Assessment of the Air Quality of Isfahan City, Iran, Using Selected Air Quality Parameters

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ABSTRACT

Background: Today, air pollution is one of the major problems in large cities including Isfahan.

Methods: The objective of this study was to investigate the variations of ozone (O_3), carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2), and particulate matter (PM_{10}) concentrations in different months at three stations and also to explore the correlations between pollutants. Monthly averages of air pollutant concentrations recorded in three pollution monitoring stations (Bozorgmehr, Azadi, and Laleh) were obtained in 2008 and 2009.

Results: There were significant monthly variations in the concentrations of air quality parameters. Results showed that there was a correlation between ozone and particle matter (p<0.05), and between nitric oxide and nitrogen oxides (p<0.01). The statistical analysis indicated that there were significant differences in the O_3, NO, NO_x and PM_{10} concentrations.

Conclusion: The air quality monitoring data collected in city center of Isfahan showed seasonal variations for O_3, CO, NO, NO_2, NOx, SO_2, and PM_{10}.

Keywords: Air Pollution**,** Carbon Monoxide**,** Isfahan City**,** Nitrogen Oxides**,** Sulphur Dioxide**,** Urban Area.

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INTRODUCTION

Quality of the air is one of the basic indicators of the overall quality of the environment. Developing regions often face critical air pollution problems due to the rapid growth of transportation and industry and the large number of people exposed. Three of the world's four largest cities can be found in the rapidly developing world, where many are plagued by severe air pollution [1,2]. In particular, the levels of air pollutants are increasing rapidly in many urban areas throughout the developing world [3]. Studies of urban air quality have shown that human health is negatively impacted by many types of gases and particles that result from the chemical reactions of exhaust gases with the atmosphere [4]. Many studies have also shown the association of air pollution with increased daily mortality, in total and due to cardiovascular and respiratory disorders [5]. Worldwide, there are more than 2.7 million deaths per year (with cities accounting for approximately 33%) due to air pollution [6]. Adverse effects of air pollution on human health and a close relationship between the levels of air pollution and increased frequencies of certain diseases have been proved by numerous epidemiological studies [7].

In Asia, pollution is one of the greatest challenges for the region. In general, Asian environmental quality has deteriorated and the environmental problems in many countries are severe. The air in Asia's cities is among the most polluted in the world. The levels of ambient particulate matter, smoke particles and dust are generally twice the world average and more than five times higher than industrial countries' [8,9]. In Iran, as in most other regions of Asia, air pollution has been aggravated by the growth in the size of cities, rapid economic development, industrialization and increasing traffic and

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energy consumption. The movement of people into urban areas together with the increase in energy consumption and unplanned urban and industrial development has led to the serious problem of air pollution. Besides transport and industrial sectors, construction activities and roadside airborne dust due to vehicular movement also contribute to the overall pollution load in most of the cities in Iran. Motor vehicles, the major source of air pollution in most parts of Iran, emit a complex mixture of airborne pollutants, many of which may have harmful ecological effects. These include nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM) and metals [9]. The pollutants CO, NO_x, PM_{10}, O_3 and SO_2 are the main air pollutants in the urban areas, like Isfahan, where peculiar orographic and atmospheric conditions can lead to pollutant accumulation. Hence, the objective of this study was to investigate how air pollutants (O_3, CO, NO, NO_2, NO_x, SO_2 and PM_{10}) varied among the three monitoring sites in Isfahan, focusing on monthly averages.

MATERIALS AND METHODS

Site description

Isfahan is the capital city of Isfahan province, located in the center of Iran. The Isfahan metropolitan area had a population of 3,430,353 in the 2006 census, the second most populous metropolitan area in Iran after Tehran. Its latitude and longitude are 32° 38' N and 51° 39' E, It has a moderate and mountainous climate. Its average rainfall is 113 mm and is unevenly distributed throughout the year. Isfahan experiences rather cold winters and most rainfall occurs in autumn (Nov and Dec), winter (Jan, Feb and Mar) and spring (Apr and May), with the highest in Mar and Dec. During the winter, days are mild but nights can be very cold and snow is not unknown. Summer in Isfahan is fairly hot. The elevation of Isfahan city is 1590 m above the sea level. The average annual temperature is 16.2ºC with the warmest month in Jul (high average 29.3ºC) and the coldest in Jan (low average 2.9ºC). The average annual wind speed is 2.5 m/s.

Methods

The present analysis is based on the data obtained from three monitoring stations of the city of Isfahan, namely Bozorgmehr, Azadi and Laleh. The monitoring stations were fully automated and provided daily readings of ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and PM_{10} concentrations. The concentrations of these parameters were monitored by continuous monitoring equipment (UV absorption O_3 analyser-model 400A, chemiluminescent NO_x analyser-model 200A, fluorescent SO_2 analyzer-model 100A, gas filter correlation CO analyser-model 300). The inlets of sampling are located approximately 5 m above the ground at each station. The locations of these stations are selected based on the traffic conditions. The three stations are located in east, west and south of the city, which are the locations with higher rate of transportation and traffic jams. The locations of the stations in the city are presented in Figure 1.

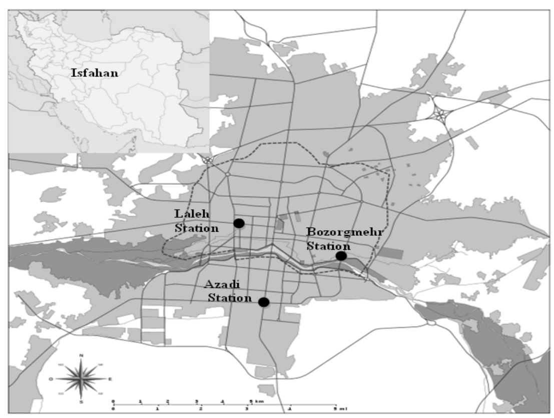

Figure 1. Location of monitoring stations of air quality parameters in Isfahan city.

One-way analysis of variance (ANOVA) was used to evaluate the differences between the air quality parameters (O_3, NO, NO_2, NO_x, SO_2, CO and PM_{10}) of the Isfahan city (period of two years, 2008-2009), by Tukey's Honest. Pearson's correlation coefficients (r) were used when calculating correlations among these parameters. Data analyses were carried out using the statistical package Minitab (Release 14).

RESULTS

Monthly mean ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and PM_{10} concentrations at air quality monitoring stations during 2008-2009 are shown in Table 1, 2 and 3. The O_3 concentration ranged between the highest value of 60.6 ppb obtained from Bozorgmehr station in March and the lowest of 17.7 ppb obtained from Laleh square station in January, 2009. Significant differences were observed among the stations and between these two years (P<0.05). Nitric oxide concentrations fluctuated between the lowest monthly mean of 8.5 ppb obtained in February from Laleh square station and the highest monthly mean of 165 ppb recorded in October at Bozorgmehr station. A statistically significant difference (p<0.05) was observed in the nitric oxide concentrations among the stations.

DISCUSSION

A few studies have demonstrated associations between ozone concentrations and lower respiratory symptoms [10]. The means of O_3 concentrations in three stations were between 26.3 and 34.5 ppb, which are lower than the primary and secondary standards of EPA for O_3 (75ppb). Therefore, the concentration of O3 is not harmful, however with increasing number of population and vehicles this might be problematic in the future.

Nitrogen dioxide (NO_2) concentrations varied between 21.1 and 133.6 ppb. There was no significance difference in NO_2 concentrations between the two years of the study. Nitrogen dioxide has a fundamental role in the formation of the photochemical smog because it constitutes the intermediary base for the production of a series of secondary pollutants such as ozone, nitric acid, nitrous acid and peroxyacetly nitrates. NO_2 is responsible for both acute and chronic effects, particularly in sensitive people [11]. Some epidemiological studies have reported gender effects of NO_2 on asthma or lung function changes but these are inconsistent. Horak *et al*. [12] found seasonal changes in NO_2 concentration, which enhance the effect of PM_{10} on lung function in the summer and vice versa in the winter. Nitrogen oxides (NO_x) and nitric oxide showed similar patterns in their concentrations among the stations and seasons. The concentrations of these two pollutants were significantly higher in the summer and autumn and also at Bozorgmehr station. The concentrations of NO_x observed in the present study were higher than what found by Dongarrà *et al*. [13]. The monthly averages of NO_x concentration ranged between 67.6 and 202 ppb.

Table 1. Pollutant concentrations during different months at Bozorgmehr station in Isfahan city (All parameters are in ppb except PM10 in μg m^{-3}).

PM10	CO	SO2	NOx	NO2	NO	O3			
152.5	0.01	25.5	172	33.2	138.7	32.3	Jul	Summer	2008
160.1	0.005	28.7	155.7	38.1	117.4	27.7	Aug		
155	0.005	27.3	168.7	34.5	144.3	28	Sep		
193.8	0.008	25.3	202.3	36.8	165.4	34.3	Oct	Autumn	
162	0.006	39.4	153.7	31.7	122	30.9	Nov		
173.3	0.008	26.4	195.2	37.2	157.9	34.4	Dec		
159.7	0.008	24.8	110	26.1	84.8	31.1	Jan	Winter	2009
198	0.006	27.4	101.9	133.6	31.6	30.1	Feb		
159.5	0.007	20.8	113.8	37	76.8	60.6	Mar		
206.1	0.006	18.7	127.9	31.6	96.3	39.7	Apr	Spring	
157.8	0.005	21.6	105.5	26.3	79.2	30.4	May		
222.9	0.006	20.7	130.9	31.7	99.1	34.9	Jun		
175.1	0.006	25.5	144.8	41.4	109.4	34.5	Overall	mean	

Table 2. Pollutant concentrations during different months at Azadi station in Isfahan city (All parameters are in ppb except PM10 in μg m^{-3}).

PM10	CO	SO2	NOx	NO2	NO	O3			
79.1	0.007	17.9	110.9	37.1	73.9	22.1	Jul	Summer	**2008**
86.9	0.007	11.7	97.9	37.9	60	24.3	Aug		
101	0.007	15.2	102.5	29.9	75.3	25.4	Sep		
119.2	0.004	30.5	133.7	29.2	104.5	29.7	Oct	Autumn	
95.3	0.007	40.5	90.4	27.4	64.3	21.9	Nov		
84.2	0.044	7	122.6	40.1	82.9	19.6	Dec		
88.1	0.003	39.1	74.7	114.4	39.9	18.4	Jan	Winter	**2009**
154.5	0.004	27.4	98	30.5	67.5	25.3	Feb		
110.4	0.006	11.3	100.6	28.8	71.1	33.2	Mar		
182	0.005	30.3	75.5	22.8	52.9	35.1	Apr	Spring	
193.4	0.005	29.9	72.6	24.8	49.5	28.7	May		
241.3	0.005	44.6	67.6	21.1	46.5	26.3	Jun		
127.9	0.008	25.4	95.5	37.0	65.6	25.8	Overall	mean	

Table 3. Pollutant concentrations during different months at Laleh station in Isfahan city (All parameters are in ppb except PM10 in μg m^{-3}).

PM10	CO	SO2	NOx	NO2	NO	O3			
112.3	0.016	13.4	150.9	36.1	114.7	40.8	Jul	Summer	**2008**
123.3	0.004	16.3	129.7	66.4	64.5	32.8	Aug		
108.6	0.006	12.7	144.7	49.1	95.5	22.2	Sep		
135.7	0.003	18.2	130.2	40.6	89.6	18.5	Oct	Autumn	
115.7	0.004	19.8	136.8	49.5	87.3	36.3	Nov		
100.5	0.003	39.4	115.1	41.7	73.4	19.2	Dec		
93.6	0.002	50.7	107	38.4	68.6	17.7	Jan	Winter	**2009**
117.8	0.029	60.6	102	35.4	8.5	35.2	Feb		
156.7	0.003	41.6	79.6	27.4	52.1	37.8	Mar		
143.2	0.003	19.2	98.2	65.2	33	40.5	Apr	Spring	
142.8	0.004	21.2	99.2	65.1	34.1	41.1	May		
133.1	0.003	16.4	79.8	43	36.7	48.6	Jun		
123.6	0.006	27.4	114.4	46.4	63.1	32.5	Overall mean		

The concentrations of SO_2 observed in the present study were higher than those reported by Yang *et al*. [14]. SO_2 has a pungent irritating smell at about 3.0 ppm which is the smell 'detection limit' [15]. The main source of SO_2 emission in Isfahan city is intermittent road transport of diesel vehicles and large power stations and industrial process around the city [16]. The average SO_2 concentrations at the present study were between 25 and 27 ppb, which are lower than EPA standard for SO_2 (75ppb). Thus, SO_2

concentrations have no health issues at the current situation, however with the city development and population increase it might cause environmental issues in the future.

The concentrations of CO observed in the present study are lower than those found by Pourmahabadian and Mansouri [17], Mansouri *et al*. [18] and Yang *et al*. [14]. The main source of CO concentration in Isfahan is vehicular traffic. The pollution emissions are the greatest where the movement of the traffic is slowed down. Besides, CO emissions tend to be the greatest in those vehicles lacking pollution control devices [11]. The heart is one of the most sensitive organs to hypoxia caused by carbon monoxide. Carbon monoxide exposure may lead to a significantly shorter life span due to heart damage [19]. The toxic effects of acute exposure to carbon monoxide are due to the ability of CO to bind with blood haemoglobin, forming the COHb, thus reducing the blood ability to transport oxygen into the various parts of the body [11].

Ambient particles, when mixed with atmospheric gases (ozone, sulfur and nitric oxides, and carbon monoxide), can generate ambient aerosols [20]. Most frequently, the dust fractions of particles of size below 10 µm (PM_{10}), 5 µm (PM_5) and 2.5 µm ($PM_{2.5}$) are analyzed. The concentrations of PM_{10} observed in the present study were higher than what reported by Adhikari *et al*. [21], Yang *et al*. [14] and Dongarrà *et al*. [13]. Dust is an exception among these parameters, because the dust originates from the Iraqi deserts and covers west, south and center of the country for months. One of the most important issues regarding the dust is that the government of Iran cannot restrict the arrival of it to Iran. However, Iran and Iraq have signed a $1.2 billion agreement to bring dust storms under control over the next five years, through application of biological solutions or pouring oil derivative mulch in deserts of Iraq. The mean concentrations of PM_{10} were 175, 127 and 123 µg m^{-3} in Bozorgmehr, Azadi and Laleh stations, respectively. Only the PM_{10} concentration in Bozorgmehr station was higher than the primary and secondary standards of EPA for PM_{10} (µg m^{-3}).

Table 4. Pearson's correlation coefficients of monthly air pollution data during 2008-2009 in Isfahan.

PM_{10}	CO	SO_2	NOx	NO_2	NO	O_3	
						1	O_3
					1	-0.03	NO
				1	-0.32	-0.06	NO_2
			1	-0.10	0.90**	0.04	NOx
		1	-0.21	-0.03	-0.23	-0.18	SO_2
	1	-0.06	0.10	-0.10	-0.01	-0.08	CO
1	-0.24	0.13	0.08	-0.10	0.16	0.36*	PM_{10}

Correlation is significant at the 0.05 and 0.01** level*

Table 5. The analysis of variance (ANOVA) of Isfahan air pollutants at different stations.

p	*F*	Parameter
$p<0.05$	3.4	O_3
$p<0.01$	8.6	NO
$p<0.61$	0.4	NO_2
$p<0.001$	10.0	NOx
$p<0.90$	0.1	SO_2
$p<0.70$	0.3	CO
$p<0.01$	7.9	PM_{10}

P significance level

The correlation coefficients of air quality parameters are shown in Table 4. Significantly positive correlations were observed between O_3 and the PM_{10} concentrations ($p < 0.05$), and between NO and NO_x concentrations ($p < 0.01$). On the other hand, there were no significant correlations between SO_2 with other air pollutants (O_3, CO, NO_x and dust). The lack of correlation between SO_2 and other pollutants might be because it is generated mostly by buses rather than by cars. Wheeler *et al*. [22], suggest that there is a significant contribution of SO_2 from diesel fuels. The air quality monitoring data collected in Isfahan city showed seasonal variations for ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and PM_{10} concentrations (Table 5). There were significant differences in the concentrations of air pollution parameters at different stations (at four seasons: spring, summer, autumn and winter).

CONCLUSION

The results of this study clearly showed that significant differences were observed among the stations and between these two years. Also, the results indicated that significantly positive correlations were observed between O_3 and the PM_{10} concentrations, and between NO and NO_x concentrations. In conclusion, the motor vehicles (traffic) are the major source of air pollution in most parts of Isfahan.

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