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Status and prediction of sulfur dioxide as an air pollutant in the city of Ahvaz, Iran

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ABSTRACT : The present research analyzes air quality in Ahvaz, a city in the south of Iran, paying special attention to sulfur dioxide (SO_2). In order to prepare the average data in the city, measurements have been carried out between 2009 and 2010 in two different locations. Relations between sulfur dioxide and some meteorological parameters have been calculated statistically, using the daily average data. The wind data (velocity, direction), relative humidity, temperature, sunshine periods, evaporation and rainfall have been considered as independent variables. The RMSE Test showed that among different prediction models, the stepwise one is the best option. The average concentrations have been calculated for every 24 hours, during each month and each season. Results show that the highest concentration of sulfur dioxide occurs generally in the morning while the lowest concentration is found before the sunshine. In case of the monthly concentrations of sulfur dioxide, the highest value belongs to January, while the lowest one occurs in October. And as for the seasonal concentrations, it has been shown that the highest amounts belong to winter. Results show that quantities of SO_2 in different seasons as well as the entire year can be estimated by climate parameters. Results also indicate that the relations between the SO_2 and meteorological parameters are stronger than the entire year during the seasons.

Keywords: air pollution, meteorological parameters, regression model, sulfur dioxide.

INTRODUCTION

Air sustains life; however, the air we breathe is not pure as it contains lots of pollutants, mostly toxic (Majidnezhad, 2014; Fleischer et al., 2014; Asghari Esfandani & Nematzadeh, 2016; Khader et al., 2016). Although during the last century developed countries kept making progress, their air quality continuously got worse. Particularly in developing countries air pollution exceeds all health standards, e.g. in Lahore and Xian (China) dust is ten times higher than health standards.

Sulfur dioxide (SO_2) is one of the seven conventional (criteria) pollutants (in addition to CO, particulates, hydrocarbons, nitrogen oxides, O_3, and lead). These substances produce the highest volume of pollution in the air, causing the most serious threats for human health and welfare. The concentration

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of these pollutants, especially in cities, has been regulated by the Clean Air Act of 1970 (Cunningham & Cunningham, 2002).

In one study, the relation between monitored air pollutants and meteorological factors, such as wind speed, relative humidity ratio, and temperature has been statistically analyzed in the city of Trabzon, using SPSS (Cuhadaroglu & Demirci, 1997). According to the results, obtained from multiple linear regression analysis, for some months there was a moderate and weak relation between the level of air pollutants, such as SO_2, and the meteorological factors.

Mandal (2000) has shown the progressive decrease of air pollution from west to east in Kolkata. In another study, Chelani et al. (2001) studied the modeling of ambient air pollutants in Delhi, developing some statistical models to predict air pollutants for the city. Abdul-Wahab and Al-Alawi (2002) developed a neural network model to predict the tropospheric (surface or ground) ozone concentrations as a function of meteorological conditions and various air quality parameters, their results showing that the Artificial Neural Network (ANN) is a promising method for air pollution modeling. The observed behavior of pollution concentrations to prevailing meteorological conditions has been studied in the Metropolitan Area of Sao Paulo for the period between June 13 and September 2, 1994, (Sánchez-Ccoyllo & Andrade, 2002). Results have shown that low concentrations are associated with intense ventilation, precipitation, and high relative humidity, whereas high values of concentrations prevail due to weak ventilation, absence of precipitation, and low relative humidity for some pollutants. Also in order to predict CO, Sabah et al. (2003) have used a statistical model.

Elminir (2005) stated the dependence of air pollutants on meteorology in the city of Cairo, Egypt. His results hinted that wind direction had an influence not only on pollutant concentrations but also on the correlation among the pollutants. As expected, the pollutants, associated with traffic, stood at the highest ambient concentration levels as long as the wind speed was low. At higher wind speeds, dust, and sand from the surrounding desert was entrained by the wind, thus contributing to ambient particulate matter levels. It was also found that the highest average concentration for NO_2 and O_3 occurred at a humidity level equal to or below 40%, indicative of strong vertical mixing. For CO, SO_2, and PM_{10} the highest average concentrations occurred at a humidity level above 80%. In another research, data on the concentrations of seven air pollutants (CH_4, NMHC, CO, CO_2, NO, NO_2, and SO_2) and meteorological variables (wind speed and direction, air temperature, relative humidity, and solar radiation) have been used to predict the concentration of ozone in the atmosphere, using both multiple linear and principal component regression methods (Abdul-Wahab et al., 2005). Results showed that while high temperature and high solar energy tended to increase the day time ozone concentrations, the pollutants NO and SO_2, emitted to the atmosphere, got depleted. However, the model did not predict the night time ozone concentrations as precisely as it did for the day time. Asrari et al. (2007) studied the effect of meteorological factors for CO prediction. Also, their study showed the variations of CO concentration in different times.

Li et al. (2014) presented the spatial and temporal variation of Air Pollution Index (API), examining the relation between API and various meteorological factors during 2001–2011 in Guangzhou, China. Temperature, relative humidity, precipitation, and wind speed were negatively correlated with API, while diurnal temperature range and atmospheric pressure were positively correlated with API in the annual condition. Yoo et al. (2014) mentioned that all of the pollutants show significant negative correlations between their concentrations and the intensity of rain due to washout or convection. The relative effect of the precipitation on the air pollutant concentrations was estimated to be: PM_{10}> SO_2> NO_2> CO> O_3, indicating that PM_{10} was most effectively cleaned by rainfall.

Wang et al. (2015) studied the air quality in Chongqing, the largest mountainous city in China, from 2002 to 2012, conducting a statistical analysis of SO_2, PM_{10}, and NO_2 concentrations. The analysis of Pearson correlation in their study indicated that concentrations of SO_2, PM_{10}, and NO_2 were positively correlated with atmospheric pressure, while it was negatively correlated with temperature and wind speed. The analysis of Multi-Pollutant Index (MPI) showed that air quality in Chongqing was an issue to be concerned about.

The climatology of tropospheric ozone at Irene has been investigated via SHADOZ network data to assess the correlation between the observed seasonal ozone enhancement and meteorological factors (Mulumba et al., 2015). For doing so, a multiple linear regression model has been used to provide seasonal correlation between ozone and temperature and relative humidity. All seasons display strong regression coefficients between ozone and temperature and similar trends have also been observed for relative humidity and ozone concentrations in autumn, spring, and summer.

Statistical modeling of ozone in Shiraz and PM_{10} in Tehran has been studied by Masoudi et al. (2016a, 2016b). According to their results, obtained through multiple linear regression analysis, for seasonal and annual conditions there are significant relations between ozone and PM_{10} levels and the meteorological factors in both cities.

The present study exhibits diurnal, monthly, and seasonal variations of sulfur dioxide concentration, offering a statistical model that is able to predict the amount of sulfur dioxide too, which is based on linear regression technique. Linear Regression estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable (the amount of sulfur dioxide in this study). For this purpose, it has used a large statistical and graphical software package (SPSS, Software Package of Social Sciences, V. 20), which is one of the best known statistical packages (Kinnear, 2002).

MATERIAL AND METHOD

The research area, Ahvaz, capital of Khuzestan Province, is the biggest city of south-western Iran, located around 31° 19' N and 48º 40' E, with an altitude of about 20 m above the mean sea level. With an annual precipitation of about 230 mm, the city has arid climate, its residential population equal to 1,112,021 in 2011. Ahvaz is consistently one of the hottest cities on the planet during summer, its summer temperature sometimes exceeding 50°C, while in winter the minimum temperature can be around +5°C (Guardian, 2016). Built on the banks of the Karun River, it is situated in the middle of Khuzestan Province. There are lots of cars travelling within the city as well as many factories and industrial hubs that generate lots of air pollutants like sulfur dioxide. As a result, Ahvaz is one of the most polluted cities in Iran which needs an ambient air quality analysis to conduct.

Recently, Ahvaz is considered as the worst polluted city of the world according to a survey by the World Health Organization in 2011, owing to high concentration of dust throughout the year (Guinness World Records, 2013). Growing amount of dust (Fig. 1) can cause different problems such as increasing number of cancer and lung damages, which have been recorded by healthcare offices of this region during recent years.

Fig. 1. Two photographs from the same place in Ahvaz, showing impacts of dust pollution during recent years

Two available sampling stations in the city, namely Administration and Naderi that belong to Environmental Organization of Iran, have been selected to represent different traffic loads and activities.

The sampling has been done every 30 minutes on a daily basis for each pollutant in 2009 and 2010. SO_2 has been chosen among the varied measured data in both stations; its average rate calculated from both stations by means of Office Excel for each hour, during every month and every season. At the end, data averages at the two stations have been used to show air pollution situation via diurnal, monthly, and seasonal graphs of sulfur dioxide concentration in the city.

The next step has involved studying correlation of sulfur dioxide along with metrological parameters of synoptic station of the city, with the latter including temperature (min & max), humidity (min & max), precipitation, sunshine, wind direction, wind speed, and evaporation.

In the following step, daily average data at both stations in 2010 has been considered to be dependent variable in statistical analysis, while daily data of meteorological parameters during this year has been selected as independent variables in SPSS program. The linear regression equation shows that the concentration of sulfur dioxide depends on the kind of meteorological parameters, also giving an idea about the levels of this relation. The relationship between the dependent variables and each independent variable should be linear. The significant values in output are based on fitting a single model. Also linear regression equation has been made for different seasons, perhaps to show the relations, which have remained unobserved, using annual data.

There are some options available in this software which is applied when the ‘enter’, ‘forward’, ‘backward’, or ‘stepwise’ variable selection method has been specified. Method selection allows one to specify how independently the variables are entered into the analysis. Using different methods, it is possible to construct a variety of regression models from the same set of variables. The model for predicting sulfur dioxide has been determined using two multiple regression modeling procedures of ‘enter method’ and ‘stepwise method’. In ‘enter method’ all selected independent variables are added to a single regression model. In ‘stepwise’ which is better, all variables can be entered or removed from the model depending on the significance; therefore, only the ones with more influence on dependent variable are observed in a regression model.

RESULTS AND DISCUSSION

In Figures 2, 3 and 4 present the diurnal, monthly, and seasonal variations of sulfur dioxide concentration. As it can be seen in Figure 1, the high concentration of sulfur dioxide occurs in the morning while the least concentration happens in the midnight and before sunrise. Monthly concentration of the sulfur dioxide shows that the highest values belong to January and the least ones to October (Fig. 3). Based on the seasonal concentrations, the highest and lowest amounts exist in winter and summer respectively (Fig. 4). Unfortunately, results in the morning and cold months show that the concentration levels of sulfur dioxide are greater than Primary Standards of sulfur dioxide, recommended by National Ambient Air Quality Standards (NAAQS) of Iran (0.007 ppm) that protect human health. These results are almost in good agreement with other results regarding SO_2 assessment, obtained from other Iranian cities such as Tehran (Behzadi & Sakhaei, 2014) and Esfahan (Gerami, 2014), though they somehow differ from Shiraz in case of monthly and seasonal conditions (Ordibeheshti & Rajaipoor, 2014).

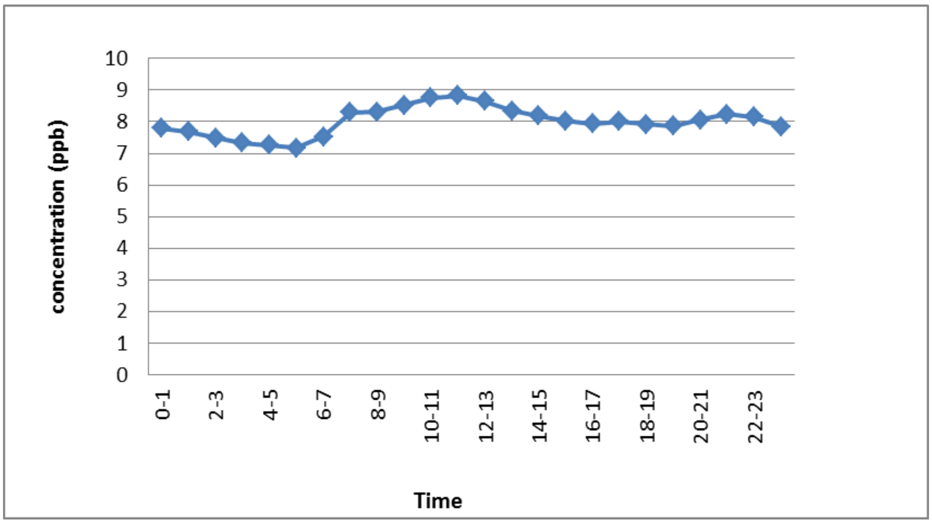

Fig. 2. Diurnal variation of sulfur dioxide concentration in Ahvaz

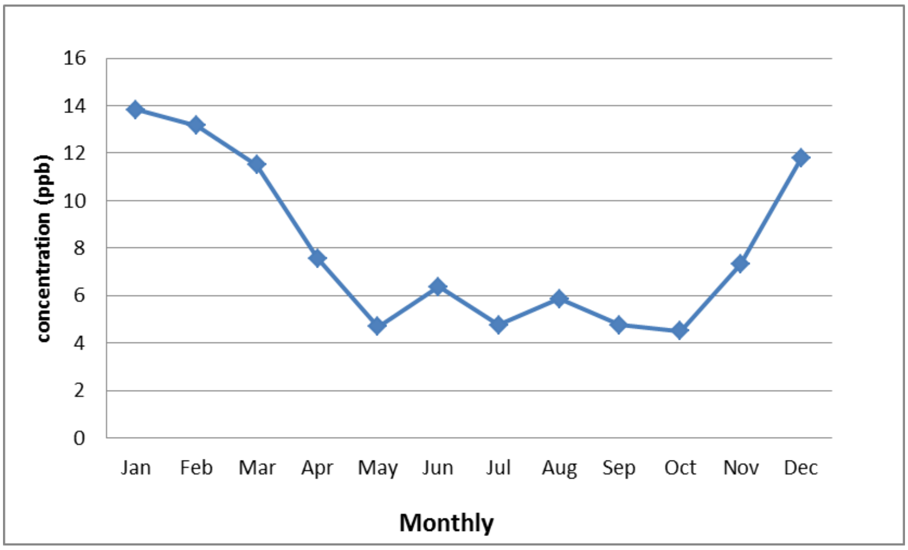

Fig. 3. Monthly variation of sulfur dioxide concentration in Ahvaz

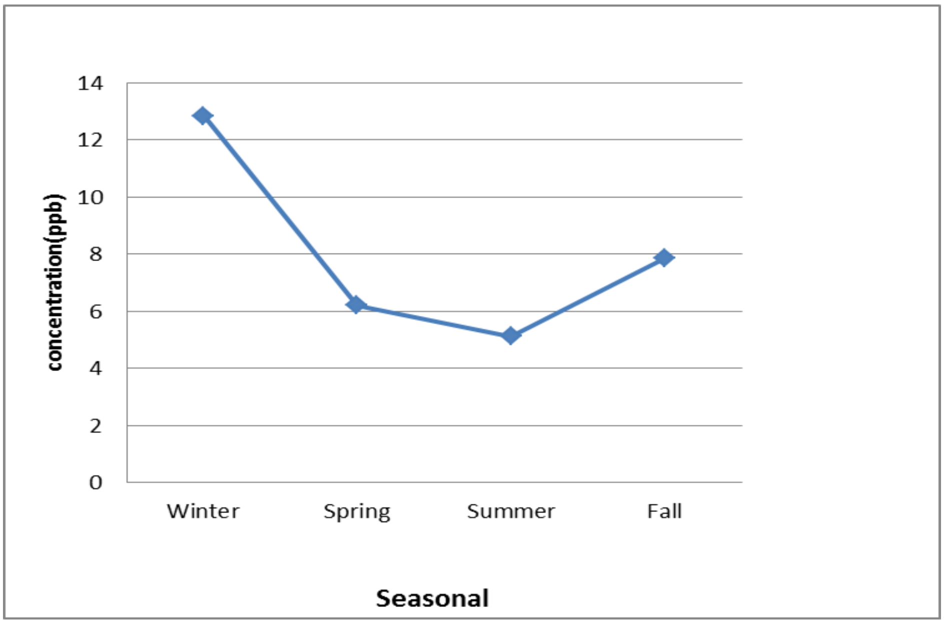

Fig. 4. Seasonal variation of sulfur dioxide concentration in Ahvaz

Table 1. Correlation between air pollutants and sulfur dioxide

	CO	**NO_2**	**NO_x**	**O_3**	**PM_{10}**
Pearson Correlation	-0.580**	0.443**	0.250**	0.749**	-0.044
Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.449
N	298	286	286	298	298

Table 2. Variance analyses for both regressions of ‘enter’ (a) and ‘stepwise’ (b) methods for annual condition

Analysis of variance (a)

Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	2014.091	10	201.409	4.085	.000**
Residual	17455.048	354	49.308		
Total	19469.139	364			

Dependent Variable: SO_2

Predictors: (Constant), Rain, Wind direction (max), Wind speed (max), Temperature (max), Temperature (min), Sunshine Hours, Ratio of Humidity (min), Ratio of Humidity (max), Ratio Humidity (avg), Evaporation.

Analysis of variance (b)

Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	1729.565	2	864.782	17.647	.000**
Residual	17739.574	362	49.004		
Total	19469.139	364			

Dependent Variable: SO_2

Predictors: (Constant), Wind direction (max), Evaporation.

Table 1 shows the relationships between Sulfur dioxide and other air pollutants. For example the concentration of Sulfur dioxide shows negative correlation with CO and PM_{10}, while it is positively correlated with NO_2, NOx, and O_3. These results are almost in good agreement with other results concerning SO_2 assessment in Tehran (Behzadi & Sakhaei, 2014) but differ to some extent from other Iranian cities of Shiraz (Ordibeheshti & Rajaipoor, 2014) and Esfahan (Gerami, 2014). Correlation coefficients, significant at the 0.05 level, are identified with a single asterisk (significant), and those significant at the 0.01 level, are identified with two asterisks (highly significant).

Table of variance analysis (Table 2) shows that regressions of 'enter' and 'stepwise' methods for annual condition are highly significant, indicating an outstanding relation among the different variables.

Tables 3 present the coefficients of sulfur dioxide pollution model and regression lines for both enter and stepwise methods in annual condition, namely regression coefficients, standard errors, standardized coefficient beta, t values, and two-tailed significance level of t.

Table 3. Coefficients of sulfur dioxide pollution model and regression lines for both enter (a) and stepwise (b) methods for annual condition

Coefficients (a)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	11.312	5.138		2.202	0.028
Temperature (max)	0.197	0.178	0.276	1.110	0.268
Temperature (min)	-0.277	0.201	-0.294	-1.380	0.168
Ratio of Humidity (max)	-1.040	0.750	-3.770	-1.386	0.167
Ratio of Humidity (min)	-1.051	0.750	-2.694	-1.401	0.162
Ratio of Humidity (avg)	2.092	1.502	6.207	1.393	0.165
Rain	0.058	0.121	0.027	0.476	0.634
Sunshine Hours	-0.083	0.147	-0.041	-0.564	0.573
Evaporation	-0.193	0.160	-0.151	-1.208	0.228
Wind direction (max)	-0.010	0.005	-0.115	-1.866	0.063
Wind speed (max)	-0.132	0.133	-0.054	-0.988	0.324

Dependent Variable: SO_2

Coefficients (b)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	13.021	1.126		11.559	0.000
Evaporation	-0.267	0.070	-0.209	-3.815	0.000**
Wind direction (max)	-0.013	0.005	-0.145	-2.639	0.009**

Dependent Variable: SO_2

The linear regression equations show that the sulfur dioxide pollution depends on the meteorological parameters. They also give an idea about the levels of relations. The linear model equations after using 'enter method' and 'stepwise method' for annual condition are:

Sulfur dioxide amount (ppb) using 'enter method' for annual condition = 11,312 + (-0.277) $\text{Temperature}_{(min)}$ + (0.197) $\text{Temperature}_{(max)}$ + (-1.051) Ratio of $\text{Humidity}_{(min)}$ + (-1.040) Ratio of $\text{Humidity}_{(max)}$ + (2.092) Ratio of $\text{Humidity}_{(avg)}$ + (0.058) Rain + (-0.083) Sunshine Hours + (-0.010) Wind $\text{direction}_{(max)}$ + (-0.132) Wind $\text{speed}_{(max)}$ + (-0.193) Evaporation R= 0. 322 (significant at 0.01)

Sulfur dioxide amount (ppb) using 'stepwise method' for annual condition = 13.021 + (-0.267) Evaporation + (-0.013) Wind $\text{direction}_{(max)}$ R= 0.298 (significant at 0.01)

Results of linear regression model show that evaporation and wind direction have reverse effect on SO_2concentration, e.g. when these parameters increase, the concentration of SO_2 plummets (Table 3b). Other meteorological parameters show different effects on SO_2 amounts, even though these results are not significant. For example Ratio of Humidity $_{(avg)}$ has direct effect on concentration of SO_2 (Table 3a). These results are almost in good agreement with other results, regarding SO_2 measurements such as the one by Elminir (2005). Actually some of these events happen in reality. Increased rainfall, wind speed, and temperature (inversion happens in low temperatures) usually decrease most of the air pollutants (Asrari et al., 2007).

The values and significance of R (multiple correlation coefficients) in both equations show their capability to predict sulfur dioxide amount. The amount of Adjusted R^2 in enter model is 0.103 and in stepwise model, 0.089, showing that different parameters can calculate almost 10% variability of sulfur dioxide. This indicates that in order to predict most of the air pollutants like sulfur dioxide, one should take fossil fuel consumption into consideration. Major sources of fuel burning include vehicles, thermal power plants, industrial processes, transportation, etc. Fossil fuels' burning in thermal power plants produces 2/3 of total SO_2, whereas exhaust from cars produces 75% of total air pollution and rapid industrialization is responsible for 20% of total air pollution (Sharma, 2001). On the other hand, R in enter method (0.322) is equal to stepwise method (0.298), without any variation; therefore, the second equation, based on stepwise method, can be used to predict sulfur dioxide in the city instead of the first equation which requires more data. On the other hand, no difference between the two R values indicates that the excluded variables in second equation have less effect on sulfur dioxide measurement in the city.

Beta in Table 3 shows the independent variables (meteorological parameters) with more effect on the dependent variable (sulfur dioxide). It indicates a highly significant effect of some variables like ratio of humidity and evaporation, compared to other meteorological parameters for measuring sulfur dioxide, which is close to the results of Masoudi and Asadifard (2015), and Masoudi et al. (2014a, 2014b, 2016a and 2016b) in case of other pollutants. Parameter Sig (P-value) from Table 3 shows amount of relation between sulfur dioxide and meteorological parameters. For example, Table 3a shows that wind direction has higher influence on sulfur dioxide than wind speed.

On the other hand, Table 4 presents the linear regression equations of sulfur dioxide amount for both enter and stepwise methods in different seasonal condition. Results show all of the models are significant. Stepwise methods show the meteorological parameters of highest account during these seasons to estimate the pollution. Among the models, spring models have the highest R while in case of winter models it is ranked the least. R in all seasonal models is higher than the annual model, indicating that relations between the pollutant and meteorological parameters are stronger than whole year during the seasons. These results are almost in good agreement with other results with regards to SO_2 assessments in Tehran (Behzadi & Sakhaei, 2014), Shiraz (Ordibeheshti & Rajaipoor, 2014), and Esfahan (Gerami, 2014).

Furthermore, the nonlinear multiple regression equation of sulfur dioxide amount by means of linear stepwise method parameters for annual condition is calculated, which is significant:

Sulfur dioxide amount (ppb) using nonlinear regression for annual condition = $13.808\,(\text{Evaporation})^{-0.122} + (-0.086)e^{-1.812(\text{Wind direction}_{(max)})}$

$R^2 = 0.083$ (significant at 0.01)

Table 4. Sulfur dioxide amount (ppb) using two methods of enter and stepwise for different seasonal condition.

season	enter method	R	stepwise method	R
spring	= 6.056 + (-0.675) $Temperature_{(min)}$+ (0.677) $Temperature_{(avg)}$ + (-0.056) Ratio of $Humidity_{(min)}$ + (-0.071) Ratio of $Humidity_{(max)}$ + (0.080) Ratio of $Humidity_{(avg)}$ + (-0.034) Rain + (-0.143) Sunshine Hours + (-0.001) Wind $direction_{(max)}$ + (0.066) Wind $speed_{(max)}$ + (-0.199) Evaporation	0.685 (significant at 0.01)	= 6.408 +(-0.195) Evaporation + (0.324) $Temperature_{(max)}$+ (-0.334)$Temperature_{(min)}$ + (-0.151) Sunshine Hours + (-0.054) Ratio of $Humidity_{(avg)}$	0.680 (significant at 0.01)
summer	= 1.608 + (0.164) $Temperature_{(min)}$+ (0.087) $Temperature_{(max)}$ + (0.333) Ratio of $Humidity_{(min)}$ + (0.418) Ratio of $Humidity_{(max)}$ + (-0.835) Ratio of $Humidity_{(avg)}$ + (0.000) Sunshine Hours + (-3.537*$10^{-0.005}$) Wind $direction_{(max)}$ + (-0.213) Wind $speed_{(max)}$ + (-0.176) Evaporation	0.513 (significant at 0.01)	= -3.743 +(0. 245) $Temperature_{(max)}$ + (-0.129) Evaporation	0.401 (significant at 0.01)
autumn	= 30.423 + (-0.158) $Temperature_{(min)}$ + (-0.284) $Temperature_{(max)}$ + (-0.194) Ratio of $Humidity_{(min)}$ + (-0.264) Ratio of $Humidity_{(max)}$ + (-0.377) Ratio of $Humidity_{(avg)}$ + (-0.039) Rain + (-0.225) Sunshine Hours + (-0.007) Wind $direction_{(max)}$ + (-0.046) Wind $speed_{(max)}$ + (0. 344) Evaporation	0.671 (significant at 0.01)	=19.070+ (-0.447) $Temperature_{(avg)}$	0.615 (significant at 0.01)
winter	= -9.840 + (0.431) $Temperature_{(min)}$+ (0.703) $Temperature_{(max)}$ + (-4.449) Ratio of $Humidity_{(min)}$ + (-4.338) Ratio of $Humidity_{(max)}$ + (8.836) Ratio of $Humidity_{(avg)}$ + (0.258) Rain + (-0.081) Sunshine Hours + (-0.010) Wind $direction_{(max)}$ + (-1.164) Wind $speed_{(max)}$ + (-0.116) Evaporation	0.410 (significant at 0.01)	= -8.347 + (0.840)$Temperature_{(max)}$	0.344 (significant at 0.01)

To test which annual model is better for use, RMSE (Root Mean Square of Error) is calculated for different linear models of enter and stepwise and nonlinear model. Predicted amounts, using the different annual models for 30 days during 2010, are calculated and compared with observed data during those days, using RMSE equation:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(O_{obs} - O_{cal})^2}{n}}$$

O_{obs}: observed SO_2 value
O_{cal}: predicted SO_2 value using model

The values of RMSE in both linear models of enter (9.52) and stepwise (5.71) demonstrate their capability to predict sulfur dioxide amount, compared to nonlinear model value (5.81). This result, which is the same as the results of Behzadi and Sakhaei (2014), Ordibeheshti and Rajaipoor (2014), Gerami (2014), Masoudi and Asadifard (2015) and Masoudi et al. (2014a, 2014b, 2016a, 2016b), indicates that in order to predict most of the air pollutants such as sulfur dioxide, one may only consider linear models of stepwise, which need less data, compared to enter model, the calculation of which is easier than nonlinear model.

CONCLUSION

The present research has conducted air quality analyses for SO_2 in Ahvaz, a city in the south of Iran. Ahvaz is one of the most polluted cities in Iran and also world. Hence there it is greatly required to carry out an ambient air quality analysis in this city. Results have shown that there are significant relations between SO_2 and some meteorological parameters. Based on these relations, different multiple linear and nonlinear regression equations for SO_2 for both annual and seasonal conditions have been prepared. Results illustrate that among different prediction models, stepwise model is the best option. Also different variations in concentration during day, months, and seasons have been observed. Results in the morning and cold months show that the concentration levels of SO_2 are higher than Primary Standards of SO_2, showing an unhealthy condition.

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