STATISTICAL ANALYSIS OF METEOROLOGICAL FACTORS AND AIR POLLUTION AT WINTER MONTHS IN ELAZIĞ, TURKEY

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Abstract: In the present study, relationship between monitored air pollutant concentrations such as SO₂ and the total suspended particles (TSP) data and meteorological factors such as wind speed, temperature, relative humidity and atmospheric pressure was investigated in months of October, November, December, January, February, and March during the period of three 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.

Keywords: Sulphur dioxide; total suspended particles (TSP); meteorological parameters; statistical analysis; Elazığ; Turkey; winter months

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INTRODUCTION

The air pollution in urban areas has different characteristics on account of the changing meteorological factors depending on the geographical and topographical peculiarities of the urban area. The level of the air pollution concentrations is correlated with the combination of the various meteorological factors. For that reason, the air pollution concentrations and meteorological data should be evaluated statistically in order to correlate them (Demirci & Cuhadaroglu, 2000).

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 (Turaloglu 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 (Escourou, 1990), Ravenna (Tribassi et al., 1990) and Shangai (Chao, 1990). Also, characterization of the concentration and distribution of urban submicron PM<sub>1</sub> aerosol particles at the city of Kaohsiung were investigated by (Lin & Lee, 2004). (Cuhadaroglu & 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<sub>2</sub> and particle concentrations between meteorological factors. Their results indicated that there is a moderate and weak level of relation between the SO<sub>2</sub> level and the meteorological factors in Trabzon city. In their other study (Demirci & Cuhadaroglu, 2000), they 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-ENE and SSW-NNE in the urban. In the study presented by (Bridgman et al., 2002), the relationship of SO<sub>2</sub> concentrations to six major meteorological parameters has been investigated. Results found that SO<sub>2</sub> concentrations strongly related to colder temperature, higher relative humidity and lower wind speed. For prediction of SO<sub>2</sub> and smoke concentrations of Kayseri-Turkey, multiple regression equations including meteorological parameters and previous day’s pollutant concentrations have been used by (Kartal & Ozer, 1998). The changes of air quality in Erzurum-Turkey and the correlation of SO<sub>2</sub> and TSP pollution in Erzurum city with meteorological parameters such as wind speed, temperature, atmospheric pressure, precipitation, and relative humidity were researched by the (Turaloglu 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. Ando et al. (2000) proposed models for the enforcement of the air quality standards in both urban and industrial areas.

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. The correlation of SO<sub>2</sub> and TSP pollution in Elazığ city with meteorological parameters such as wind speed, temperature, atmospheric pressure, solar radiation, and relative humidity were researched by the (Akpinar et al., 2006, Akpinar et al., 2008). Akpinar et al. (2006) investigated the relationship between air pollution concentrations and meteorological data such as wind speed, temperature, relative humidity and atmospheric pressure for Elazığ at winter, autumn and spring seasons. The mentioned study has contained analysis for only two years (2003–2004) but it is actually not enough for these kinds of studies.

In the study, analysis was made to season of autumn, spring and winter. During autumn and spring seasons, investigation of effects of meteorological variables on the air pollutants are not necessarily, since they were at low levels in the warm periods. Moreover all heaters are active in winter season at full capacity. Akpinar et al. (2008) examined relationship between monitored air pollutant concentrations such as SO<sub>2</sub> and the total suspended particles (TSP) data and meteorological factors such as wind speed, temperature, relative humidity, sun intensity and atmospheric pressure was investigated for all month in winter seasons during the period of three years (2003, 2004 and 2005) for Elazığ city.

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, and atmospheric pressure for Elazığ.
city. The characteristics of topographic, climatic and air quality of Elazıg city were presented first, then the relationship of SO2 and TSP concentrations with the combination of meteorological parameters for each of months at winter seasons of the 2003–2005 was investigated.

MATERIAL AND METHODS
Features of study area
Elazıg city (longitude; 40º 21’ and 38º 30’, latitude; 38º 17’ and 39º 11’) is situated in north part of Euphrates River of east Anatolia region of Turkey. The area of Elazıg city is 9.281 km2 which is equivalent to 0.12 percent 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. Elazıg 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 Elazıg city can be shown from Fig. 1.

The wind speed, outside temperature, relative humidity and atmospheric pressure were the measured meteorological parameters of this research. The measurements have been carried out by conventional meteorological instruments at the station located in the east of the Elazıg city by the Turkish Meteorological State Department (TMSD). Figure 2 shows the monthly average wind speed, temperature, relative humidity 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 Elazıg city, the annual average temperature is about 13ºC, the annual average wind speed is about 2.5 m/s, the annual average relative humidity is about 54% and the annual average atmospheric pressure is about 902 mbar.

The Elazıg city needs at least six 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 km and 2 km, respectively.

Fig. 2 Some meteorological data ((a) mean of wind speed, (b) temperature, (c) relative humidity and (d) atmospheric pressure) of Elazıg city in 2003–2005.
SO₂ and total suspended particles (TSP) concentrations measurements

The Environmental and Forestry State Department have been doing sulphur dioxide and particle concentrations measurements at two stations in the Elazığ city. Measurements were made with neutralization titration for SO₂ and with refractometric evaluations for 24 h integrated dust filter samples in accordance with WHO recommended measurement methods (Elbir, 2000). The daily average values of SO₂ and total suspended particles (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 Institution (2003-2004-2005).

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:

$$ Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + e $$  

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

$$ R^2 = 1 - \frac{\sum(Y_{\text{pre}} - \bar{Y})^2}{\sum(Y_{\text{obs}} - \bar{Y})^2} $$  

where $Y_{\text{pre}}$ is the value of $Y$ predicted by the regression line, $Y_{\text{obs}}$ is the value of $Y$ observed, and $\bar{Y}$ is the mean value of the $Y$.

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 (Turalioğlu et al., 2005, Norusis, 1990).

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:

$$ Y = f(X_1), $$

$$ Y = f(X_2), \ldots, Y = f(X_2, X_3), \ldots, $$

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

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.

In addition to $R^2$, the various statistical parameters such as; mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the fit. These parameters can be calculated as follows:

$$ MBE = \frac{1}{N} \sum_{i=1}^{n} (Y_{\text{pre},i} - Y_{\text{obs},i}) $$  

$$ RMSE = \left[ \frac{1}{N} \sum_{i=1}^{n} (Y_{\text{pre},i} - Y_{\text{obs},i})^2 \right]^{1/2} $$  

$N$ is the number of observations.

SO₂ and particle concentrations data together with meteorological parameters such as wind speed, temperature, relative humidity and atmospheric pressure, were analyzed by multiple linear regression using the SPSS programme. SO₂ and total suspended particles (TSP) concentrations were considered as dependent variables while meteorological parameters such as temperature, wind speed, relative humidity and atmospheric pressure were considered as independent variables.

RESULTS AND DISCUSSION

The monthly averages of SO₂ and TSP values in 2003–2005 are graphed in Figs 3a and 3b to see the monthly
trends in concentrations. As seen from Fig. 3, the maximum SO2 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 SO2 and TSP concentrations and meteorological parameters in months of October, November, December, January, February, and March during the period of tree years (2003, 2004 and 2005). Figures 4(a-c) and 5(a-c) are presented to show variations of wind speed with SO2 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 SO2 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.

Table 1. The means and standard deviations of SO2 and TSP concentrations and meteorological parameters in 2003–2005 winter seasons

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean SO2 concentration, µg/m³</th>
<th>Mean TSP concentration, µg/m³</th>
<th>Mean Wind speed, m/s</th>
<th>Mean Temperature, °C</th>
<th>Mean Relative humidity ratio, %</th>
<th>Mean Atmospheric pressure, mbar</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>134.044</td>
<td>67.961</td>
<td>2.522</td>
<td>5.118</td>
<td>67.986</td>
<td>904.85</td>
<td>182</td>
</tr>
<tr>
<td>2004</td>
<td>94.098</td>
<td>39.890</td>
<td>2.401</td>
<td>5.137</td>
<td>64.318</td>
<td>905.982</td>
<td>183</td>
</tr>
<tr>
<td>2005</td>
<td>57.318</td>
<td>41.890</td>
<td>2.338</td>
<td>5.024</td>
<td>64.187</td>
<td>905.311</td>
<td>182</td>
</tr>
</tbody>
</table>

Fig. 3 Monthly average (a) SO2 and (b) TSP (total suspended particles) concentrations values in 2003–2005 winter seasons.
When two figures (Figs 4 and 5) are compared, it is seen that wind speed is more effective on \( \text{SO}_2 \) concentration than that of \( \text{TSP} \) concentration. Effects of variations of mean temperature on \( \text{SO}_2 \) and \( \text{TSP} \) concentrations are presented in Figs 6(a–c) and 7(a–c), respectively. Data consist of the same effect as wind speed on \( \text{SO}_2 \) and \( \text{TSP} \) concentrations that both \( \text{SO}_2 \) and \( \text{TSP} \) concentrations are decreased with increasing temperature. Maximum values of \( \text{SO}_2 \) and \( \text{TSP} \) 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 & Ozer, 1998). Variations of relative humidity with \( \text{SO}_2 \) and \( \text{TSP} \) concentrations are shown in Figs 8(a–c) and 9(a–c), respectively. On the contrary of wind speed and temperature, which was plotted in Figs 4–7, \( \text{SO}_2 \) and \( \text{TSP} \) 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 & Ozer, 1998). Variations of \( \text{SO}_2 \) and \( \text{TSP} \) concentrations with atmospheric pressure are plotted in Figs 10(a–c) and 11(a–c), respectively.

![Fig. 6 SO\(_2\) concentrations versus temperature in 2003–2005 winter seasons.](image-url)

![Fig. 7 TSP (total suspended particles) concentrations versus temperature in 2003–2005 winter seasons.](image-url)

![Fig. 8 SO\(_2\) concentrations versus relative humidity in 2003–2005 winter seasons.](image-url)
These figures show that SO₂ and TSP concentrations are slightly increased with increasing atmospheric pressure. However, atmospheric pressure is more effective parameter on SO₂ concentration than on TSP concentration.

The regression equations between meteorological parameters (temperature, wind speed, relative humidity and atmospheric pressure) and SO₂ and TSP concentrations and the correlation coefficients were defined separately for 2003–2005 years, by linear regression analysis. The correlations (R) between daily average SO₂, TSP concentrations and daily average meteorological parameters are shown in Table 2. As seen in Table 2, the correlation of SO₂ 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 relationship between SO₂ and TSP and meteorological parameters (temperature, wind speed, relative humidity and atmospheric pressure) in September - October - November - December - January - February - March - April of 2003–2004 years
Table 2. The correlations coefficients and the regression equations between various meteorological parameters for SO$_2$ and total suspended particles (TSP)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>SO$_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>148.16-5.5957*[WS]</td>
<td>95.317-0.5076*[WS]</td>
<td>55.065-0.9638*[WS]</td>
</tr>
<tr>
<td></td>
<td>0.0088</td>
<td>0.0004</td>
<td>0.0021</td>
</tr>
<tr>
<td></td>
<td>8.6261+1.8447*[RH]</td>
<td>78.551+0.2417*[RH]</td>
<td>37.188+0.3136*[RH]</td>
</tr>
<tr>
<td></td>
<td>0.0713</td>
<td>0.0106</td>
<td>0.0254</td>
</tr>
<tr>
<td></td>
<td>0.2258</td>
<td>0.1369</td>
<td>0.1639</td>
</tr>
<tr>
<td></td>
<td>537.16+0.7418*[P]</td>
<td>-482.07+0.636*[P]</td>
<td>-1060.6+1.2178*[P]</td>
</tr>
<tr>
<td></td>
<td>0.0022</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Total</td>
<td>= 68.397-0.1724*[WS]</td>
<td>= 41.407-0.6313*[WS]</td>
<td>= 46.798-2.099*[WS]</td>
</tr>
<tr>
<td>Suspended</td>
<td>= 15.765+0.7677*[RH]</td>
<td>= 36.536+0.0522*[RH]</td>
<td>= 45.176-0.6541*[RH]</td>
</tr>
<tr>
<td>Particles</td>
<td>= 78.128-1.9864*[T]</td>
<td>= 11.151</td>
<td>= 0.03964*[RH]</td>
</tr>
<tr>
<td>(TSP)</td>
<td>= 125.52+0.0636*[P]</td>
<td>= 44.993</td>
<td>= 1.2178*[P]</td>
</tr>
<tr>
<td></td>
<td>5E-05</td>
<td>0.0021</td>
<td>0.0631</td>
</tr>
<tr>
<td></td>
<td>0.0718</td>
<td>0.0914</td>
<td>0.0197</td>
</tr>
<tr>
<td></td>
<td>0.1151</td>
<td>0.0134</td>
<td>0.0631</td>
</tr>
</tbody>
</table>

was investigated by stepwise multiple linear regression analysis. The correlations (R) between daily average SO$_2$, TSP concentrations and daily average meteorological parameters are shown in Table 3. It is shown from Table 3 that there is a weaker and moderate correlation between the pollutants concentrations and meteorological parameters.

In this study, the resulting equations are consistent that all of meteorological parameters for 2003, 2004 and 2005 years were investigated using non-linear regression analysis. Correlations are given with statistical parameters, as follows:

For 2003 year
SO$_2$ = -143.510-4.1434*[WS] -6.2312*[T] + 0.5930*[RH] + 0.3089*[P], R=0.60997, MBE=2.806, RMSE=37.86 (5)

TSP = -37.3234+0.8893*[WS] -1.5918*[T] + 0.5006*[RH] + 0.0853*[P], R=0.50236, MBE=0.941, RMSE=12.70 (6)

For 2004 year
SO$_2$ = -719.017+1.4873*[WS] -1.0077*[T] + 0.0882*[RH] + 0.89342*[P], R=0.42259, MBE=0.841, RMSE=11.35 (7)

TSP = 737.5768 - 2.0849*[WS] + 0.1860*[T] + 0.03964*[RH] -0.7684*[P], R=0.41344, MBE=0.275, RMSE=3.71 (8)

For 2005 year
SO$_2$ = 351.1286+0.7563*[WS] - 2.1831*[T] - 0.0411*[RH] - 0.3133*[P], R=0.51258, MBE=0.589, RMSE=7.95 (9)

TSP = -1491.15+2.1592*[WS] + 0.3605*[T] + 0.6692*[RH] + 1.6383*[P], R=0.51916, MBE=0.71, RMSE=9.59 (10)

Considering Eqs 5–10, measured SO$_2$ and TSP values were compared with calculated ones. Figures 12, 13 and 14 show the predicted and measured values of SO$_2$ and TSP.
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, SO2 and total suspended particles (TSP) were weakly decreased with increasing wind speed and temperature. However, it was weakly increased with increasing relative humidity and atmospheric pressure. Because SO2 and TSP concentrations were decreased with increasing wind speed and circulation of air flow. 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 SO2 and TSP concentrations with regard to meteorological parameters, statistical models were developed for each month. The correlation coefficients of the statistical model of SO2 and TSP including meteorological parameters changed between 0.2844 and 0.8156, and 0.3011 and 0.7333, respectively. However, the statistical models of SO2 and TSP including all of meteorological parameters were investigated for each year. The correlation coefficients of these models showed changing between 0.41344 and 0.60997. 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.

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NOMENCLATURE

P    atmospheric pressure (mbar)
RH   relative humidity (%)
T    temperature (°C)
WS   wind speed (m/s)