PAPER DETAILS

TITLE: The Relation Between Meteorological Factors and Pollutants Concentrations in Karabük City

AUTHORS: M Bahattin ÇELIK,Ibrahim KADI

PAGES: 87-95

ORIGINAL PDF URL: https://dergipark.org.tr/tr/download/article-file/83081

G.U. Journal of Science
20(4): 87-95 (2007)

www.gujs.org

The Relation Between Meteorological Factors and Pollutants Concentrations in Karabük City

M. Bahattin ÇELİK, İbrahim KADI

Karabuk University, Technical Education Faculty, Karabuk, Turkey

Received: 22.08.2005 Revised: 28.04.2007 Accepted: 14.06.2007

ABSTRACT

Karabuk, situated in the northwest of Turkey, is among the cities which suffer most from the air pollution in Turkey. Due to the heavy industrial foundations and the usage of low quality coal for heating purposes, air pollution has been the primary environmental problem in Karabuk. Meteorological factors are known to be effective in decreasing air pollution, but the meteorological properties of Karabuk do not allow for the diminishment of air pollution. In this study, the relationship between SO_2 and particulate matter; and wind speed, relative humidity and air temperature has been investigated from 1998 to 2001 on the bases of 24-hour continuous measurements. The relationship between air pollution and the meteorological factors was statistically analyzed. According to the results of the analysis, for some years, there is a moderate and weak level relation between meteorological factors and particulate matter concentrations in Karabuk city.

Key words: Meteorological factors, Air pollution, Regression

1. INTRODUCTION

The air quality in cities varies depending on the industrialization, population and traffic density; and meteorological and topographical properties of the region. Especially in industrialized cities, the pollutants exhausted, emitted and discharged by the industrial foundations have the most significant effect in environmental pollution. Among the meteorological parameters, wind speed can be effective in decreasing pollutant concentration.

In a study by Mayer [1], air pollution in some cities throughout the world was investigated and it was stated that by increasing industrialization and energy consumption, there is a rapid increase in pollution level which seriously threatens the human health. Sánchez-Ccoyllo and Andrade [2] investigated the influence of meteorological conditions on the behavior of pollutants concentrations for the determined period in the city of Sao Paulo. In this study, it was seen that high values of pollution concentrations prevailed due to weak ventilation, low relative humidity and an absence of precipitation. Romero et al. [3] investigated the air pollution levels in various regions of Santiago and determined that in some regions wind decreases the pollution. Cuhadaroglu and Demirci [4] investigated the relationship between air pollution and meteorological factors statistically. They determined weak and moderate level relationships between meteorological factors and the SO_2 level for some months. In conclusion of the investigation of Cuhadaroglu and Demirci [5], it was claimed that there was a weak relationship between the speeds of the current winds and air pollution concentration in the city of Trabzon and this resulted from not taking the prevailing winds of the region into consideration when the city was being planned. They also proposed some policies for Trabzon. Triantafyllou [6] investigated the prevailing meteorological conditions during days with high concentrations of PM10, collected in the Eordea mountain basin. According to the results of this study, the highest concentrations were found to be associated with stagnant conditions and it was determined that local circulations developed in the area, resulting in recirculation and accumulation of pollutants. In the study presented by Tirabassi et al. [7], there is a close relationship between wind speed and pollution level in the coastal city of Ravenna. Shively and Sager [8] investigated the relationship between meteorological factors and ozone (O_3) in the air using a semi-parametric regression model. Chao [9] studied the characteristics of the climate in urban Shanghai, which

♠Corresponding author, e-mail: mbcelik@gmail.com

is the greatest industrial and commercial city in China. In addition, the distribution of SO_2 and total suspended particle concentration and their seasonal variations; as well as the relationship of air pollution, distribution of factories and meteorological conditions, were analyzed. Some policies and measures were proposed. Gassmann and Mazzeo [10] investigated the effect of two atmospheric parameters on the air pollution. In this paper, a statistical analysis of mixing height and transport wind, in order to determine the areas with high or poor atmospheric ventilation in Argentina, was presented. Kandlikar and Milind [11] investigated the causes and consequences of particulate air pollution in urban India. They determined that the main categories of urban air pollution sources in India are vehicular emissions, industrial emissions and fuel use for domestic purposes. Şen [12] investigated the inversions and air pollution in Istanbul. He stated that the air pollution increased in Istanbul owing to the rapidly growing and inefficient usage of fuel, and the air pollution level was affected by the weak dispersion conditions in the city.

This study aims to analyze the relationship between meteorological factors and air pollution in urban Karabuk. For this purpose, the data for temperature, humidity, wind speed and air pollution concentrations (APCs), during specific hours of the day in the winter seasons between 1998 and 2001, have been recorded and statistically analyzed.

As seen in Figure 1, Karabuk is a city in the West Black Sea region, surrounded by high hills and mountains. The distance to the Black Sea is approximately 80 kilometers. Its area is around 20 kilometers square and it has 103,000 inhabitants. The population density is 5150 per square kilometer. The climate characteristics of the region are warm and dry in summers, and rainy but not too cold in winters. Sometimes the humidity ratio is high. The prevailing wind in urban Karabuk comes from the southwest.

2. AIR POLLUTION IN KARABUK AND THE HISTORICAL EVOLUTION

Karabuk, which was a quarter consisting of thirteen houses until 1937, became a sub-district with the foundation of the iron-steel factory, then a town, and later became a city in 1995. After 1937, it became an industrial region, with immigrants coming from the neighbouring districts and cities. The iron-steel factory and other industrial companies were built before housing. During the city's development, houses for the public were built near the factory that causes the environmental pollution. Throughout the historical period, the industrial sector and private houses have potentially increased.

There are heavy industrial plants in Karabuk and there is also an annual coal and fuel oil consumption, for residential heating and industry, of approximately 190,000 tons and 30,000 tons, respectively. The sources of air pollution in Karabuk are Kardemir A. S. (Iron – Steel Factory), Kardemir A.S. slag collection area, rolling mills built randomly within the city, fuels used for heating and engine vehicles [13]. Karabuk is surrounded by high hills in four different directions, creating an artificial greenhouse. The high hills and mountains make slower wind speeds, causing turbulences air-flows and whirlpools in the city. Emissions- exhausted into the atmosphere by industrial organisations- have been transported from one region of the city to another by this wind circulation. Because the pollution is not transported out of the city by the air, a cloud of pollutant particles can easily be seen in winter months. The highest air pollution level in the city is in the districts around Kardemir A.S. In other parts of the city, there is also dense air pollution due to the emissions from the rolling mills and residential buildings. In addition, due to the fact that the wind comes from the south, the pollutants exhausted by the iron-steel factory are transported to urban areas and thus the air pollution level in the city has sometimes been maximized.

3. EVALUATION OF THE DATA

On the bases of 24-hour continuous measurements were recorded in the winter months (October, November, December, January, February and March) of the years 1998, 1999, 2000 and 2001. The measurements were made with a mobile air-quality measuring analyzer, which was borrowed from the Directorate of Environment and Meteorology of Karabuk. The measurement analyzer is fully automatic and computer controlled. To prevent measurement errors, the analyzer was calibrated in the certain periods. For SO_2 and PM measurements, a UV Fluorescent SO_2 Analyzer (Model AFM 21M) and an Ambient Suspended Particulate Monitor (MP 101M) were used, respectively; and in two different locations in the town SO_2 and PM measurements were recorded continuously for 24 hours to calculate the average values. In addition, wind speed, temperature and relative humidity ratio were measured using this analyzer.

The pollution and meteorological parameters in the place in which the pollution level is relatively high were taken into consideration. The hourly average APCs, wind speed, relative humidity ratio and temperature data taken into consideration in this study are presented in Table 1.

Average particulate matter (PM) and SO_2 per season recorded according to the hours of the day in winter months are; 145.04 $\mu g\ m^{-3}$ and 116.95 $\mu g\ m^{-3}$ in 1998; 159.25 $\mu g\ m^{-3}$ and 118.16 $\mu g\ m^{-3}$ in 1999; 156.75 $\mu g\ m^{-3}$ and 85.21 $\mu g\ m^{-3}$ in 2000; and 124.04 $\mu g\ m^{-3}$ and 84.62 $\mu g\ m^{-3}$ in 2001, respectively. Some amounts recorded exceed the limit set by the World Health Organization and National Standards. PM and SO_2 values exceeded the limits 16 and 3 times in a year, respectively. Average PM and SO_2 levels of four years are 146.27 $\mu g\ m^{-3}$ and 101.24 $\mu g\ m^{-3}$ respectively.

Figure 2 shows the average values variation of the APCs and meteorological factors for the hours of day in winter months between 1998 and 2001. Maximum PM and SO_2 concentration were measured at 6-8 pm and 9-11 am, respectively. (See Figure 2.)

Figures 3, 4 and 5 were obtained from all the data (not average values) recorded for the hours of day in winter months between 1998 and 2001 in order to determine the relationship level between the meteorological factors and the air pollution concentrations more accurately.

Figure 3 shows the relationship between the wind speed and APCs. As seen in Figure 3, PM concentration decreases and SO_2 increases as the wind speed increases.

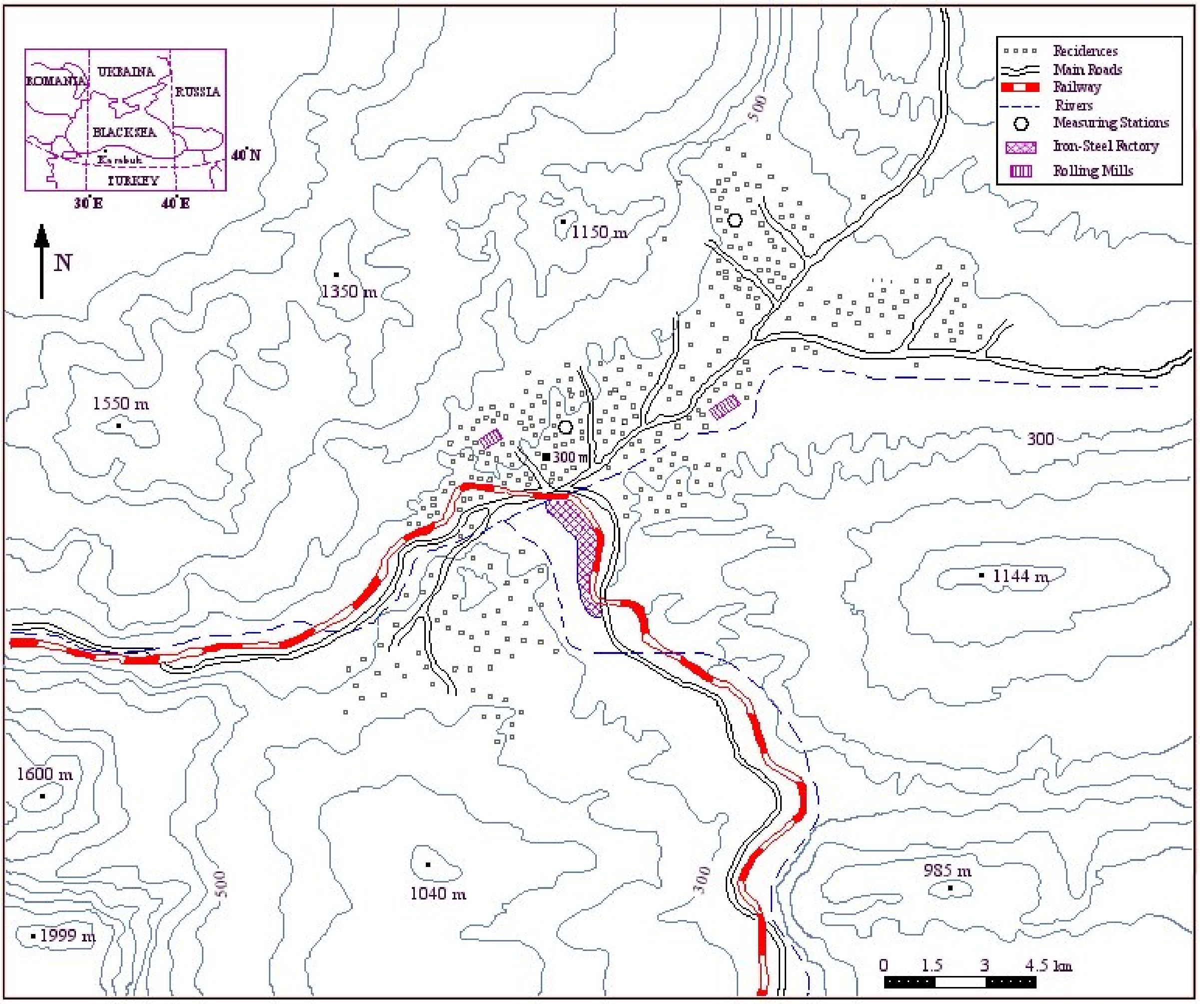

Figure 1. Karabuk city map.

Table 1.Hourly average values of the variables in Karabuk (1998-2001, winter months)

Hours	SO_2 ($\mu g\ m^{-3}$)	PM ($\mu g\ m^{-3}$)	Wind speed ($cm\ s^{-1}$)	Relative humidity ratio (%)	Temperature (ºC)
1	84.75	131.5	87.5	85.75	7.25
2	76.25	107.25	88.5	87	6.5
3	69.25	93	123.75	89	7.25
4	64.5	81.75	129.75	89.5	7
5	63.75	83.5	129.75	90.75	6.5
6	67.25	85.5	128.25	90.75	6.25
7	78	94.5	127.5	91.25	6.25
8	106.75	127.75	135	90	6.25
9	153.75	172.25	133	84.5	7.25
10	167.5	174.25	117	76	8.25
11	155.75	184.75	109.5	68	9.25
12	139	163.75	109.5	61.5	11.25
13	104	153	109.25	56.5	12.25
14	118.75	145.25	106.5	53.25	13.25
15	112	157.25	106.25	52	13.25
16	95.75	152.5	106.5	53	13.25
17	92.25	177.75	100.5	58	12.5
18	92.25	186	86.25	64.5	11.25
19	94.5	208.5	80.25	70.25	10.25
20	95.5	199	80	74	9.25
21	96.25	179.75	80.25	77.25	8.25
22	102	158.5	82.5	80.5	8
23	104.5	155.5	85.25	82.25	7.5
24	95.5	137.75	87	84.5	7.25
Average	101.24	146.27	105.39	75.41	8.98
1998	116.95	145.04	142.25	78.7	10
1999	118.16	159.25	119.91	76.75	9.71
2000	85.21	156.75	73.79	72.95	7.25
2001	84.62	124.04	85.62	73.25	8.96
Average	101.24	146.27	105.39	75.41	8.98

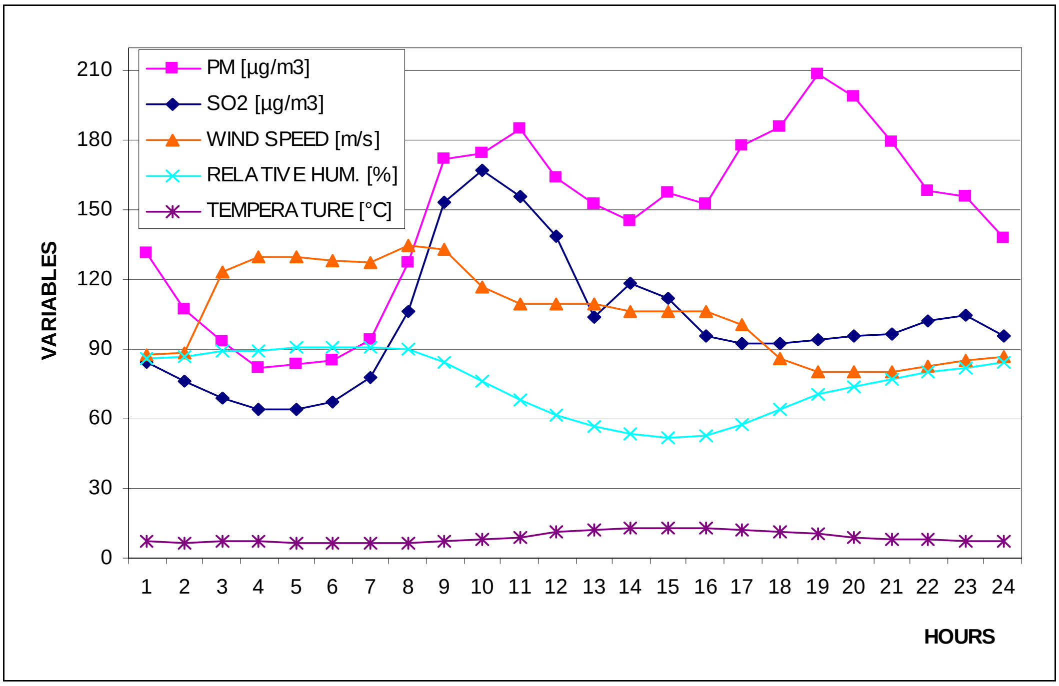

Figure 2. The variation of the APCs and meteorological factors for the hours of day in winter months in 1998-2001.

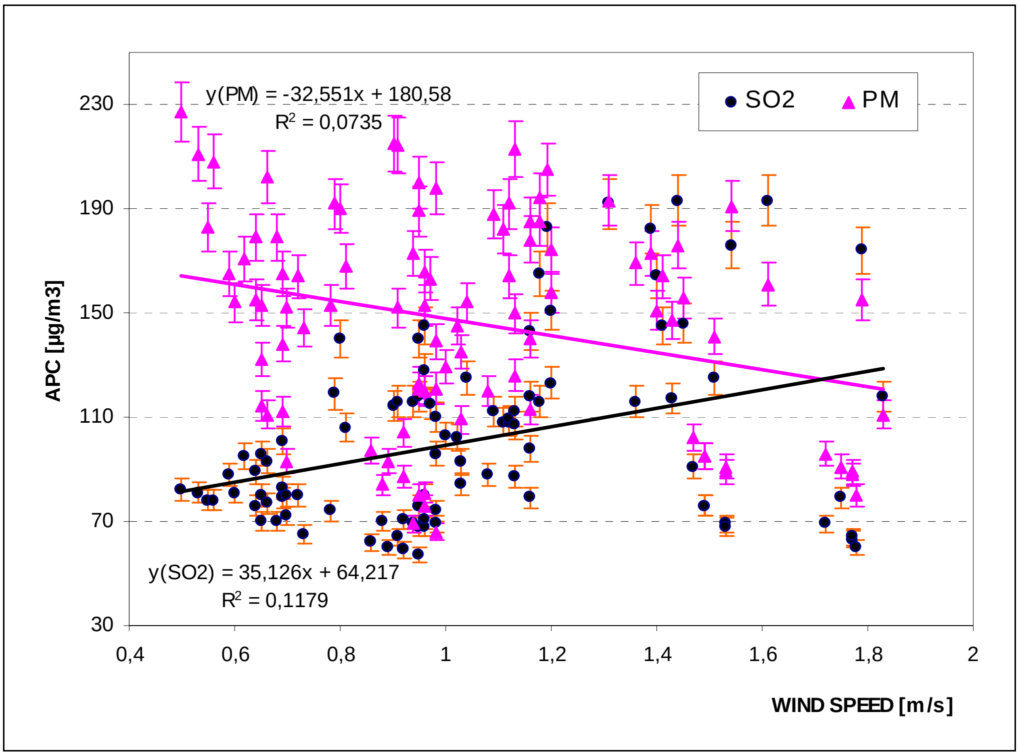

Figure 3. The relationship of the wind speed and APCs.

As seen in Figure 4, PM concentration decreases with the increase in the relative humidity ratio. Dependency of particle concentration upon the relative humidity ratio is more than that of SO_2 concentration.

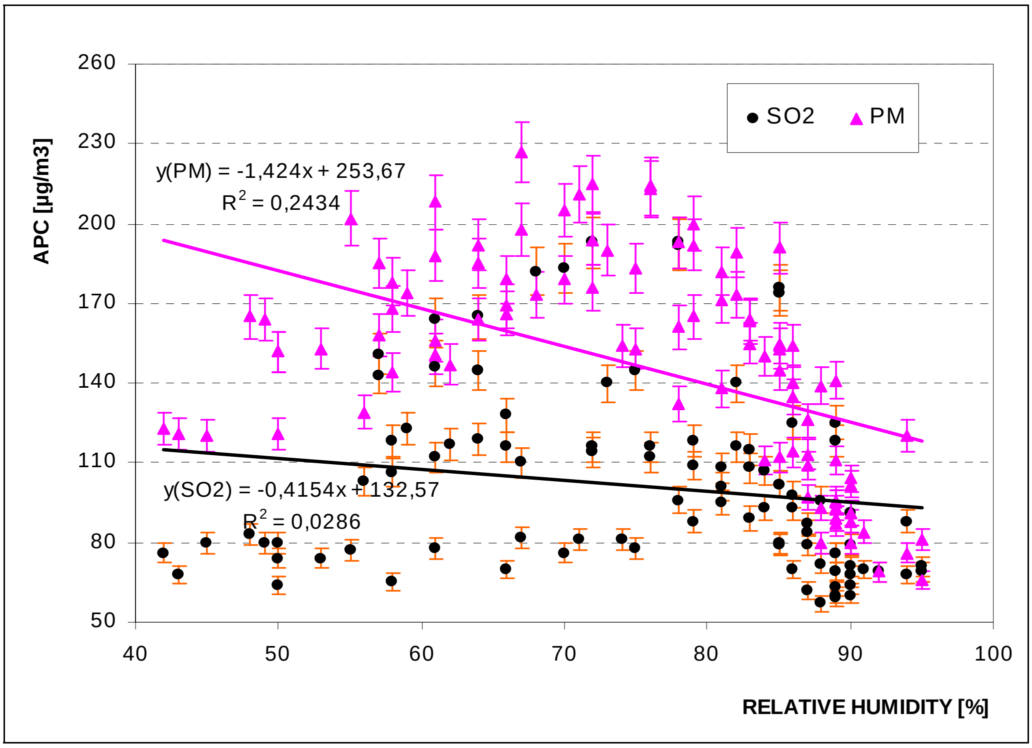

Figure 4. The relationship of the relative humidity ratio and APCs.

Figure 5 shows the relationship between the temperature and the pollution. It can be seen that both PM and SO_2 concentrations increase with the temperature. Maximum average PM concentration was recorded as 227 µg m^{-3} in 2000 at 19 o'clock at the values of SO_2 of 82 µg m^{-3}, temperature of 9 °C, relative humidity ratio of 67% and wind speed of 0. 5 m s^{-1}. The maximum value of SO_2 concentration was recorded as 193 µg m^{-3} in 1998 at 10 o'clock at the values of PM of 161 µg m^{-3}, temperature of 10 °C, relative humidity ratio of 78% and wind speed of 1. 61 ms^{-1}.

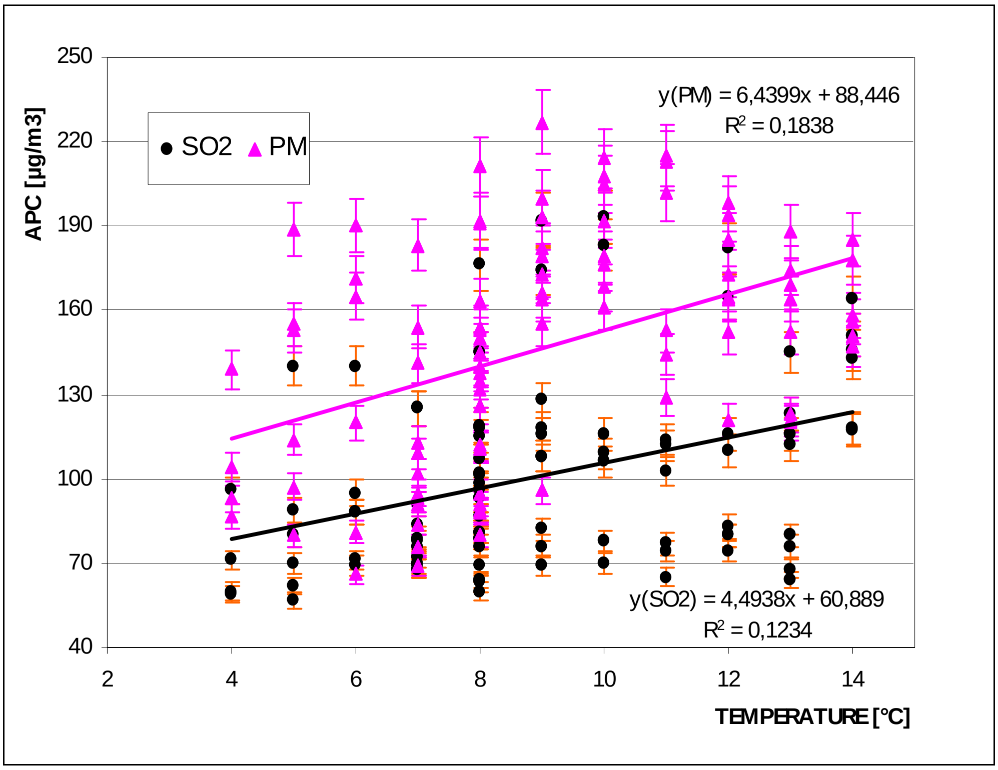

Figure 5. The relationship of the temperature and APCs.

As seen in Figures 3, 4 and 5, PM concentration decreases in low temperatures, high wind speed and high humidity ratio. SO_2 concentration decreases in low temperatures, low wind speed and high humidity ratio. As seen in Figures 3, 4 and 5, the R^2 values of trend lines (0.0735, 0.2434, 0.1838, 0.1179, 0.0286 and 0.1234) are very low and thus there is a weak relationship between APCs and meteorological factors.

The error bars shown in the Figures 3, 4 and 5 express 5% positive and negative potential error amounts in the results of the measurement. Potential error amounts do not have a significant effect on the relationship between APC concentration and meteorological factors.

4. DATA ANALYSIS

A statistical analysis technique was applied to the APCs data recorded hourly by the official stations during the winter months of 1998-2001 and to the meteorological data such as wind speed, relative humidity ratio and temperature. To determine the best relation between the variables particularly the hourly data was used. Regression analysis procedure is used to state the mathematical relationship between the variables and identify whether there is a meaningful relationship between those variables or not. Due to the fact that the number of independent variables is more than one, multiple linear regression analysis was used in the present analysis. A general regression equation, which has three independent variables and one dependent variable, can be expressed as:

$$y = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + e \qquad [1]$$

where a is the constant of regression and b is the coefficient of regression. Each coefficient b represents the effect of the independent variable on y. The APCs (PM and SO_2) are considered to be dependent variables and wind speed, relative humidity ratio and temperature are considered to be independent variables. The values of the constant and the coefficients are determined using the least-squares method which minimizes the error, appearing as e in the above regression equation. The significance level of the constant and coefficients is statistically tested using the t distribution.
R^2 (coefficient of determination) determines the direction and significance level of relation between the

*Corresponding author, e-mail: mbcelik@gmail.com

variables in the mathematical model and shows how much the dependent variable in the mathematical model is affected by the independent variables. R^2 is expressed as:

$$R^2 = 1 - \frac{\sum(\hat{y}_i - \bar{y})^2}{\sum(y_i - \bar{y})^2} \qquad [2]$$

where $\hat{y}_i$ is the value of y predicted by the regression line, y_i is the value of y observed, and $\bar{y}$ is the mean value of the y_is. R^2 is found between –1 and +1. R^2 is ‘‘0” if there is no linear relationship between the dependent and independent variables [14].

Various methods can be used to construct a regression model. In this study a stepwise regression model was used. The most important step in multiple regression analysis is to determine the independent variables to be taken into consideration. Among the x_i independent variables the one whose simple correlation coefficient with y is the biggest is chosen and the simple regression equation is obtained between this variable and y. Then it is examined whether there is a significant increase in the correlation coefficient R when one of the other variables is included in this equation. The variable which causes the biggest increase is included in the regression. In each step, after adding a new variable, one of the current variables is excluded to examine whether it causes a significant increase in R or not. The process is continued until the value of R reaches the maximum.

In this analysis, the hourly data provided by the official departments for the winter months of each year, and the correlations between the APCs and meteorological factors, have been analyzed. To find the best regression model;

$y=f(x_1)$, $y=f(x_2)$, $y=f(x_3)$, $y=f(x_1, x_2)$ ….., $y=f(x_1,x_2,x_3)$ equations were analyzed separately and the independent variables with the lower R^2 values are eliminated. Using the remaining variables, equations with one, two or three variables were constructed. For some conditions, no regression equation between the variables was found. Regression analysis results of 4 years, according to the hours of the day, are given in Table 2. A multiple regression analysis is applied for each year. For example, the regression equation constructed for PM in 2000 is expressed as follows:

PM = 1094.457 – 34.278 x Temperature – 7.546 x Humidity – 1.879 x Wind speed (R^2 = 0.661)

According to this equation, the PM level decreases with the increase of the ambient temperature, humidity and wind speed. As seen in Table 2, 66% of PM depends on temperature, humidity and wind speed, and 34% of PM is indeterminate. In 2000, no relationship between the independent variables and SO_2 was found. In 1999, the regression equation obtained for SO_2 is expressed as follows:

SO_2 = 1165.3 – 36.9 x Temperature – 8.97 x Humidity (R^2 = 0.45)

The above equation reveals that the SO_2 decreased with increasing temperature and humidity. In 1999, no relationship was found between the SO_2 and the wind speed; thus the wind speed was eliminated from the equation.

5. RESULTS AND DISCUSSION

As known in general, APCs decrease with an increase in wind speed. According to the results of 4 years obtained from data analysis, as the wind speed increases, PM concentration decreased slightly and SO_2 concentration increased, as seen in Fig. 3. Statistical analysis results show that there is not a strong relationship between APCs and the wind speed. As seen in Table 2, PM concentration has a moderate level of relation and also 64% of coefficient of determination with the wind speed in conjunction with the humidity ratio in 1998. In 1999, there is a moderate level of relation with 57% of R^2 between PM, and wind speed and humidity. In 2000 and 2001, it has a moderate level relationship with 66% and 54% of R^2 respectively between PM concentration and the humidity, temperature and wind speed. There is not a relationship between the SO_2 concentration and the wind speed for every year.The reason why there is not a strong relationship between the wind speed and the APCs is that the situation of Karabuk is like a dish surrounded by mountains and hills and the wind cannot transport the pollution away from the city.In addition, average wind speed in Karabuk for 4 years is as low as 1.05ms^{-1}.

As seen in Table 1, because the difference between the annual average humidity ratio values is small, a strong relationship between APCs and the humidity ratio cannot be expected in the yearly analysis. As seen in Figure 4, PM concentration decreases slightly with increasing humidity ratio, but the SO_2 concentration is not effectively influenced by humidity ratio. According to statistical analysis results, there is a weak level of relation between SO_2 and humidity ratio in 1998, where the value of R^2 is 40%. In the same year, there is a moderate level of relation having the value of 64% of R^2 between PM, and the wind speed and humidity, as seen in Table 2.

As seen in Figure 5, according to the results obtained from data, SO_2 and PM concentrations increase with rising temperature. The results of the statistical analysis show that there is not a strong relationship between temperature and APCs, as seen in Table 2. In 1999, a weak level relation having the value of 45% of R^2 is obtained between SO_2 concentrations, and temperature and humidity ratio. In 2000 and 2001, temperature, humidity and wind speed have an influence on PM concentrations and the values of R^2 are 66% and 54%.

There is no relation between temperature and APCs in 1998.

Table 2. Regression results for 4 years analyzed.

Years	Dependent variables	Independent variables	Variables in the equation	Linear relation	Coefficient of determination, R^2 (%)	Level of relation
1998	SO_2	Humidity Wind Temperature	SO_2/humidity	Negatively	40	Weak
	PM		PM/wind, humidity	Wind-negatively Humidity-neg.	64	Moderate
1999	SO_2	Humidity Wind Temperature	SO_2/humidity, temperature	Humidity-neg. Temperature-neg.	45	Weak
	PM		PM/humidity, wind	Humidity-neg. Wind-negatively	57	Moderate
2000	SO_2	Humidity Wind Temperature	-	-	-	-
	PM		PM/wind, humidity, temperature	Wind-negatively Humidity-neg. Temperature-neg.	66	Moderate
2001	SO_2	Humidity Wind Temperature	-	-	-	-
	PM		PM/wind, humidity, temperature	Wind-negatively Humidity-neg. Temperature-neg.	54	Moderate

6. CONCLUSIONS

According to the results obtained from the multiple linear regression analysis, there is not a strong relationship between the meteorological factors and the SO_2 and PM concentrations in urban Karabuk. Humidity, wind speed with humidity, humidity with temperature, and wind speed with humidity and temperature are correlated with APCs for some years. Although the wind speeds in 1998 and 1999 are higher than the 4-year average wind speed, there is no a strong relationship in these years either. The major reason for this condition is that the city is surrounded by mountains and hills and the wind speed is not high enough to transport the pollution away from the city atmosphere.

Because of the heavy industrial foundations in the city center in Karabuk, and usage of low quality coal for heating residences, this city lives with a heavy air pollution level. The ultimate solution for the pollution is natural gas. For a short term solution, the coal and fuel oil used for heating residences and for energy should be of high quality. In addition, to improve the wind circulation in the city, new streets should be opened, taking the direction of the prevailing winds in the city into consideration. Thus the air pollution can be reduced slightly.

ACKNOWLEDGEMENTS

This research was supported by the State Planning Organization of Turkey and the University of Zonguldak Karaelmas Research Fund. The authors wish to thank the Directorate of Environment and Meteorology of Karabuk for supplying the data used in this research.

REFERENCES

[1] Mayer, H., ‘‘Air pollution in cities’’, ***Atmospheric Environment***, 33: 4029-4037, (1999).

[2] Sánchez-Ccoyllo, O. R. and Andrade, M. de F., ‘‘The influence of meteorological conditions on the behavior of pollutants concentrations in Sao Paulo, Brazil’’, ***Environmental Pollution,*** 116: 257-263, (2002).

[3] Romero, H., Ihl, M., Rivera, A., Zalazor, P. and Azacar, P., ‘‘Rapid urban growth, land-use changes and air pollution in Santiago, Chile’’, ***Atmospheric Environment***, 33: 4039-4047, (1999).

[4]Cuhadaroglu, B. and Demirci, E., ‘‘Influence of some meteorological factors on air pollution in Trabzon city’’, ***Energy and Buildings,*** 25: 179-184, (1997).

[5] Cuhadaroglu, B. and Demirci, E., ‘‘Statistical analysis of wind circulation and air pollution in urban Trabzon’’, ***Energy and Building,*** 31: 49-53, (2000).

[6] Triantafyllou, A. G., ‘‘PM10 pollution episodes as a function of synoptic climatology in a mountainous industrial area’’, ***Environmental Pollution***, 112 (3): 491-500, (2001).

[7] Tirabassi, T., Fortezza, F. and Vandini, W., ‘‘Wind circulation and air pollutant concentration in the coastal city of Ravenna’’, ***Energy and Buildings,*** 15: 699-704, (1990).

[8] Shively, T.S. and Sager, T.W., ‘‘Semi parametric Regression Approach to Adjusting for Meteorological Variables in Air Pollution Trends’’, ***Environmental Science and Technology***, 33: 3873-3880, (1999).

[9] Chao, Z., ‘‘Urban climate and air pollution in Shanghai’’, ***Energy and Buildings***, 16 (1-2): 647-656, (1991).

[10] Gassmann, M. and Mazzeo, N. A., “Air pollution potential: Regional study in Argentina”, ***Environmental-Management***, 25 (4): 375-382, (2000).

[11] Kandlikar, M. and Ramachandran, G., “The causes and consequences of particulate air pollution in urban India”, ***The Annual Review of Energy and the Environment***, 25: 629-684, (2000).

[12] Sen, O., “Inversions and air pollution in Istanbul”, ***International Journal of Environment and Pollution,*** 8 (1-2), 158-162, (1997).

[13] Celik, M.B., Ozdalyan, B., Kadi, I. and Borat, O., ‘‘Gunun saatlerine gore Karabuk’te hava kirliligi’’, ***G.U. Journal of Science,,*** Ankara, 15 (1): 181-189, (2002).

[14] Terzi, E., ‘‘Cok degiskenli regresyonda adimsal regresyon yontemiyle en iyi regresyon modelinin secimi ve bir uygulama’’, Ondokuz Mayıs Universitesi, Fen Bilimleri Enstitusu, ***Yuksek Lisans Tezi***, Samsun, 25-26, (1994).