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Influence of Meteorological Parameters on Air Pollution in Isfahan

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Abstract. In this study air pollutant concentrations and meteorological parameters have been analyzed by using statistical methods. The original measured concentration of NOx, SO2 and O3 pollutants in the city of Isfahan are statistically analyzed in different time series. The relationship between monitored ambient air quality data and meteorological factors, such as wind speed, temperature, air pressure and sunshine hours was investigated. According to the results obtained by the linear and stepwise regression analysis, it was found that there is a strong relation between SO2 and O3 in Lale station, and the coefficients of determination (R2) for the regression models range from 0.51 to 0.89. The result showed that the pollution concentrations on the previous day are the most important factor contributing to heighten air pollution concentrations. The statistical models proved that weather variables such as temperature and pressure have a significant impact on the most air pollution.

Keywords: Regression analysis, Pollutant standard index (PSI), Pollutant concentrations, Meteorological factors

1. Introduction

Air pollution and its impact on human health have been considered as a serious problem in urban areas. Since the beginning of the last century, many events of air pollution have been associated with increase in mortality. Some examples are the Meuse Valley in 1930 (Firket, 1931), Donora in 1948 (Ciocco and Thompson, 1961) and the most famous, London in 1952 (Logan, 1953) and Sa˜o Paulo City (Gonc, et. al., 2004). During the last decades a growing body of research has investigated worldwide the extremely vast subject of urban air quality (Costabile, et al., 2006).

The causes of air pollution episodes depend on various factors including emissions, local and synoptic scale meteorological conditions, topography, and atmospheric chemical processes. The relative importance of such factors is dependent on various factors including emissions, local and synoptic scale meteorological conditions, atmospheric chemical processes, geographical region, its surrounding emission source areas and the season of the year. After decades of industrialization, air pollution has become a major environmental issue for developed and developing countries. Poor air quality has both acute and chronic effects on human health. In 1976 the U.S.EPA established a Pollutant Standard Index (PSI) which rated air quality from 0-500, with 100 equal to the National Ambient Air Quality Standards (NAAQS). The PSI is calculated for every pollutant with a NAAQS (Cheng, et. al., 2007). It is a referential parameter describing air pollution levels that provides information to enhance the public awareness of air pollutions (Wang and Lu, 2006). The daily PSI is determined by the highest value of one of the five main air pollutants: particle material (PM10), ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), and nitrogen dioxide (NO2). The daily PSI was revised, renamed to the Air Quality Index (AQI) and subsequently implemented in 1999 by the USEPA. The new system includes breakpoints for ozone (O3), a sub-index of 8-hour average O3 concentrations, and a new sub-index for fine particulate matter (PM2.5). However, even though AQI has completely replaced PSI in the United States, a greater part of the world still could not adopt the AQI system, mainly because the lack of PM2.5 measurement capability. For instance, monitoring of PM2.5 necessitates installation of expensive instruments to establish nationwide networks of monitoring stations, and the costs are prohibitively high for most countries to afford (Cheng, et. al., 2007).

2. Air Pollution and Relationships to Meteorology

2.1. Trends and Air Pollution Control Measures

In recent years many statistical methods have been used to study air pollution in urban areas. Time series analysis is a useful tool for better understanding the cause, effect and relationship of environmental pollution and meteorological parameters.

The city of Isfahan is located in the central part of Iran [32.38ºN, 51.39°W, elevation 1550-1650m], with 1.6 million population. The city of Isfahan is characterized by southwesterly or northwesterly winds throughout the year. The winds are westerly in winter and spring with the maximum value in April. During autumn the winds change to easterly and finally in the autumn the prevailing wind is westerly. The Environmental Protection Department of Isfahan provides air pollution database containing hourly measurements of ozone (O3), sulfur dioxide (SO2), carbon monoxide (CO), and nitrogen oxide (NOx) from April 2005 to March 2006. Figure 1 shows the position of the two stations.

The air pollution data for two stations are shown in Table 1. Figure 2 shows 24-h average variations of major pollutants, i.e., SO2, NOx, CO and O3, at two monitoring station during April 2005 to March 2006, which are used as examples to specify the typical hourly pollutant levels during 24-h period. This Figure indicates that NOx and CO levels generally had two peaks, in 07:00- 08:00 am and 20:00- 21:00, O3 level has peak around 14:00- 15:00 and SO2 value is maximum between 12:00 and 13:00. Figure 3 presents the monthly average variations of SO2, NOx, CO and O3, at two monitoring station during April 2005 to March 2006. It can be seen that, NOx, CO levels in December are higher than other

February), the SO2 concentration are almost fixed in autumn (September, October, November) and winter (December, January, February)and the highest level is in May. Air pollutants trend (Fig.4) and regression were found.

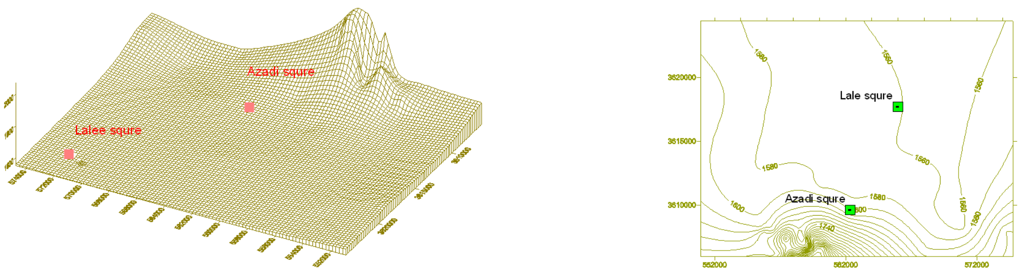

Fig. 1: Two-dimensional topography of the Isfahan city(left) and Three- dimensional topography of the Isfahan city (right).

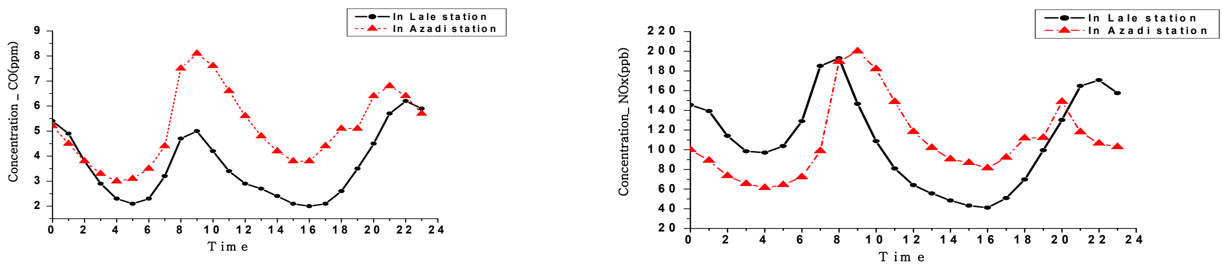

Fig. 2: Average diurnal variations of major air pollutant levels during April 2005 to March 2006

Table 1: Descriptive statistic of air pollutions concentration data

CO(ppm)	5.1	3.6	4.1	2
NO_2(ppb)	34.4	34.4	27.6	11.4
NO_x(ppb)	75	75	5	5
SO_2(ppb)	26	---	4.5	---
O_3(ppb)	---	23.8	---	5

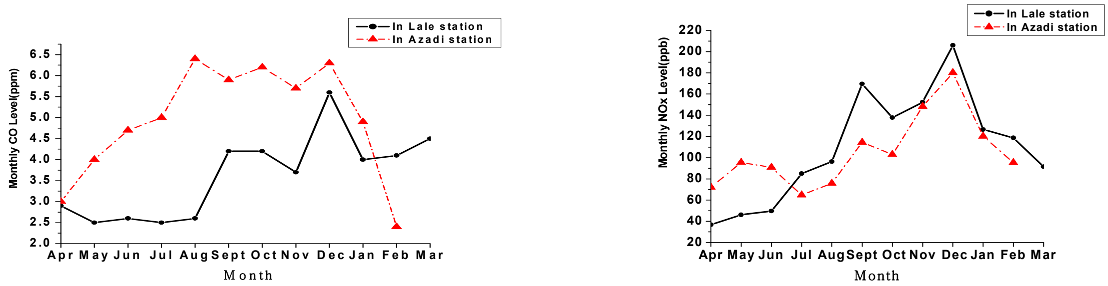

Fig. 3: Monthly variations of main air pollutant levels during April 2005 to March 2006.

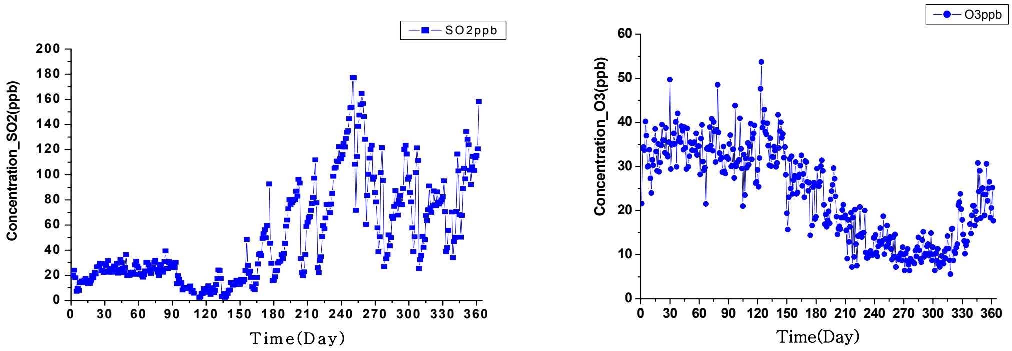

Fig.4: Time series plots of selected air pollutions in Lale station

2.2. Analysis of Correlations between the Different Pollutants

To better understand the relation between different air pollutants, the correlation coefficients were found. The correlation coefficients (r) between NO, NO2 and NOX for Lale are positive. The NO and NO2 are nor significantly correlated (r=0.06). Also, the correlation between all Nitrogen Dioxides and SO2 is positive, which means they increase together. The high correlation between CO and all Nitrogen Dioxides means that they are from the same sources. The negative correlation between O3 and all pollutants indicates that O3 is synthesized in the environment by chemical reactions as a Secondary pollutant.

The maximum correlation is between NO and NOX (r=0.97). SO2 is significantly correlated only to NO2. The correlation coefficients(r) between CO and all Nitrogen Dioxides are positive for this station. The pollutants at two stations are weakly correlated. These correlation coefficients and hours that air pollutions concentrations are peak indicate that motor vehicles have the greatest contributions to NOx and CO.

2.3. Relationships to Meteorological Parameters

There are considerable correlations between CO levels and meteorological parameters in Lale station, however, the strongest correlations occur between CO with temperatures and pressure, higher CO occurring when temperatures are lower and pressures are higher. At this station, there are correlations between higher CO with lower sun shine and wind speed.

In Azadi station, only three meteorological parameters show correlation with CO level. In there, higher CO occurs under lower wind speed too. The strongest correlations occur between CO and wind direction, with higher CO occurring when wind is from lower (more easterly) directions.

In two stations, wind direction shows no correlation with NOx levels, but correlation between NOx concentrations and other meteorological parameters in both stations is similar. The strongest correlations occur between NOx with temperatures and pressure, higher NOx occurring when temperatures are lower and pressures are higher. Increasing wind speed helps air pollutions dispersion and decreases its level. In other hand, NOx levels decrease with increasing sun shine and solar radiation, hence formation the secondary pollutions. Studies show that higher NOx correlated with higher relative humidities.

The relationship between SO2 concentrations and the meteorological situation is not clear and is difficult to establish. In Lale station, higher concentrations of SO2 are correlated with lower temperature, sun shine, solar radiation but with higher relative humidity and pressure. The wind direction show weak correlation with SO_2 levels with due attention to this correlation, westerly winds and southern increase SO_2 levels.

In Azadi station, higher concentration of SO_2 is correlated with higher temperature, sun shine, solar radiation and lower relative humidity, pressure. The other meteorological parameters show no or very weak correlations with SO_2 levels.

Ozone concentration has positive correlation with temperature, radiation and sun shine but it has negative correlation with pressure, relative humidity and wind direction. This negative correlation with wind direction indicates winds from more easterly directions than average bring higher O_3 concentration at Lale station.

The most effect of the meteorological parameters for air pollution is related to O_3 concentration. The most important meteorological variables contributing to heightened O_3 concentrations, are temperature, relative humidity, sun shine, pressure and radiation with the coefficients of determination (R^2) 0.59, 0.44, 0.34, 0.25 and 0.22 respectively.

After ozone, the most important effect is related to SO_2 levels of Lale station with coefficients of determination (R^2) 0.45 (with temperature), 0.27 (with relative humidity), 0.22 (with sun shine) and 0.20(with pressure). In Azadi station, SO_2 levels is affected by temperature with the coefficients of determination (R^2) 0.22 and, NO_x by temperature and pressure with the coefficients of determination (R^2) 0.18 and 0.2 respectively.

3. Regression Analysis

The use of individual weather variables poses a different dilemma, because air pollutants are known to respond to the entire suite of meteorological elements which comprise an air mass, rather than to arbitrary selected meteorological variables. An air pollution concentration is controlled by the totality of all weather variables rather than the individual meteorological elements. Development of an appropriate means to evaluate weather-pollution relationships is warranted. This can be achieved through multiple linear regressions. The procedure facilities the prediction of the arrival of meteorological parameter associated with high air pollution concentrations, hence the prediction of concentrations by using the developed regression models. The regression procedure was accomplished by defining each day in terms of seven meteorological elements (air dry- temperature, wet- temperature, relative humidity, pressure, sun shine, wind direction and wind speed for during April 2005- March 2006). These element were measured three times daily (03:00, 09:00 and 15:00GMT), then daily mean was found. Wind speed and wind direction were converted into south- north and west- east scalar velocities by sine- cosine transformation (Kin-Che and Shouquan, 1998).

The U and V wind components were computed as follows:

$U = - VH \sin\varphi$

$V = - VH \cos\varphi,$

Where VH= horizontal wind velocity and φ= azimuth of wind direction, south wind=180, east wind = 90

°, etc., (Davis and Walker, 1992)

The results are followed:

For Azadi station:

$C_{CO} = -177 + 0.212\,P + 0.246\,V$ R- sq= 0.15

$C_{NOx} = -3513 + 7.74\,T - 12.6\,TW + 1.36\,RH + 4.21\,P$ R- sq= 0.27

$C_{SO2} = 459 - 0.916\,P + 2.01\,SS$ R- sq= 0.28

$C_{O3} = 341 - 0.986\,TW - 0.226\,RH - 0.38\,P + 0.756\,SS$ R- sq= 0.64

A stepwise regression procedure was performed on all days to determine which environmental factors can account for the high air pollution concentrations. The dependents variable is the mean values of SO_2, NO_x, CO and O_3, and the independent variables used in the regression procedure are daily values of air dry- temperature(T), wet-temperature(TW), relative humidity(RH), pressure(P), sun shine(SS), south- north velocities (V), west- east velocities (U) and air pollution concentration on the previos day(PDC) (Kin-Che and Shouquan, 1998).

The regression models, the entry and significance level of 95%, for prediction air pollution concentrations are expressed as follow: For Azadi station:

$C_{CO} = -66.3 + 0.079\,P + 0.667\,PDC$ R- sq= 0.54

$C_{NOx} = -2022 + 4.76\,T - 7.53\,TW + 0.77\,RH + 2.39\,P + 0.589\,PDC$ R- sq= 0.54

$CSO2 = 0.858$ PDC   R- sq= 0.80

strong correlations are given for SO2 and O3 in Lale station, and the coefficients of determination (R2) for the regression models range from 0.51 to 0.89.Comparing these models with the regression models yielding by meteorological variables only, we find that pollution concentrations on the previous day are the most important factor contributing to heightened air pollution concentrations, pointing to the persistence of high pollution episodes. It proves to be the key variable for heightened air pollution because stable weather situations in the most polluted weather types reduce the ability of the atmosphere in dispersing air pollutants and weather variables such as temperature and pressure have a significant impact on the most air pollution.

3.1. Case Study: 3- 8 December 2005

We calculated daily PSI and then achieved average of PSI according to data at the two stations. It should be mentioned that the December was the most polluted month and February was the most clean month during April 2005 to March 2006, with average PSI of 99 and 56 respectively. During December, amounts of pollutant standard index in Lale station had exceeded the accepted level (i.e. PSI=100) in 12 days. This number was 9 days in Azadi station. In December, three periods were found that pollution level clearly was increased relevant to average monthly. These periods included 3-8, 13-16 and 20-23 December. The most polluted day was 6th of December in during April 2005 to March 2006, therefore we analyze the meteorological parameters during first polluted period. Details of a fog event effected Isfahan which occurred between 3rd and 6th of December 2005, provides a good supporting case study. The atmospheric condition on these days provided a relatively prolonged period when the synoptic situation was conductive to fog development and continuance, as well as elevated pollution concentrations (Bridgman et. al., 2002). The PSI has increased on 3rd of December relative to the previous day. It has oscillation on the 4th and 5th but the PSI reaches to maximum value on December, 6. The PSI showing that the air quality is getting better on 7th and it is at standard level for December, 9. Wind is not blowing almost through the year and the atmospheric pressure has increased about 3hpa, but from the 3rd day the pollutants are increased. Between the day of third and sixth the relative humidity has increased but the atmospheric pressure is uniform. Only, at fifth day the pollutant reduced due to reduction of atmospheric pressure about 1hpa. Sun shine reduces during this period at it is minimum at sixth day. High air pollution at six of December is due to low sun shine, no wind and high atmospheric pressure. On the next day the sun shine has increased and then pollutants are decreased. Winds along with increasing sun shine and air temperature have reduced the pollutants on the 8 of December.

4. Summary

Air pollution concentrations and meteorological parameters in the city of Isfahan were analyzed from April 2005 to March 2006. Severe air pollutions, has occurred in Isfahan, and December was the most polluted month and February was the most clean month during April 2005 to March 2006, with average PSI of 99 and 56 respectively. During December, amounts of pollutant standard index in Lale station had exceeded the accepted level (i.e. PSI=100) in 12 days. In two stations, wind direction shows no correlation with NOx levels, but correlation between NOx concentrations and other meteorological parameters in both stations is similar. The high air pollutions in December are due to low temperature, low wind speeds and high air pressure. It is interesting to note from regression analysis that strong correlations are given for SO2 and O3 in Lale station, and the coefficients of determination (R2) for the regression models range from 0.51 to 0.89.The direction of wind and meteorological conditions throughout the year must be taken into consideration in the city of Isfahan for the plan of industrial zones.

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