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Evaluation of Seasonal and Spatial Variations of Air Quality Index and Ambient Air Pollutants in Isfahan Using Geographic Information System

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ABSTRACT

Introduction: Due to more than 1.7 million population, many vehicles and large industries around Isfahan, it has become one of the most polluted cities in Iran. The aim of this study was a spatial analysis of the concentrations of air pollutants and the air quality index (AQI).

Materials and Methods: In this descriptive and evaluative study, the air quality data of 7 monitoring stations in 2012 were taken from the Isfahan Department of Environment. The calculation of AQI was done as per the EPA guidelines. The zoning pollutant concentrations and AQI in the study area was determined with the use of the Arc map software, version 10.1.

Results: The results showed that the highest concentrations of pollutants and the AQI were related to the Ahmadabad station. Moreover, the air quality in Isfahan in 2012 was 4.38% (4 days) in good conditions, 12.7% (47 days) in moderate conditions, 42.56% (156 days) in unhealthy conditions for sensitive groups, 39.49% (144 day) in unhealthy conditions, 2.8% (10 days) in a very unhealthy and 1.2% (4 days) in dangerous conditions, respectively.

Conclusion: It was found that particulate matter was the main cause of Isfahan air pollution while Ahmadabad is the most polluted point in Isfahan. According to the calculations, during 314 days of the year 2012, the air quality of Isfahan was in unhealthy conditions and only 4 days was in good conditions. This is one of the biggest health challenges in this city.

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Introduction

Air pollution is one of the most important environmental issues that impact on human health. This has been proven in the twentieth century [1, 2]. In the recent two decades, epidemiological studies have shown that outdoor air pollution causes diseases such as cardiovascular and respiratory problems, lung function decrease, chronic bronchitis and death [3-5]. Air pollution is one of the ten major causes of increased mortality in the world [6]. According to the World Health Organization report, each year, 800,000 people worldwide die due to cardiovascular diseases, respiratory diseases and lung cancer. Among these, close to 150,000 of them were reported in South Asia [7]. Air pollutants such as CO, NO_2, SO_2, O_3 and particulate matter can cause respiratory problems, headaches, dizziness, heart attacks and threaten human health [8, 9]. For example, the WHO report shows that PM_{10} can cause respiratory and cardiovascular diseases such as asthma, bronchitis, heart attacks, reduced lung function and mortality. In some cities in Europe, for every increase of 10 µg/m^3 of PM_{10} concentration, the mortality rate increased 6% [10]. Today, many major cities in Iran face the problem of air pollution. The statistics show that the air quality index (AQI) in many metropolitan cities is higher than the safe amount determined by the WHO [6]. According to the WHO report, the annual health costs of air pollution in Austria, France and Switzerland are about 30 billion pounds [6, 11]. In the recent decades, urbanization, increasing number of vehicles and population in cities has led to the increase in air pollutants resulting in the reduction of the AQI. In Iran, due to the rising population, increased number of industries and vehicles, the AQI in most cities has reduced. According to the study by Kermani et al in 2011, the AQI in large Iranian cities such as Tehran, Isfahan, Arak, Mashhad and Tabriz in more than 80 days a year are higher than the permissible standard described by the Department of Environment. The main cause of pollution in the cities was reported due to PM_{10} [12]. The study of Mohammadi et al in Mashhad showed that AQI was unfavorably compared to previous years [13]. The study was performed in Yazd in 2015 and showed that during 10 % of the days of the year, the air quality was in an unhealthy condition [14]. Another study, conducted by Kermani et al in Tehran during 2007-14 showed that the AQI had exceeded the standard level [6] during 95%, 92%, 73%, 65%, 57%, 65%, 52% and 46% days of the year 2007-14, respectively. In 2004, a study was conducted in Delhi, India, over 9 years. It showed that the stations near industrial or high traffic areas had unfavorable air quality index [15]. In another study, an analysis of the particles in the air was performed in Taiwan during the years 1999-1994. The results showed that the concentration of PM in the cold months were more than that during the warm months. The main reasons were found as reduced temperatures, reduced rainfall and regional storm [16, 17]. In a study that was carried out during the years 2005-2004 in Tehran, researchers, using the GIS software, found that the airborne pollutants were zoning around the map of the urban sprawl and estimated the highest rate of contamination in Tehran [18]. Isfahan with an area of 493.8 km^2 is one of the largest metropolises in Iran. Due to a population of more than 1.7 million, many vehicles and very large industries, this city has become one of the most polluted cities [19, 20]. Hence, this study aimed to perform a spatial analysis of the PM_{10}, $PM_{2.5}$, O_3, SO_2 and NO_2 for determining the AQI of Isfahan to help healthcare managers and urban planners for monitoring the air pollution and accurately notify the citizens about the air quality.

Materials and Methods

This study was a descriptive and evaluative study of Isfahan's air quality index. The air quality data of 7 monitoring stations in 2012 were taken from the Isfahan Department of Environment. The data was related to the Ahmedabad, Azadi, Azadegan, Bank Sepah, Valiasr, Eliaderan and Vahid monitoring stations. The position of the monitoring stations and the study area is shown in Figure 1.

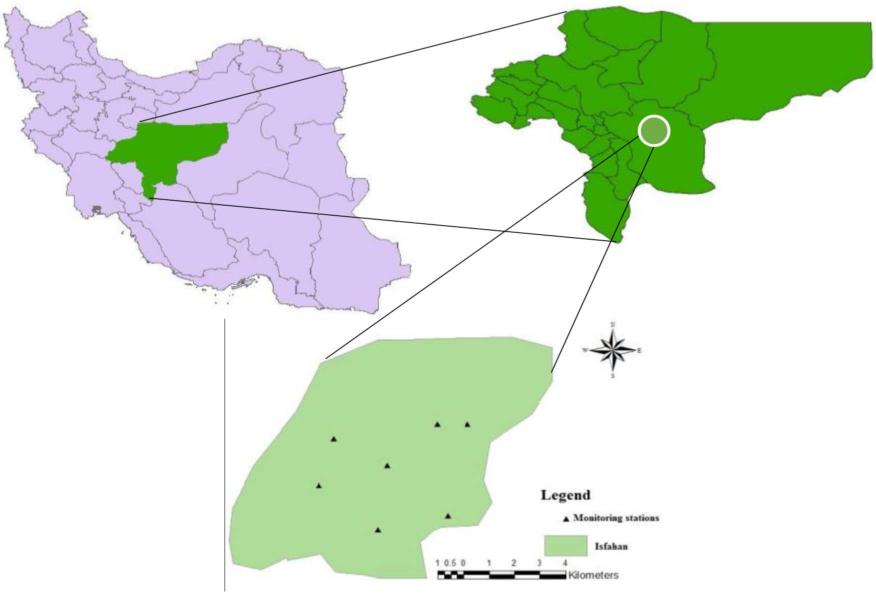

Figure 1: Location of air pollution monitoring stations in the study area

The Air Quality Index (AQI)

To calculate the air quality index, the pollutants information, such as, PM_{10}, SO_2, NO_2, CO and O_3 were collected from the Isfahan Department of Environment. The AQI calculation was carried out in two stages: first, according to the ambient air standard, the maximum amounts of 1-hour ozone, maximum 1-hour NO_2, maximum amounts of 8-hour ozone and maximum 24-hour and maximum 8-hours for PM_{10} and SO_2 were extracted. In the second stage, the AQI was calculated as per the EPA guidelines, according to Formula 1 by use of Excel software. For accreditation, some of the AQI results were compared with the results of the EPA online application [21].

Formula 1:

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}$$

Where I_p = the index for pollutant p

C_p = the rounded concentration of pollutant p

BP_{HI} = the breakpoint that is greater than or equal to C_p

BP_{Lo} = the breakpoint that is less than or equal to C_p

I_{HI} = the AQI value corresponding to BP_{HI}

I_{Lo} = the AQI value corresponding to BP_{Lo}

After AQI calculation to judge the air quality in Table 1 were used.

Table 1: Classification of AQI and a description of each class

AQI	Levels of Health Concern	Color
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
300 to 500	Hazardous	Maroon

For the analysis, the data was used from Excel and Arc map GIS software version 10.1. For the zoning of concentration of pollutants and AQI in the monitoring stations of IDW, conventional methods for zoning and distribution of air pollutants were used. Using this method, the same analysis can be carried out to determine the exact distribution of air pollution in other areas.

Results

Table 2 shows the monthly and annual average concentrations of air pollutants in the total monitoring stations recorded during 2012. According to the above table, the highest average of PM_{10} was related to the spring and autumn while the maximum concentrations of CO were observed in autumn. The highest amount of O_3 was related to spring and summer and the highest annual mean with 99.15 $\mu g/m^3$ is related to the PM_{10}. Figure (2 A, B, C, D and E) 3 and Figure 4 show monthly concentrations of PM_{10}, SO_2, NO_2, CO and O_3 in the monitoring stations. According to the above figures, the highest concentration of PM_{10}, SO_2, NO_2, CO and O_3were registered in the Ahmedabad station. Table 3 indicates the maximum value of AQI in spring, summer, autumn and winter in the study area. According to Table 3, the highest AQI is related to the Ahmadabad station. In 60% of the cases, the main pollutant was PM_{10}.

Figure 3 shows the zoning of the annual mean concentration of PM_{10}, SO_2, NO_2, O_3 and CO in the monitoring stations. According to Figure 3, the highest amounts of PM_{10}, SO_2 and CO were recorded in the Ahmedabad station, NO_2 in the Azadi station and the maximum amount of $O_3$was recorded in the Ahmedabad and Vahid stations.

Figure 4 shows the zoning of the AQI in the monitoring stations in different seasons. In this figure, the highest seasonal AQI was related to the Ahmedabad station.

Table 2: Monthly and annual mean concentration of air pollutants in monitoring stations

Months / Pollutants	CO (ppm)	O_3 (ppm)	SO_2 (ppb)	NO_2 (ppb)	PM_{10} ($\mu g/m^3$)
March	3.59	48.35	75.00	42.37	62.13
April	4.26	58.88	39.47	45.56	140.09
May	3.58	44.76	45.55	16.99	146.17
June	3.10	62.19	78.82	51.72	106.51
July	3.72	45.32	40.62	45.37	74.69
August	4.62	35.81	33.37	45.46	85.35
September	6.31	24.04	38.71	70.88	105.80
October	8.72	*	50.28	35.96	78.36
November	10.28	*	50.74	22.36	115.60
December	3.28	27.56	39.99	47.22	124.27
January	8.43	26.98	11.47	17.48	85.37
February	3	*	7.55	30.96	65.48
Annual Mean	5.24	41.54	42.63	39.36	99.15

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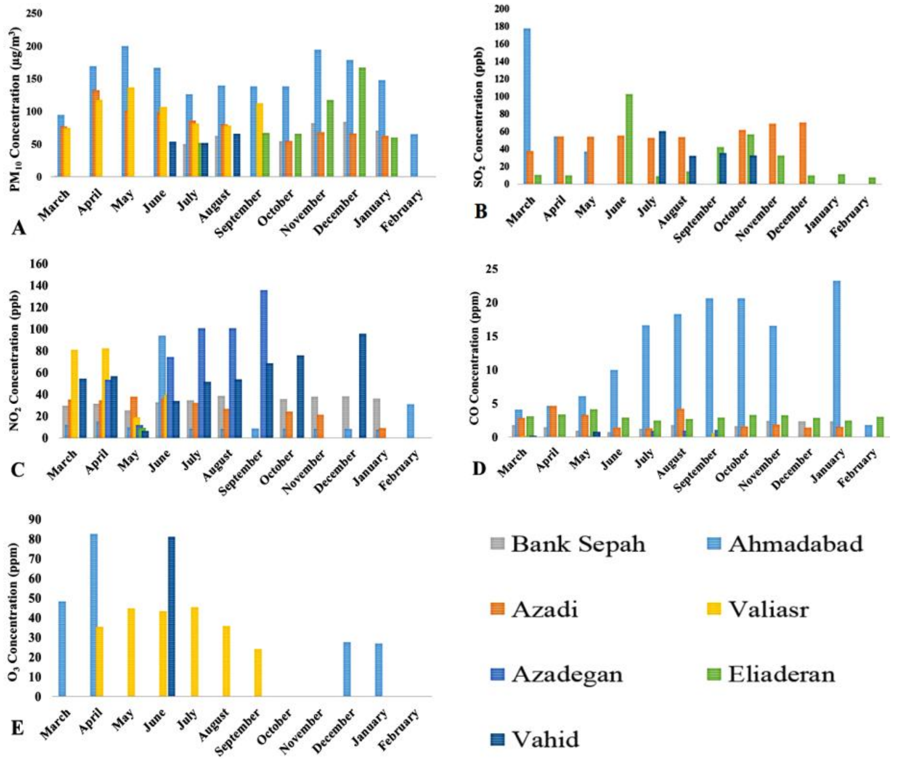
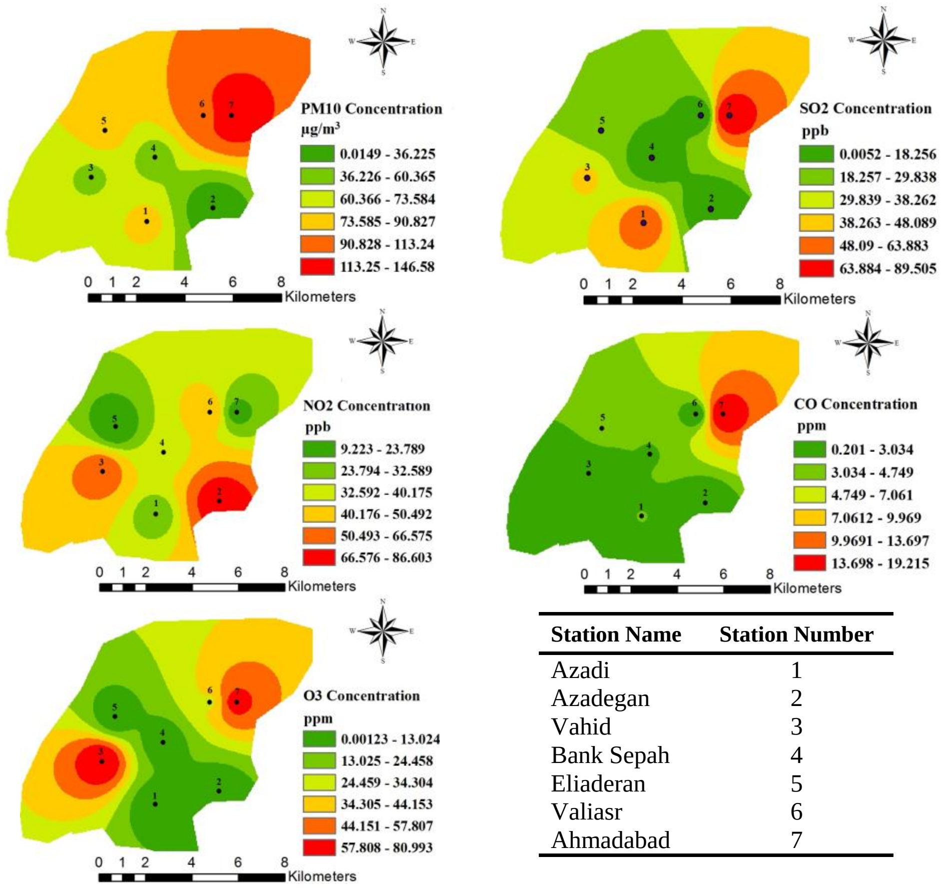


Figure 2: Monthly concentrations PM_{10} (A), SO_2 (B), NO_2 (C), CO (D) and O_3 (E) in monitoring stations

Table 3: Maximum AQI in monitoring stations in different seasons

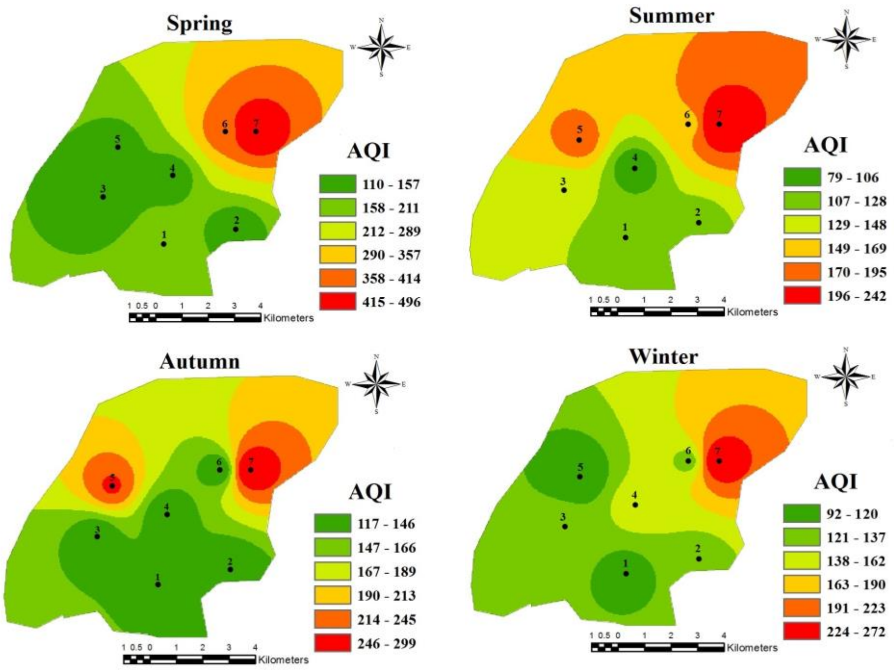
Pollutants	Seasons	AQI in Monitoring stations						
		Ahmadabad	Azadi	Bank Sepah	Valiasr	Azadegan	Eliaderan	Vahid
CO	Spring	100	71	52	6	6	136	26
	Summer	242	69	53	13	18	82	23
	Autumn	280	72	78	31	18	87	13
	Winter	272	44	81	35	21	62	25
O_3	Spring	213	61	*	71	47	49	11
	Summer	65	53	54	51	50	42	35
	Autumn	53	23	35	31	28	24	37
	Winter	41		51	*	*	*	45
SO_2	Spring	198	153	111	97	45	27	31
	Summer	67	102	63	61	*	74	134
	Autumn	71	139	95	78	*	144	122
	Winter	168	106	123	112	*	39	*
NO_2	Spring	17	72	46	105	110	58	78
	Summer	12	64	43	52	116	*	103
	Autumn	11	52	58	40	118	*	104
	Winter	40	10	50	13	106	*	112
PM_{10}	Spring	496	184	31	406	76	66	111
	Summer	193	110	79	157	98	189	113
	Autumn	299	92	120	117	107	253	82
	Winter	201	98	152	124	123	92	133

* Missing data



Station Name	Station Number
Azadi	1
Azadegan	2
Vahid	3
Bank Sepah	4
Eliaderan	5
Valiasr	6
Ahmadabad	7

Figure 3: Zoning of mean annual concentration of PM_{10}, SO_2, NO_2, O_3 and CO in the study area



Station Name	Azadi	Azadegan	Vahid	Bank Sepah	Eliaderan	Valiasr	Ahmadabad
Station Number	1	2	3	4	5	6	7

Figure 4: Zoning of AQI in monitoring stations in different seasons

Discussion

PM_{10} is the main cause of air pollution in Isfahan. These emissions can be attributed to traffic vehicles, excessive construction, stone cutting activities, numerous industries around the city, the lack of adequate plant coverage suburbs, surrounding deserts and dust intrusion from the neighbors such as Iraq and Saudi Arabia. All these factors have an impact in exacerbating the pollution caused by particulate matter [16]. According to Table 2, the maximum amount of PM_{10} was found in the month of May, June and December and the annual mean of PM_{10} was recorded at 99.15 µg/m^3, which is approximately 5 times the WHO standard [22]. Surveys of the monthly concentrations of PM_{10} in the monitoring stations showed that the Ahmedabad station, one of the most crowded areas with high traffic, recorded the highest contamination PM_{10} among all the monitoring stations. This could be due to the high volume of traffic as it is close to the historical monuments and the old texture of Isfahan. The zoning of pollutant concentrations by GIS also showed that the Ahmedabad station, due to its geographical conditions, has the highest concentration of PM_{10}. According to several studies, the main sources of particulate matter can be divided into four major sources such as vehicle exhaust, shell particles on dirt ground, industry emissions and secondary sulfate [16].

According to figure 2, the highest concentrations of PM_{10} in the Ahmedabad station during May, June and August could be attributed to vehicles emissions, intruding particles from the neighboring countries and the desert surrounding the area. The highest concentrations of PM_{10} in the cold seasons during the months of December, January and February could be due to cold weather, successive occurrence inversion and the density of the particles. The result of this study coincides with other studies in Tabriz in 2012 and 2014 corresponded [16, 23]. In another study that was conducted in the city of Milan, showed climatic conditions like the presence of wind and cold weather play an important role in the daily changes in the concentration of particulate matter [24].

The annual mean of SO_2 was 42.63 ppb, which was higher than WHO guidelines. The main sources of these pollutants can be mentioned as the thermal power plant, combustion of diesel and fuel oil combustion in heating systems, urban industries and diesel vehicles. According to Table 2, the average concentration of SO_2 in the warm months was more than the cold months. This can be due to the regional winds in the warm months, which cause wash-out of the chimneys of the power plants, refineries, steel industries and various other industries around the city [16, 25]. Another reason for the high concentration of pollutants in the warm season can be noted in the lack of sufficient information of SO_2 in some monitoring stations in the cold seasons. Figure 7 shows the concentration of SO_2 in the Ahmedabad and Vahid stations, located in the Aghababaei and Meysami highway routes, are more than the other stations.

Annual mean of NO_2 was 39.36 ppb hence its annual concentration was lower than the WHO standards. Also, NO_2 has a smaller share in the air pollution in Isfahan. Nevertheless, the concentration of NO_2 in the cold months, especially in the Ahmadabad station, had reached to three times of the WHO guidelines. This could be due to the cold temperature and air sustainability. The main source of this pollutant can be noted as high temperature combustion in refineries, power plants, domestic and commercial heating systems and vehicles. The annual average concentration of CO was 5.24 ppm. The highest concentration of these pollutants was registered in the Ahmedabad station, which was several times higher than the permissible level for this pollutant. According to Figure 5, the concentration of CO was increasing with the decreasing temperature during the different months. This increased concentration of pollutants in winter, which can be due to inversion and air sustainability. These results correspond with the previous studies [1, 16, 23]. The incomplete combustion of fossil fuels, increasing number of vehicles, poor quality of emissions of the vehicles and city buses are the main reasons for the production of CO in urban air.

The annual mean of O_3 was 41.54 ppm in Isfahan, however, considering that the information regarding this pollutant in some months of the year had not been recorded in the monitoring stations. Appropriate analysis cannot be provided on this pollutant. According to Figure 6, the highest amount of O_3 recorded was during the warm seasons. Considering that vehicles are the main source of hydrocarbons and nitrogen oxides in town, the increasing concentration of these pollutants in the warm season can be due to the photochemical reactions between nitrogen oxides and hydrocarbons in sunlight resulting in O_3 gas production.

Table 3 shows the maximum AQI values in all monitoring stations during 2012. According to this table, the highest AQI values have been recorded in the Ahmedabad station. The highest and lowest share in the Isfahan air pollution was related to PM_{10} and O_3, respectively. The highest and the lowest share in Tabriz's air pollution was PM_{10} and SO_2, respectively [16]. But the highest share of air pollution in Tehran during 2009-2008 has been reported with the 52 % of the O_3, 24% for PM_{10} and the lowest share with an amount of 4% related to SO_2 [26]. PM_{10} in Yazd in the 11 months of 2014 due to its climate conditions had the highest share in air pollution [14].

In this study, the air quality in Isfahan in 2012 was 4.38% (4 days) in good condition, 12.7% (47 days) in moderate, 42.56% (156 days) in unhealthy conditions for sensitive groups, 39.49% (144 days) in unhealthy conditions, 2.8% (10 days) in very unhealthy and 1.2% (4 days) in dangerous conditions, respectively. In other words, during 314 days of the year 2012, the air quality of Isfahan was higher than the standard level (AQI > 100). The air quality in Tehran, Isfahan and Shiraz cities in 341, 322 and 85 days of year 2011 were reported higher than the standard level (AQI > 100) [27].

In the entire zoning, the concentration of various pollutants in Isfahan city showed that Ahmedabad station was the most contaminated regions. Figure 8 also indicates that Ahmadabad station in most seasons had the highest AQI value. This station located near the Isfahan historical buildings, connecting West and East Isfahan, due to the existence of administrative and academic complexes in the region, has become the most polluted area in the city.

The main limitations of this study can be noted as the lack of pollutants information in some months of the year in the air pollution monitoring stations.

Conclusion

According to the study results, PM_{10} was the main cause of air pollution in Isfahan. The Ahmadabad station was the most polluted spot in the city. According to the AQI calculations, 314 days of the year 2012 in Isfahan had unhealthy conditions and only 4 days had the normal conditions. This issue was one of the biggest health challenges and now there are many concern about it. Other issues raised in the discussion of urban air pollution is an inadequate number of monitoring stations and the lack of information in the monitoring stations. So, we see that sometimes the concentration of a pollutant in the monitoring stations not been reported for several days and weeks. The most important step in the management and control of air pollution is the addition of more monitoring stations in the city and to equip them with more advanced devices combined with source identification of pollutant and their control in order to improve the public health and welfare of the citizens.

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Conflict of interest

The authors declare no competing interests.

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