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# Evaluation of relationship between meteorological parameters and air pollutant concentrations during winter season in Elazığ, Turkey

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**Abstract** In recent years, due to the rapid increase in population density, building density and energy consumption, the outdoor air quality has deteriorated in the crowded urban areas of Turkey. Elazığ city, which is located in the east Anatolia region of Turkey, is also influenced by air pollutants. In the present study, relationship between monitored air pollutant concentrations such as $SO_2$ and the total suspended particles (TSP) data and meteorological factors such as wind speed, temperature, relative humidity, solar radiation and atmospheric pressure was investigated in months of October, November, December, January, February, and March during the period of 3 years (2003, 2004 and 2005) for Elazığ city. According to the results of linear and non-linear regression analysis, it was found that there is a moderate and weak level of relation between the air pollutant concentrations and the meteorological factors in Elazığ city. The correlation between the previous day's $SO_2$, TSP concentrations and actual concentrations of these pollutants on that day was investigated and the coefficient of determination $R^2$ was found to be 0.64 and 0.54, respectively. The statistical models of $SO_2$ and TSP including all of meteorological parameters gave $R^2$ of 0.20 and 0.12, respectively. Further, in order to develop this model, previous day's $SO_2$ and TSP concentrations were added to the equations. The new model for $SO_2$ and TSP was improved considerably with $R^2$=0.74 and 0.61, respectively.

**Keywords** Sulphur dioxide · Total suspended particles (TSP) · Meteorological parameters · Regression analysis · Elazığ–Turkey

**Nomenclature**

| | |
|---|---|
| AP | atmospheric pressure (mbar) |
| RH | relative humidity (%) |
| SR | solar radiation (cal/cm$^2$) |
| T | temperature (°C) |
| WS | wind speed (m/s) |

## Introduction

The level of air pollution concentrations monitored in an urban area depends on several factors such as types of fuels consumed, geographical and topographical peculiarities, meteorological factors and town planning, etc. As with other crowded urban areas in Turkey, the outdoor air quality in urban Elazığ has deteriorated due to air pollution. The main causes of air pollution in Turkish residential areas are low

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quality coal and fuel-oil consumption, as well as also exhaust gases emitted by transportation vehicles (Demirci and Cuhadaroglu 2000).

Meteorology, along with emissions and atmospheric chemistry, is well known as a major contributor to air pollution episodes. For that reason, the air quality in cities has been correlated with the combination of the various meteorological factors statistically in several studies over the past decade.

Given a set of observations from air monitoring and meteorological stations, calculating statistical relationships 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 requirements (Turalıoglu et al. 2005).

There are some studies in the literature which investigate the air pollution in some big cities in the world such as Paris (Escourrou 1990), Ravenna (Tribassi et al. 1990) and Shangai (Chao 1990). Also, characterization of the concentration and distribution of urban submicron $PM_1$ aerosol particles at the city of Kaohsiung were investigated by Lin and Lee (2004). Cuhadaroglu and Demirci (1997) performed a study to show the influence of some meteorological factors on air pollution in Trabzon city in Turkey. They used SPSS code to make statistical analyses and obtained correlations for $SO_2$ and particle concentrations between meteorological factors. Their results indicated that there is a moderate and weak level of relation between the $SO_2$ level and the meteorological factors in Trabzon city. In their other study, Demirci and Cuhadaroglu (2000) considered wind circulation and air pollution by taking into account wind directions with the same statistical code. They found that there is a weak relationship between wind speeds blowing from different directions and pollutant concentrations. Also, they suggested that the newly constructed residential blocks should be divided by the main roads and streets on directions of WNW-ESE and SSW-NNE in the urban. In the study presented by Bridgman et al. (2002), the relationship of $SO_2$ concentrations to six major meteorological parameters has been investigated. Results found that $SO_2$ concentrations strongly related to colder temperature, higher relative humidity and lower wind speed. For prediction of $SO_2$ and smoke concentrations of Kayseri-Turkey, multiple regression equations including meteorological parameters and previous day's pollutant concentrations have been used by Kartal and Ozer (Kartal and Ozer 1998). The changes of air quality in Erzurum-Turkey and the correlation of $SO_2$ and total suspended particles (TSP) pollution in Erzurum city with meteorological parameters such as wind speed, temperature, atmospheric pressure, precipitation, and relative humidity were researched by the Turalıoglu et al. (2005). Ensar et al. (2003) statistically analyzed the relationship between outdoor air quality data and meteorological factors, such as wind speed, rainfall, temperature, sunshine hours and relative humidity using the code SPSS. Latini et al. (2002) investigated the effects of meteorological conditions on the urban and suburban air pollution. Ezzatian (2007) studied the effect of meteorological parameters on Esfahan Air Quality Index by Isfahan Meteorological Weather Station, Environmental Organization Stations. Yordanov (1977) performed statistical processing of air pollution data in the planetary boundary layer in terms of meteorological conditions. Andò et al. (2000) proposed models for the enforcement of the air quality standards in both urban and industrial areas.

The main purpose of the present study is to obtain relationship between air pollution concentrations and meteorological data such as wind speed, temperature, relative humidity, solar radiation and atmospheric pressure for Elazığ city. The characteristics of topographic, climatic and air quality of Elazığ city were presented first, then the relationship of $SO_2$ and TSP concentrations with the combination of meteorological parameters for months of October, November, December, January, February and March of the 2003-2004 was investigated. Finally, the contribution of the previous day's air quality level to the actual air quality concentration was examined.

## Material and Methods

### Features of study area

Elazığ city (longitude; 40° 21′ and 38° 30′, latitude; 38° 17′ and 39° 11′) is situated in north part of


**Fig. 1** The location of Elazığ city

Euphrates River of east Anatolia region of Turkey. The area of Elazığ city is 9.281 km$^2$ which is equivalent to 0.12% of Turkey. Height above sea level is 1067 m. It is a peninsula due to dams in its boundaries such as Keban, Kralkizi, Karakaya and Özlüce. Elazığ city 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. Location of Elazığ city can be shown from Fig. 1.

The wind speed, outside temperature, relative humidity, solar radiation and air atmospheric pressure were the measured meteorological parameters of this research. The measurements have been carried out by

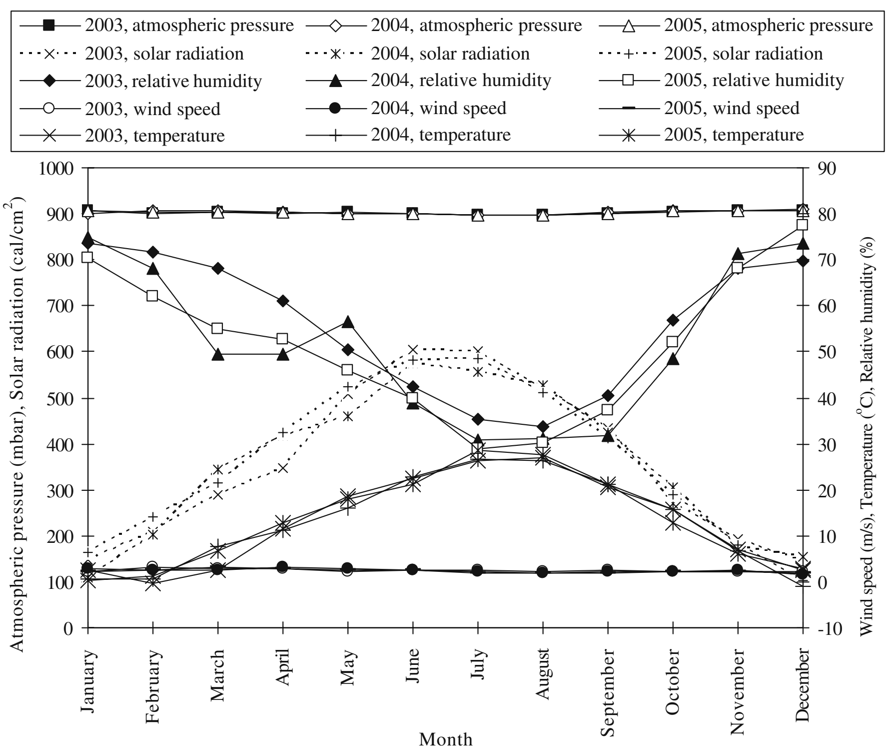



**Fig. 2** Some meteorological data (mean of wind speed, temperature, relative humidity and atmospheric pressure) of Elazığ city in 2003, 2004 and 2005

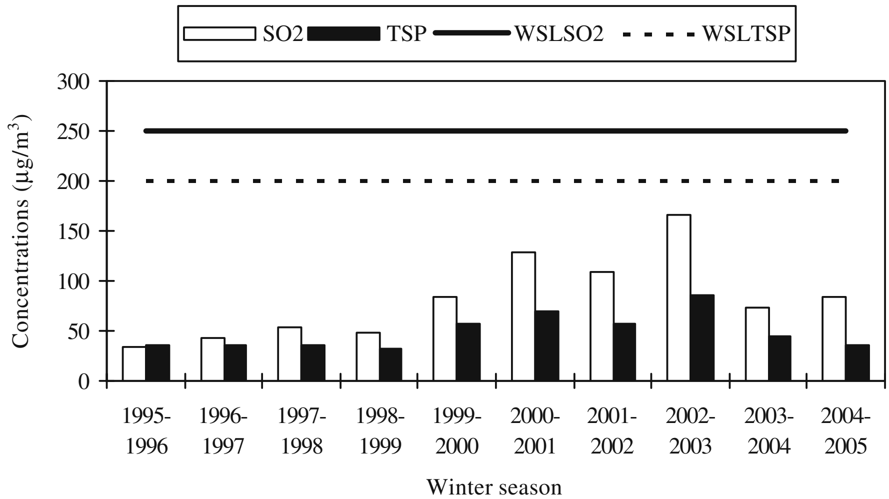



**Fig. 3** $SO_2$ and total suspended particles (*TSP*) concentrations between years of 1995–2005 at winter season in Elazığ city (*WSL*: winter season limit value)

conventional meteorological instruments at the station located in the east of the Elazığ city by the Turkish Meteorological State Department (TMSD). Figure 2 shows the monthly average wind speed, temperature, relative humidity, solar radiation and atmospheric pressure values in the years of 2003, 2004 and 2005. It can be seen from the figure that the values are very close to each other for both years. As it was shown from Fig. 2, for Elazığ city, the annual average temperature is about 13°C, the annual average wind speed is about 2.5 m/s, the annual average relative humidity is about %54, the annual average solar radiation is about 357 cal/cm$^2$ and the annual average atmospheric pressure is about 902 mbar.

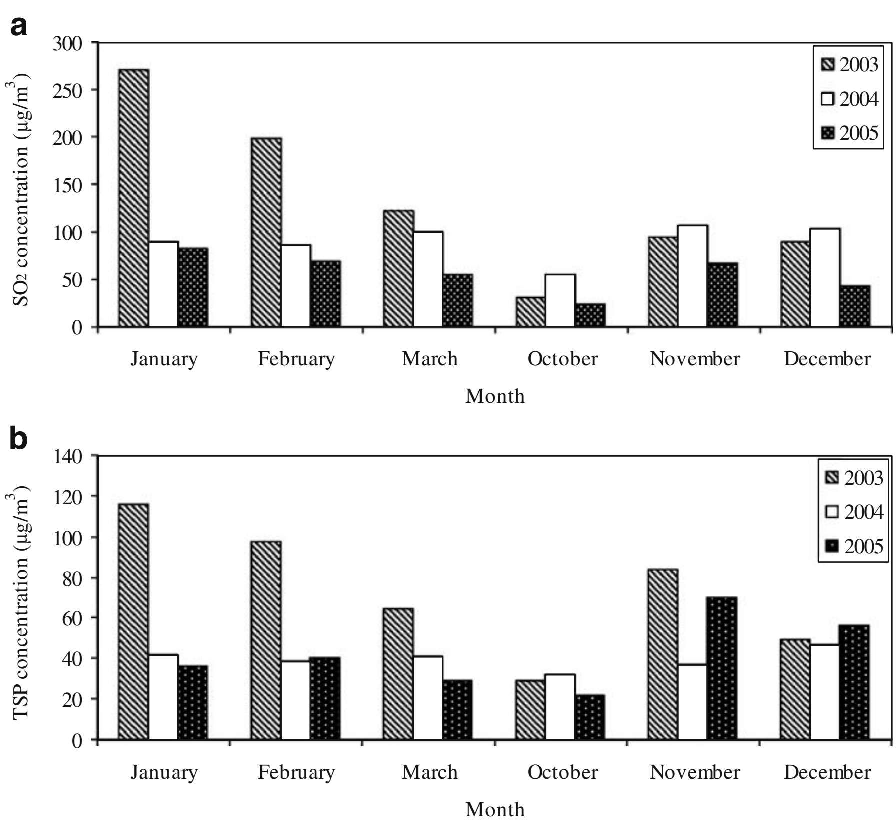



**Fig. 4** Monthly average **a** SO2 and **b** total suspended particles (*TSP*) concentrations values in 2003–2005 winter seasons

**Table 1** The means and standard deviations of $SO_2$ and TSP concentrations and meteorological parameters in 2003–2005 winter seasons

| | Mean | Standard deviation | *N* |
|---|---|---|---|
| $SO_2$ concentration, μg/m$^3$ | 95.1517 | 65.84136 | 547 |
| TSP concentration, μg/m$^3$ | 49.8958 | 31.1001 | 547 |
| Wind speed, m/s | 2.4208 | 1.4419 | 547 |
| Temperature, °C | 5.0934 | 6.1871 | 547 |
| Relative humidity ratio, % | 65.4952 | 14.54688 | 547 |
| Solar radiation, cal/cm$^2$ | 212.8410 | 112.7333 | 547 |
| Atmospheric pressure, mbar | 905.3821 | 5.4121 | 547 |

The Elazığ city needs at least 6 months of artificial heating. As no important industrial company as a point source of air pollution exists in the city, the major source of air pollution is heating. Sugar and cement factories, the most important point sources near the city, are far away from city center, about 15 and 2 km, respectively.

## $SO_2$ and TSP concentrations measurements

The Environmental and Forestry State Department have been doing sulphur dioxide and particle concentrations measurements at two stations in Centrum of the Elazığ city. Measurements were made with neutralization titration for $SO_2$ and with refractmetric

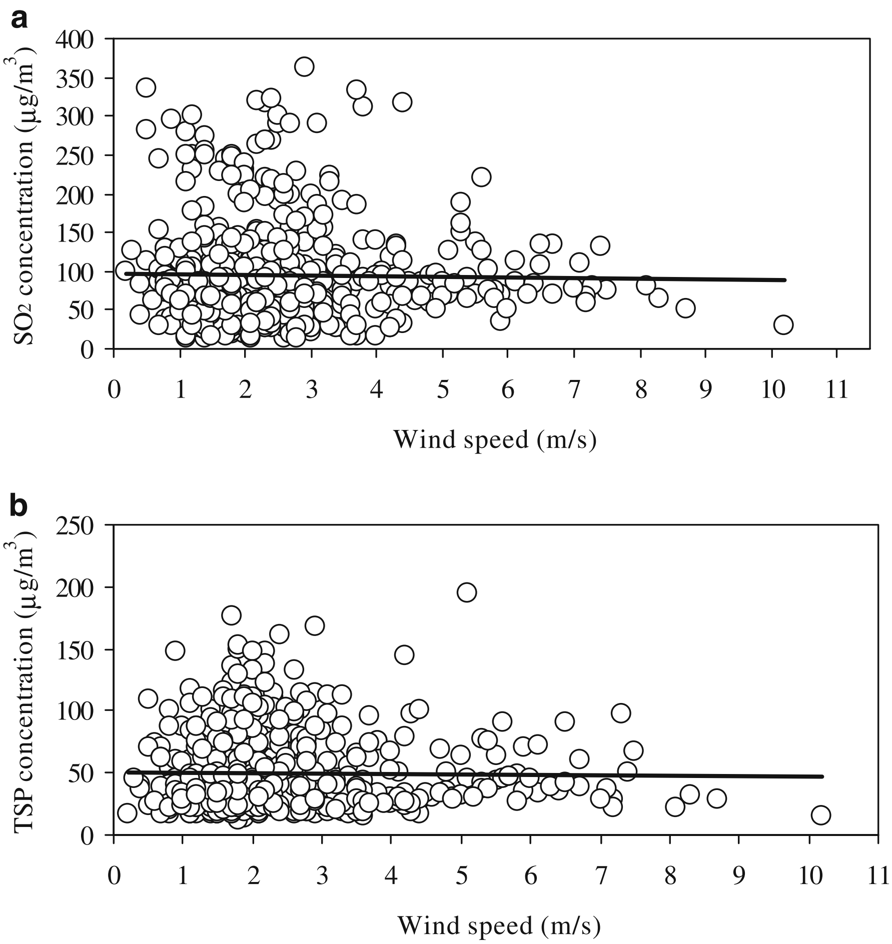



**Fig. 5** **a** $SO_2$ and **b** total suspended particles (*TSP*) concentrations versus wind speed in 2003–2005 winter seasons

evaluations for 24 h integrated dust filter samples in accordance with World Health Organization (WHO) recommended measurement methods (Elbir et al. 2000). The daily average values of $SO_2$ and TSP concentrations in the city were calculated by using arithmetic averages of the data obtained from the two stations. The air pollution data used in the study were obtained from the Environmental and Forestry State Department and Turkish Statistical Instution (Environmental and air pollution statistics 2003–2004).

## Data analysis

Regression analysis is used to find the relationship between variables and to obtain the best available prediction equation for the model chosen. If the number of independent variables more than one, multiple linear regression analysis is used and a general regression equation, which has five independent variables, can be expressed as:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + e \quad (1)$$

where $a$ is the constant of regression and $b$ is the coefficient of regression. 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 are statistically tested using the $T$ and $Z$ distribution. A generally used measure of the goodness of fit of a linear model is $R^2$, sometimes called the coefficient of determination. The coefficient of determination is that proportion of the total variability in the dependent

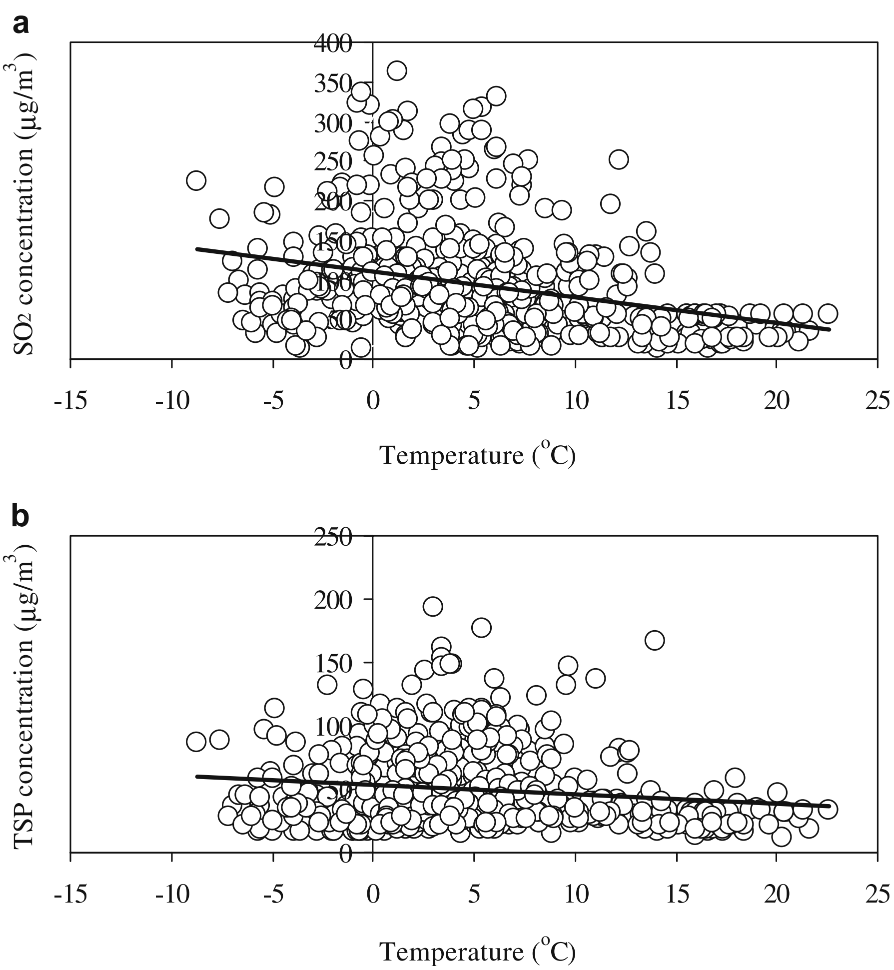



**Fig. 6** **a** $SO_2$ and **b** total suspended particles (*TSP*) concentrations versus temperature in 2003–2005 winter seasons

variable that is accounted for by the regression equation and expressed as:

$$R^2 = 1 - \frac{\sum \left(Y_{i,pred} - \overline{Y}\right)^2}{\sum \left(Y_{i,obs} - \overline{Y}\right)^2} \quad (2)$$

where $Y_{i,pred}$ is the value of $Y$ predicted by the regression line, $Y_{i,obs}$ is the value of $Y$ observed, and $\overline{Y}$ is the mean value of the $Y_i$.

A value of $R^2=1$ indicates that the fitted equation accounts for all the variability of the values of the dependent variables in the sample data. At the other extreme, $R^2=0$ indicates that the regression equation explains none of the variability. It is assumed that a high $R^2$ assures a statistically significant regression equation and that a low $R^2$ proves the opposite (Norusis 1990; Turalıoglu et al. 2005).

In the present study, a stepwise regression model was used. Stepwise regression of independent variables is basically a combination of backward and forward procedures in essence and is probably the most commonly used method. 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 elimination. In the next step, variables not included 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. As well as establishing the correlations between pollutant concentrations and meteorological parameters by Eq. 1, the equation expressed as:

$$Y = f(X_1),\ Y = f(X_2), \ldots\ldots,\ Y = f(X_2, X_3), \ldots,$$
$$Y = f(X_1, X_2, X_3, X_4, X_5)$$

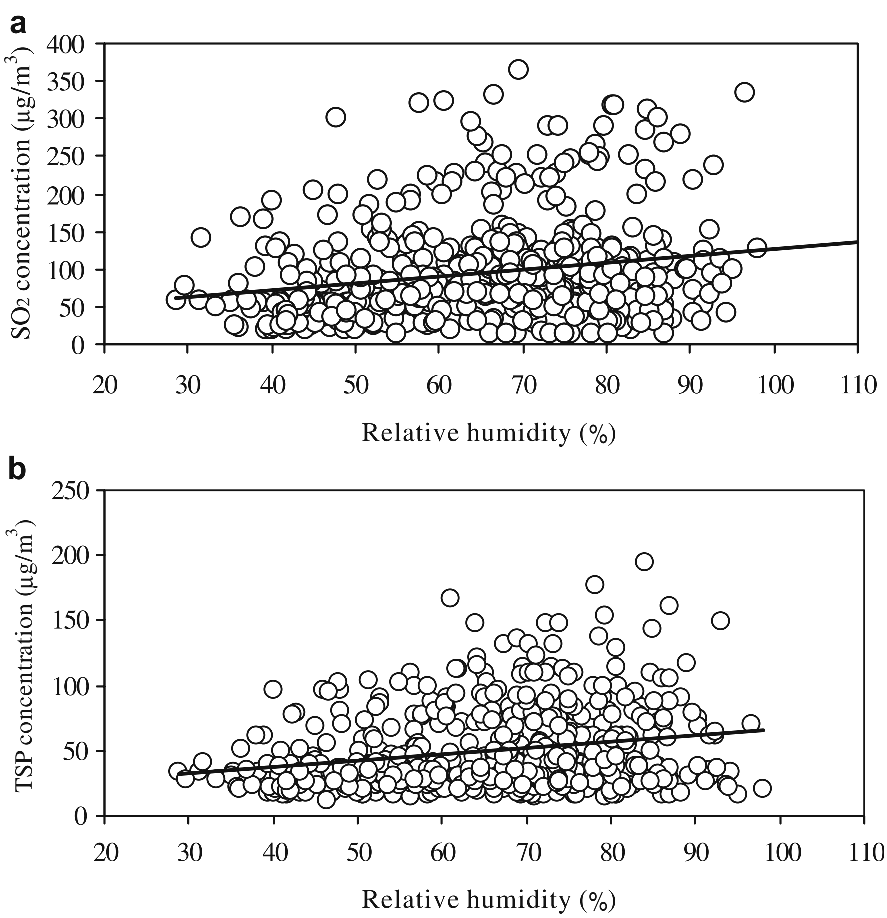



**Fig. 7** **a** $SO_2$ and **b** total suspended particles (*TSP*) concentrations versus relative humidity in 2003–2005 winter seasons

has 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.

$SO_2$ and particle concentrations data together with meteorological parameters such as wind speed, temperature, relative humidity, solar radiation and atmospheric pressure, were analyzed by multiple linear regression using the SPSS programme. $SO_2$ and TSP concentrations were considered as dependent variables while meteorological parameters such as temperature, wind speed, relative humidity, solar radiation and atmospheric pressure were considered as independent variables. Then, multiple linear regression analysis was applied by adding previous days' $SO_2$ and TSP concentrations to the independent variables.

## Results and discussion

The mean values of sulphur dioxide and TSP concentrations obtained from daily observation network including two stations for the winter seasons (November-December-January-February-March) of the 1995–2005, were graphed together with winter season limit values as 250 μg/m$^3$ for $SO_2$ and 200 μg/m$^3$ for TSP in Turkish Air Quality Protection Regulation (MOE 1986), are shown in Fig. 3. It is seen from Fig. 3 that winter season limit (WSL) of Turkish Air Quality Protection Regulation have not been exceeded by the values of $SO_2$ and TSP concentrations for all years. But, these values of the pollutant concentration levels on winter days were higher than the standard values accepted by the WHO and the United States. The monthly averages of $SO_2$ and TSP

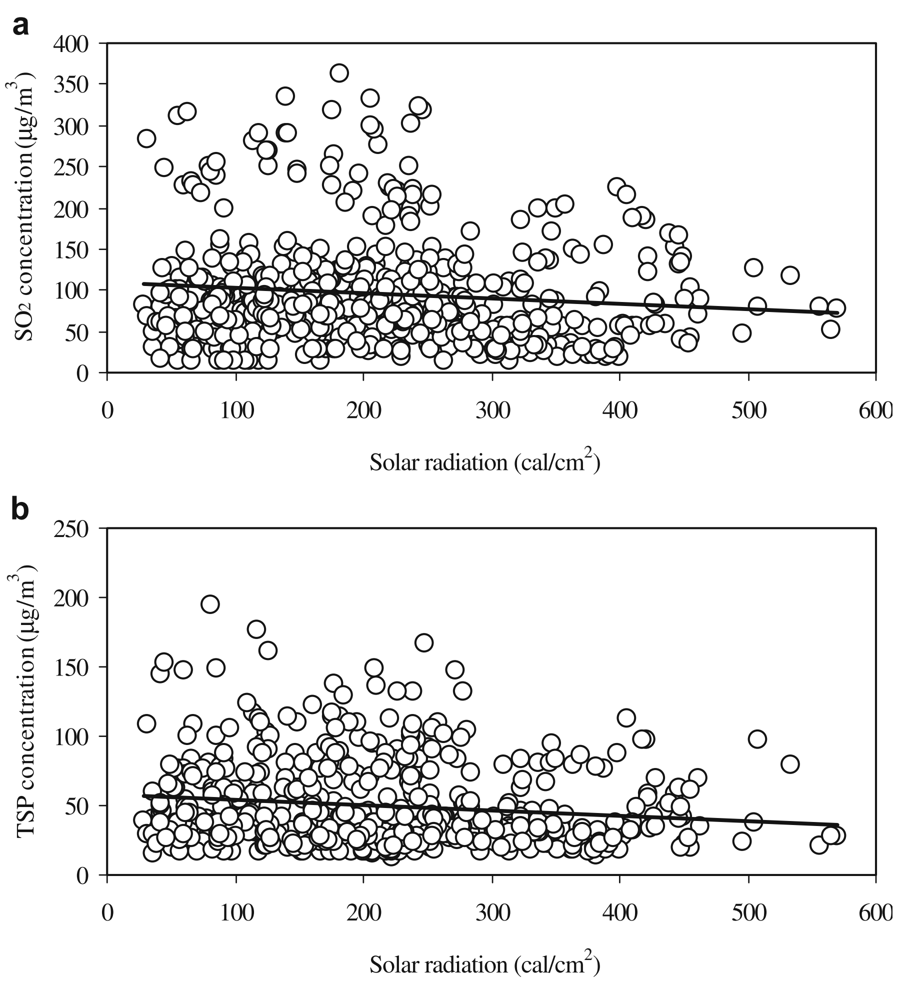



**Fig. 8** **a** $SO_2$ and **b** total suspended particles (*TSP*) concentrations versus solar radiation in 2003–2005 winter seasons

values in 2003, 2004 and 2005 are graphed in Fig. 4a and b to see the monthly trends in concentrations. As seen from Fig. 4a and b, the maximum $SO_2$ and TSP values are in January-February months, which are the coldest months of the year in Elazığ city. However, Table 1 shows means and standard deviations of $SO_2$ and TSP concentrations and meteorological parameters in months of October, November, December, January, February, and March during the period of 3 years (2003, 2004 and 2005).

Figure 5a and b are presented to show variations of wind speed with $SO_2$ and TSP concentrations, respectively. Data belongs to months of October, November, December, January, February, and March of 2003–2005 years. It can be seen from the figures that both $SO_2$ and TSP concentrations are slightly decreased with increasing wind speed. This situation shows that when wind speed is high, pollutants dilute by dispersion. Because, the volume and dilution of the polluted air are controlled by wind speed and its directions. When two figures (Fig. 5a and b) are compared, it is seen that wind speed is more effective on $SO_2$ concentration than that of TSP concentration. Effects of variations of mean temperature on $SO_2$ and TSP concentrations are presented in Fig. 6a and b, respectively. Data consist of the same effect as wind speed on $SO_2$ and TSP concentrations that both $SO_2$ and TSP concentrations are decreased with increasing temperature. Maximum values of $SO_2$ and TSP concentrations are obtained around the 0°C of air temperature. 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 (Kartal and Ozer 1998). Variation of relative humidity with $SO_2$ and TSP concentrations are shown in Fig. 7a and b, respectively. On the contrary of wind speed and temperature, which was plotted in

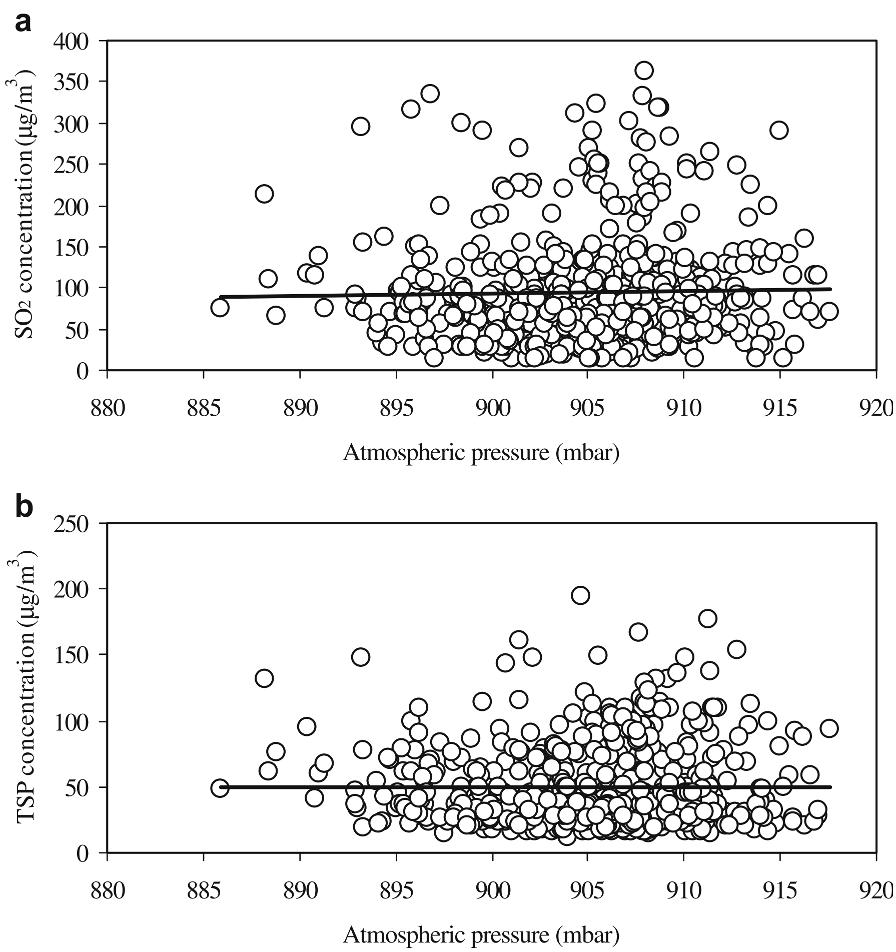



**Fig. 9** **a** $SO_2$ and **b** total suspended particles (*TSP*) concentrations versus atmospheric pressure in 2003–2005 winter seasons

**Table 2** Correlations for $SO_2$ and TSP with wind speed, temperature, relative humidity and atmospheric pressure

| Pollutants | | $R^2$ |
|---|---|---|
| $SO_2$ | =96.991−0.7596*[WS] | 0.00028 |
| | =35.596+0.9093*[RH] | 0.04036 |
| | =111.68−3.2445*[T] | 0.09296 |
| | =108.3445−0.0620*[SR] | 0.01130 |
| | =−159.84+0.2816*[AP] | 0.00054 |
| | =0.8047*Previous day's $SO_2$ concentration+18.598 | 0.64786 |
| TSP | =50.994−0.4537*[WS] | 0.00044 |
| | =17.3112+0.4975*[RH] | 0.05420 |
| | =53.927−0.7915*[T] | 0.02477 |
| | =58.1932−0.0390*[SR] | 0.01999 |
| | =16.77428+0.03658*[AP] | 0.00004 |
| | =0.7283*Previous day's TSP concentration+13.576 | 0.54568 |

*WS* wind speed, *RH* relative humidity, *T* temperature, *SR* solar radiation, *AP* atmospheric pressure

Figs. 5, 6, $SO_2$ and TSP concentrations are increased with increasing relative humidity. Relative humidity should also be inversely related to pollutant concentrations since it controls the rate of absorption of pollutants (Kartal and Ozer 1998). Impacts of variation of mean solar radiation with $SO_2$ and TSP concentrations are shown in Fig. 8a and b, respectively. Solar radiation 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. Variations of $SO_2$ and TSP concentrations with atmospheric pressure are plotted in Fig. 9a and b, respectively. These figures show that $SO_2$ and TSP concentrations are slightly increased with increasing atmospheric pressure. However, atmospheric pressure is more effective parameter on $SO_2$ concentration than on TSP concentration.

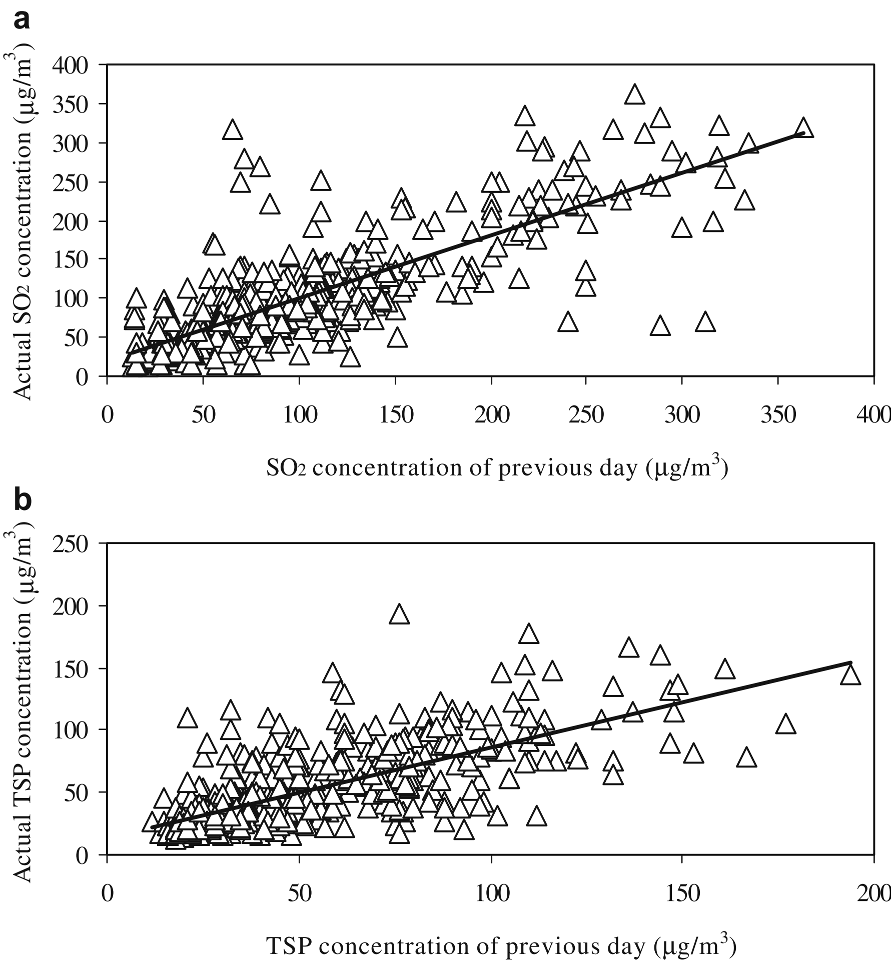



**Fig. 10** Actual concentrations versus previous day's concentrations **a** for $SO_2$ and **b** for total suspended particles (*TSP*)

**Fig. 11** $SO_2$ concentration versus total suspended particles (*TSP*) concentration in 2003–2005 winter seasons

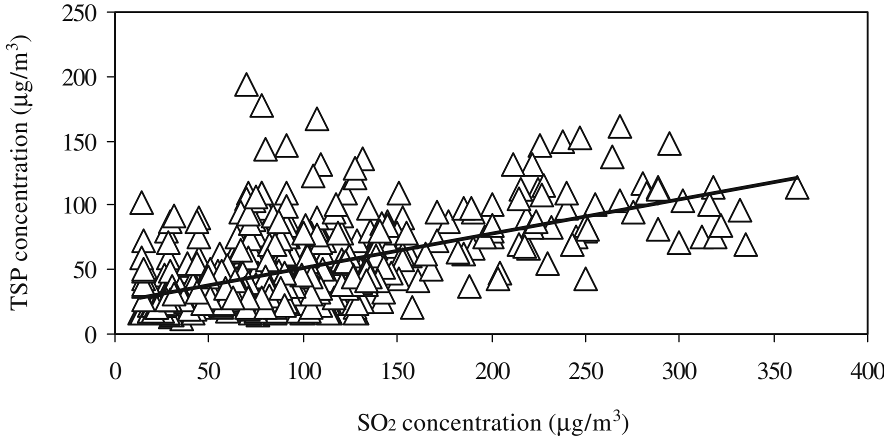
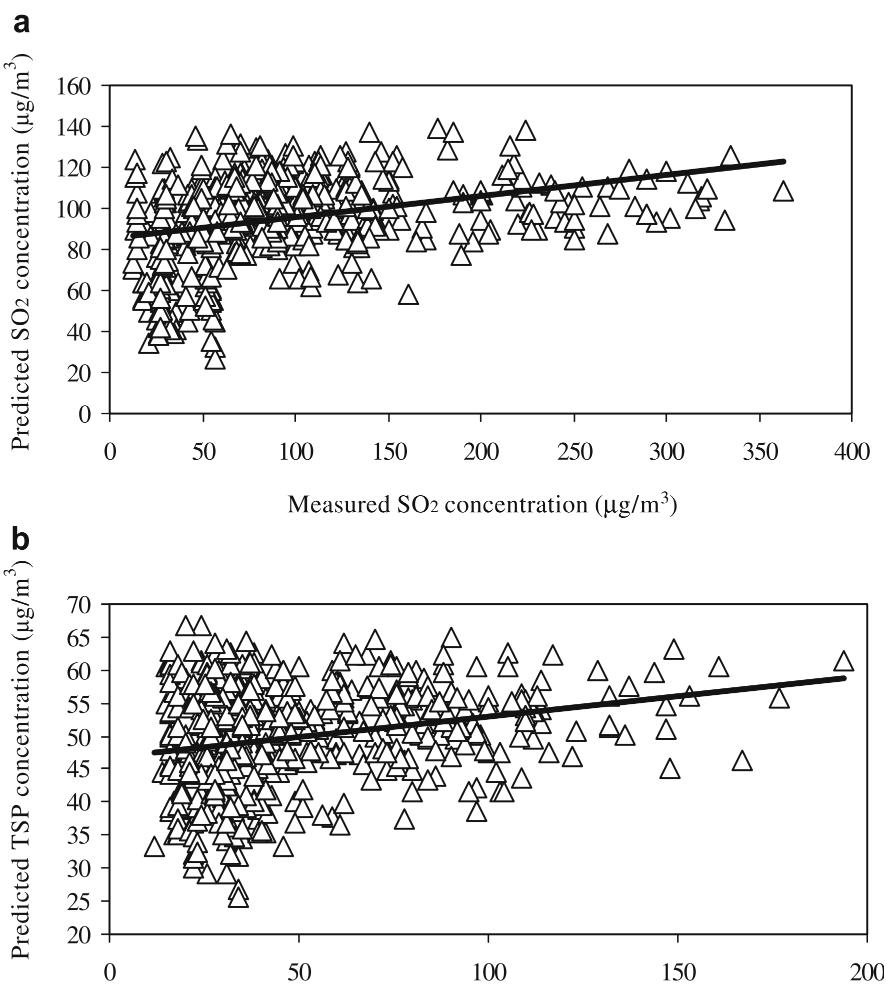



**Fig. 12** Measured and predicted concentrations **a** $SO_2$ value according to Eq. 4 and **b** TSP value according to Eq. 5



The relationship between $SO_2$ and TSP and meteorological parameters (temperature, wind speed, relative humidity, solar radiation and atmospheric pressure) in October-December-November-January-February-March of 2003–2005 years was investigated by stepwise multiple linear regression analysis. The correlations ($R^2$) between daily average $SO_2$, TSP concentrations and daily average meteorological parameters are shown in Table 2. As seen in Table 2, the correlation of $SO_2$ with meteorological parameters is very similar to the relation of TSP with meteorological parameters. It is shown from Table 2 that there is a weaker correlation between the pollutants concentrations and meteorological parameters.

The correlation between the previous day's $SO_2$ and TSP values and actual concentrations is investigated and found as 0.64 and 0.54, respectively and their correlations are shown in Fig. 10a and b. And also the correlation between $SO_2$ and previous day's $SO_2$, and the correlation between TSP and previous day's TSP is shown in Table 2.

Figure 11 shows the variations of TSP and $SO_2$ for years of 2003, 2004 and 2005. The figure indicates that TSP values are increased linearly with increasing $SO_2$ and correlations obtained are as follows

$$TSP = 0.2689*(SO_2) + 24.309,\ R^2 = 0.36 \tag{3}$$

In this study, the resulting equations are consistent that all of meteorological parameters were investigated using non-linear regression analysis. Correlations are given with regression coefficients as follows:

$$SO_2 = -134.061 + 1.173*[WS] + 0.7089*[RH] - 2.7634*[T] + 0.0459*[SI]+0.2035*[P],\ R^2 = 0.20 \tag{4}$$

$$TSP = -186.820 + 1.0614*[WS] + 0.589*[RH] - 0.3002*[T] + 0.0202*[SI]+0.2129*[P],\ R^2 = 0.12 \tag{5}$$

Considering Eqs. 4 and 5, measured $SO_2$ and TSP values were compared with calculated ones. Figure 12a and b show the predicted and measured values of $SO_2$ and TSP.

Meteorological factors are not able to disperse and clean the pollutants concentrations completely from atmosphere. Daily concentrations essentially contribute to the concentrations of next day. Thus, it has been proposed in some studies that the value of pollutant parameter belonging to previous day should be considered in air quality prediction studies (Van der Auwers 1977; Kartal and Ozer 1998; Turalıoglu et al. 2005). In this study, previous day's $SO_2$ concentration was added to Eq. 4 and $R^2$ calculated as 0.74, and previous day's TSP was included into Eq. 5 and, $R^2$ was computed as 0.61. In that case the regression equations have been found as:

$$SO_2 = 533.6617 - 4.13588*[WS]+0.146921*[RH] -0.788049*[T]+0.019607*[SI]-0.567087*[P] +0.789957*[\text{Previous day's } SO_2]\left(R^2, = 0.74\right) \tag{6}$$

$$TSP = 56.19656 - 0.985130*[WS]+0.146734*[RH] -0.152204*[T]+0.005021*[SI]-0.054579*[P] +0.713758*[\text{Previous day's TSP}]\left(R^2 = 0.61\right) \tag{7}$$

The comparison of measured $SO_2$ and TSP values with predicted ones according to Eqs. 6 and 7 are shown in Fig. 13a and b. As seen from Fig. 13a and b, there are good agreements between predicted and measured values. In other words the new equations are able to predict effectively the daily variations of measured $SO_2$ and TSP values.

## Conclusions

Impacts of meteorological factors on air pollutant concentrations were evaluated for Elazığ, Turkey during the winter seasons of 2003–2005 years, using a statistical code. During the summer seasons, the effects of meteorological variables on the air pollutants were not investigated, since they were at low levels in the warm periods. As a general result, $SO_2$ and TSP were weakly decreased with decreasing wind speed temperature and solar radiation. However, it was weakly increased with increasing relative humidity and atmospheric pressure. Because $SO_2$ and TSP concentrations were decreased with increasing wind speed and circulation of air flow. When outside temperature and solar radiation was decreased, consumption of fuel such as coal, fuel-oil was increased to supply necessity of heating. Also, atmospheric pressure was increased with the cooling of air since density of air was increased. Finally, the results from this study show that there were no strong relationships between the meteorological parameters and the ground level air pollutant concentrations in Centrum of Elazığ city within the terms statistically analyzed. In order to predict the $SO_2$ and TSP concentrations with regard to meteorological parameters, a statistical model was developed. The statistical model of $SO_2$ and TSP including meteorological parameters gave $R^2$ of 0.20 and 0.12, respectively. Further, the correlation between previous day's $SO_2$ and TSP concentrations and actual $SO_2$ and TSP concentrations were found as 0.64 and 0.54, respectively. In order to enhance this model, previous day's $SO_2$ and TSP concentrations were added to the equations. The new model for $SO_2$ and TSP was improved considerably ($R^2$=0.74 and 0.61, respectively). These equations can be employed for a wide variety of purposes, for example, when data were lacking because of instrument failure or other reasons. By inserting forecasted values of the meteorological parameters into the multiple regression equations, future prediction of air pollution concentrations may be performed in the Elazığ, Turkey.

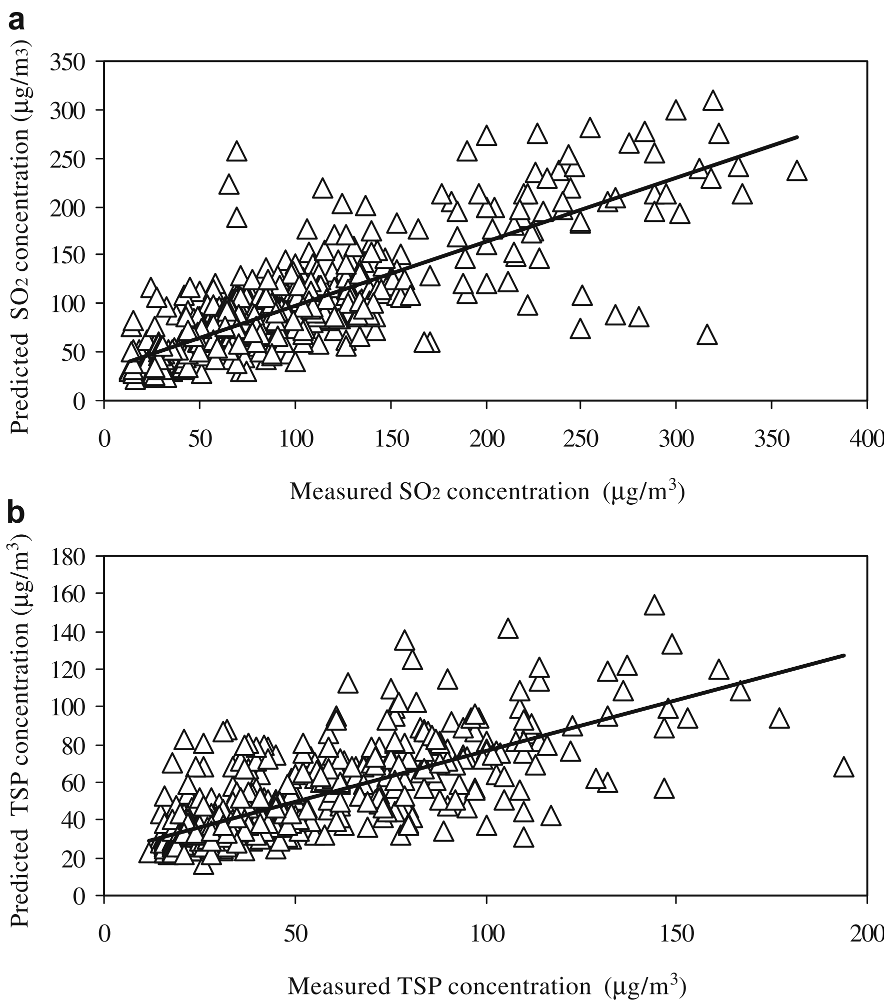



**Fig. 13** Measured and predicted concentrations **a** $SO_2$ value according to Eq. 6 and **b** TSP value according to Eq. 7

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