuwait) where there is a heavy motor traffic by statistically analyzing the data collected by a mobile air pollution measurement laboratory. Pollutants such as CO, NO, NO_2, and O_3, and meteorological parameters such as relative moisture, pressure, solar radiation, and wind speed and direction were analyzed.

In the present study, the relationships between the meteorological factors and the concentrations of the air pollutants have been investigated in Ankara. Air pollution data collected by the state air pollution management agency and the meteorological data collected by a station established by the authors in the same area were statistically analyzed together to obtain the correlations between pollutant concentrations and the meteorological factors.

2. – Topography and climate of Ankara

The metropolitan area of Ankara is located between 39°50′-40°00′ north latitude and 32°35′-33°00′ longitude. The city of Ankara is settled on Ankara plain which has an altitude of 800–850 meters and shaped by the Ankara creek and its side creeks. The surroundings of the plain are mountainous and hilly with altitude ranging from 1250 to 1500 meters. Ankara plain is surrounded by Mire mountains from north, the west remaining of the Idris mountain from east, and Çal and Elmadag Mountains from south (fig. 1). The plain is open in west and extends to Mürted plain. The centre of the city is located at the bottom of a bowl-like region. New neighborhoods have been formed at the skirts of the hills surrounding the city.

In Ankara, summer is hot and dry, but winter is cold with high precipitation. The annual average temperature is 11.7 °C. The average January temperature is – 0.1 °C. The annual average precipitation is 377.6 mm, and the average humidity is 60 percent. The dominant wind direction in Ankara and neighboring areas is in northeast direction, and the average annual wind speed is 2.1 ms^{-1}. Koppen climate classification, Bsk-type climate is dominant in Ankara. A semi-dry climate is dominant in summer in Ankara with an average temperature below 18.0 °C [8]. According to the Thorntwaite climate

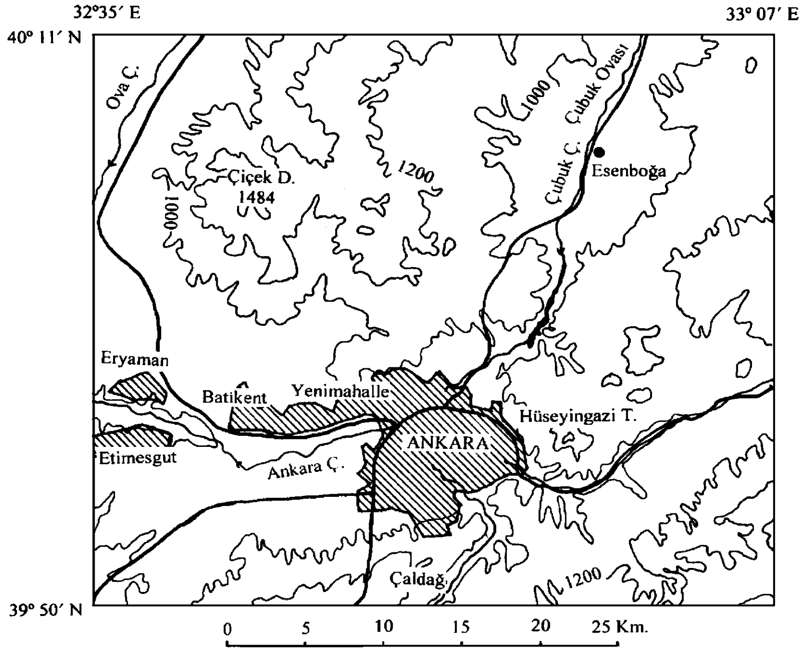

Fig. 1. – Map of Ankara.

classification, Ankara has a mesothermal climate of the first degree ($\mathrm{D\,B'\,1\,s_2\,b'_3}$ climate) with excessive water insufficiency in summer [9].

There is no heavy industry in Ankara. Therefore, the main sources of pollutants are emissions from the heating systems of buildings and the motor vehicles in traffic. Hence, in winter months, considerable air pollution is seen in Ankara. Due to these sources of pollutants and the topographical structure of Ankara, the central parts of the city (Kızılay, Sıhhıye, Kurtulus, Cebeci, Maltepe, Bahcelievler, Kücükesat and Ulus) have higher pollutant concentrations than the outer parts of the city.

3. – Data and methodology

In this study, air pollution and meteorological data for the period of November 2001 and April 2002 has been analyzed. The air pollution data were recorded by Refik Saydam Hygiene Centre of The Ministry of Health. The climatologic data were collected by a station installed in the same area where Refik Saydam Hygiene Centre is located. The anemometer used at this station is 2 meters high from the ground and its measurement range is 0–54 $\mathrm{ms^{-1}}$ with 0.5 $\mathrm{ms^{-1}}$ accuracy. The measurement range of the relative moisture sensor is 0–100% and its accuracy is 1%. The data is collected with one-hour interval and stored in the data logger.

A statistical approach has been used to observe the relationships between the air pollutant concentrations and the meteorological factors. The regression analysis was conducted to investigate the relations between air pollutant concentrations and the meteorological factors, and to obtain mathematical expressions. In formulating the regression equations, the pollutant concentrations (SO_2, PM_{10}, NO, NO_2 and CO) were taken as

TABLE I. – *Monthly average values of the variables in urban Ankara (November 2001-April 2002).*

Month	Temperature (°C)	Wind speed ($m\,s^{-1}$)	Relative humidity (%)	SO_2 ($\mu g\,m^{-3}$)	PM ($\mu g\,m^{-3}$)	CO ($\mu g\,m^{-3}$)	NO ($\mu g\,m^{-3}$)	NO_2 ($\mu g\,m^{-3}$)
Nov. 2001	4.76	0.48	63.91	57.03	138	3963.70	115.63	143.97
Dec. 2001	2.74	0.07	72.51	56.85	67.25	2019.67	80.12	124.32
Jan. 2002	−3.73	0.79	76.79	100.27	98.52	3562.86	76.55	167.73
Feb. 2002	4.86	0.71	58.91	85.98	118.91	3017.27	140.44	184.97
Mar. 2002	8.58	1.11	51.22	49.55	63.45	1660.64	77.14	136.89
Apr. 2002	10.32	0.88	62.32	38.25	55.4	1371.36	56.79	127.68
Mean	4.59	0.67	64.28	64.66	90.26	2599.25	91.11	147.59

dependent variables and the meteorological factors (wind speed, temperature and relative humidity) were taken as independent variables. Since there is more than one independent variable, the multiple linear regression analysis was performed. A general linear regression equation can be expressed as

$$Y = A + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \,.$$

In this equation, Y is the dependent variable, X's are independent variables, A is the constant of regression, β's are the coefficients of the regression, and ε is the error. In this analysis, the regression constant A, and coefficients β_1, β_2, and β_3 were determined using the least-square regression method. The significance level of the constant and regression coefficients were tested by using the T-distribution.

For the reason that there are more than one independent variable (meteorological factors) and that the significances of these variables are varied, a stepwise regression analysis was applied. This method is a stepwise algorithm in which a variable is added to or removed from the equation at each step. The criterion concerning the addition or removal of a variable is the partial F-test. At the first step, the independent variable with the highest correlation is selected and a simple linear line is approximated. The selected independent variable provides the highest F_j value with regard to the other independent variables. At the second step, a one-by-one trial is made for the remaining variables, and F_j values are calculated. The variable which gives the highest F_j value could be inserted in the equation as a second variable [10].

In order to indicate what percentage of the change in the dependent variable Y is defined by the independent variable X, the coefficient of determination R^2 is calculated as

$$R^2_{Y,X} = 1 - \frac{\sum^{n} (\hat{Y}_i - \bar{Y})^2}{\sum^{n} (Y_i - \overline{Y})^2}\,,$$

where $\hat{Y}_i$ the value of Y predicted by the regression line, Y_i is the value of Y observed and $\bar{Y}$ is the mean values of Y_i's. If there is a good correlation between X and Y, R^2

TABLE II. – *Average values of pollutant concentrations in selected intervals of wind speed values.*

Wind speed ($m\ s^{-1}$)	SO_2 ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	NO ($\mu g\ m^{-3}$)	NO_2 ($\mu g\ m^{-3}$)	CO ($\mu g\ m^{-3}$)
0–1	75.2	101.2	105.4	165.1	2887.2
1–2	52.1	65.2	61.6	121.8	1848.8
2–3	44.0	53.1	53.3	108.6	1413.2
3+	38.5	53.2	33.4	84.5	1477.6

approaches to 1, but if the correlation between X and Y is not good, R^2 approaches to zero. When R^2 is 1, it is concluded that the dependent variable is affected only by the independent variable and not by any other variable [11, 12].

4. – Results and discussion

To observe the relations between meteorological factors and the pollutant concentrations, recorded data for the period studied are presented as tables, graphs and mathematical expressions. Monthly average values of all the variables are given in table I. In this table, it is seen that in the cold months (November, December, January and February) pollutant concentrations are much higher than the warmer months (March and April). This indicates the fact that the main source of the pollution in the region studied is the emission from the heating systems and the motor vehicles in traffic. All the average values of the pollutant concentrations given in table I are below the long-term critical values set for Ankara. (For Ankara, the long-term critical values for SO_2, PM_{10}, CO, NO and NO_2 are 150 mgm^{-3}, 150 mgm^{-3}, 10 000 mgm^{-3}, 200 mgm^{-3} and 100 mgm^{-3}, respectively.)

Considering the whole period studied, average pollutant concentrations in certain

TABLE III. – *Average values of pollutant concentrations in selected intervals of temperature values.*

Temperature	SO_2	PM_{10}	NO	NO_2	CO
-10°C	131.3	112.0	63.0	152.4	3833.6
-10– -5°C	118.8	105.8	95.6	180.4	3408.7
-5–0°C	72.7	90.2	84.9	148.5	2970.2
0–5°C	66.7	93.9	102.0	150.8	2529.5
5–10°C	52.4	79.9	75.2	131.8	2185.2
10–15°C	54.6	76.1	91.0	151.9	2049.1
15–20°C	47.4	77.6	81.0	146.9	1898.0
20+ °C	36.5	62.9	43.1	101.2	864.8

TABLE IV. – *Relative average values of pollutant concentrations in selected intervals of relative humidity values.*

Relative humidity	SO_2	PM_{10}	NO	NO_2	CO
20%	42.6	67.9	64.7	141.9	1303.6
20–40%	51.8	77.2	92.0	158.8	1859.4
40–60%	66.3	86.2	88.3	147.4	2166.2
60–80%	72.3	90.0	78.4	138.4	2530.3
80+%	58.5	89.2	108.6	161.2	3065.6

intervals of the wind speed, temperature and relative humidity are given in tables II, III and IV, respectively. When table II is evaluated, it is seen that the concentrations of all the polluters decrease with increasing wind speed. Analysis of table III reveals that the concentrations of SO_2, PM_{10} and CO decrease with increasing temperature. However, there is not a clear relation between temperature, and NO and NO_2 concentrations. This indicates that in the region studied the main source of NO and NO_2 is the emission from the motor vehicles in the traffic. Table IV shows that SO_2, PM_{10}, NO and NO_2 concentrations do not show any clear trend with increasing relative humidity. On the other hand, CO concentration increases with increasing relative humidity.

To quantify the effects of meteorological factors (wind speed, temperature and humidity) on the pollutant concentrations (SO_2, PM_{10}, NO, NO_2 and CO concentrations), the linear multi-regression analysis was applied separately for November 2001, December 2001, January 2002, February 2002, March 2002 and April 2002. Mathematical expressions showing the effects of wind speed, temperature and humidity on the concentration of pollutants in each month considered have been obtained. As an example for these mathematical expressions, the mathematical expressions obtained for PM_{10} and CO for February 2002 are given below:

$$[PM_{10}] = 35.01 - 69.4 \times [\text{wind speed}] + 2.35 \times [\text{humidity}] \qquad R^2 = 0.65\,.$$

According to this equation, the PM_{10} concentration decreases as the wind speed increases, but it increases with the increasing relative moisture. In this particular month, temperature does not appear in the mathematical expression. These imply that the relation between PM_{10} and wind speed is negative, the relation between PM_{10} and humidity is positive, and there is not a considerable effect of temperature on PM_{10} concentration. The coefficient of determination R^2 of this expression is 0.65. This shows that 65 percent of PM_{10} depends on wind speed and humidity, the remaining 35 percent of PM_{10} is uncertain. It means that 35 percent of the particle concentration (PM_{10}) is due to factors other than wind speed and humidity. For February 2002, the regression equation obtained for CO is expressed as

$$[\text{CO}] = 832.77 - 2192.36 \times [\text{wind speed}] + 64.47 \times [\text{humidity}] \qquad R^2 = 0.67\,.$$

This equation shows that CO concentration decreases with increasing wind speed, but it increases with increasing humidity. 67 percent of CO depends on wind speed and humidity, the remaining 33 percent of CO is uncertain.

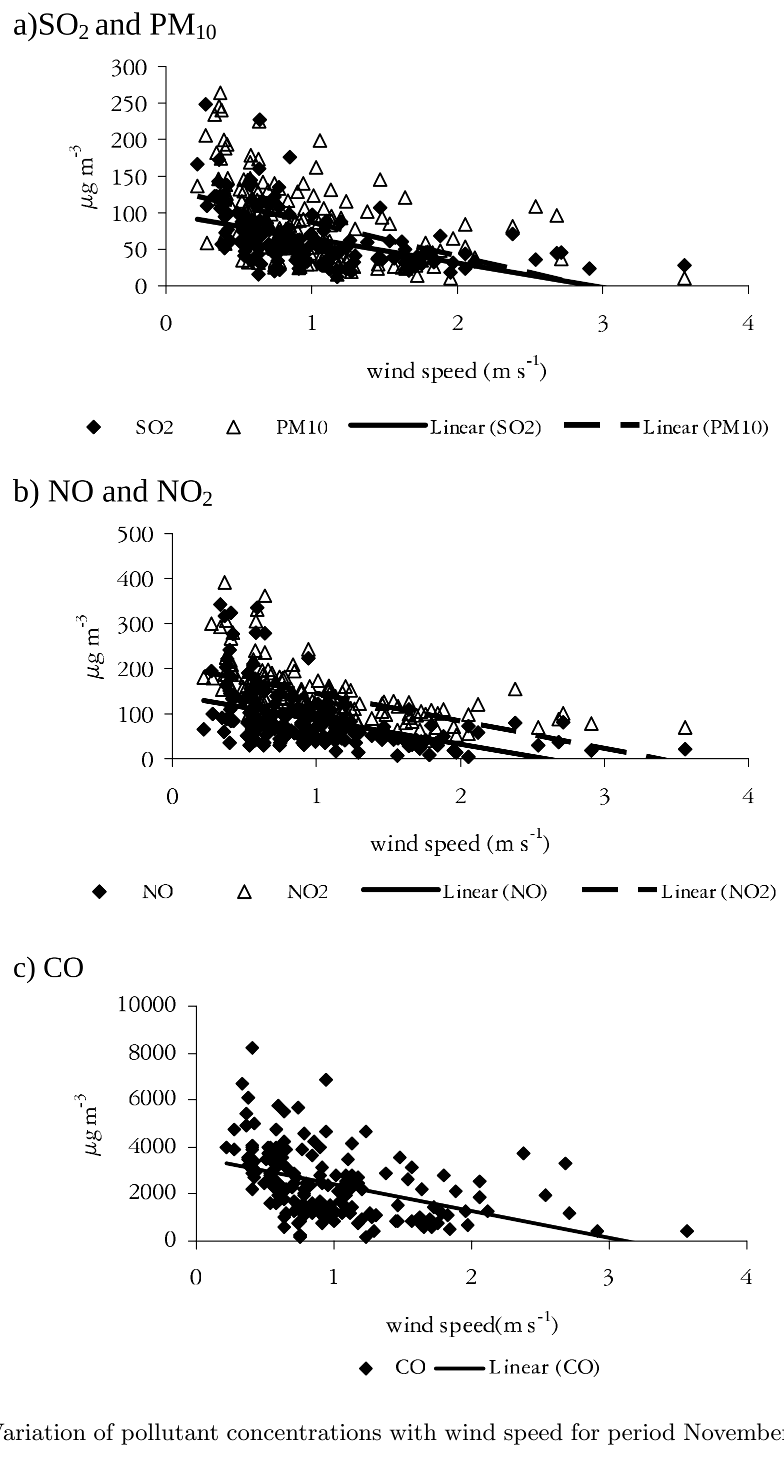

Fig. 2. – Variation of pollutant concentrations with wind speed for period November 2001-April 2002.

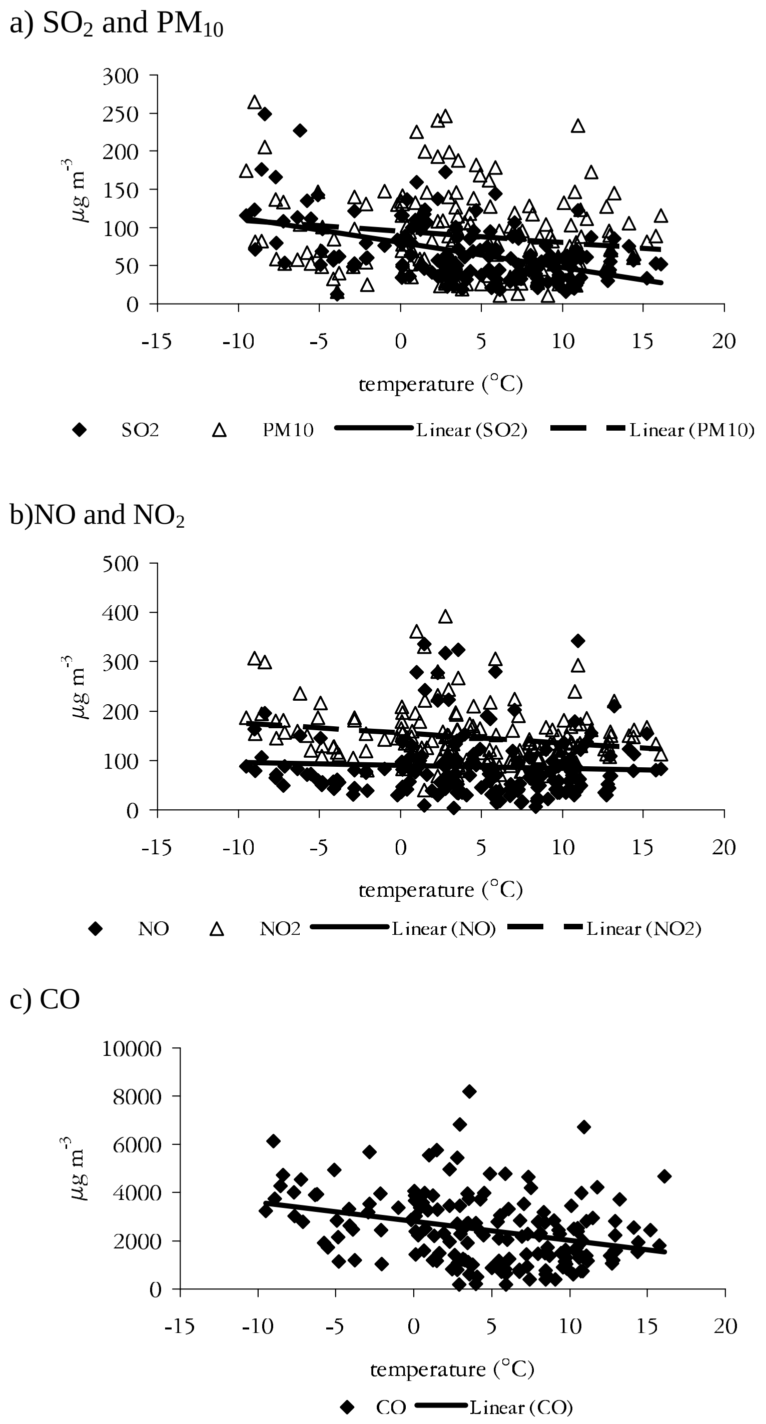

Fig. 3. – Variation of pollutant concentrations with temperature for period November 2001-April 2002.

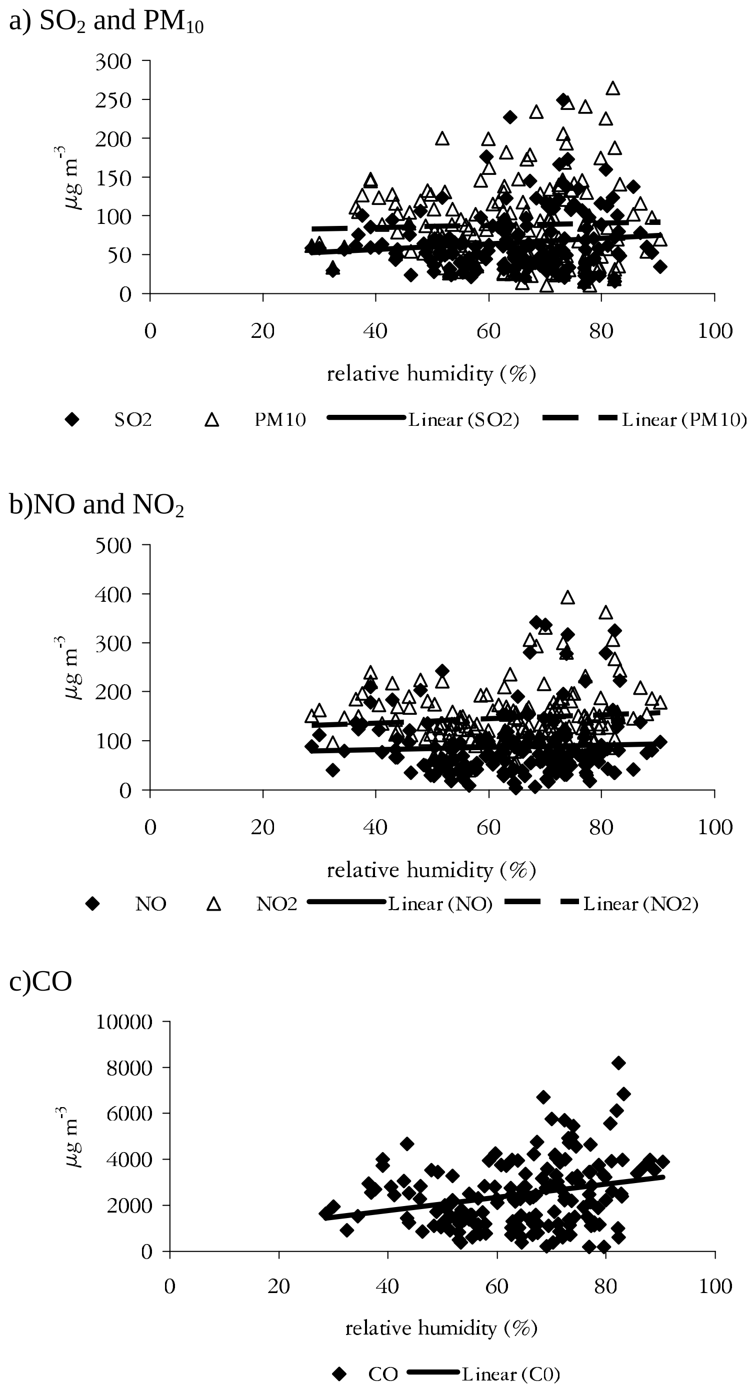

Fig. 4. – Variation of pollutant concentrations with relative humidity for period November 2001-April 2002.

TABLE V. – *Summary of the results of the regression analysis.*

Month	Dependent variables	Independent variables	Variables in the equation	Linear relation	Coefficient of determination, R^2 (%)	Level of relation
Nov 2001	SO_2	Temperature	SO_2/wind speed	Negatively	45	Moderate
	PM_{10}	Wind	PM_{10}/wind speed	Negatively	48	Moderate
	NO	Humidity	NO/wind speed	Negatively	47	Moderate
	NO_2		NO_2/wind speed	Negatively	58	Moderate
	CO		CO/hum, temp	Positively	49	Moderate
Dec.2001	SO_2	Temperature	SO_2/temp	Negatively	33	Weak
	PM_{10}	Wind				
	NO	Humidity	NO/wind speed	Negatively	22	Weak
	NO2		NO_2/wind speed	Negatively	35	Weak
	CO					
Jan.2002	SO_2	Temperature	SO_2/wind speed, hum	Negatively	45	Moderate
	PM_{10}	Wind	PM_{10}/wind speed	Negatively	22	Weak
	NO	Humidity	NO/temp	Negatively	15	Weak
	NO_2		NO_2/wind speed, temp	Negatively	40	Moderate
	CO		CO/wind speed	Negatively	25	Weak
Feb.2002	SO_2	Temperature	SO_2/wind speed, hum	Wind speed −, hum +	51	Moderate
	PM_{10}	Wind	PM_{10}/wind speed, hum	Wind speed −, hum +	65	Moderate
	NO	Humidity	NO/wind speed, hum	Wind speed −, hum +	48	Moderate
	NO_2		NO_2/wind speed, hum	Wind speed −, hum +	47	Moderate
	CO		CO/wind speed, hum	Wind speed −, hum +	67	Moderate
Mar.2002	SO_2	Temperature	SO_2/wind speed, temp	Wind speed −, temp +	65	Moderate
	PM_{10}	Wind	PM_{10}/wind speed, temp	Wind speed −, temp +	62	Moderate
	NO	Humidity	NO/wind speed, temp	Wind speed −,temp +	62	Moderate
	NO_2		NO_2/wind speed, hum	Wind speed −, hum −	68	Moderate
	CO		CO/wind speed, temp	Wind speed −, temp +	65	Moderate
Apr.2002	SO_2	Temperature	SO_2/hum	Negatively	30	Weak
	PM_{10}	Wind	PM_{10}/hum,temp	Hum −, temp +	60	Moderate
	NO	Humidity	NO/temp	Positively	16	Weak
	NO_2		NO_2/wind speed	Negatively	19	Weak
	CO		CO/temp	Positively	19	Weak

For all the pollutants, for all the months considered, the regression analyses have been carried out and similar expressions have been derived. The results of these regression analyses are summarized in table V. When this table is evaluated, significant relations are seen between pollutant concentrations and meteorological parameters, except that no significant relations are found between PM_{10} and CO concentrations, and meteorological factors in December 2001.

The results of the regression analyses summarized in table V show that the wind speed is a dominant meteorological factor affecting the pollutant concentrations. In 21 of the 30 regression equations obtained, the wind speed is the primary factor that influences the pollutant concentrations. In nine of these 21 equations, the wind speed is the only meteorological parameter that has a significant relation. In all the cases considered, the pollutant concentrations decrease with increasing wind speed, as also seen in table II. In other words, the correlation between the wind speed and all the pollutant concentrations is negative.

The relation between the pollutant concentrations and the meteorological factors in February and March is stronger than that of other months. It is obvious that the wind speed and relative moisture are the influential meteorological variables in February. In this month, there are moderate relations between wind speed and humidity, and all the pollutant concentrations. In March, the wind speed and temperature are the governing independent variables and the relation between these meteorological factors and the pollutant concentrations is moderate.

Considering the whole data for the period studied the relations between the pollutant concentrations and the meteorological factors are plotted in figs. 2, 3 and 4. In these figures, the measured values and also the linear line fitted to these measured data is depicted. Figure 2 shows the variation of the pollutant concentrations with the wind speed. It is clearly seen in this figure that the concentrations of all the pollutants decrease with increasing wind speed. The variation of the pollutant concentrations with the temperature is given in fig. 3. A considerable decrease in the SO_2, PM_{10} and CO concentration, and a slight decrease in the NO and NO_2 concentrations with increasing temperature are observed in this figure. The weak effect of the temperature on the NO and NO_2 can be attributed to the fact that emission from the motor vehicles is the main source of the NO and NO_2 in the region studied. There is a very weak positive correlation between pollutant concentrations and the relative humidity. As seen in fig. 4, the changes in the pollutant concentrations with the changing humidity are very small except the change in the CO concentration.

5. – Conclusion

In this study, the relations between air pollutant (SO_2, PM_{10}, NO, NO_2 and CO) concentrations and the meteorological factors have been statistically analyzed for the period of November 2001 and April 2002. The results of the analysis show that the concentrations of all the pollutants decrease with increasing wind speed. In the majority of the regression expressions obtained the relation between the wind speed and the pollutant concentrations is moderate. With the increasing temperature, SO_2, PM_{10} and CO concentrations decrease. However, there is not a clear relation between temperature, and NO and NO_2 concentrations. This leads to the conclusion that NO and NO_2 are mainly emitted by motor vehicles in the region studied. Changes in SO_2, PM_{10}, NO and NO_2 concentrations with the changing relative humidity are insignificant. However, CO concentration increases with increasing relative humidity.

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