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Effect of Meteorology on the Atmospheric Concentrations of Traffic-Related Pollutants in Erzurum, Turkey#

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Abstract The studies of the relationship between air pollutants and meteorological factors can provide important information about air pollution. According to proposed statistical model in this study, daily traffic-related pollutant concentrations are not only influenced by daily meteorological parameters but also by the pollutant concentration of previous day. In this study, the relationship between daily CO (carbon monoxide), NOx (nitrogen oxides), O_3 (ozone) concentration with the pollutant concentration of previous day and meteorological factors (wind speed, temperature, relative humidity) in 1995-1997 winter seasons was statistically analyzed using the stepwise multiple linear regression analysis. The statistical models of CO, NO_x and O_3 including meteorological parameters with previous day's pollutant concentration gave R^2 of 0.48, 0.28 and 0.75, respectively. The model was good for O_3, but for NO_x was weak. According to first equation the level of CO decreases with increasing temperature, but CO increases with increasing relative humidity and CO concentration of previous days. According to second equation the level of NO_x decreases with increasing wind velocity and temperature, but NO_x increases with increasing NO_x concentration of previous days. O_3 concentration increased with increasing wind speed, temperature, relative humidity and O_3 concentration of previous days.

Key Words: *air pollution, meteorological parameters, pollutant concentration of previous day, regression analysis.*

Introduction

Air pollution occurs within the atmospheric planetary boundary layer under the combined effects of meteorological factors, earth surface topographic features and releases air pollutants from various sources. Meteorological factors such as wind velocity, wind direction, temperature, relative humidity together with earth surface roughness are effective agents for mixture of air pollutants. The most important role of meteorology is in the dispersion, transformation and removal of air pollutants from atmosphere. The wind speeds determine the amount of dispersion of pollutants in the atmosphere. The temperature contributes transformation of pollutants in the atmosphere.

The topography and solar heating of region surrounding a particular pollution source affects the concentration. High pollution levels can be expected during fair weather conditions resulting local wind system and strong temperature inversions in cities situated in mountainous region.

Air pollution may be classified into two types according to the nature of formation: primary pollutants which are emitted from their sources directly to the atmosphere such as industry, traffic, domestic heating in winter season and secondary pollutants which results from the chemical reaction between the primary pollutants. Examples of primary pollutants are sulphur dioxide (SO_2), nitrogen oxide (NO), and carbon monoxide (CO). Examples of secondary pollutants are photochemical oxidants and ozone (O_3). Air pollutants such as CO, O_3, NO_x concentrations are strongly affected by traffic.

CO is an important trace gas in the earth's atmosphere, which performs several important roles in the troposphere. There are a variety of sources, both natural and anthropogenic, for ambient CO. Natural sources include oxidation of methane and natural hydrocarbons, ocean emissions, and

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emissions from vegetation. In rural areas, these are the most dominant sources; therefore, in a remote location, CO is one of the most dominant precursors for photochemical ozone production. In urban areas, however anthropogenic sources including fossil fuel combustion, industrial activities, motor vehicles, biomass burning, and oxidation of anthropogenic hydrocarbons, contribute far more to the concentration of CO than natural sources. The lifetime of CO is approximately 1-3 months, representing the slow rate of mixing and the consumption by reaction with OH. In the troposphere, a significant CO background concentration exists (~150ppbv in Northern Hemisphere and ~50ppbv in Southern Hemisphere) based on continuous CO production from the oxidation of methane and its long lifetime (Aneja et al., 2001).

Nitrogen in the atmosphere originate either from natural processes or anthropogenic activity. In the lower atmosphere, nitric oxide (NO) is converted to nitrogen dioxide (NO_2) by reaction with peroxyradicals (RO_2) or O_3. The NO_2 generated is then photolyzed in the atmosphere and the atomic oxygen released combines with molecular oxygen to form O_3 (Aneja et al., 2001). The life time of nitrogen oxides ($NO+NO_2$) in the troposphere ranges from less than one day in summer to several days in the absence of active photochemistry.

Trapospheric O_3 may originate by interchange with the stratosphere and/or photochemical production. In the urban atmosphere, nitrogen oxides (NOx) and volatile organic compounds may either increase or decrease O_3 concentrations. O_3 formation is closely related to meteorological parameters such as temperature, solar radiation, and wind speed (Barrero, 2006).

The relationship between traffic related air pollutants and meteorological parameters such as wind velocity, temperature and relative humidity can provide important information about air pollution. The wind speeds may tansport air pollutants (O_3, CO, NO_x) from distant sources. There are a negative correlation between air pollutants concentration and wind speed data. Analysis of the surface wind speed and direction alone will not adequately explain the variability in the concentrations of air pollutants. The association between temperature and air pollutants such as O_3, CO, NO_x are found to be important. For CO, NO_x higher concentrations occured at lower ambient temperature in winter season. But O_3 concentration increased with increasing temperature. Daily polluting concentrations are not only influnced by daily meteorological parameters but also by the values of previous day. There have been a direct link between air pollutants (O_3, CO, NO_x) concentration and their previous day's concentration (Ocak, 1997).

Given a set of observations from air monitoring and meteorological stations, calculating statistical relationship among the variables is possible by using some statistical techniques such as regression analysis. Some statistical models, establish how close relationships are between concentration estimates and values actually measured under similar circumstances. Effects of all factors that determine atmospheric pollutant concentrations are implicitly accounted for in the air quality data used to develop and optimize the models. These models also have low development cost and resource reqirements (Turalıoglu et al., 2005).

There are numerous research presented statistical relationship between meteorological parameters to air pollutants. Witz and Moore (1981) showed the relationship between air pollutants (CO, NO, NO_X, hydrocarbons) and meteorological parameters (wind direction, wind speed, early morning temperature, and frequency of inversions) using a stepwise multilinear regression analysis in Los Angeles in 1979. There is a close relationship between air pollutants and meteorological parameters. Katsoulis (1996) presented that air pollutants such as CO, O_3, NO_x concentrations were strongly affected by traffic, wind speed, height of inversion during 1984-1993 in Athens, Greece. Ocak and Demircioglu (2002) used multiple liner regression analysis to estimate SO_2 and PM concentrations using meteorological parameters (relative humidity, temperature, wind speed) and previous day's pollutants concentration in Erzurum for 1995-1996 winter season. It is found positive correlation between previous day's concentration and the pollutants concentration. Turalıoglu et al. (2005) predicted SO_2 and PM concentrations using multiple regression equation including previous day's pollutants concentration and meteorological parameters such as wind speed, temperature, relative humidity, pressure and precipitation for 1995-2002 winter season in Erzurum. The results showed good relationship between the meteorological parameters, previous day's SO_2 concentration and actual SO_2 concentration. The pollutants associated with traffic were at the highest ambient concentration levels when wind speed was low (Elminir, 2005). Chiu et al. (2005) presented that local meteorological parameters such as solar radiation, wind speed and wind direction effects O_3, NO_2

concentration. They found a positive correlation between ozone levels and solar radiation during daytime, increasing level of ozone with increased radiation. Hargreaves et al. (2000) found that a weak negative association was observed between NO_2 concentration and wind speed. Xu and Zhu (1994) showed that high O_3 concentrations were related to high pressure weather system, low relative humidity, low cloudiness, light wind speed, and fog formation. O_3 formation is closely related to meteorological parameters such as temperature, solar radiation and wind speed. Ozone concentration depends on previous day's ozone concentrations, also (Bloomfield et. al., 1996; Barrero et al., 2006). Spellman (1999) found that O_3 concentrations were related to maximum temperature, hours of sunshine and previous day's ozone concentration.

Materials and Methods

Description Area

Erzurum is one of the cities located in eastern part of Turkey, situated on plateau surrounded by mountains to east, North and South. The height this plateau is 1950 m a.s.l. It lies in a NE-SW direction, on an area about 20km long and 5km wide (Figure 1). The altitude difference between the upper and lower limits of the city is approximately 200m. The annual average temperature of the city is 6^{o}C and the number of days below zero are 161. The city's severe climate and unfavorable geomorphoogy and topography cause serious air pollution problems. The main contributors to air pollution in Erzurum city are domestic heating and private cars, public vehicles. Cars are the sources of CO, HC, and NO_x. The increase in the vehicle fleet in Erzurum for the 1990-95 years is shown Figure 2.

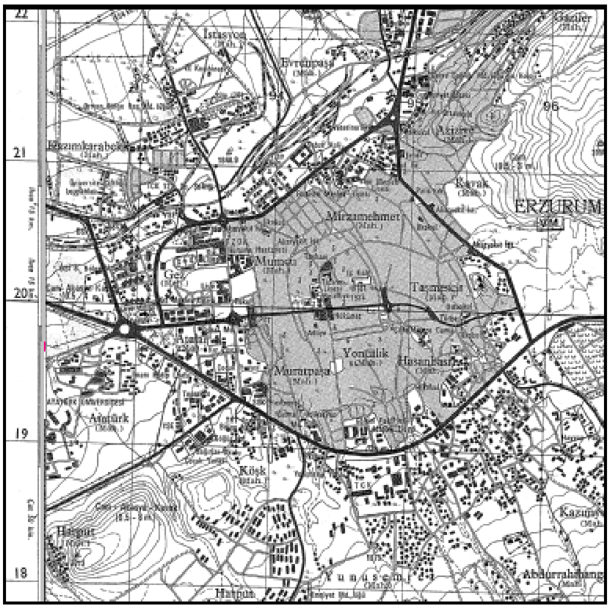


Figure1. Map of Erzurum city

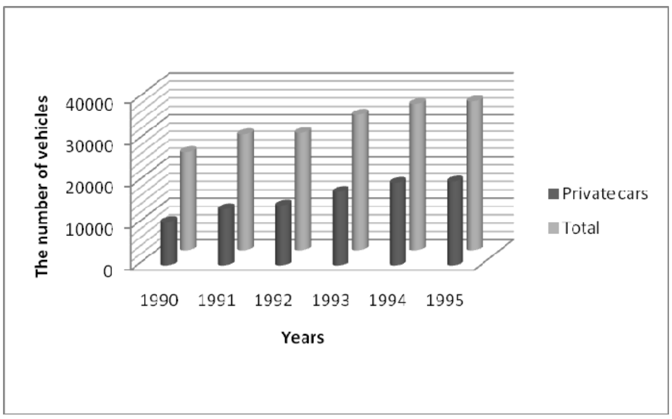


Figure 2. The number vehicles during 1990-1995 years in Erzurum city

There has been a rapid increase of the number of private cars in these years. On the other hand, public transport comprises 1056 buses, 1448 minibus in 1995. All these vehicles move in streets resulting in traffic congestion problems in Erzurum especially during rush hours. Traffic related emissions are highest near congested urban streets where vehicle density is high, engine efficiency low, and the ventilation is restricted. The microscale and mesoscale meteorological parameters commonly associated with high levels of air pollutants. The air pollution monitoring sites in the city center were used for this study. These sites typically record the levels of three air pollutants (CO, O_3, NO_x) and meteorological data (wind speed, temperature, relative humidity) in the city center during 1995-97 winter season.

Collection of Ambient Air Quality Data

CO, NO_x and O_3 together with meteorological parameters (wind speed, relative humidity and temperature) were monitored in mobile laboratory by Provincial Environmental Directoriate. The data used in this study are belonging to 1995-1997 winter season. Measurements were carried out for every 15 min. CO concentration were measured using an instrument that operates on principle of infrared absorption (CO 11M). The detection limit for CO measurements with this instrument is 0.1 ppm. NOx measurements were measured using a sensor (AC 31M) that works on the principle of chemiluminescence involving a gas phase reaction with ozone. NO_x measurements range varies between 0.1 and 10ppm. The detection limit for NO_x measurements with this instrument is 0.35 ppb. The laboratory was operative 24h in a day. O_3 measurements were made with an ultraviolet absorption instrument (O_3 41M). The detection limit for O_3 measurements with this instrument is 1 ppb. O_3 measurements range varies between 0.1 and 1 ppm. The location of the mobile laboratory was selected as the sampling site on the basis of availability of power and security and topography of the area. Care was taken that no high buildings or trees were present for 200m of the site in any direction. The reason for this condition is to eliminate the effect of downwash due to high structures. The mobile laboratory was fitted with the monitors and meteorological sensors. 24 h averaged values of CO, NOx, O_3 and meteorological data were used in this study. Statistical parameters of CO, NOx, O_3 and meteorological data of two winter seasons are given in Table1.

Table 1. The means, maximum, minimum and standart deviation of meteorological paramaters and O_3, NOx, CO concentration between years 1995-1997.

	Mean	Maximum	Minimum	Standart Deviation	Number of observation
CO concentration (mg/m^3)	1.4	11.8	0	1.3	185
NOx ($NO+NO_2$) concentration ($\mu g/m^3$)	76.9	305	9.1	57	185
O_3 concentration ($\mu g/m^3$)	24.8	67.8	0.3	15.8	185
Temperature (^oC)	-5.1	9	-26	7.5	185
Relative Humidity (%)	60	98	18	21	185
Wind speed (m/s)	0.8	6.8	0	0.9	185

Data Analysis

Regression analysis can be used to summarize data as well as to study relations between the variables. If the number of independent variables more than one, multiple linear regression analysis is used and general regression equation which four independent variables can be expressed as:

$$Y = A + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + E \qquad (1)$$

where A is constant of regression and B is coefficient of regression. The values of the constant and coefficients are determined using the least-squares method which minimizes the error, seen as E in the above regression equation (Akkaya, 1995). A commonly used measure of goodness of fit of a linear model is R^2, sometimes called the coefficient of determination. It is defined as the proportion of the variation in the dependent variable and expressed as:

$$R^2 = 1 - \frac{\sum(\hat{Y}_i - \overline{Y})^2}{\sum(Y_i - \overline{Y})^2} \tag{2}$$

where $\hat{Y}_i$ is the value of Y predicted by the regression line, Y_i is the value of Y observed, and $\overline{Y}$ is the mean value of the $Y_i s$. If all the observations fall on the regression line, R^2 is 1. If there is no linear relationship between the dependent and independent variables, R^2 is 0. The significance level of the constant and coefficients are statistically tested using the T distrubution (Koutsoyiannis,1989; Çuhadaroğlu and Demirci, 1997).

A variety of regression models can be constructed from the same set of variables. In the present study, a stepwise regression model was used. Stepwise regression of the independent variables is basically a combination of backward and forward procedures in esence and is probably the most commonly used method. In this method, the first variable is selected in the same manner as in the forward selection. If the variable fails to meet the entry requirements, the procedure terminates with no independent variables entering into the equation. If it passes the criterion, the second variable based on the highest partial correlation is selected. If it passes the entry criterion, it also enters the equation.

After the first variable is entered, stepwise selection differs from forward selection: the first variable is examined to see whether it should be removed according to the removal criterion as in backward eliminiation. In the next step, variables not in the equation are examined for removal. Variables are removed until none of the remaining variables meet the removal criterion. Variable selection terminates when no more variables meet entry and removal criteria.

In the statistical analysis, the correlations between the air pollutant concentrations and meteorological factors have been analyzed. In spite of establishing the correlations between the air pollutant concentations and meteorological factors by Eq.(1), the equations expressed as $Y = f(X_1), Y = f(X_2),...., Y = f(X_2, X_3),..., Y = f(X_1, X_2, X_3, X_4)$ have also been analyzed separately and the independent variables which have small values of R^2 have been eliminated. Using the remaining variables, equations having one, two, three or four variables are developed (Bowerman and O'Connell, 1987; Çuhadaroğlu and Demirci, 1997) .

CO, NO_x and O_3 data together with meteorological parameters such as wind speed, temperature, relative humidity, were analyzed by multiple linear regression using the RATS (Regression Analysis Time Series) programme. CO, NOx and O_3 were considered as dependent variables while previous day's pollutant concentration and meteorological parameters such as temperature, wind velocity and relative humidity were considered as independent variables.

Results and Discussion

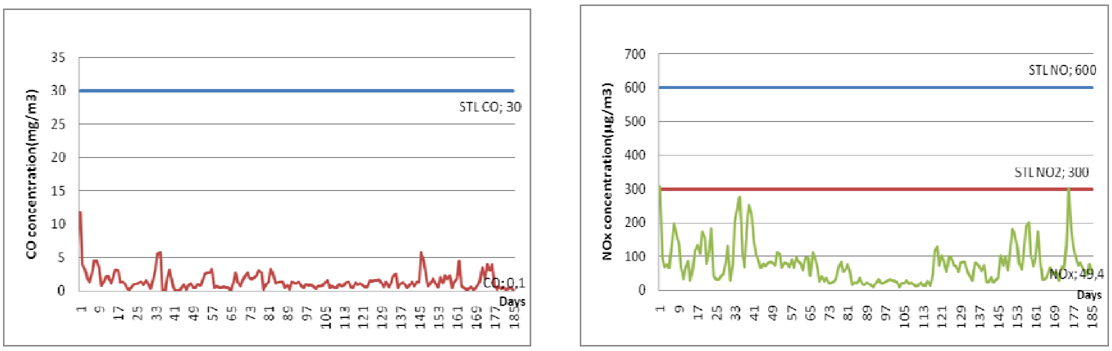
Evaluation of CO, NOx and O_3 concentrations and meteorological parameters in 1995-1997 winter season

CO, NOx and O_3 were monitored in 1995-1997 in Erzurum city. The limit values of the pollutants in Turkish Air Quality Protection Regulation is shown Table 2 (MOEF, 1986).

Table 2. The limit values of the pollutants in Turkish Air Quality Protection Regulation

	Unit	Long-term limit value	Short-term limit value
CO concentration	(μg/m^3)	10.000	30.000 (maximum value for a day)
NO_2 concentration	(μg/m^3)	100	300 (maximum value for a day)
NO concentration	(μg/m^3)	200	600 (maximum value for a day)
O_3 concentration	(μg/m^3)	-	240 (maximum value for an hour)

Air pollutants concentration not exceed short term limit value during 1995-1997 winter season. The daily CO and NOx concentration were graphed together with short term limit (STL) values are shown in Fig. 3.



(a) (b)

Figure 3: (a) The daily change of CO and (b) NOx concentration in winter perios (STL: short term limit value)

Montly averages of CO and NOx values in 1995-1996 are higher than the next winter season due to meteorological parameters. Montly averages of O_3 are lower than the next winter season due to meteorological parameters, also. Maximum CO and NOx concentrations occur in January, 1450µg/m^3 and 118 µg/m^3, respectively. These high CO and NOx values were due to low temperature (-11^{o}C) and low winds (0.6 m/s). The pollutants levels are high also in other colder months as December 1995 and February 1996. Maximum O_3 concentrations occur in December 1996, 31µg/m^3. The temperature in this months were higher than other months. The relative humidity and wind speed in this month were lower than other months. O_3 formation is closely related to meteorological factors. O_3 concentration depends on higher temperature and lower wind speed and lower relative humidity (Xu and Zhu; Blomfield et al., 1996).

Relationship between CO, NOx, O_3 and meteorological factor

The relationship between CO, NOx, O_3 and meterorological parameters (temperature, wind speed, relative humidity) and previous day's pollutant concentration in 1995-1997 winter periods was investigated by stepwise multiple linear regression analysis. The correlation (r) between daily average CO, NOx, O_3 concentrations and daily average meteorological parameters and previos' day pollutants concentration are shown Table 3.

Table 3. Correlation (r) between daily average CO, NOx, O_3 and daily average meteorological parameters in this study and other studies

Pollutants	Temperature	Wind speed	Relative humidity	Previous day's concentration	References
CO	-0.08	-0.01	0.09	0.54	This study
NO_x	-0.36	-0.39	0.09	0.68	This study
O_3	0.17	0.31	0.13	0.77	This study
CO	-0.49		0.20		Elminir (2005)
NO_2	0.18		-0.13		Elminir (2005)
O_3	0.69		-0.42		Elminir (2005)
CO	-0.28	-0.52	0.19		Barrero et al.(2006)
NO_2	0.20	-0.38	0.09		Barrero et al.(2006)
O_3	0.38	0.61	-0.48	0.56	Barrero et al.(2006)
NO_2	-0.59	-0.50	-0.15		Gupta et al. (2007)
O_3	0.43	0.45	-0.51		Dueñas et al. (2002)

Air pollutants concentrations as a function of meteorological parameters are graphed in Figure 4a-4k. As seen from Table 3, it was found that the moderate correlation occurs between NOx and temperature for which $p<0.01$. It is obvious that CO and NOx concentrations decrease with high increasing temperature. But O_3 concentration increase with increasing temperature. There is a negative correlation between pollutants (CO and NOx) concentrations and wind velocity ($p<0.01$ for CO and NOx). CO and NOx concentrations decrease with increasing wind speed as seen from Fig.4c, 4g. O_3

concentration increase with increase wind speed (p<0.01 for O_3). The relative humidity is a weakly linked parameter to all pollutants (p<0.01). The correlation between the previous day's CO, NOx and O_3 values and actual concentration is investigated and found as 0.54, 0,68 and 0.77, respectively and their correlations are shown in Fig. 4a and 4e (p<0.01). Also, the findings of others related to correlations between air pollutants (O_3, NO_2, CO) and meteorological parameters are shown in Table 3. It is seen from Table 3 that correlations of air pollutants for temperature, wind speed and, relative humidity obtained at this study is similar to those of found at other studies. Also the correlation between O_3 and previous day's O_3 (this study) is near by Barrero et al. (2006). It is obvious that the correlation values are highly site-specific.

The regression analysis

The CO, NOx and O_3 concentrations are considered to be dependent variables, whereas meteorological factors and previous day's air pollutants concentration are considered to be independent variables. Multiple regression analysis was applied for each day, and it was shown that there are relationships between air pollutants and meteorological factors and previous day's air pollutants concentration. In this study, since the relative humidity gave weakest significance in statistical analysis, it was removed from the regression equation for NOx. The wind speed gave weakest significance in statistical analysis, it was removed from the regression equation for CO, also. Consequently, the regression equation for air pollutants are presented as:

$$CO = -0.03*\textit{(temperature)} + 0.01*\textit{(relative humidity)} + 0.6*\textit{(previous day's CO concentration)}$$
$$R^2 = 0.48 \qquad (3)$$

According to this equation, the concentration of CO decreases with increasing temperature and the concentration of CO increases with increasing relative humidity and previous day's CO concentration. The regression equation obtained for the NOx concentration is expressed as:

$$NO_X = 55.2 - 17.5*\textit{(wind speed)} - 1.6*\textit{(temperatue)} + 0.4*\textit{(previous day's } NO_X \textit{ concentration)}$$
$$R^2 = 0.28 \qquad (4)$$

According to this equation, the concentration of NOx decreases with increasing temperature, wind speed and the concentration of NOx increases with increasing previous day's NOx concentration. The regression equation obtained for the O_3 concentration is expressed as:

$$O_3 = 5.3*\textit{(winds ped)} + 0.4*\textit{(temperature)} + 0.1*\textit{(relative humidity)} + 0.7*\textit{(previous day's } O_3 \textit{ concentration)}$$
$$R^2 = 0.75 \qquad (5)$$

This equation reveals that O_3 concentration increases with increasing wind speed, temperature, relatative humidity and previous day's O_3 concentration.

Considering Eq. (3)-(5), measured air pollutants values were compared with calculated ones. The data set (all values) of 1995-1997 winter season was used for testing model. As seen Fig. 5c, there is a good agreement between predicted and measured values. The good correlation coefficients reflects the effectiveness of this equation as well. However, the equations did not enhance the predictions for CO and NOx (Fig. 5a,b). The lower enhancement in Eq. (3) and (4) may be due to a fact that the lifetime of air pollutants in atmosphere are different because of previling meteorological factors.

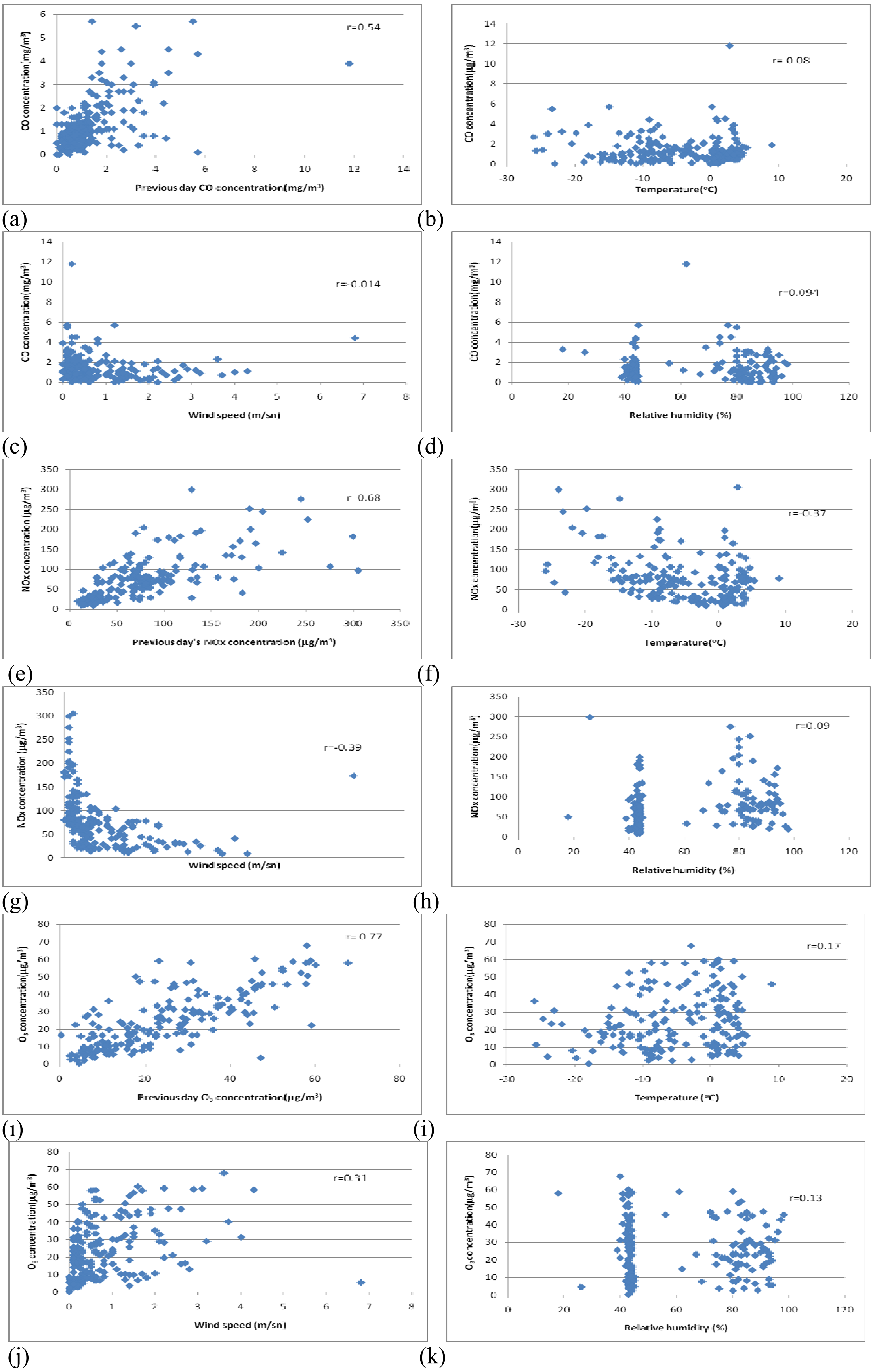
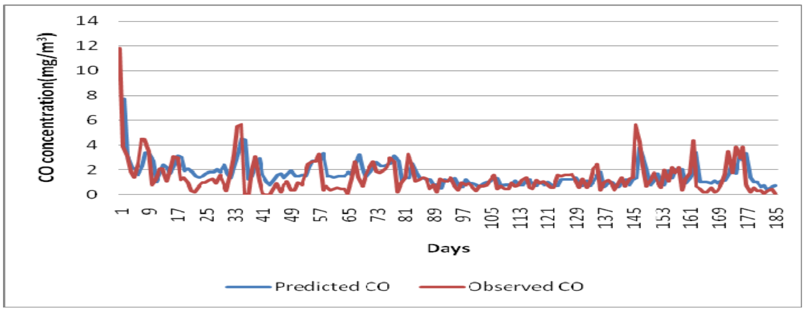
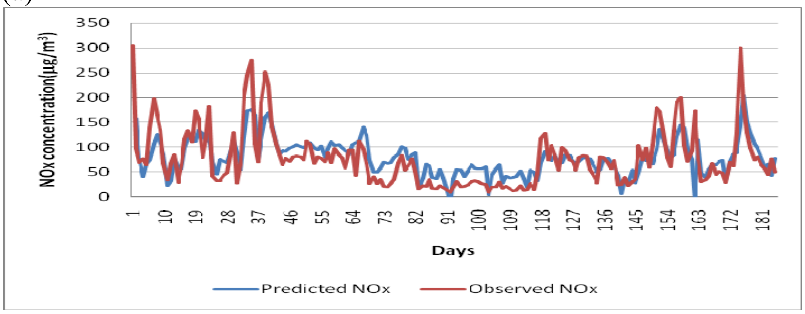


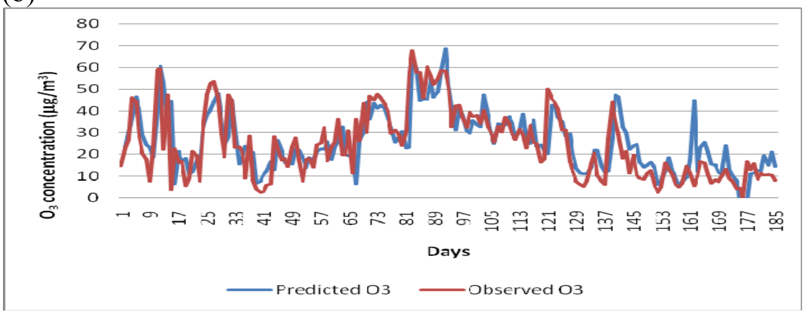
Figure 4: CO concentration versus: (a) previous day's CO concentration; (b) temperature; (c) wind speed; (d) relative humidity. NOx concentration: (e) previous day's NOx concentration; (f) temperature; (g) wind speed; (h) relative humidity.O_3 concentration: (ı) previous day's O_3 concentration; (i) temperature; (j) wind speed; (k) relative humidity.



(a)



(b)



(c)

Figure 5: Measured and predicted (a) CO concentration according to Eq. (3), (b) NOx concentration according to Eq. (4) and (c) O_3 concentration according to Eq. (5).

The O_3 concentration has a good dependence and a 75% coefficient of determination; this means that 75% of O_3 depends on wind speed, temperature, relative humidity and previos day's O_3 concentration, and 25% is indeterminate. As regards the CO concentration, there is a moderate dependence on wind speed, temperature, relative humidity and previos day's CO concentration: 48% of CO depends on these factors, and 52% is indeterminate. The NOx concentration has a weak dependence and a 28% coefficient of determination; this means that 28% of NOx depends on wind speed, temperature, relative humidity and previos day's NOx concentration, and 72% is indeterminate. Wind speed, temperature are effective meteorological variables in decreasing CO and NOx concentrations. Relative humidity are effective meteorological variables in incresing CO and O_3 concentration. It was found that previous day's pollutants concentrations has effect for CO, NOx and O_3 concentrations.

It is seen from literature that the number of meteorological parameters included in regression equations are variable. Witz and Moore (1981) found the regression coefficients varied 0.68-0.73 between air pollutants (CO, NO, NO_X, hydrocarbons) and meteorological parameters (wind direction, wind speed, early morning temperature, and frequency of inversions). Elminir (2005) found that the highest average concentration for NO_2, O_3 and CO occurred at humidity $\leq$40% . Chiu K.H. et al (2005) found the regression coefficients between O_3 levels and solar radiation as 0.82.

There are limited studies in literature considering the previous day's pollutant concentration in regression equation. Spellman (1999) calculated that the regression coefficient between O_3 and maximum temperature and hours of sunshine, previous day's ozone concentration as 0.63. Ocak and

Demircioglu (2002) calculated that the regression coefficient between SO_2 and meteorological parameters (temperature) as 0.73 and between TSP and meteorological parameters (temperature, wind speed) the coefficient estimated as 0.68. Turalıoglu et al. (2005) added previous day's SO_2 concentration in regression equation and R^2 value of 0.92 was found. Also previous day's TSP concentration was introduced regression equation and R^2 was found as 0.89. In a study performed by Barrero et al. (2006), the regression coefficient computed maximum between O_3 and variables as NO, NO_2, previous day maximum O_3 as 0.60.

Conclusions

Traffic related air pollution level has existed in Erzurum during winter seasons. Maximum air pollutants concentrations especially occur in colder months (December, January and February) in the city. These high CO and NOx values were due to lower temperature and lower winds. O_3 values were due to higher temperature and higher wind speed and higher relative humidity. The results from this study show that there are moderate relationships between the meteorological parameters and CO in Erzurum within the terms statistically analyzed. However, there are weak relationships between the meteorological parameters and NOx. There are good relationships between the meteorological parameters and O_3. The wind speed, temperature and relative humidity are well correlated with O_3 in 1995-1997. The relative humidity, temperature are moderately correlated with CO. The wind speed are also weakly correlated with CO. The wind speed, temperature are moderately correlated with NOx. The relative humidity are also weakly correlated with NOx. In order to predict the air pollutants concentrations with regard to meteorological parameters and previous day's pollutants concentration, a statistical model was developed. The correlation between previous day's CO, NOx and O_3 concentrations and actual CO, NOx and O_3 concentations were found as 0.54, 0.68 and 0.77, respectively. The statistical model of CO, NOx and O_3 including meteorological parameters and previous day's pollutant concentrations gave R^2 of 0.48, 0.28 0.75, respectively.

Since increasing population, increasing private cars and requested modifications in traffic are insufficient in Erzurum city, the statistical model is able to predict well the next several days O_3 pollution whenever the days of meteorological parameter values are supplied.

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