Modeling of sulfur dioxide emissions in Ahvaz City, southwest of Iran during 2013

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ABSTRACT

Sulfur dioxide has two important sources in the atmosphere and this is why most of scientists believe in a geographic split in the globe. Power plants, major emitter of SO₂, are located in north hemisphere such as in Russia, China, Canada and the USA. In south hemisphere, phytoplankton produces a massive amount of dimethyl sulfide (DMS) and dimethyl disulfide (DMDS). Then these types of reduced products dissociate in the atmosphere and convert into SO₂. It is a colorless gas which is released from burning coal, high sulfur coal and diesel fuel. The sulfur dioxide emissions from transportation systems, steel, oil and other industries are major concerns of air pollution in Ahvaz city, Iran. The main objective of this study was to determine the behavior of data over the time in a specific statistical model framework and compare through intended one to implement the Box-Jenkins method to make time series models in Ahvaz (located in Southwestern Iran), during 2013. Data of sulfur dioxide from four monitoring stations were collected at the first step and processed by Excel software; finally, the model of sulfur dioxide dispersion were evaluated. Time series analysis showed that air pollutants were associated with one step delay of sulfur dioxide and two steps delay of moving average. The finding of this study showed that the average concentration of sulfur dioxide in winter was higher than in summer. According to the results of this study,
the distribution of sulfur dioxide data has a correlated structure over the time; therefore the time series model is an appropriate model to explain the behavior of sulfur dioxide over the time.

**Keywords:** Sulfur dioxide, Emissions, Time series analysis, Iran.

**INTRODUCTION**

Many investigations have conducted to estimate the number of cases in terms of mortality and morbidity attributed to air pollutants such as sulfur dioxide, nitrogen dioxide, ozone, PM₁₀ and carbon monoxide (Samoudi 2006; Pope III & Dockery 2006; Goudarzi et al. 2012; Soleimani et al. 2013; Su et al. 2016; Neisi et al. 2016).

Epidemiological studies showed that air pollution is responsible for damaging to human health such as increasing death rates. It may reduce the quality of life and welfare too (Hoseinshokoooh 2008; Goudarzi et al. 2014b; Mastaneh & Mouseli 2013; Ehsan & Kiammehr 2013; Dobaradaran et al. 2016). Sulfur dioxide is originated from biogenic sources such as volcanoes and anthropogenic sources such as industrial processes.

Coal and petroleum with high percentages of sulfur in the process of combustion, generate sulfur dioxide. Sulfur dioxide is a colorless gas with a pungent odor; it can irritate eye, respiratory and nasopharynx systems (Törnqvist et al. 2007; Ehsan & Kiammehr 2013; Rahila & Siddiqui 2014; Sepideh et al. 2014; Zallagh et al. 2014). Ahvaz city has been well known due to industries as well as environmental pollution over the time (Goudarzi et al. 2014a, b).

Time series and case–crossover analyses are the most common methods which have been used to estimate the short-term effects of air pollution on health (Fung et al. 2003; Schwartz 2004).

There have been numerous community time series studies about the effect of air pollution on mortality (Smith 1989; Schwartz & Zanobetti 2000; Dominici et al. 2002).

Development and use of statistical and other quantitative methods in the environmental sciences have been a major communication between environmental scientists and statisticians (Herzberg & Frew 2003).

The common descriptive statistical approach used for air quality measurement and modeling is rather limited as a method to understand the behavior and variability of air quality (Modarres & Dehkordi 2005; Masoudi 2014). Time series analysis is a useful tool for better understanding of cause and effect relationship in environmental pollution (Schwartz & Marcus 1990).

The main aim of time series analysis is to describe the movement history of a particular variable in over the time.

Many authors have tried to detect changing behavior of air pollution through over the time, using different techniques (Hies et al. 2000).

Many others have tried to relate air pollution to human health through time series analysis (Gouveia & Fletcher 2000; Saffarinia & Odat 2008). Nowadays time series models are depriving in environmental research works.

Time series models have two advantages in comparison with other methods such as regression and polynomial regression.

Firstly, each value is a model about the past events or past stochastic terms (chocks), so interpretations and monitoring of air characteristics are so easy through these models. The second is forecasting or estimation of values in future; means to predict the future values based on the past values and stochastic structure governed on data.

Also, studies of the health effects of air pollution on mortality and morbidity in China have mostly been conducted in Beijing, Shanghai, Shenyang, Wuhan, and Taiyuan.

Air pollution is predominant among environmental concerns in Ahvaz, Iran.

In this research, we are intended to implement the Box–Jenkins method to make time series models on sulfur dioxide data in Ahvaz. In such context, the aim of this study was planned and carried out to assess the modeling of sulfur dioxide dispersion in the air of Ahvaz (located in southwestern part of Iran) during 2013.
MATERIALS AND METHODS

Methods

The time series analysis, using MINITAB ver. 16 statistical software packages were used in this ecological and retrospective study. As we mentioned, the time series data consist of the sequential data points taken at equal increments over the time.

A broad class of time series model is ARMA (p, q), combined two models AR (Auto Regressive), MA (Moving Average); therefore, ARMA is autoregressive and moving average together. Auto Correlation Function (ACF) and Partial Auto Correlation Function (PACF) are two important and useful instruments to identify q and p, respectively. The order of time series model (Box-Jenkins steps) was used to make the model consisted three steps. The first is, identification of p and q. The second one is, estimation of parameters and the third is, verification of the model adequacy (Lee 2002; Goudarzi et al. 2014c).

Since the design of the model’s default is carried out by the World Health Organization in Eastern Mediterranean region, so we can generalize it for Ahvaz city. Sulfur dioxide data were taken from Ahvaz Department of Environment (ADoE). Sampling was performed for 24 hours in four stations. In this study, 35040 (24 × 365 × 4) samples of Ahvaz air were taken for sulfur dioxide during 2013. Raw air quality monitoring data were in a Microsoft Office Excel spread sheet. These data were in volumetric base (PPM). Stations were “Downtown”, “Old School of Public Health”, “Bureau of Meteorology” and “Head office of ADoE”. In order to do the analysis, first of all, the basic time series models were analysed, using MINITAB software.

Description of study area

Ahvaz, the capital of Khuzestan Province of Iran, with one million people approximately, an area of 8152 km², is located at 48° to 49°29′ east of Greenwich meridian and 31° 45′ north of the equator (Goudarzi et al. 2015; Geravandi et al. 2015b; Mohammadi et al. 2015; Geravandi et al. 2015a). Air pollution data particularly sulfur dioxide was collected from ADoE. Air quality monitoring stations were located in “Naderi”, “Behdasht Ghadin”, “Havashenasi” and “Mohitzist”. The areas of study and air quality monitoring stations in Ahvaz are illustrated in Fig. 1.

![Fig 1. The study location and sampling station in Khuzestan Province (Ahvaz), southwest of Iran.](image)

RESULTS

Time series plot (TSP), which is the first step in time series analysis, should be depicted. A preliminary concept of the behavior of data is given by time series plot in Fig. 2. It shows the TSP of sulfur dioxide concentration over the
time. There is no increasing or decreasing pattern over the time so data have stochastic behavior through time. Therefore, it is assumed that the difference between low and high concentration is large, resulting in the largest skewers and variation in all examined air pollutants.

As illustrated in this Fig., the average concentration of sulfur dioxide in winter was higher than in summer; indicating more fuel usage due to the abundance of industries and lower maximum mixing depth in the atmosphere during winter. In addition, low-sulfur diesel is not used in industries and transportation systems. Bear in mind, sulfur content of diesel in Iran is about 7000 ppm and this is why the Department of Environment (DoE) has prevented commuting cars which have been using this type of diesel.

Figs. 3 and 4 suggested the order of model. Both figures suggest $p = 1$, $q = 2$, on first five lag of partial correlations showed significance except the second lag (Fig. 4) and autocorrelation had decay pattern indicated no moving average term in model (Fig. 3).
Fig 4. Time series partial autocorrelation function for sulfur dioxide concentration.

We carried out ARMA (1, 3) or AR (1); the estimation of parameters are given in Table 1. MINITAB result shows that the coefficients of first order of autoregressive is significant (p-value > 0.05); therefore, we select its term. Furthermore, Ljung–Box results are given for both models which are in turn. It suggests no any seasonal pattern in models. The final model is given as follows:

\[ SO_{2r} = 1.12 + 0.98SO_{2r-1} + a_t - 0.095a_{t-1} - 0.16a_{t-2} \]  

(1)

Where \( a_t \sim N(0, 159.4) \), N stand for normal distribution.

### Table 1. Time series table of sulfur dioxide concentration.

<table>
<thead>
<tr>
<th>Type</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR 1</td>
<td>0.9792</td>
<td>0.0145</td>
<td>67.68</td>
<td>0.000</td>
</tr>
<tr>
<td>MA 1</td>
<td>0.0945</td>
<td>0.0583</td>
<td>1.62</td>
<td>0.106</td>
</tr>
<tr>
<td>MA 2</td>
<td>0.1582</td>
<td>0.0591</td>
<td>2.68</td>
<td>0.008</td>
</tr>
<tr>
<td>Constant</td>
<td>1.1183</td>
<td>0.4893</td>
<td>2.29</td>
<td>0.023</td>
</tr>
<tr>
<td>Mean</td>
<td>53.79</td>
<td>23.53</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of observations: 320

Residuals \[ SS = 50202.5 \) (backforecasts excluded)

<table>
<thead>
<tr>
<th>MS</th>
<th>159.4</th>
<th>DF = 315</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Box-Pierce (Ljung-Box) Chi-Square statistic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lag</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Chi-Square</td>
<td>6.8</td>
<td>19.0</td>
</tr>
<tr>
<td>DF</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>P-Value</td>
<td>0.445</td>
<td>0.455</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Ahvaz is located in an arid area in southwest of Iran with long and hot summertime. Keep in mind, high density of industries (steel, oil and gas) makes Ahvaz as one of the most important emitter. Daily air pollution time series analysis of Ahvaz city was performed in this study. Time series analysis which let us compare many pollutants with different levels and units indicates various health adverse periods from the beginning of the year to the end. It was also shown that most daily air pollution time series have high persistence of air pollution conditions through time. The influence of weather conditions like rainfall, air moisture and wind velocity-direction on the air pollution temporal dynamics are also very important in the air pollution management and control which will be ongoing author’s task to investigate. The air pollution prediction and
Modeling of sulfur dioxide forecasting is another important aspect which has already been extensively analyzed worldwide. Models which can perfect fit the data may completely fail to predict (also known as over fitting). Although the time series analyses explain the historic air pollution data very well, it maybe produces very poor prediction results. Atkinson et al. (2014) studied the epidemiological time series studies of PM$_{2.5}$ and daily mortality and hospital admissions: a systematic review and meta-analysis. Their findings showed that a 10 µg.m$^{-3}$ increase in PM$_{2.5}$ concentration was related to a 1.04% increase in risk of death (Atkinson et al. 2014). Annual air pollution time series analysis of Al-Hashimeya area has been performed (Saffarinia & Odat 2008). It has shown different temporal behavior of different air pollutants. This different time behavior is not only the reason of correlation of different pollutants with each other, but the seasonal variation on increasing or decreasing air pollutants as well. It was also shown that most annual air pollution time series have high persistence of air pollution conditions through time. This persistence is not only harmful for public health but also makes the air pollution management and control very demanding. The best fitted model of sulfur dioxide concentration at 95% CIs were given for the current ARMA (6, 6) (Saffarinia & Odat 2008). The results of this study showed that the best fitted model of current was ARMA (1, 3) that relatively lower because of different SO$_2$ concentration in Ahvaz city. In another study Hosseinpoor et al. (2005) conducted a work to find the relation between hospitalizations due to angina pectoris exposed to air pollution with used time-series study. The results of this study showed that there was a significant association between the SO$_2$ level and the number of daily admission due to angina pectoris (Hosseinpoor et al. 2005). Based on the results of our study, there was a significant association between the SO$_2$ level and human health. Su et al. (2016) observed in their study the adverse effects of fine particulate air pollution on cardiovascular hospital emergency room visits obtained from time-series study (PDL model) in Beijing, China. Also, in our study, health endpoints was associated with low concentration of measured SO$_2$ in Ahvaz by time-series study (ARMA model).

**CONCLUSIONS**

This study was the first report of modeling of sulfur dioxide emissions in Ahvaz city, southwest of Iran. Statistical model is an applicable method to evaluate the behavior of pollutant and its dispersion. Time series plot of SO$_2$ showed some anomalies in trend of winter and summer, so that, the concentration of sulfur dioxide in winter was higher and implied to inversion condition as well as more usage of high sulfur diesel. In this study, data showed that the sulfur dioxide has a correlated structure over the time. ARMA model showed that the sulfur dioxide at each time can be estimated based on the previous value AR (1) and the second last value of MA (2). The MA term express some stochastic factor occurred at the previous steps which were not determined exactly but their effects were estimated by the MA. Moreover, the sulfur dioxide could be forecast through the time series model that creates constructive tools for monitoring and managing of sulfur dioxide. The major limitations of this study were shortcoming in databases and the lack of temporal behavior parameters of SO$_2$. We recommend further studies to evaluate the model of emissions and a method to evaluate the behavior of sulfur dioxide in all megacities of Iran.

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