JJEES
Jordan Journal of Earth and Environmental Sciences

Volume 6, Number 1, September, 2014
ISSN 1995-6681
Pages 21- 28

Shiraz Air Pollution: Dependency on Meteorology and Temporal Variability

Amir sasha Banankhah [1], Farhad Nejadkoorki [2] and Hamid Sodaeezadeh [3 *]

[1] Department of Environmental Engineering, Yazd University, Yazd, Iran
[2] Department of Environmental Engineering, Yazd University, Yazd, Iran
[3] Department of Soil Science, Yazd University, Yazd, Iran

Received 31 January, 2013; Accepted 20 August, 2014

Abstract

An effective policy on air quality control in urban areas requires a detailed understanding of how pollutants interact with meteorological conditions and an understanding of how variations of concentrations of air pollutants are affected at temporal and local scales. This paper analyses air pollution in Shiraz in terms of three considerations: meteorological effects; temporal variability and impacts recorded at two urban stations located in Shiraz. Results imply that meteorology has an effect on pollutant concentrations and their variations in different months and situations. Results indicate that dependency on meteorology for dust, ozone (O_3), nitrogen oxides (NO_x) and sulphur dioxide (SO_2) are more than that of carbon monoxide (CO). Temporal variations in different years showed that some pollutants, such as CO and SO_2, demonstrated a decreasing trend in recent years as a result of air quality control policies, but dust had an increasing trend because of natural events. The difference between the two stations for all pollutants that were analyzed was significant. The findings of this study confirm that human activity and natural events have an effective impact on urban air pollution.

Keywords: Air pollution, Urban areas, Meteorology, Temporal variability.

1. Introduction

Most cities of the world have serious problems concerning air quality, which have received increasing attention in last decade. Some of these problems can be attributed to urban population growth and changing land use that has resulted in larger urban areas (Fenger, 1999). The main goal for air quality improvement in urban areas is the protection of human health (Bigi and Harrison, 2010). One of the major metropolitan cities in southern Iran is Shiraz and its residents have been suffering from health problems related to air pollution during recent years (Hadad et al.,2005). Health concerns associated with air pollution include effects on the respiratory system such as reduced lung function, increased hospital admissions, chronic bronchitis and mortality (Kan and Chen, 2004). Emissions that contribute to air pollutants are from different sources, they can be categorized as follows; motor traffic, industry, power plants and domestic fuel (Fenger, 1999). Pollutants do not act independently in eliciting their effects; therefore, it is important to understand relationships between air pollutants and meteorological parameters (Bigi and Harrison, 2010).

It is well known that concentrations of air pollutants within a local environment are affected by meteorology (Pearce et al., 2010). But to fully understand these relations a thorough analysis of local and regional meteorology is required especially wind direction, wind speed, turbulence and atmospheric stability associated with concentrations of air pollutants (Elminir, 2005). Emitted air pollutants are dispersed and diluted in the atmosphere with chemical reactions and they are strongly influenced by meteorological conditions. Furthermore, topography and urban structures such as streets and canyons have a great effect on meteorological conditions. Chemical reactions depend on ambient weather conditions because they are influenced by short wave radiation, air temperature and relative humidity (Fenger, 1999). Understanding temporal variability in urban air quality is a key consideration for policy on air pollution and epidemiological studies. The temporal pattern of air pollutants is related to seasonal atmospheric processes and hydrological cycles, influenced by human activities and natural events (Bigi and Harrison, 2010).

Furthermore measured characteristics of air pollutants depend on the location of the measurement site with respect to the sources of that air pollution and its features (Stulov et al.,2010).

This paper investigates air pollution in Shiraz in three sections. The first section relates to the interrelation of air pollutant to meteorological parameters. Weather patterns and different meteorological conditions are classified. This analysis was done for the year 2009.

The second part shows the temporal variability for air pollutants in Shiraz for the period 2005-2010 that identifies concentrations of pollutants in different years and daily variations of average concentrations.

The third part shows significant differences of average concentrations of air pollutants between the two stations in Shiraz that monitor air quality for the period 2005-2010

* Corresponding author. e-mail: a.s.banankhah@gmail.com, f.nejadkoorki@gmail.com, hsodaei@yazdun.ac.ir

2. Materials and Methods

2.1. Case study

Shiraz is the capital city of Fars province, located in southern Iran; the city covers an area 40 km long and 15 to 30 km wide, a total of 1268 km^2. The geographical coordinates are 29.617° N and 52.533° E. It has moderate and mountainous climate zones with an average annual rainfall of 335 mm unevenly distributed throughout the year. Shiraz experiences rather cold winters and there is usually rainfall in autumn (November and December), winter (January, February and March) and spring (April and May), with the highest in February and March. Summer in Shiraz is hot. The height of Shiraz city is 1468 meters above sea level. The average annual temperature is 18°C and the warmest month is July (high average 38.1°C) and the coldest is January (low average -7°C). Monthly sunlight is 109 h. The average annual wind speed is 13ms^{-1}.

2.2. Methods

Monitoring air quality in Shiraz is already well established by the Department of Environment (DOE) of Iran. Air quality monitoring is continually active in the city. There are two stations located in the city center where traffic is highly concentrated. The first one, Falakeh-Setad Station is located at a major road junction with 29.655˚ N and 52.532˚E coordinates surrounded by commercial-official land use applications. The second station, Darvazeh-Kazaroon having coordinates of 29.609˚ N and 52.532˚E is at a five ways within residential-commercial land use applications surrounding (Figure 1). Therefore, the stations are exposed to urban road traffic mainly. The daily air pollutants under evaluation are carbon monoxide (CO), dust, nitrogen oxides (NO_x), sulphurdioxide (SO_2). Concentrations of these parameters were monitored by continuous monitoring equipment (gas filter correlation method for CO (Chen et al.,2005), ultraviolet fluorescence method for SO_2 (Chang et al.,2005), ultraviolet absorption method for O_3 (O'Keeffe et al.,2007), pressure-reduced hemi luminescence method for NO_x (Maghzal et al.,2012) and radioactive absorption method for dust (Rodriguez et al.,2012). Daily meteorological parameters such as relative humidity, temperature (°C), maximum wind direction and maximum wind speed (ms^{-1}) were taken from the Iranian meteorological organization. Due to malfunctioning of the system to take measurements of air pollutants for some of the time, some data was not available.

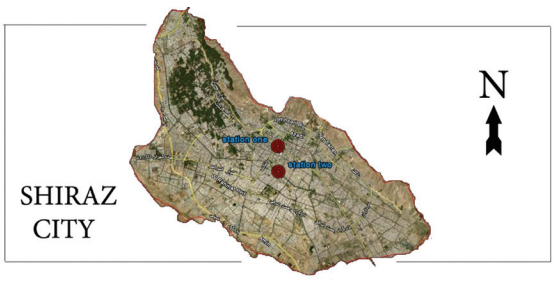

Figure 1: Shiraz city with two monitoring air pollutant stations.

The normality of data for statistical analysis was checked by the Kolmogrovsmirnov test (Baklizi, 2006). Pearson correlation coefficients (Wang et al.,2013) were used to obtain relationships between air pollutants and meteorological parameters. One-way analysis of variance (ANOVA) was used to evaluate differences for air pollutant concentrations between different years and the (T- STUDENT) test was carried out for differences in air pollutant concentrations between the two air quality-monitoring stations (Wheater and Cook, 2005). The statistical analysis was done by SPSS (version 16) and analysis each station was analyzed.

3. Results and Discussions

3.1. Meteorology

This section presents relations between air pollutants and metrological parameters. The results are divided into two categories; impacts of meteorological parameters on concentrations of air pollutants and correlations between air pollutants and meteorological data. Tables 1 and 2 summarize average values for concentrations determined within ambient air temperature ranges for each station. The results show that the highest average concentrations for O_3 and dust occurred at ambient air temperatures higher than 30ºC but for CO and NO_x the highest average concentrations occurred at temperatures less than 10ºC. This appears to be reasonable as Dust increases during daytime because soil gets dry which makes dirt more susceptible to be picked up by wind and/or wakes generated by motor vehicles. Ozone is a photosynthetic gas. Therefore, it is expected that its concentration will be higher around noon where air temperature is highest. The results for SO_2 varied between the two stations.

Table 1: Average concentrations values determined within ranges of temperature for station #1.

range	CO	DUST	NO_x	O_3	SO_2
	(ppm)	(µg/m^3)	(ppb)	(ppb)	(ppb)
National Standard	9	150	21	50	37
T≤10	3.5	97.9	136.02	7.9	80.27
T=10-15	3.18	115.2	96.22	9.96	27.57
T=15-20	3.03	134.09	98.23	11.34	16.44
T=20-30	2.59	197.61	69.42	19	16.2
T>30	2.83	269.78	65.75	19.42	17.06

At station #1 the maximum concentration of SO_2 occurred at air temperatures less than 10ºC but for station #2 maximum concentrations occurred at air temperatures higher than 30ºC. O_3 sources in the planetary boundary layer are photochemical generation in reactions with precursors (Tarasova et al.,2003). Therefore, surface ozone showed a clear trend of increasing with temperature. NO_x and CO decreased with air temperature (Pearce et al.,2010). This may be due to the improvement of air mixing, as mixing height is low in the morning and evening where air temperature is low. During daytime air temperature increases and mixing height increases as well which dilutes air pollutants and thus reduces their ambient concentrations.

Table 2: Shows average values for concentrations determined within ranges of temperature for station #2

range	CO	DUST	NO_x	O_3	SO_2
	(ppm)	(µg/m^3)	(ppb)	(ppb)	(ppb)
T≤10	2.33	43.1	124.88	11.95	69.97
T=10-15	1.86	51.37	87.2	12.76	86.38
T=15-20	1.72	58.86	83.07	17.62	119.82
T=20-30	1.38	86.37	62.33	21.71	141.66
T>30	1.39	123.98	66.88	30.24	163.82

The statistical analysis of daily air pollutants and daily values for relative humidity for the two stations are summarized in Tables 3 and 4.The highest average concentrations for O_3 and dust for both stations occurred at humidity less or equal to 40% and that can be mainly attributed to strong vertical mixing of the boundary layer air masses to the 3 km level (Elminir, 2005). This is not always true as strong vertical mixing height leads to low concentrations of air pollutants. It is very important to keep in mind that relative humidity is often collinear with air temperature; low relative humidity is associated with high air temperature.

Table 3: Average values for concentrations determined within ranges of relative humidity for station #1

range	CO	DUST	NO_x	O_3	SO_2
	(ppm)	($\mu g/m^3$)	(ppb)	(ppb)	(ppb)
R.H<40	2.71	202.57	74.09	17.56	17.04
R.H≥ 40-60	3.36	111.32	104.56	9.3	62.11
R.H> 60-80	3.33	97.58	141.34	8.67	40.45
R.H> 80	3.58	61.58	141	6	36.5

Concentrations of NO_x and CO increased with increasing relative humidity. High values of relative humidity are associated with low air temperatures in the morning and evening, which are associated with a weak mixing height. The results for SO_2 were varied at station #1 with maximum concentration in relative humidity of 40-60% and a reverse behavior after wards and for station #2 decreased pollutant concentrations are associated with increased humidity. The difference between two stations may be due to their locations having contribution of dissimilar sources.

Table 4: Average values of concentrations determined within ranges of relative humidity for station #2

range	CO	DUST	NO_x	O_3	SO_2
	(ppm)	($\mu g/m^3$)	(ppb)	(ppb)	(ppb)
R.H≤40	1.41	89.8	67.01	22.56	147.27
R.H=40-60	1.85	49.44	96.23	12.84	105.2
R.H=60-80	2.52	43.53	122.27	13.86	41.78
R.H>80	3.03	27.08	126.33	10	26.67

The wind directions that affect air pollutants are shown in Tables 5 and 6 for both stations. Comparing prevailing directions to concentrations of air pollutants closely reflects the geological structure of the region (Elminir, 2005).

Table 5: Average concentrations of air pollutants as a function of wind direction for station #1

Wind direction	CO(ppm)	DUST($\mu g/m^3$)	NO_x(ppb)	O_3(ppb)	SO_2(ppb)
E	3.58	79.62	139	8.13	52.88
ENE	2.39	98.07	86	11	66
ESE	3.56	149.75	161.44	9.82	22.06
N	2.34	273.14	73.57	18.11	16.11
NNE	2.64	117.58	68	21.33	17
NNW	2.94	141.14	91.29	14.73	41.16
S	3.3	155.77	87.94	11.8	47.56
SSE	3.53	115.88	126.75	12	52.15
SSW	3.31	179.11	105.32	11.33	29.38
W	2.81	140.81	81.22	13.07	40.17
WNW	2.86	169.62	91.56	15.71	29.79
WSW	3.11	164.15	100.55	11.76	24.78

Prevailing winds in the city of Shiraz are mostly from the south and southwest to north and northeast (Hadad et al.,2003); concentrations of dust for both stations where highest when the wind blew dust from the south to the north. NO_x concentrations were highest in the east and the southeast. SO_2 concentrations were highest in east, north east direction in station one and for station two were highest in north, north east direction and this could have been due to higher concentrations of SO_2 in the southern parts of Shiraz (Hadad et al.,2005).

Table 6: Average concentrations of air pollutants as a function of wind direction at station #2

Wind direction	CO (ppm)	Dust ($\mu g/m^3$)	NO_x(ppb)	O_3 (ppb)	SO_2 (ppb)
E	2.28	34.11	117.13	14.13	84
ENE	1.55	46.81	84.67	15.33	85
ESE	2.63	68.7	133.72	16.28	61.18
N	1.36	123.32	68.33	22.67	128
NNE	1.32	51.93	63.67	21.33	146.33
NNW	1.67	60.87	83.77	18.72	118.81
S	1.58	68.45	79.69	17.5	131.6
SSE	2.25	48.25	109.23	16.92	115.69
SSW	1.68	81.1	84.88	17.25	108.78
W	1.59	64.29	77.55	16.31	125.79
WNW	1.76	74.3	85.39	20.21	115.98
WSW	1.74	72.61	82.1	16.87	109.53

For CO the concentrations are almost identical in all aspects, indicating that this pollutant has uniform origin. Finally, the highest concentrations of O_3 occurred in north and northeast direction for station one and south to north for station two.

Table 7: Correlation matrix for air pollutants and temperature at station one

Pearson correlation	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	OCT	NOV	DEC	yearly
CO	.124 NS	-.047 NS	.232 NS	.316 NS	-.243 NS	.596⋆⋆	.161 NS	-.003 NS	.224 NS	.048 NS	-.145 NS	-.387⋆⋆
Dust	.211 NS	.060 NS	.040 NS	.024 NS	-.095 NS	-.221 NS	-.263 NS	.218 NS	.080 NS	.332 NS	-.194 NS	.414⋆⋆
NO_X	-.001 NS	-.078 NS	.170 NS	.362⋆	.106 NS	.577⋆⋆	-.029 NS	-215. NS	.143 NS	-.122 NS	-.206 NS	-.447⋆⋆
O_3	-.053 NS	-.054 NS	-.314 NS	-.302 NS	.234 NS	-.562⋆⋆	.012 NS	.101 NS	.462 NS	.045 NS	.167 NS	.697**
SO_2	.785⋆⋆	-.633⋆⋆	-.285 NS	.659⋆⋆	.304 NS	.254 NS	.351 NS	.219 NS	.268 NS	.381⋆	-.301 NS	-.447**

NS: Not Significant, Degree of significant ($\star p < 0.05$, $\star\star p < 0.01$)

In order to study the relationships between air pollutants and temperature correlation further analyses was performed and the results are shown in Tables 7 and 8; the correlation matrix between temperature and corresponding data for CO, NO_x, dust, ozone and SO_2 concentrations are shown.

It is noteworthy that there is a negative weak relation between temperature and both CO and NO_x at both stations. There is a strong positive relation between ozone and temperature and a weak positive relation for dust. The relationship between SO_2 and temperature was different for each station; with a negative relation at station 1 and a positive relation at station 2.

Table 8: Correlation matrix for air pollutants and temperature at station #2

Pearson correlation	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	OCT	NOV	DEC	yearly
CO	.093 NS	.058 NS	.264 NS	.477⋆	-.022 NS	.619⋆⋆	.137 NS	-.274 NS	-.174 NS	-.206 NS	-.136 NS	-.439⋆⋆
Dust	.295 NS	.017 NS	.007 NS	.132 NS	-.293 NS	-.119 NS	-.255 NS	.205 NS	.266 NS	.486⋆⋆	-.242 NS	.380⋆⋆
NO_X	-.092 NS	-.469⋆	.001 NS	.493⋆⋆	-.072 NS	.500⋆⋆	.240 NS	-.264 NS	.055 NS	-.206 NS	-.252 NS	-.561⋆⋆
O_3	.070 NS	-.146 NS	-.117 NS	-.321 NS	.234 NS	-.439⋆	.428⋆	.330 NS	.560 NS	.066 NS	.087 NS	.724⋆⋆
SO_2	-.031 NS	-.004 NS	.274 NS	.665⋆⋆	.318 NS	.528⋆⋆	.443⋆	.401⋆	.247 NS	.443⋆	-.264 NS	.500⋆⋆

NS: Not Significant, Degree of significant ($\star p < 0.05$, $\star\star p < 0.01$)

Positive relations are observed in April and June for CO at both stations and in June for NO_x. There is a negative relation in June for ozone, implying that strong positive relations are in January and April for SO_2 and there are negative relations at station one positive relations in April and June for SO_2 at station two. These results show that temperature has a high effect on photochemical production of ozone (Elminir, 2005).

Table 9: Correlation matrix for air pollutants and relative humidity at station #1

Pearson correlation	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	OCT	NOV	DEC	yearly
CO	-.118 NS	.326 NS	-.219 NS	.019 NS	.052 NS	-.094 NS	-.208NS	-.217 NS	-.356 NS	-.428⋆	-.145 NS	.324⋆⋆
Dust	.070 NS	-.173 NS	.016 NS	-.226 NS	.526⋆⋆	-.248 NS	.317 NS	-.132 NS	-.407⋆	-.706⋆⋆	-.266 NS	-.377⋆⋆
NO_X	-.264 NS	.038 NS	-.230 NS	-.180 NS	-.125 NS	-.155 NS	-.101 NS	-.030 NS	.430⋆	-.420⋆	-.402⋆	.463⋆⋆
O_3	.180 NS	-.410⋆	-.028 NS	-.165 NS	-.520⋆⋆	.029 NS	.139 NS	-.352 NS	-.285 NS	.115 NS	-.156 NS	-.664⋆⋆
SO_2	.061 NS	.425⋆	-.474⋆	-.723⋆⋆	-.137 NS	-.310 NS	-.276 NS	-.505⋆⋆	-.683⋆⋆	-.799⋆⋆	-.558⋆⋆	.281⋆⋆

NS: Not Significant, Degree of significant ($\star p < 0.05$, $\star\star p < 0.01$)

The results in Tables 9 and 10 show correlations between air pollutants and relative humidity. There is a negative correlation between Ozone and relative humidity and weak negative correlation between relative humidity and dust, and barely positive relations for CO and NO_x at both stations. For SO_2 various functions can be seen in both stations; with a weak positive relation at station one and a strong negative relation at station two. In addition, a strong negative correlation is observed in November for dust and in May for ozone. SO_2 has significant negative correlations with relative humidity in April, October, November and December at station one and in April, October and December at station two. Significant correlations of air pollutants with relative humidity could be due to precipitation conditions of high moisture in air masses (Stulov et al.,2010).

Table 10: Correlation matrix for air pollutants and relative humidity at station #2

	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	OCT	NOV	DEC	yearly
CO	-.062 NS	.072 NS	-.035 NS	-.377 NS	-.026 NS	-.088 NS	-.288 NS	-.099 NS	.013 NS	-.167 NS	-.104 NS	.520⋆⋆
Dust	.109 NS	-.183 NS	.022 NS	-.257 NS	.264 NS	-.175 NS	-.298 NS	-.186 NS	-.573⋆⋆	-.723⋆⋆	-.232 NS	-.343⋆⋆
NO_X	-.168 NS	.171 NS	.119 NS	-.547⋆⋆	.213 NS	-.234 NS	-.357⋆	-.418⋆	-.181 NS	-.377⋆	-.363 NS	.540⋆⋆
O_3	.185 NS	-.105 NS	-.339 NS	-.048 NS	-.619⋆⋆	.-.080 NS	-.026 NS	-.451⋆	-.448⋆	-.216 NS	-.399⋆	-.590⋆⋆
SO_2	-.386⋆	-.321 NS	-.466⋆	-.861⋆⋆	-.291 NS	-.379⋆	-.338 NS	-.132 NS	-.534⋆⋆	-.209 NS	-.525⋆⋆	-.658⋆⋆

NS: Not Significant, Degree of significant ($\star p < 0.05$, $\star\star p < 0.01$)

The relationship between air pollutants and maximum wind speed was determined and the results are shown in Tables 11 and 12 indicating positive significant correlations in May for dust at both stations, and significant negative correlations for ozone in this month, and these relations could be due to a high wind speed in this month.

Table 11: Correlation matrix between air pollutants and maximum wind speed at station #1

Pearson correlation	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	OCT	NOV	DEC	yearly
CO	-.324 NS	-.001 NS	-.326 NS	.328 NS	.035 NS	-.366⋆	-.041 NS	-.263 NS	.065 NS	.038 NS	-.324 NS	-.216⋆⋆
Dust	-.301 NS	.108 NS	.314 NS	.051 NS	.644⋆⋆	.392⋆	-.249 NS	-.189 NS	-.011 NS	-.267 NS	-.301 NS	.140⋆⋆
NO_X	-.255 NS	-.302 NS	-.400⋆	.243 NS	-.191 NS	-.397⋆	.065 NS	.197 NS	.066 NS	.057 NS	-.255 NS	-.384⋆⋆
O_3	.232 NS	.206 NS	.213 NS	-.227 NS	-.518⋆⋆	-.057 NS	-.067 NS	.005 NS	-.265 NS	.176 NS	.232 NS	.221⋆⋆
SO_2	.254 NS	-.353 NS	-.384 NS	.419⋆	-.321 NS	-.271 NS	-.022 NS	-.302 NS	-.153 NS	-.145 NS	.254 NS	-.151⋆⋆

NS: Not Significant, Degree of significant ($\star p < 0.05$, $\star\star p < 0.01$)

The relationship between air pollutants and maximum wind speed was determined and the results are shown in Tables 11 and 12 indicating positive significant correlations in May for dust at both stations, and significant negative correlations for ozone in this month, and these relations could be due to the high wind speed in this month.

Table 12: Correlation matrix between air pollutants and maximum wind speed at station #2

Pearson correlation	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	OCT	NOV	DEC	yearly
CO	-.257 NS	-.037 NS	-.274 NS	.097 NS	.109 NS	-.266 NS	.118 NS	-.047 NS	.100 NS	-.049 NS	-.067 NS	-.367⋆⋆
Dust	-.218 NS	.098 NS	.352 NS	.074 NS	.782⋆⋆	.266 NS	-.256 NS	-.172 NS	-.139 NS	-.181 NS	.003 NS	.142⋆⋆
NO_X	-.264 NS	-.490⋆⋆	-.449⋆	.235 NS	.266 NS	-.078 NS	.107 NS	-.215 NS	.170 NS	-.135 NS	.047 NS	-.401⋆⋆
O_3	.162 NS	.193 NS	.228 NS	-.242 NS	-.637⋆⋆	-.177 NS	-.178 NS	-.268 NS	-.281 NS	-.131 NS	-.303 NS	.026⋆⋆
SO_2	-.024 NS	-.204 NS	-.288 NS	.355 NS	-.201 NS	-.097 NS	.037 NS	-.329 NS	-.102 NS	-.155 NS	-.072 NS	-.225⋆⋆

NS: Not Significant, Degree of significant ($\star p < 0.05$, $\star\star p < 0.01$)

3.2. Temporal variability:

This section shows variations of air pollutants in different months and different years in the period 2005-2010 for both monitoring air quality stations in Shiraz city.

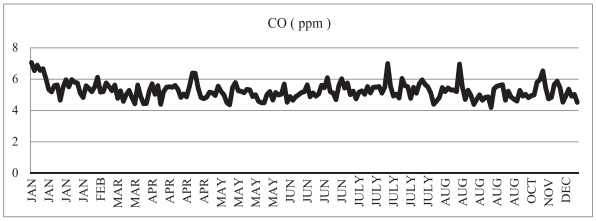

Figure 2: Daily variations of average CO concentrations for period 2005 – 2010 at station #1

Monthly variations of CO concentrations are shown in Figures 2 and 3 and these results imply that a slight fluctuation of CO is in January at both stations. This could be due to low temperature, low mixing depth, pollution inversion and traffic density (Elminir, 2005).

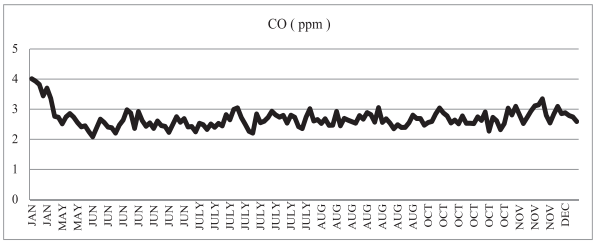

Figure 3: Daily variations of average CO concentrations for period 2005 – 2010 at station #2

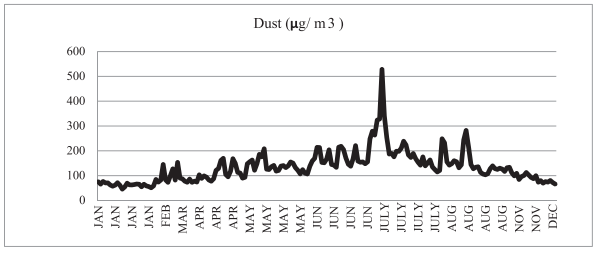

Figure 4: Daily variations of average dust concentrations for period 2005 – 2010 at station #1

Monthly dust variations are presented in Figures 4 and 5 at both stations, higher concentrations were evident in July with very clear variations in difference between months showing that particulate matter variations depend on the time of year and meteorology (Pearce, et al., 2010). Monthly variations for NO_x are shown in Figures 6 and 7; they indicate higher concentrations of NO_x in January at both stations and given that NO_x is a primary pollutant (Beaver and Palazoglu, 2010), with decreasing temperature in winter, its concentrations increased.

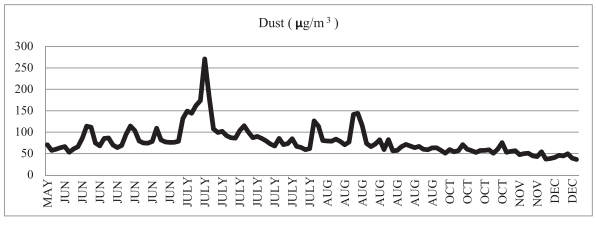

Figure 5: Daily variations of average Dust concentrations for period 2005 – 2010 at station #2

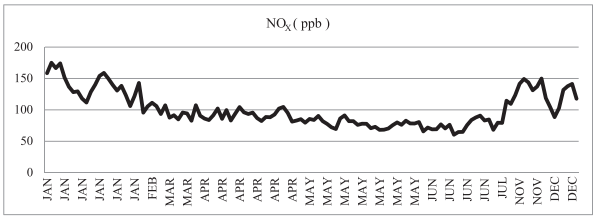

Figure 6: Daily variations of average NO_x concentrations for period 2005- 2010 at station #1

Ozone concentrations show clear variation across different months at both stations, as shown in Figures 8 and 9. There are higher concentrations of Ozone in June and July. The reason for this higher level of ozone is mainly due to the active photochemical production mechanism along with favorable meteorological conditions in summer months (Elminir, 2005).

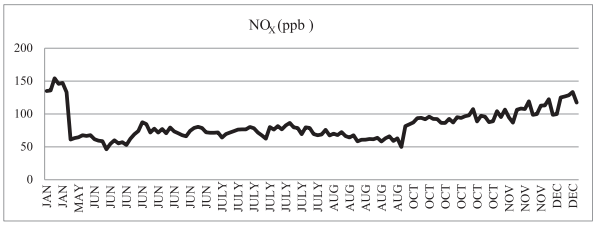

Figure 7: Daily variations of average NO_x concentrations for the period 2005 – 2010 at station #2

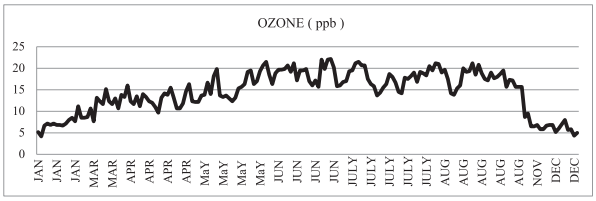

Figure 8: Daily variations of average O_3 concentrations for period 2005 – 2010 at station #1

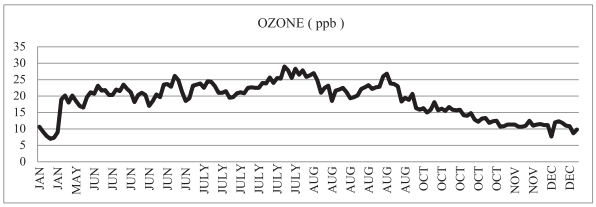

Figure 9: Daily variations of average O_3 concentrations for period 2005 – 2010 at station #1

Finally, monthly variations for SO_2 concentrations at both stations are presented in Figures 10 and 11. There is a steady trend at station one with higher concentrations in October at station two. Therefore, these results revealed the effect of weather conditions on the distribution pattern of air pollutants in different months.

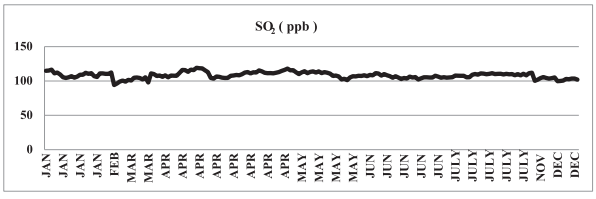

Figure 10: Daily variations of average SO_2 concentrations for period 2005 – 2010 at station #1

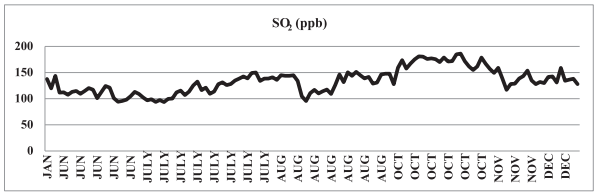

Figure 11: Daily variations of average SO_2 concentrations for period 2005 – 2010 at station #2

Variations of CO concentrations in different years are shown in Figures 12 and 13 for both stations. These results show that concentrations varied in different years, there is a decreasing trend at both stations that could be related to the air pollution control master plan and other strategies employed in the country especially those to control vehicles' emissions of CO. Some of these measures are improvements in fuel quality, limited promotion of alternative fuels, introduction of the auto emission inspection and some improvements in public transport (Atash, 2007). CO concentrations have increased slightly in 2010 at station two, which can be attributed to increasing concentrations of people and motor vehicle volume at this station.

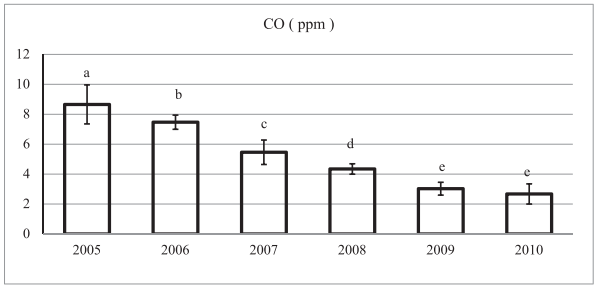

Figure 12: CO concentrations in different years at station #1, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

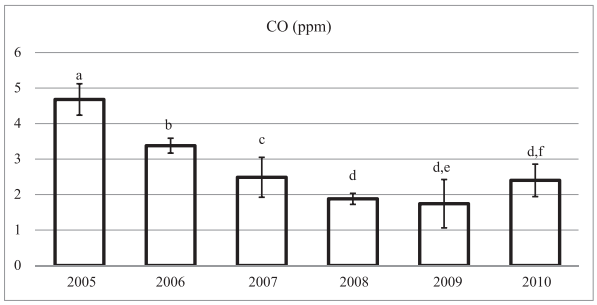

Figure 13: CO concentrations in different years at station #2, each bar represents ± SD, and same letters indicate no significant difference at 5%, after applying HSD test

Averages for concentrations of dust in different years for the period 2005 – 2010 are shown in Figures 14 and 15. These results show a relatively increasing trend for both stations, because the biggest source of dust is naturally occurring from the Iraqi dry deserts that have covered Fars province in recent years, especially in 2009 (Mansouri et al.,2011). With consideration of the effect of dust on public health it is important for policy makers and the Iranian government to restrict the entry of particulate matter to Iran.

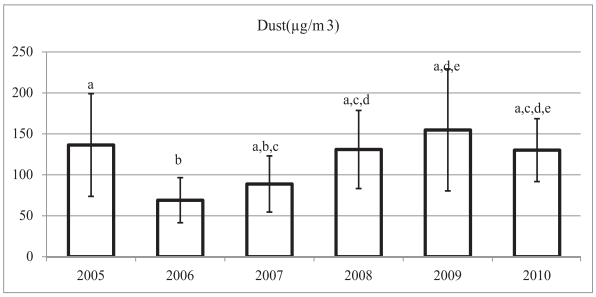

Figure 14: Dust concentrations in different years at station #1, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

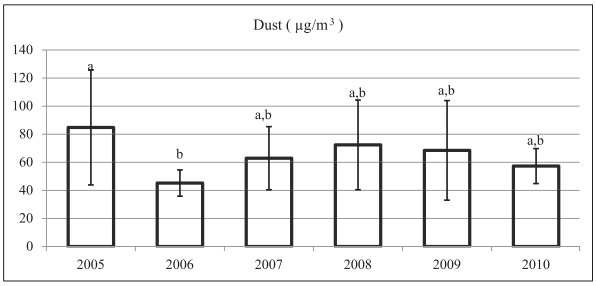

Figure 15: Dust concentrations in different years at station #2, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying HSD test

Ozone average concentrations in different years are shown in Figures 16 and 17 for both stations. These results show a uniform trend at station one and a comparative increase for station two. This increase could be due to oxidation of atmospheric primary air pollutants that are emitted from motor vehicles and industries at station#2 (Fenger, 1999). Also average concentrations of Ozone at station two are higher than at station one for the period 2005-2010.

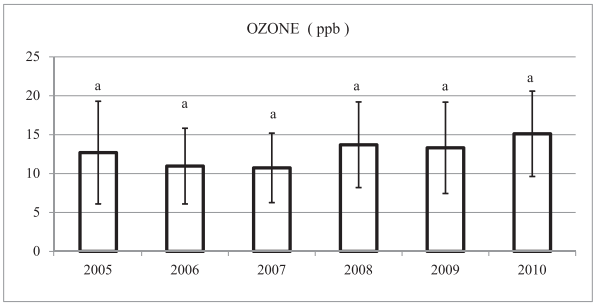

Figure 16: O_3 concentrations in different years at station #1, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

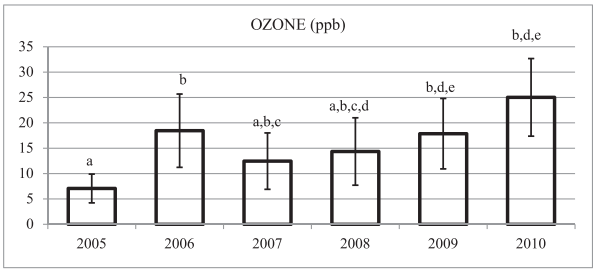

Figure 17: O_3 concentrations in different years at station #2, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

NO_x average concentration variations in different years are shown in Figures 18 and 19. These results show a smooth increase for the period 2005–2010 especially during 2010 at both stations; this increase could be due to fuel combustion from motor vehicles and industries in recent years. Finally, SO_2 average concentrations in different years are shown in Figures 20 and 21 for both stations. The results have shown increasing trend up to the year 2008 and a decreasing trend in the years 2009 and 2010 for both stations.

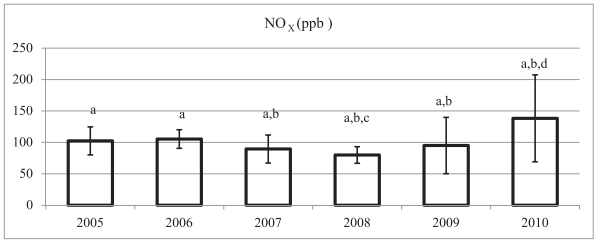

Figure 18: NO_x concentrations in different years at station #1, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

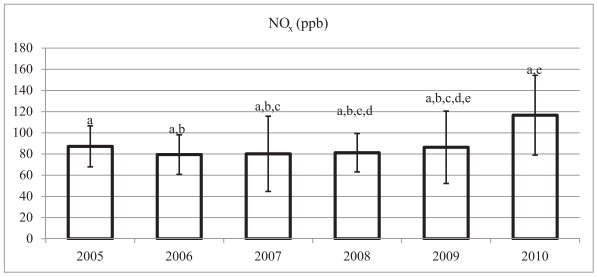

Figure 19: NO_x concentrations in different years at station #2, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

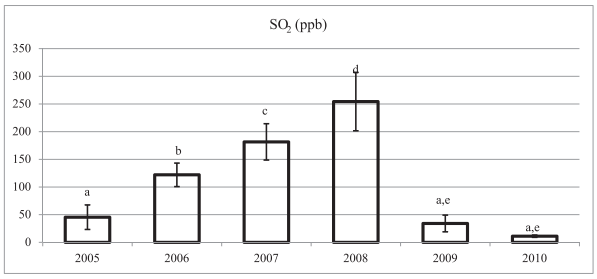

Figure 20: SO_2 concentrations in different years at station #1, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

This fluctuating trend of increasing and decreasing could be due to the use of fuels with low sulphur content, for example natural gas or oil instead of coal or established desulphurization of the flue gas techniques in industries (Fenger, 1999).

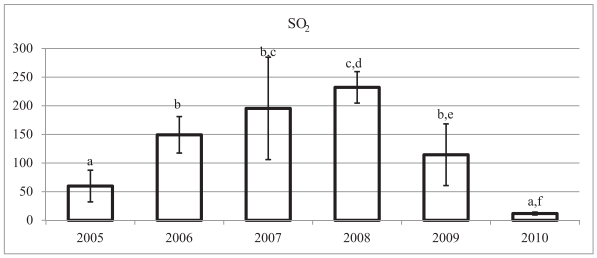

Figure 21: SO_2 concentrations in different years at station #2, each bar represents ± SD, same letters indicate no significant difference at 5%, after applying the HSD test

3.3. Stations differences:

This section shows differences of concentrations of air pollutants between two air quality monitoring stations in the city of Shiraz and results indicate that air pollutant concentrations are higher at station one than at station two for CO, dust and NO_x and for station two ozone and SO_2 are higher than at station one. These significant differences show that pollutants have different origins, the highest rate of CO, dust and NO_x at station one could be related to the heavy vehicle traffic and the highest rate of SO_2 and ozone at station two could be due to industrial activity, for example there is a cement factory in the southern part of Shiraz (Hadad et al.,2003).

4. Conclusion

This paper explored air pollution in Shiraz using meteorological parameters and concentrations of air pollutants in various temporal and spatial scales. The results make it obvious that meteorological conditions have an effect on pollutant concentrations in urban areas and air pollutant concentrations are variable according to months and situations and that this could be related to the interaction with meteorological parameters. These results also demonstrate that the affinities of some pollutants such as dust, Ozone, NO_x, and SO_2 on meteorology are more than that of carbon monoxide. Temporal variability shows that human activity and natural events have an effective role on concentrations of pollutants in different years and time scales, for example, dust had an increasing trend because of natural events and CO had a decreasing trend because of control measures in recent years. Significant differences between the two air quality monitoring stations implies that more air quality monitoring stations are needed to make monitoring air pollution in Shiraz more effective because of the city's urban structure.

Acknowledgements

The authors would like to thank Iran Department of Environment and Iran Meteorological Organization for providing the required data to carrying out this research.

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