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Investigating the impacts of some meteorological parameters on air pollution in Balikesir, Turkey

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Abstract Air pollution is one of the most important environmental problems in Balikesir, situated in the western part of Turkey, during the winter periods. The unfavorable climate as well as the city's topography, and inappropriate fuel usage cause serious air pollution problems. The air pollutant concentrations in the city have a close relationship with meteorological parameters. In the present study, the relationship between daily average total suspended particulate (TSP) and sulphur dioxide (SO_2) concentrations measured between 1999–2005 winter seasons were correlated with meteorological factors, such as wind speed, temperature, relative humidity and pressure. This statistical analysis was achieved using the stepwise multiple linear regression method. According to the results obtained through the analysis, higher TSP and SO_2 concentrations are strongly related to colder temperatures, lower wind speed, higher atmospheric pressure and higher relative humidity. The statistical models of SO_2 and TSP gave correlation coefficient values (R^2) of 0.735 and 0.656, respectively.

Keywords Sulphur dioxide · Total suspended particulate · Meteorological parameters · Regression analysis · Air pollution

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Introduction

The increase in global population and associated industrializations, urbanization and motorization has inevitably led to a greater demand for energy. Production and consumption of both renewable and non-renewable energy have steadily increased since the last century. The combustions of fossil fuels for electricity generation, industrial processes, transportation, and space heating are predominant source of primary pollutants in developed and industrialized countries. Generally, pollutant emissions can be considered coming from the combustion of fossil fuels. Eighty percent (80%) of total world energy consumption has been provided by fossil fuels (Goldemberg 2006). Emissions from domestic heatings are the main source of air pollution in Turkey, as well as in other cold countries of the world. Sulphur is usually emitted during the combustion of fossil fuels and is among the most prevalent air pollutants in cities. It contributes to the formation of sulphuric acid and sulphate aerosols, and the deposition of sulphate at the ground surface (Khoder 2002; Boubel et al. 1994).

Air pollution problems may vary greatly with the geography, demography, and socioeconomic profile of the region. These factors determine the source and emission rate of the pollutants. The climate and topography of a region also influence the distribution and atmospheric processes of pollution and its effects on environment and/or human health. Monthly average concentrations of PM_{10} and $PM_{2,5}$ in Istanbul were investigated for the period of July 2002–2003 and the results of over 86 daily aerosol samples were reported (Karaca et al. 2005) It was emphasized that in elderly people with pre-existing cardiopulmonary illness, exposure may even lead to increased mortality and hospitalization rates. For that reason, over the past decade, the air quality in cities has been correlated with the combination of various meteorological factors in several studies (Cuhadaroglu and Demirci 1997; İlten and Selici 2004; Tasdemir et al. 2005). Total suspended particles (TSP) are a general term used for a mixture of solid particles and liquid droplets present in the air. TSP has wide range of particle sizes and originates from many different stationary and mobile sources. They may be emitted directly by a source or can be formed in the atmosphere by the transformation of gaseous precursor emissions such as SO_2. Scientific studies show that there are significant relation between emitted particulates and a series of significant health effects. In addition, particulates cause adverse impacts on the environment via reduced visibility and changes in the nutrient balance through deposition processes (Aneja et al. 2001). Particle concentrations in urban areas are strongly dependent on the source types and emission patterns. Consequently, concentrations may show considerable spatial variability within cities and great diversity from city to city. During transport, air pollutants are dispersed, diluted and subjected to photochemical reactions (Mayer 1999). Meteorology, along with emissions and atmospheric chemistry, is well known as a major contributor to air pollution episodes.

There are numerous studies reported in the literature which statistically determine the effects of meteorological parameters on SO_2 and TSP concentrations. In one study, concentrations of criteria air pollutants such as CO, NO_x, SO_2 and PM were measured for the period of May 2001 and April 2003 in the city of Bursa, Turkey. Correlations among pollutant concentrations and meteorological parameters showed weak relation nearly in all data (Tasdemir et al. 2005). Tayanç (2003) has studied the severity of the level of sulphur dioxide concentrations and possible sources in Ýstanbul. It was reported that the increase in air pollution levels is linked to a switch to the use of low-quality fossil fuels, and an increase in the population and population densities due to uncontrolled immigration to the city. A study about the air quality model including pollutants (NO_x), non-methane hydrocarbons (NMHC) and meteorological parameters (wind speed, solar radiation, rain, relative humidity and temperature) has also been published for the formation of ozone in Ýstanbul city (Tecer et al. 2003).

SO_2 and TSP concentrations have been related with meteorological factors and based on this relation some policies have been proposed for Shangai (Chao 1990). Ýlten and Selici (2004) used multiple linear regression analysis to assess the relation of SO_2 and TSP concentrations with wind speed, pressure and temperature between 1999 and 2003. Miyazaki and Yamaoka (1991) found a good correlation between the mean dust concentration and several meteorological factors in Osaka City. Tirabassi et al. (1991) found that there is a close relationship between wind speed, SO_2 and particle concentrations in the coastal City of Ravenna. Cuhadaroglu and Demirci (1997) used multiple linear regression analysis to assess the relation of pollutant concentrations with several meteorological factors. According to their results, some months there was a moderate and weak level of relation between the amount of pollutant and meteorological factors in Trabzon City. In the study presented by Bridgman et al. (2002), the relationship of SO_2 concentrations with the six major meteorological parameters has been investigated. Their results revealed that SO_2 concentrations were strongly related to colder temperature, higher relative humidity and lower wind speed. For prediction of SO_2 and smoke concentrations, multiple regression equations including meteorological parameters and previous day's pollutant concentrations have been used (Kartal and Özer 1998). In another study presented by Turalıoğlu et al. (2005), the relationship between daily average total suspended particulate and sulphur dioxide concentrations with meteorological factors for 1995–2002 winter seasons was statistically analyzed using the stepwise multiple linear regression analysis for Erzurum City. They have shown that, higher TSP and SO_2 concentrations are strongly related to colder temperatures, lower wind speed, higher atmospheric pressure and weakly correlated with rain and higher relative humidity.

Sulphur dioxide is one of the important air pollutants that have been closely associated with urban air quality problems during winter periods in Balikesir, similar to many cities in Turkey. The aim of this study is to evaluate the changes of air quality in Balikesir and to investigate the correlation of SO_2 and TSP pollution with meteorological parameters such as wind speed, temperature, pressure and relative humidity in the winter months (October through March), during which severe air pollution episodes are most likely to occur. For this reason firstly, the characteristics of topography, climate and air quality of Balikesir City were presented. Then the relationship of SO_2 and TSP concentrations with the combination of meteorological parameters for 1996–2005 winter seasons was investigated.

Materials and methods

Features of study area

The City of Balikesir is situated in north of west Anatolia. The area of Balikesir is about 14,292 km^2 and total population of the city is about 215,000. The population density is about 5,000 people per square kilometer. Balikesir has weak wind speed in the winters when compared with the other seasons. The annual average temperature in the city is 14.5°C. The city's severe climate and topography cause serious air pollution problems.

With annual average temperature of 14.5°C, Balikesir can be considered as a warm city of the country. The average days in a year with a temperature below 10°C are 119 days. However, space heating is a requirement for at least 6 months every year. The average energy consumption for space heating during 1995 to 2005 ranged between 1.73 and 2.40 PJ per year (Selici 2006). The wind speed average was above 2.216 m/s during the summer season, whereas it was 1.961 m/s in winter periods. The severe climate conditions and unfavorable geomorphology and topography of city cause frequent episodes of high atmospheric pollution in Balikesir during the winter periods. Since there is no important industrial plant as a point source, the major sources of air pollution in the city are space heatings and transportations.

SO_2 and TSP measurements

The Environmental Pollution Research Center and Public Health Laboratory has been measuring wintertime sulphur dioxide and total suspended particulate concentrations at five different locations of the city since 1995. The air quality sampling stations together with main arteries of the city are shown in Fig. 1. Measurements were made with neutralization titration for SO_2 and with refractometric evaluations for 24 h integrated dust filter samples in accordance with WHO recommended measurement methods (Elbir et al. 2000). The daily average values of SO_2 and TSP in the city were calculated by using arithmetic averages of the data obtained from the five stations. The daily meteorological data was provided from Meteorology Department of the Balikesir.

Data analysis

Regression analysis was 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 is more than one, multiple linear regression analysis is used and a

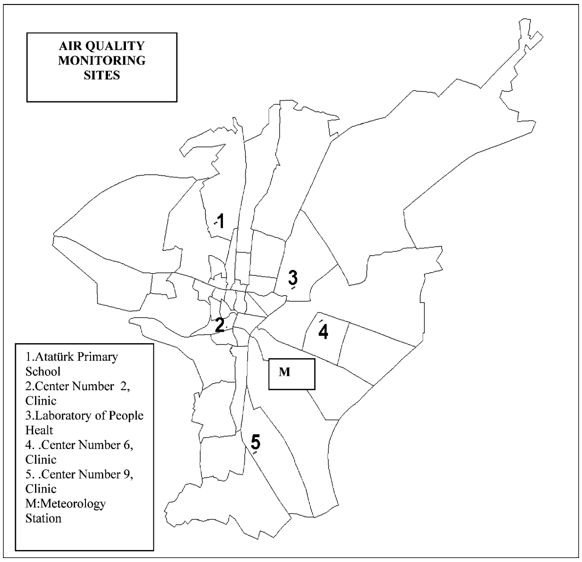


Fig. 1 Map of the location of air quality monitoring sites in Balikesir

general regression equation that has four independent variables can be expressed as:

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

Where a is the constant of regression and b is the regression coefficient. The values of the constant and the coefficients are determined using the least-squares method which minimizes the errors.

Linear regression estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable. For each variable: number of valid cases, mean, and standard deviation need to be calculated. For each model: regression coefficients, correlation matrix, part and partial correlations, multiple R, R^2, adjusted R^2, change in R^2, standard error of the estimate, analysis-of-variance table, predicted values, and residuals are also need to be calculated.

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, some times called the coefficient of determination. The coefficient of determination is that proportion of the total variability in the dependent variable that is accounted for by the regression equation. The value of R^2=1 indicates that the fitted equation accounts for all the variability in 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 statically significant regression equation and that a low R^2 proves the opposite (Norusis 1990).

In the present study, a stepwise regression model was used. Stepwise regression of independent variables 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:

$$Y = f(X_1), Y = f(X_2), \ldots, \quad Y = f(X_2, X_3), \ldots, \quad Y = f(X_1, X_2, X_3, X_4, X_5) \quad (2)$$

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 TSP data together with meteorological parameters such as wind speed, temperature, relative humidity and atmospheric pressure were analyzed by multiple regression using the SPSS software. SO_2 and TSP were considered as dependent variables while meteorological parameters such as temperature, wind speed, relative humidity and pressure were considered as independent variables.

Results and discussion

The change of SO_2 and TSP concentration from 1996 to 2005 in Balikesir

Sulphur dioxide and total suspended particulate concentrations for the winter seasons (October through March) obtained from daily observation network that includes five stations. These winter season values are presented in Fig. 2 together with the Turkish Air Quality Control Regulation standard value of 120 μg/m^3 for SO_2 and TSP (MOE – Ministry of Environment 1986). Figure 2 shows that winter season limit of Turkish Air Quality Control Regulation have been exceeded significantly both for SO_2 and TSP until 1998. After 1998, SO_2 level have declined rapidly. The most important reason for this improvement in the urban air quality is the replacement of the usage of poor-quality local hard coal, which has high sulphur and ash content as well as low calorific value, with high quality fuels. In 1998, local government has banned importing of poor-quality local hard coal into the city. It is required that domestically produced coal should have the lower heating value of 17,556 kJ/kg, sulphur and ash contents of 1.5 and 25%, respectively. For the imported coals these limits are 25,916 kJ/kg for the lower heating value, 0.9% for total sulphur, and 10% for ash content.

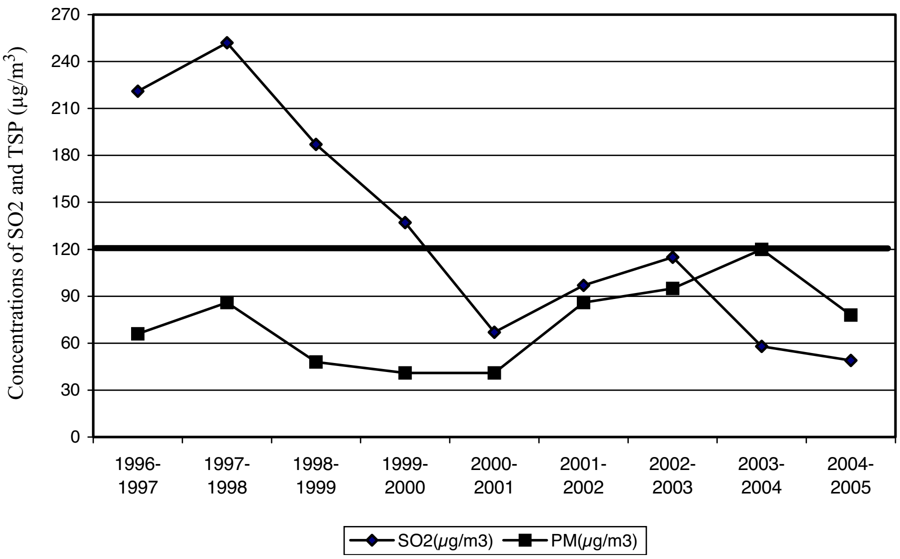


Fig. 2 The variation of SO_2 and TSP concentrations in winter periods from 1996 to 2005

Monthly averages of SO_2 and TSP values between 1996 and 2005 are presented in Figs. 3 and 4, respectively. These figures show that both the maximum SO_2 and TSP values are between December and February, which are the coldest months of the year in Balikesir.

The change of SO_2 and TSP concentration with meteorological parameters

The mean and standard deviation values of meteorological parameters and SO_2 and TSP concentrations for the years of 1999 to 2005 are presented in Table 1. In this study, daily average SO_2 and TSP concentrations and daily average meteorological parameters for the 1999–2005 winter periods were used, because the quality of fuel consumed in the city until 1999 was different than that of used after 1999.

It can be seen from Fig. 2, the annual averages of SO_2 were exceeding the aimed limit values (ALV) of 120 until the year of 1999–2000, whereas the annual averages of TSP were below the required standard for the whole period of the study. For the investigated seven winter periods, daily SO_2 and TSP values exceeded the ALV for 253 and 134 days, respectively. Those days the average temperature was 8.265°C and the wind speed was 1.961 m/s. These values are higher than their winter period average of 5.18°C, 1.32 m/s, respectively. These episode days may be attributed to the consumption of more fuel due to lower temperature resulting in high SO_2 emissions and also unfavorable meteorological factors. In addition to the meteorological

Fig. 3 Monthly average SO_2 values from 1996 to 2005 winter periods

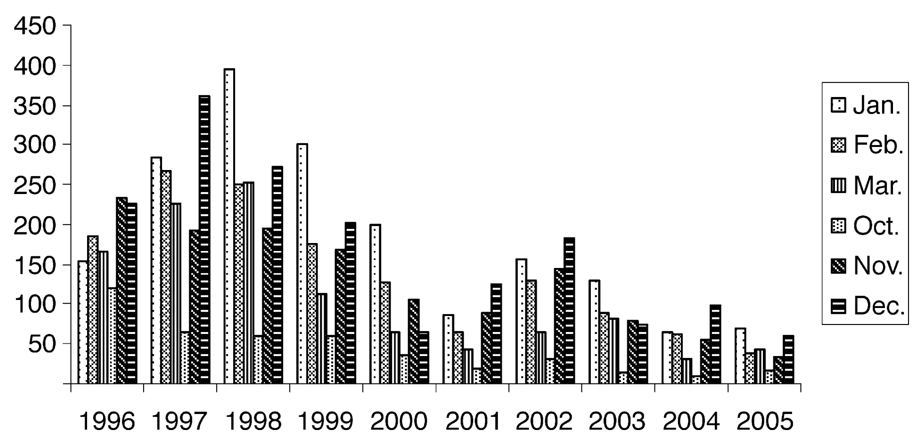
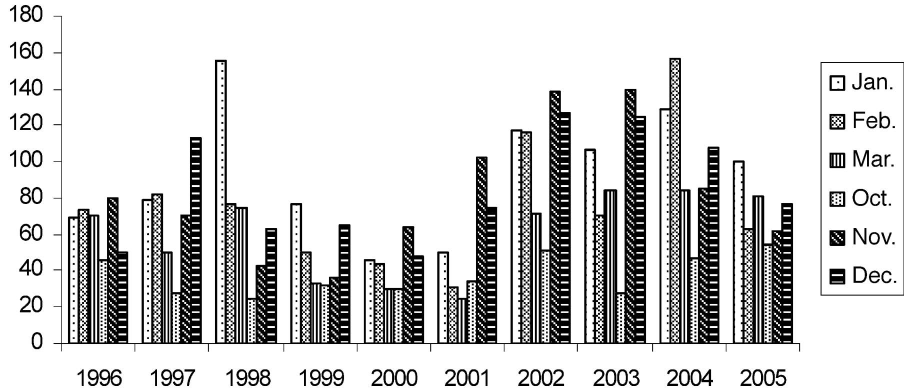


Fig. 4 Monthly average TSP values from 1996 to 2005 winter periods



factors, inversion that affects negatively air pollutant distribution has seen frequently in winter season due to the fact that Balikesir is a climate-passing region.

Relationship between SO_2, TSP and meteorological factors

The relationship between SO_2, TSP and meteorological parameters (temperature, wind speed, relative humidity and pressure) in 1996–2005 winter periods was analyzed by stepwise multiple linear regression analysis. The correlation coefficients (*R*) between daily average SO_2, and TSP concentrations and daily average meteorological parameters are shown in Table 2. As it can be seen in the Table 2, the correlation of SO_2 with meteorological parameters is very similar with the relation between TSP and meteorological parameters. Thus, only SO_2 concentration as a function of meteorological parameters is graphed in Fig. 5a–d.

It was found that statistically significant correlation ($p<0.01$) occurs between SO_2, TSP and temperature as shown in Table 3. It is obvious that the pollutants concentrations decrease effectively with increasing temperature and high pressure. There is a negative correlation between SO_2 and TSP concentrations with wind speed ($p<0.01$). SO_2 and TSP concentrations decrease with increasing wind speed as depicted in Figs. 5a and 6a. This situation shows that when wind speed is high, pollutants dilute by dispersion. The correlation between pollutants and pressure is strong ($p<0.01$). Pollutants concentrations decrease with decreasing pressure. Since Balikesir City is affected by anticyclone system in winter periods originating from Siberians region, pollutants concentrations steadily stay over the city and result in increased air pollution. The relative humidity is also a weakly linked parameter to SO_2 and TSP ($p>0.01$) and their correlations are shown Figs. 5d and 6d. Also, the relation between SO_2 and TSP concentrations is presented in Fig. 6e.

The findings of others related to correlations between SO_2, TSP and meteorological parameters are given in Table 3. It can be clearly seen from the Table 3 that correlations of SO_2 and TSP with temperature, wind speed and, relative humidity obtained at this study is different from those of found at other studies (Prendez et al. 1995; Gupta et al. 2003).

Table 1 The means and standard deviation of meteorological parameters and SO_2 and TSP concentrations from 1999 to 2005 (Selici 2006)

	Mean	Standard deviation	*N*
SO_2 concentration (μg/m^3)	80.53	67.44	1,151
PM concentration (μg/m^3)	77.21	59.49	1,151
Wind speed, (m/s)	1.96	2.33	1,151
Temperature (°C)	8.27	5.84	1,151
Station pressure (mbar)	1,006.52	6.28	1,151
Relative humidity ratio (%)	75.35	10.98	1,151

Note: All meteorological parameters were measured at ground level

Table 2 Results of regression analysis and equations between pollutants and meteorological parameters

State	*R*	R^2	*p* value	Equation
SO_2 with wind speed	−0.2615	0.068	0.000	$103.554-25.570(WS)+3.9937(WS)^2-0.1551(WS)^3$
SO_2 with temperature	−0.51645	0.267	0.000	$112.232\ \exp(-0.0870T)$
SO_2 with pressure	0.18119	0.038	0.000	$-623.70+6.9\times10^{-7}(P)^3$
SO_2 with humidity	0.09	0.0081	0.000	$46.1195-1.6602(H)+0.0585(H)^2-0.0004(H)^3$
TSP with wind speed	−0.43126	0.186	0.000	$109.323-30.091(WS)+3.8439(WS)^2-0.1365(WS)^3$
TSP with temperature	−0.30342	0.092	0.000	$82.0693\ \exp(-0.0407T)$
TSP with pressure	0.18371	0.034	0.000	$-509.14+5.7\times10^{-7}(P)^3$
TSP with humidity	0.28046	0.079	0.000	$14.0651+0.5288(H)-0.0025(H)^2+8.4\times10^{-5}(H)^3$
SO_2 with TSP	0.57251	0.328	0.000	$28.3162+0.6325(TSP)+0.0010(TSP)^2-4\times10^{-6}(TSP)^3$

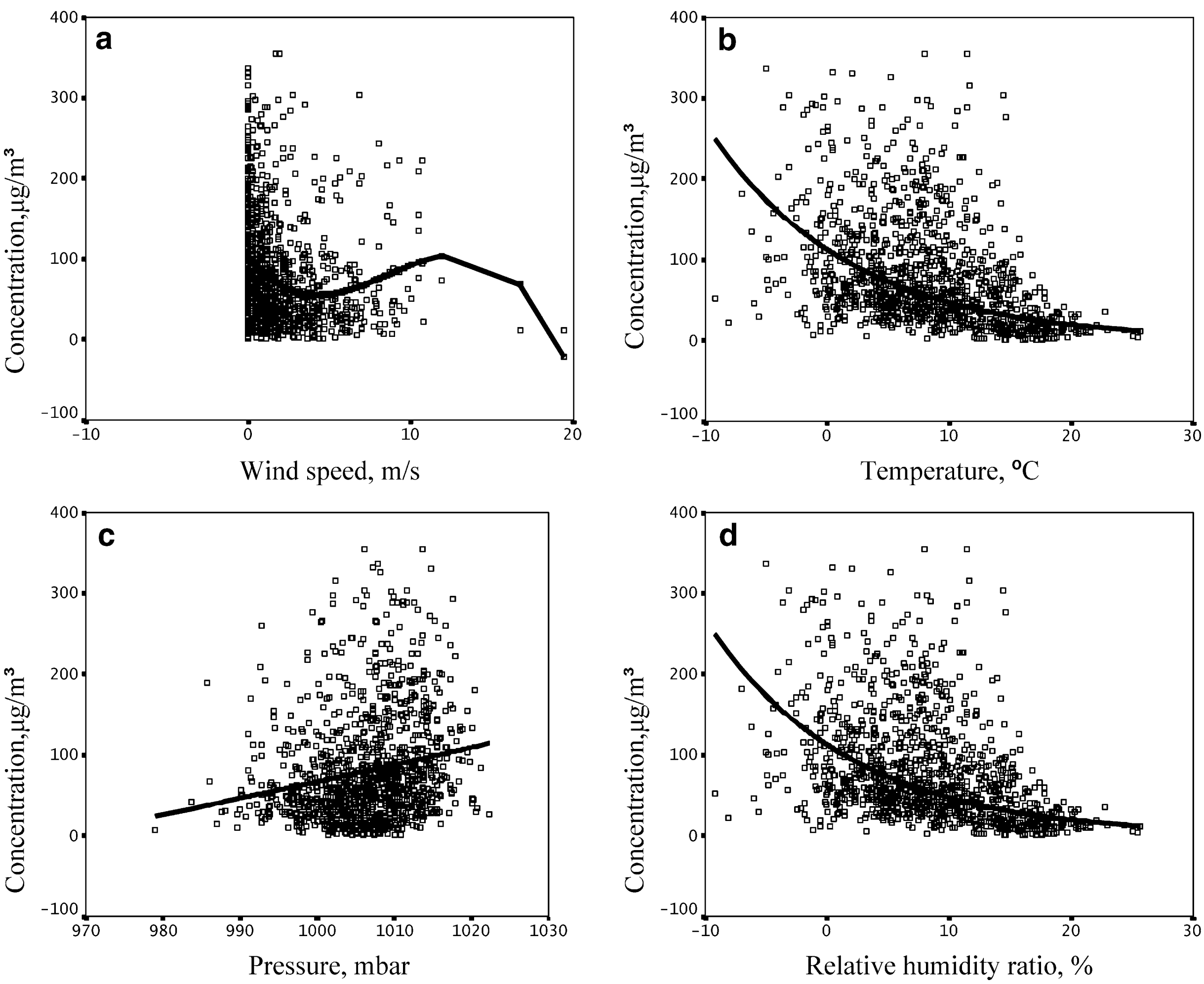


Fig. 5 SO_2 concentration versus **a** wind speed; **b** temperature, **c** pressure, **d** relative humidity ratio

Table 3 Correlation (R) between daily average SO_2, total suspended particulate (TSP) and daily average meteorological parameters in this study and other studied

Pollutants	Temperature	Wind speed	Pressure	Relative humidity	References
SO_2	−0.51645	−0.2615	0.18119	0.09	In this Study
TSP	−0.30342	−0.43126	0.18371	0.28046	In this Study
SO_2	−0.755	−0.493	0.522	0.028	(Turalıoğlu et al. 2005)
TSP	−0.795	−0.640	0.520	0.130	(Turalıoğlu et al. 2005)
SO_2	(−0.39)–(−0.68)	(−0.13)–(−0.42)	–	0.03–0.37	(Bridgman et al. 2002)
SO_2	−0.42	−0.88	–	–	(Gupta et al. 2003)
PM_{10}	(−0.05)–(−0.65)	(−0.15)–(−0.35)	–	0.08–(−0.058)	(Monn et al. 1995)
TSP	0.63–0.78	–	–	–	(Prendez et al. 1995)
SO_2	–	−0.46	–	−0.32	(Kartal and Özer 1998)
Smoke	–	−0.55	–	−0.52	(Kartal and Özer 1998)

The regression analysis

The model equation for SO_2 and TSP prediction, including the transformation of the dependent and independent variables, was formulated as follows:

$$\begin{aligned}SO_{2(t)} = & -684.314 + 0.324(\mathrm{TSP})_{(t)} \\ & - 6.240(\mathrm{WS})_{(t)}1.147(\mathrm{WS})^2_{(t)} \\ & - 4.886 \times 10^{-2}(\mathrm{WS})^3_{(t)} + 0.687(P)_{(t)} \\ & - 2.512(H)_{(t)} + 5.285 \times 10^{-2}(H)^2_{(t)} \\ & - 3.422 \times 10^{-4}(H)^3_t \\ & - 7.955 \times 10^{-11}\exp(T)_{(t)} + 0.687(SO_2)_{(t-1)} \\ R = 0.857 \quad & R^2 = 0.735\end{aligned} \tag{3}$$

$$\begin{aligned}\mathrm{TSP}_{(t)} = & -827.850 + 0.259(SO_2)_{(t)} \\ & - 13.783(\mathrm{WS})_{(t)} + 1.544(\mathrm{WS})^2_{(t)} \\ & - 5.435 \times 10^{-2}(\mathrm{WS})^3_{(t)} + 0.876(P)_{(t)} \\ & - 1.133(H)_{(t)} + 9.344 \times 10^{-3}(H)^2_{(t)} \\ & + 2.652 \times 10^{-5}(H)^3_{(t)} \\ & + 2.189 \times 10^{-10}\exp(T)_{(t)}0.496(\mathrm{TSP})_{t-1} \\ R = 0.810 \quad & R^2 = 0.656\end{aligned} \tag{4}$$

SO_2 and TSP values can be calculated from the measured meteorological and pollutant values using Eqs. 3 and 4. It is known that previous concentration has an effect on the present one (Tecer et al. 2003). On the calculation the effect of the previous days value also considered. The whole data set for SO_2, TSP, wind speed, temperature, humidity and pressure were 6,936 which were belong to 1,151 days of 1999–2005 winter season. The regression coefficients (R) for Eqs. 3 and 4 found as 0.857 and 0.810, respectively. The other equations for SO_2 and TSP with meteorological parameters and determined values of R, R^2, and p are given in Table 2.

It has been reported in the literature that the number of meteorological parameters included in regression equations are highly variable. In a study performed by Cuhadaroglu and Demirci (1997), the regression coefficient computed between SO_2 and meteorological parameters (wind speed, humidity) as 0.53 and between PM and meteorological parameters (temperature, humidity) as 0.56. In another study the regression coefficient between SO_2 and meteorological parameters (wind speed, temperature) was found as 0.62 (Gupta et al. 2003).

Conclusion

Severe air pollution, especially during winter seasons, has occurred in the City of Balikesir since 1996. Due to the limitation placed by the local government on burning low quality fuels, the SO_2 and TSP concentrations have gradually decreased since the beginning of 1998. Maximum SO_2 and TSP concentrations have been observed between December and February. It has been shown in our previous work that these high SO_2 and TSP values were due to low temperature, low wind speeds, high-pressure system and shortage

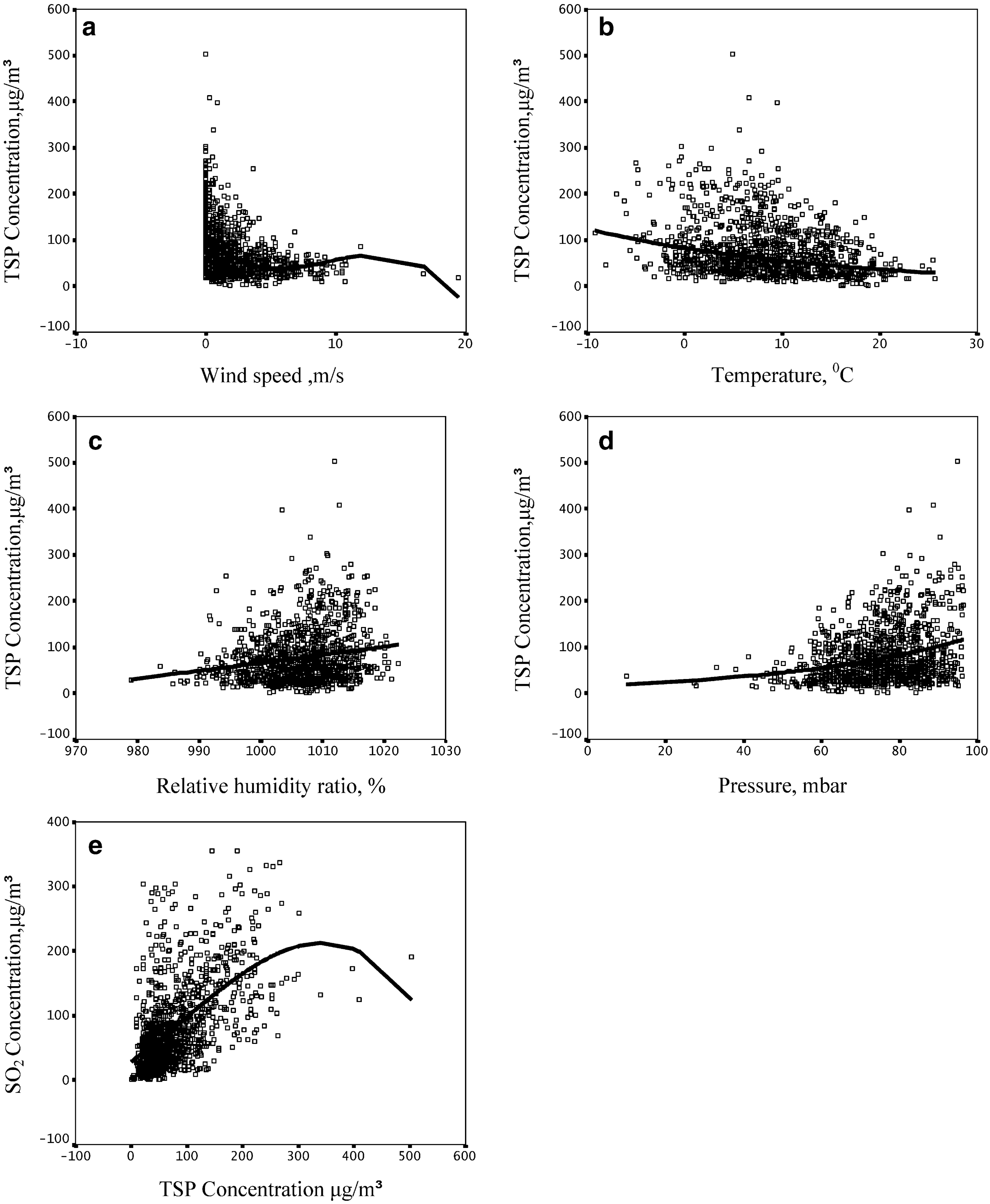


Fig. 6 TSP concentrations versus **a** wind speed; **b** temperature, **c** pressure, **d** relative humidity ratio; **e** SO_2 concentration

of rainfall observed during the winter seasons (İlten et al. 2006).

The results showed a statistically significant relationship between the meteorological parameters and SO_2 and TSP values obtained in the city center of Balikesir. It has been shown that there is a strong inverse relation between SO_2 and temperature (R^2= 0.267). This is consistent with the high fuel consumption that leads to higher emissions of SO_2 during the low temperature periods. The second strong inverse relation is seen between TSP and wind speed (R^2= 0.186). High wind speeds reduce TSP concentration due to the dilution effect. In addition to the strong inverse correlation exist between temperature and wind speed, pollutant concentrations had also a significant correlation with air pressure. The humidity showed a weak correlation with SO_2.

SO_2 values are affected by meteorological factors, TSP and previous day of SO_2 values and have shown strong correlation with these parameters, (R^2=0.735, see Eq. 3). Similar correlation was also observed between TSP values and meteorological factors, SO_2 and previous day of TSP values (R^2=0.656, see Eq. 4). However, the direct correlation between pollutants concentrations and individual parameters were found to be low (Table 2). Since good correlations were observed, the Eqs. 3 and 4 can be used as a model for the air pollutants in Balikesir. This model may help the city authorities to decide using the alternative energy resources according to SO_2 and TSP levels that are well known global warming pollutants.

In addition to these results, following precautions can be suggested to succeed the reduction in air pollution:

- The direction of wind throughout the winter periods must be taken into consideration in city plan of structuring. The plans of residential and industrial buildings and also the heights of buildings must be designed in a way that they will not prevent the wind flow.
- An understanding of pollution sources and emissions, and their interactions with terrain and the atmosphere should be considered as a most important first step in developing appropriate air pollution management plans and action strategies. Without this type of knowledge, incorrect decision related to air pollution management is possible, creating the wasted resources and undesirable results (Bridgman et al. 2002).
- Increasing green areas in the city will help in decreasing the concentration of air pollutants.
- Since topographical structures of cities and meteorological parameters are different form city to city, local governments should be authorized in determining the limit values of air pollutants.
- Due to insufficient information about the air quality, strategic planning on air quality management should be constructed for the city of Balikesir.
- Renewable energy sources such as solar and geothermal energy must be encouraged to be used in space and water heating since these resources have higher efficiencies and lower air pollutant emissions (Hepbasli and Utlu 2004).
- The use of natural gas, having lowest pollutant emissions, should be encouraged to be used for space heating.
- The type of coal used for space heating has a great importance in terms of air pollution in the city. Therefore, it is necessary to educate people to use the coals which have high calorific value and low sulphur contents.
- There is a need for a more comprehensive study to improve the monitoring, type of the fuel usage, and evaluation systems for urban air pollution.

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