Determination of Air Quality Index and Its Relationship With Meteorological Parameters in City of Mashhad

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A B S T R A C T

The aim of this study was to determine the air quality index (AQI) and to investigate its relationship with meteorological parameters in Mashhad for 2014. In this study, moment concentrations of air pollutants in Mashhad for 2014 were prepared and the amount of AQI was calculated and air quality was determined. Then, data analysis was performed using Kruskal-Wallis and Mann-Whitney tests at a significant level of 5% in SPSSV.23 software. Finally, data related to meteorological parameters were prepared during 2014 and ARIMA time series model and R software (3.3.0) were used to investigate its relationship with air index pollutants in non-delayed and one day late modes. The results showed that air quality of Mashhad was in a very bad condition in terms of maintaining the health of community members, especially sensitive groups, as the concentration of pollutants in this city was higher than Iranian standard (100) in 245 days of the study period. The PM2.5 was the most important pollutant during the study. It was also found that among the climatic parameters, temperature and pressure have the greatest direct effect on the concentration of air pollutants. Moreover, results showed the immediate effect of temperature on the concentration of air pollutants, although other atmospheric elements are able to significantly affect the outcome over time and with a time delay (one day in this study). The results indicated that quality of model computation depends on changes in atmospheric parameters, so that a quantitative measurement for each pollutant can be achieved based on meteorological data.

INTRODUCTION

Considering the influence of air on human life and its consumption overnight, it can be stated that the unfavorable quality of air in today's world is considered one of the most important environmental problems in many of the world's large cities [1, 2]. Air pollution refers to the existence of harmful substances and compounds in the atmosphere caused by natural phenomena or human activities [3].

Nowadays, various natural and artificial sources have changed the physical and chemical characteristics of the elements that make up the air and, in other words, have

caused air pollution [4]. In addition to human sources of air pollution including industries and transportation vehicles, natural resources also contribute to the air pollution [5]. Air pollutants contain many substances and compounds that enter into the air from various natural and manmade sources and cause atmospheric physical and chemical changes [6].

Air pollutants include ozone (O_3), nitrogen oxide (NO_X), carbon monoxide (CO), particulate matter (PM), sulfur dioxide (SO_2), etc., most of which are produced as a result of the combustion of fossil fuels [7]. Air pollution causes a wide range of acute and chronic health effects, from minor physiological disorders to death from

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respiratory and cardiovascular diseases [2]. Moreover, phenomena such as acid rains, global warming, and thickening of the ozone layer have greatly increased global attention to the issue of air pollution [3].

Considering the effects of air pollutants on human health and since determining the actual amount of pollutants, describing the air quality compared to the standard conditions, and communicating it to people at the right time is one of the most effective measures in the air quality control, assessment of the air quality health index (AQHI) based on the air quality index can be effective and helpful in this regard. The AQI is an indicator for daily reporting of air quality that informs people about the quality of air (whether it's clean or polluted) and its associated health effects. The AQI is calculated for five main air pollutants, including particulate matter, nitrogen dioxide, ozone, carbon monoxide, and sulfur dioxide, and is classified into 6 groups of good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and dangerous [2].

Various studies have shown the important and influential impact of several factors on seasonal and daily changes of pollutants., such as climatic and geographical conditions, type and location of sources of pollutants emission, and rate of pollutants emission. Therefore, it can be stated that the seasonal and daily pattern of pollutants is not the same in the different regions [8]. In the study conducted by Ahmadi et al. [9] that meteorological parameters such as relative humidity, wind speed, and frosty days play an important role in the distribution of pollutants in this city. In addition, the exploration of the effects of meteorological and urban outlook factors on the high air pollution of Beijing in 2015 showed that wind speed is the main determinant of air quality in this metropolis, as a wind speed of greater than 4 m/s can improve the air quality [10]. In this study, the role of particulate matter in air pollution and its relationship with meteorological parameters in Ahmedabad, India, it was shown that PM_{10} had a negative and significant correlation with precipitation, the highest AQI was related summer, and the environment of Ahmedabad, on average, is classified in the category of "unhealthy" [11].

Since few studies have been conducted about the relationship of the AQI and meteorological parameters in Mashhad and given that the relationship between the AQI and meteorological parameters has been proven in previous studies, it is necessary to conduct more investigations on this subject in major cities of Iran and especially Mashhad. The increasing population of Mashhad on the one hand and the annual presence of millions of pilgrims from Iran and other countries in this city to visit the Holy Shrine of Imam Reza (AS) on the other hand and also increased volume of traffic, expansion of industries, shortage of precipitation, and increased temperature in recent years have threatened the air quality of Mashhad and the health of residents. Hence,

the present study aims to determine the air quality index (AQI) and its relationship with meteorological parameters in the city of Mashhad for 2014-2015.

MATERIAL AND METHODS

The present research was a descriptive-analytical study which aimed to determine the status of air pollution in the city of Mashhad for 2014-2015 in terms of criteria pollutants (i.e. CO, SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$) based on the air quality index (AQI) and its relationship with meteorological parameters. It should be noted that, due to following reasons we have chosen time period of 2014-2015. To the best of our knowledge, the first year was 2014 with
1. Available data (in terms of hourly concentration of each variable)
2. Trustworthy data (in terms of the limited number of missing data and proper data collection techniques) air pollutant data in Mashhad.

To this end, the type and concentration of criteria pollutants in the air of Mashhad during the study period were extracted from the Environmental Pollution Monitoring Center. In addition, the data on meteorological parameters such as temperature, pressure, humidity, wind speed, and precipitation related to the study period were provided from Mashhad Meteorological Organization. Then, the data were arranged based on the daily mean for statistical computations.

In order to calculate the AQI value for CO, SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ concentration, the air quality [12] Equation 1 were used. The parameters used in Equation 1 were extracted from the pollutants concentration categories table, contained in the same book, was used which shows the breakpoints for the AQI. Then, the raw data derived from the measurement of air pollutants at each monitoring station were converted into separate AQI values for each pollutant using Equation (1). The highest AQI value calculated for each station was selected as the AQI of that station and then the highest AQI values for all measurement stations across the city were compared in order to obtain the highest AQI for the city of Mashhad.

$$IP = \left(\left(\frac{IHi - ILo}{BPHi - BPLo} \right) * (CP - BPLo) \right) + ILo \qquad (1)$$

in this equation, I_P, C_P, BP_{Hi}, BP_{Lo}, I_{Hi}, and I_{Lo} denote the AQI for Pollutant P, measured concentration of Pollutant P, a breakpoint equal to or greater than C_P, a breakpoint equal to or smaller than C_P, AQI value corresponding to BP_{Hi}, and AQI value corresponding to I_{Lo}, respectively.

To determine the air quality index (AQI), as the main objective of this study, the data were classified in one-dimensional tables and daily mean values were calculated. The statistical analyses were performed in SPSS-23 and the necessary charts were plotted using

Excel. The normal distribution of the data was tested by Kolmogorov-Smirnov test at the 5% level of significance. To examine the homogeneity of variances, Levene's test was used at the 5% level of significance (as homogeneous data). In addition, the non-parametric test of Kruskal-Wallis was used for non-normal data. It is noteworthy that the level of significance in this study was determined to be 0.05.

To investigate the relationship between pollutants and meteorological parameters, as the second aim of this study, collected data (meteorological parameters and criteria air pollutants) were classified in one-dimensional tables by the number of days and values of mean, minimum, maximum, and standard deviation were calculated. Given the high correlation between meteorological parameters and air pollutants, it was not possible to apply common statistical methods such as linear and multiple regression and Pearson correlation coefficient. Hence, time series regression was used to assess the relationship between above-mentioned factors. Therefore, after matching the data of air pollution and meteorological parameters in terms of time, the relationship between pollutants and meteorological parameters was studied in the non-lagged and lagged modes using inferential statistical methods such as the Jenkins Box Time Series Model (the autoregressive integrated moving average known as ARIMA) in Excel and R (3.3.0) software applications, at the 5% level of significance. In this statistical method, meteorological parameters are considered the independent variable, time (day or week) is the confounding factor, and air pollutants are the dependent variable. After eliminating the confounding factor (time) as well as paying attention to other features of the time series data, the relationship between meteorological parameters and air pollutants was studied in this research.

concluded that the air quality of Mashhad is in a very bad status in terms of maintaining the health of community members, especially sensitive groups. This requires more attention of authorities and urban planners and managers [13]. Because of the existence of historical and cultural monuments, especially the holy shrine of Imam Reza (AS), country-sides with a nice weather, and various universities, Mashhad is one of the most attractive cities of Iran in terms of pilgrimage and tourism which hosts millions of pilgrims and travelers from Iran and other countries. In addition to positive economic (employment, income, etc.) and sociocultural effects, the current tourism system of Mashhad has caused the city face instabilities in various ecological, sociocultural, and economic sectors, one of the most important of which is air pollution. Non-improvement of the status quo can increase the number of visits to health centers and even the hospitalization and death of sensitive people and closure of manufacturing, service, and educational centers. This will lead to the loss of national capital and the imposition of a huge economic burden on the whole society [13].

Figure 1 shows the share of each of the pollutants responsible for air pollution of Mashhad in year 2014 in cases that the AQI was above Iran's standard (100). According to the study results, it can be stated that $PM_{2.5}$ (96.73%), NO_2 (2.85%), and PM_{10} (0.4%), respectively, were the main pollutants responsible for air pollution of Mashhad in the study period (Figure 1). Increased suspended particles can be probably attributed to dust storms in recent years. These storms used to happen only during spring and summer but now they may be seen in 8 months of the year, which requires more attention of the authorities [14]. The greatest impact of dust storms on human health is related to suspended particles of PM_{10} and $PM_{2.5}$, as increased concentration of these particles

RESULTS

Assessment of the air quality status in Mashhad based on the AQI in 2014

Table 1 summarized the air quality health status of Mashhad for 2014 based on the AQI in each of the six classes by day and percentage. It should be noted that the number of days of 2014 for which valid data were available was equal to 357 that the concentration of pollutants was higher than Iran's standard (100) in 245 days. The results of this study indicated that 0.5% (0-50), 30.81% (51-100), 33.61% (101-150), 33.61% (151-200), 1.12% (201-300), and 0.28% (more than 300) of days of the study period were in a good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and dangerous status, respectively (Table 1). Considering the results of this study and taking into account the standards set by the US Environmental Protection Agency (the AQI can be above 100 only one day of the year), it can be

Table 1. The air quality health status of Mashhad for 2014 based on the AQI in 2014

AQI	Level of health importance	Color	Time (day)	Percent
0-50	Good	Green	2	0.5
51-100	Medium	Yellow	110	30.81
101-150	Unhealthy for sensitive groups	Orange	120	33.61
151-200	Unhealthy	Red	120	33.61
201-300	Very Unhealthy	Purple	4	1.12
Above 300	Dangerous	Murder	1	0.28
The number of days since 2014 when valid data was available			357	
The number of days since 2014, where the AQI was above the standard of Iran (100)			245	

during dust storms causes a wide range of diseases and even death due to penetration into the lung. $PM_{2.5}$ particles are the most serious risks for lung function and cardiovascular diseases. Recent studies report that 350,000 deaths due to cardiovascular disease and 220,000 deaths due to lung cancer caused by $PM_{2.5}$ particles annually occurred [5]. Reduced visible distance, changes in darkness coefficient, weather warming, interruption in plant growth, poisoning of animals, and filth and destruction of objects are among other harmful effects of suspended particles [15]. Moreover, reduced rainfall, increased traffic of vehicles, decreased per capital of green space, the arrival of millions of pilgrims from all over Iran and the world, and the existence of many industries around the city of Mashhad can be mentioned as other factors causing suspended particles and increasing concentration of these pollutants in Mashhad. Therefore, along with the daily production of hundreds of cars and increased fuel consumption, the art of air pollution management should be also learned to monitor and identify the criteria pollutants in each region in order to reduce then and create the most appropriate situation. It should be kept in mind that the issue of reducing pollutants in each region of this planet requires a continuous effort throughout the year and not just in certain seasons. The review of previous studies and application of experiences of other countries can also play an effective role in the advancement of management programs [14].

Descriptive statistics

Daily values of minimum, maximum, mean, and standard deviation of meteorological parameters and air pollutants of Mashhad for 2014 are presented in Table 2. According to this table, the daily mean of pressure, humidity, temperature, wind speed, and precipitation is equal to 603.26 Hpa, 48.76%, 16.21°C, 6.84 m/s, and 0.80 mm, respectively. In addition, the daily mean of $PM_{2.5}$, NO_2, O_3, CO, and SO_2 is equal to 27.60, 25.22 bbp, 14.94 bbp, 1.81 ppm, and 13.64 bbp (Table 2).
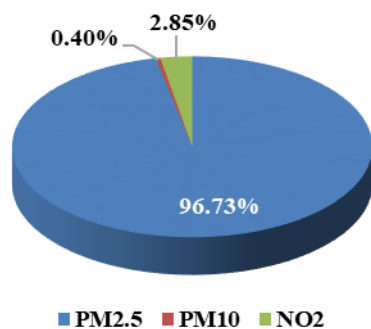

Figure 1. The share of each of the criteria pollutants in the air pollution of Mashhad for 2014

The monthly mean of meteorological parameters in different months of 2014 indicates the highest pressure, humidity, temperature, wind speed, and precipitation are related to December, December, July, and July, while the lowest monthly mean of these parameters can be observed in July, August, December, and December. In addition, the highest precipitation belongs to April and its lowest value (0 mm) relates to July, August, and September. In terms of criteria pollutants (O_3, NO_2, $PM_{2.5}$, PM_{10}, and SO_2), the highest monthly mean is related to June, January, October, October, and June and the highest values can be observed in December, March, March, March, and August, respectively. Moreover, the highest monthly mean of CO belongs to April, May, and July and its lowest value is observed in September, October, and March, December, and December. In addition, the highest precipitation belongs to April and its lowest value (0 mm) relates to July, August, and September. In terms of criteria pollutants (O_3, NO_2, $PM_{2.5}$, PM_{10}, and SO_2), the highest monthly mean is related to June, January, October, October, and June and the highest values can be observed in December, March, March, March, and August, respectively. Moreover, the highest monthly mean of CO belongs to April, May, and July and its lowest value is observed in September, October, and March.

The relationship between meteorological parameters and criteria pollutants in Mashhad for 2014

Then, the fitting of the time series to investigate the relationship between meteorological elements and air pollutants was performed using ARIMA. The results will be described in detail for each pollutant as following.

Table 2. Daily values of minimum, maximum, mean, and standard deviation of meteorological parameters and air pollutants of Mashhad for 2014

	Variable name	Minimum	Mean	Maximum	Standard deviation
Meteorological parameters	Pressure	4.872	903.256	920.713	888.725
	Wind speed	2.486	6.849	23.000	3.000
	Rain	2.841	0.823	34.800	0.000
	Humidity	24.503	48.760	99.000	14.500
	Temperature	9.483	16.126	32.600	-2.100
Air pollutants	$PM_{2.5}$	12.505	27.604	105.064	4.843
	NO_2	7.450	24.388	55.119	8.252
	O_3	6.881	14.945	33.604	2.612
	CO	0.321	1.815	3.360	1.161
	SO_2	3.629	13.646	48.422	9.206
	PM_{10}	49.986	83.282	319.180	4.000

PM$_{2.5}$

The fitting of the final model to determine the relationship between meteorological parameters and PM$_{2.5}$ in the city of Mashhad for 2014 included two ARIMA models of (3, 1, 1) and (5, 1, 0) in the non-lagged and one-day lag modes, respectively. Coefficients of meteorological parameters in the final model as well as the size of their relationship with the outcome (PM$_{2.5}$ concentration) have been shown in Table 3. In addition, Equations (2) and (3) were used for the calculation of this model in the non-lagged and one-day lag modes, respectively.

$$Y_t = 0.433 \text{ Pressure} + 0.833 \text{ Temperature} + e_t \quad (2)$$

$$Y_t = 1.522 \text{ Temperature} + e_t \quad (3)$$

where, Y_t denotes the dependent variable (PM$_{2.5}$ concentration) and e_t represents the error of the time series regression model at time t.

The results of this model in the non-lagged mode indicate that, among meteorological parameters, temperature (p=0.05) and pressure (p=0.004) have a positive and significant impact on the outcome. This means that the concentration of PM$_{2.5}$ increases with the increase in temperature and pressure. Since the temperature has the greatest impact among these parameters in terms of the absolute value, it can be found that the higher the temperature, the higher the concentration of PM$_{2.5}$. In fact, among the above-mentioned parameters, the mean temperature, with a superiority of 0.883, plays a more important role in the increased PM$_{2.5}$ concentration than pressure, because every unit of temperature increase in Mashhad raises the concentration of PM$_{2.5}$ by 0.833, while every unit of pressure increases the concentration of this pollutant by 0.433.

As it can be observed, the results totally changed when a one-day lag was considered for independent variables. Accordingly, the effect of other meteorological parameters, except temperature, was not significant at the 0.05 level of significance. This suggests that temperature significantly affects the current concentration of PM$_{2.5}$ by 1.522 units on a day before and increases its concentration.

PM$_{10}$

The fitting of the final model to determine the relationship between meteorological parameters and PM$_{10}$ in the city of Mashhad for 2014 included two ARIMA models of (1, 0, 0) and (1, 0, 0) in the non-lagged and one-day lag modes, respectively. Coefficients of meteorological parameters in the final model as well as the size of their relationship with the outcome (PM$_{10}$ concentration) have been shown in Table 4. In addition, Equation (4) was used for the calculation of this model in the non-lagged mode.

$$Y_t = 3.131 \text{ Temperature} + e_t \quad (4)$$

where, Y_t denotes the dependent variable (PM$_{10}$ concentration) and e_t represents the error of the time series regression model at time t.

The results of this model in the non-lagged mode indicated that, among meteorological parameters, only temperature has a positive and significant impact on PM$_{10}$ concentration (p=0.002). Therefore, it can be stated that the higher the temperature, the higher the concentration of PM$_{10}$. In fact, the mean temperature plays a major role in the increased concentration of this pollutant by 3.131, because every unit of temperature increase in Mashhad raises the concentration of PM$_{10}$ by 3.131.

As it can be observed, the results totally changed when a one-day lag was considered for independent

Table 3. The model parameters for determining the relationship between meteorological parameters and PM$_{2.5}$ concentration in Mashhad for 2014

Time delay	Variable name	Coefficient estimation	The standard deviation	p-value
Non-lagged (0 days)	Pressure	0.433	0.221	0.050
	Wind speed	0.118	0.233	0.613
	Rain	0.098	0.185	0.597
	Humidity	0.055	0.062	0.369
	Temperature	0.833	0.292	0.004
One-day lag	Pressure	0.006	0.218	0.979
	Wind speed	0.244	0.225	0.278
	Rain	-0.116	0.185	0.532
	Humidity	0.076	0.061	0.215
	Temperature	1.522	0.304	0.000

Table 4. The model parameters for determining the relationship between meteorological parameters and PM$_{10}$ concentration in Mashhad for 2014

Time delay	Variable name	Coefficient estimation	The standard deviation	p-value
Non-lagged (0 days)	Pressure	-0.011	0.036	0.764
	Wind speed	1.738	1.198	0.147
	Rain	-0.620	0.893	0.488
	Humidity	0.561	0.341	0.100
	Temperature	3.131	0.997	0.002
One-day lag	Pressure	1.887	1.153	0.102
	Wind speed	0.284	1.187	0.811
	Rain	-0.685	0.892	0.442
	Humidity	-0.545	0.348	0.117
	Temperature	1.900	1.112	0.088

variables. Accordingly, the effect of none of the meteorological parameters on PM_{10} concentration was significant at the 0.05 level of significance.

It is noteworthy that the data on PM_{10} were available only in 191 days from the 365 days of the studied year and the conclusions are based on this amount of data.

Nitrogen dioxide (NO₂)
The fitting of the final model to determine the relationship between meteorological parameters and PM_{10} in the city of Mashhad for 2014 included two ARIMA models of (5, 1, 1) and (5, 0, 0) in the non-lagged and one-day lag modes, respectively. Coefficients of meteorological parameters in the final model as well as the size of their relationship with the outcome (NO_2 concentrations) are summarized in Table 5. In addition, Equations (5) and (6) were used for the calculation of this model in the non-lagged and one-day lagged modes.

$$Y_t = 0.939 \text{ Temperature} + e_t \qquad (5)$$

$$Y_t = -0.390 \text{ Pressure} - 0.144 \text{ Humidity} + e_t \qquad (6)$$

where, Y_t denotes the dependent variable (NO_2 concentration) and e_t represents the error of the time series regression model at time t.

The results of this model in the non-lagged mode indicated that, among meteorological parameters, only temperature has a positive and significant impact on NO_2 concentration (p=0.000). Therefore, it can be stated that the higher the temperature, the higher the concentration of NO_2. In fact, the mean temperature plays a major role in the increased concentration of this pollutant by 0.939, because every unit of temperature increase in Mashhad raises the concentration of NO_2 by 0.939.

Table 5. The model parameters for determining the relationship between meteorological parameters and NO_2 concentration in Mashhad for 2014

Time delay	Variable name	Coefficient estimation	The standard deviation	p-value
Non-lagged (0 days)	Pressure	0.120	0.112	0.286
	Wind speed	0.059	0.109	0.588
	Rain	0.067	0.094	0.473
	Humidity	0.049	0.033	0.137
	Temperature	0.939	0.163	0.000
One-day lag	Pressure	-0.390	0.111	0.000
	Wind speed	-0.134	0.097	0.167
	Rain	-0.014	0.083	0.870
	Humidity	-0.144	0.030	0.000
	Temperature	0.251	0.158	0.111

As it can be observed, the results totally changed when a one-day lag was considered for independent variables. Accordingly, only pressure and humidity, among meteorological parameters, have a negative and significant impact on the outcome (p=0.000). This means that the concentration of NO_2 reduces with the increase in pressure and humidity. Since pressure has the greatest impact among these parameters in terms of the absolute value, it can be found that the higher the pressure, the higher the concentration of NO_2. In fact, among the above-mentioned parameters, the mean pressure, with a superiority of 0.390, plays a more important role in the reduced NO_2 concentration than humidity, because every unit of pressure increase in Mashhad lowers the concentration of NO_2 by 0.390, while every unit of humidity reduces the concentration of this pollutant by 0.144.

Ozone (O₃)
The fitting of the final model to determine the relationship between meteorological parameters and O_3 in the city of Mashhad for 2014 included two ARIMA models of (2, 1, 2) and (1, 1, 0) in the non-lagged and one-day lag modes, respectively. Coefficients of meteorological parameters in the final model as well as the size of their relationship with the outcome (O_3 concentration) have been shown in Table 6. In addition, Equations (7) and (8) were used for the calculation of this model in the non-lagged and one-day lagged modes.

$$Y_t = -0.218 \text{ Temperature} + e_t \qquad (7)$$

$$Y_t = 0.225 \text{ Wind speed} + 0.183 \text{ Pressure} - 0.155 \text{ Humidity} + e_t \qquad (8)$$

where, Y_t denotes the dependent variable (O_3 concentration) and e_t represents the error of the time series regression model at time t.

The results of this model in the non-lagged mode indicated that, among meteorological parameters, only temperature has a negative and significant impact on O_3 concentration (p=0.044). Therefore, it can be stated that the higher the temperature, the lower the concentration of O_3. In fact, the mean temperature plays a major role in the reduced concentration of this pollutant by 0.218, because every unit of temperature increase in Mashhad lowers the concentration of O_3 by 0.218.

As it can be observed, the results totally changed when a one-day lag was considered for independent variables. Accordingly, only wind speed and pressure have a positive and significant and humidity has a negative and significant impact on the outcome (p=0.001, 0.017, and 0.000). This means that the concentration of O_3 increases with the increase in pressure and wind speed and reduction in humidity. Since wind speed has the greatest impact among these parameters, it can be found that the higher the wind speed, the higher the

Table 6. The model parameters for determining the relationship between meteorological parameters and O_3 concentration in Mashhad for 2014

Time delay	Variable name	Coefficient estimation	The standard deviation	p-value
Non-lagged (0 days)	Pressure	-0.0586	0.078	0.453
	Wind speed	0.0281	0.0759	0.712
	Rain	0.0604	0.0624	0.333
	Humidity	-0.0245	0.0219	0.264
	Temperature	-0.2184	0.1087	0.044
One-day lag	Pressure	0.183	0.077	0.017
	Wind speed	0.225	0.068	0.001
	Rain	-0.029	0.055	0.594
	Humidity	-0.115	0.020	0.000
	Temperature	-0.155	0.105	0.140

Table 7. The model parameters for determining the relationship between meteorological parameters and CO concentration in Mashhad for 2014

Time delay	Variable name	Coefficient estimation	The standard deviation	p-value
Non-lagged (0 days)	Pressure	0.005	0.006	0.356
	Wind speed	0.009	0.006	0.143
	Rain	0.001	0.005	0.830
	Humidity	0.000	0.002	0.869
	Temperature	0.037	0.008	0.000
One-day lag	Pressure	-0.015	0.005	0.006
	Wind speed	-0.013	0.006	0.019
	Rain	0.010	0.005	0.033
	Humidity	-0.005	0.001	0.000
	Temperature	0.027	0.007	0.000

concentration of NO_3. In fact, among the above-mentioned parameters, the mean wind speed, with a superiority of 0.225, plays a more important role in the increased NO_3 concentration than pressure and humidity, because every unit of wind speed increase in Mashhad raises the concentration of O_3 by 0.225, while every unit of pressure and humidity, respectively, increases and reduces the concentration of this pollutant by 0.183 and 0.155.

Carbon monoxide (CO)
The fitting of the final model to determine the relationship between meteorological parameters and CO in the city of Mashhad for 2014 included two ARIMA models of (5, 1, 1) and (4, 1, 0) in the non-lagged and one-day lag modes, respectively. Coefficients of meteorological parameters in the final model as well as the size of their relationship with the outcome (CO concentrations) are summarized in Table 7. In addition, Equations (9) and (10) were used for the calculation of this model in the non-lagged and one-day lagged modes.

$$Y_t = 0.037 \text{ Temperature} + e_t \tag{9}$$

$$Y_t = -0.015 \text{ Pressure} - 0.013 \text{ Wind speed} - 0.005$$
$$\text{Humidity} + 0.01 \text{ Rainfall} + 0.027 \text{ Temperature} \tag{10}$$
$$+ e_t$$

where, Y_t denotes the dependent variable (CO concentration) and e_t represents the error of the time series regression model at time t.

The results of this model in the non-lagged mode indicated that, among meteorological parameters, only temperature has a positive and significant impact on CO concentration (p=0.000). Therefore, it can be stated that the higher the temperature, the higher the concentration

of CO. In fact, the mean temperature plays a major role in the increased concentration of this pollutant by 0.037, because every unit of temperature increase in Mashhad raises the concentration of CO by 0.037.

As it can be observed, the results totally changed when a one-day lag was considered for independent variables. Accordingly, in addition to temperature, other meteorological parameters have a significant impact on the outcome at the 0.05 level of significance. In fact, temperature (0.000) and precipitation (0.033) have a significant and positive impact and pressure (0.006), wind speed (0.019), and humidity (0.000) have a significant and negative impact on the outcome. This means that the concentration of CO increases with the increase in temperature and precipitation and reduction in pressure, wind speed, and humidity. Since the temperature has the greatest impact among these parameters, it can be concluded that the higher the temperature, the higher the concentration of CO. In fact, among the above-mentioned parameters, the mean temperature, with a superiority of 0.027, plays a more important role in the increased NO_3 concentration than precipitation, pressure, wind speed, and humidity, because every unit of temperature increase in Mashhad raises the concentration of CO by 0.027, while the effectiveness of precipitation, pressure, wind speed, and humidity is equal to 0.01, 0.015, 0.013, and 0.005, respectively.

Sulfur dioxide (SO₂)
The fitting of the final model to determine the relationship between meteorological parameters and SO_2 in the city of Mashhad for 2014 included two ARIMA models of (4, 1, 1) and (3, 1, 0) in the non-lagged and one-day lag modes, respectively. Coefficients of meteorological parameters in the final model as well as the size of their relationship

with the outcome (SO$_2$ concentrations) are summarized in Table 8. In addition, Equations (11) and (12) were used for the calculation of this model in the non-lagged and one-day lagged modes.

$$Y_t = 0.135\ Pressure + 0.317\ Temperature + 0.152 \\ Wind\ speed + e_t \tag{11}$$

$$Y_t = 0.31\ Temperature - 0.031\ Humidity + e_t \tag{12}$$

where, Y_t denotes the dependent variable (SO$_2$ concentration) and e_t represents the error of the time series regression model at time t.

The results of this model in the non-lagged mode indicated that, among meteorological parameters, pressure (0.016), temperature (0.000), and wind speed (0.021) have a positive and significant impact on the outcome. This means that the concentration of SO$_2$ increases with the increase in pressure, temperature, and wind speed. Since the temperature has the greatest impact among these parameters in terms of the absolute value, it can be stated that the higher the temperature, the higher the concentration of SO$_2$. In fact, among the above-mentioned parameters, the mean temperature, with a superiority of 0.317, plays a more important role in the increased SO$_2$ concentration than pressure and wind speed, because every unit of temperature increase in Mashhad raises the concentration of SO$_2$ by 0.317, while the effectiveness of pressure and wind speed is equal to 0.135 and 0.152, respectively.

As it can be observed, the results totally changed when a one-day lag was considered for independent variables. Accordingly, in addition to temperature, humidity has a significant impact on the outcome at the 0.05 level of significance. The results of this model demonstrated that temperature has a significant and positive impact (p=0.000) and humidity has a significant and negative impact (p=0.047) on the outcome. This means that the concentration of SO$_2$ increases with the reduction in humidity and increase in temperature. This suggests that temperature significantly affects the current concentration of SO$_2$ by 0.310 units on a day before and increases its concentration, while the effectiveness of humidity is equal to 0.031.

DISCUSSION

In general, the results of fitting the time series to determine the relationship between meteorological parameters and air pollutants using an ARIMA in the non-lagged and one-day lag modes indicate that, among meteorological parameters, temperature and then pressure have the greatest impact on the concentration of criteria pollutants. Despite the positive relationship between above-mentioned parameters and air pollutants, it can be stated that the higher the temperature and pressure, the higher the concentration of air pollutants. In addition, the

Table 8. The model parameters for determining the relationship between meteorological parameters and SO$_2$ concentration in Mashhad for 2014

Time delay	Variable name	Coefficient estimation	The standard deviation	p-value
Non-lagged (0 days)	Pressure	0.135	0.056	0.016
	Wind speed	0.152	0.066	0.021
	Rain	0.099	0.057	0.084
	Humidity	-0.014	0.016	0.379
	Temperature	0.317	0.078	0.000
One-day lag	Pressure	0.108	0.058	0.061
	Wind speed	-0.064	0.065	0.322
	Rain	0.006	0.057	0.916
	Humidity	-0.031	0.016	0.047
	Temperature	0.310	0.079	0.000

study findings suggest the momentary impact of temperature on the concentration of air pollutants (CO, SO$_2$, NO$_2$, O$_3$, PM$_{10}$, and PM$_{2.5}$). However, other meteorological parameters are able to significantly affect the concentration of pollutants over time and with a time delay (one day in this study) (Tables 3 to 8).

Temperature is one of the factors affecting chemical interactions and therefore increasing the concentration of pollutants. In some cases, reduced temperature with increasing pressure and decreasing relative humidity, which itself is the cause of inversion, increase the concentration of pollutants. In the analysis of time series of the concentration of ozone and nitrogen oxide in an urban area in Brazil, the authors concluded that the daily mean concentration of PM$_{10}$, O$_3$, NO$_2$, NO$_X$, NO, and CO has a correlation with meteorological parameters (temperature, wind speed, solar radiation, and relative humidity) in the study area [16].

Changes in pressure patterns make changes in the environment, as the intensity of the heat island, the inversion layer, and direction of winds and pollutants all are controlled by pressure patterns. For instance, in a day when a city is dominated by a high-pressure pattern, even if the inversion layer is also high, a stable layer of air is created, pollutants cannot climb, and thereby the air gets polluted. By contrast, in the case of a low-pressure pattern, the air will be clean even in the most hectic working day. In other words, because of the downward nature of wind currents, air pollutants cannot be transferred to upwards in high-pressure systems. Hence, high air pollution is expected due to the stability of the atmosphere and the absence of particles and airborne contaminants and the presence of particles and pollutants in the air [9]. In the study of seasonal and daily changes of air pollutants and their relationship with

meteorological parameters, it was shown that there are two peaks for CO, NO_2, and PM_{10}; one in the summer and other in the winter. In addition, the maximum concentration of SO_2 and O_3 was observed during the winter and the spring, respectively. The maximum values during the cold season can be attributed to increased consumption of fuels by heating devices and vehicles as well as meteorological conditions such as increasing air pressure, air stability, and temperature inversion. In addition, maximum values in the warm season may occur due to several factors such as surface temperature inversion and precipitation decrease. The comparison of daily patterns of various pollutants during the spring shows that all pollutants, except O_3, have two peaks; one early in the morning and one late at night. The O_3 pattern is different from other pollutants and its maximum usually occurs in the afternoon. Moreover, it was found that the traffic of vehicles and a temperature inversion in the early morning and night are also involved in the occurrence of these peaks. The daily mean pattern of CO during the winter and summer suggests the existence of two peaks in the morning and at night [8].

According to the results of this study, it can be stated that wind speed also has a significant effect on the concentrations of O_3, SO_2, and CO. Several studies have reported the effective role of wind in transmitting and distributing pollutants in horizontal and vertical directions. The concentration of pollutants in the ground atmosphere essentially depends on the severity and direction of the wind and its rate of decline. If the wind continuously blows in a certain direction, pollutants are transmitted in that direction. However, if the direction of the wind is variable, like the quiet conditions near the ground, pollutants are scattered on a large scale. Where there are several sources of pollution in the direction of the wind, pollutants accumulate there [9]. The exploration of the effects of meteorological and urban outlook factors on the high air pollution of Beijing in 2015 showed that wind speed is the main determinant of air quality in this metropolis, as a wind speed of greater than 4 m/s can improve the air quality [10]. In a study entitled "The Effects of Meteorological Parameters on Air Pollution in Sanandaj for 2014-2015", the authors concluded that meteorological parameters such as relative humidity, wind speed, and frosty days play an important role in the distribution of pollutants in this city [9]. The results of a study on the time series of the concentration of ozone and nitrogen oxide in an urban area in Brazil showed that there is a positive correlation between wind speed and ozone concentration, as increased speed of wind increases the scattering of pollutants in nearer sources such as highways and fixed resources, optimizes ozone formation, and increases its concentration [16].

The results of this study also indicated that humidity also affects the concentration of NO_2, O_3, SO_2, and CO. Increased relative humidity, if accompanied by rainfall, can reduce air pollutants. Therefore, this is one of the factors that reduce the concentration of pollutants in high relative humidity. By contrast, reduced relative humidity increases the concentration of pollutants [8]. The results of a study on the time series of the concentration of ozone and nitrogen oxide in an urban area in Brazil demonstrated that there is a positive correlation between the concentration of nitrogen oxide, PM_{10}, and CO and relative humidity in this area which can be attributed to the movement of new air masses in the studied area (mainly polar air masses) which can minimize the cumulative concentration of these pollutants. Moreover, the negative correlation between ozone and relative humidity could be due to the role of this meteorological element in the reduction of photochemical reactions affecting ozone production. Accordingly, high levels of relative humidity with atmospheric instability and large cloud cover can reduce photochemical processes and thereby the production of ozone [16]. Najafpoor et al. [17] also stated that considering the significant relationship between some of the meteorological parameters and concentration of pollutants, meteorological variables can be effective in the amount of air pollution in Tehran. Based on the results of their statistical surveys, the maximum concentration of pollutants is observed when the relative humidity is low. In other words, air dryness is associated with increased concentration of pollutants. Increased relative humidity, if accompanied by rainfall, can reduce air pollutants. Therefore, this is one of the factors that reduce the concentration of pollutants in high relative humidity and rainfall.

The study findings proved the relationship of CO concentration with precipitation. Despite the high mean of precipitation in Mashhad, the concentration of CO is high in this city. This can be attributed to rainfalls of less than 5 mm which cause more filth of the air . In the study of the role of particulate matter in air pollution and its relationship with meteorological parameters in Ahmedabad, India [11], it was shown that PM_{10} has a negative and significant correlation with precipitation, the highest AQI was related summer, and the environment of Ahmedabad, on average, is classified in the category of "unhealthy".

Generally, the present study shows that there is a significant relationship between meteorological parameters and the criteria pollutants of the air in Mashhad for 2014. Therefore, after computations about the relationship of the criteria air pollutants with meteorological parameters such as temperature, humidity, pressure, wind speed, and precipitation, air pollution can be reduced by controlling the concentration of pollutants from moving sources, using catalytic converters, correcting fuel quality, and modifying combustion engines. Observing the principles of urban planning and architecture in urban development in order to pave the way for the quick passage of vehicles and prevention of heavy traffic jams seems to be necessary in this regard. In addition, implementation of air pollution

control programs, environmental monitoring of constant sources of pollution, and development of comprehensive and updated environmental standards can be helpful in the reduction of air pollution. Another effective strategy can be to develop a database of industries working in Mashhad, including factories and centers that use fossil fuels. Investigations on the location of factories in terms of meteorological parameters such as wind direction, ups and downs of the land, and other relevant factors, transfer or establishment of factories or workshops in industrial towns in suburban areas, and development of green belts and forests can help us to take positive steps towards the reduction of pollutants concentration and improvement of the air quality in Mashhad. It is noteworthy that unpredictability of meteorological parameters and lack of numerical estimation of them may reduce our control over the air pollution.

CONCLUSION

The results of this study indicate that $PM_{2.5}$ has the greatest impact on the air pollution of Mashhad for 2014 and cause the AQI to exceed the standard level. The study findings also showed that 0.5% (0-50), 30.81% (51-100), 33.61% (101-150), 33.61% (151-200), 1.12% (201-300), and 0.28% (more than 300) of days of the study period were in a good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and dangerous status, respectively. Therefore, it can be concluded that the air quality of Mashhad is in a very bad status in terms of maintaining the health of community members, especially sensitive groups. This requires more attention of authorities and urban planners and managers. In addition, the results of fitting the time series to determine the relationship between meteorological parameters and air pollutants using an ARIMA in the non-lagged and one-day lag modes indicate that, among meteorological parameters, temperature and then pressure have the greatest impact on the concentration of criteria pollutants. Despite the positive relationship between above-mentioned parameters and air pollutants, it can be stated that the higher the temperature and pressure, the higher the concentration of air pollutants. Moreover, the study findings suggest the momentary impact of temperature on the concentration of air pollutants (CO, SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$). However, other meteorological parameters are able to significantly affect the concentration of pollutants over time and with a time delay (one day in this study). It was also shown that the wind speed has a significant impact on the concentration of O_3, SO_2, and CO, and humidity has the same impact on the concentration of NO_2, O_3, SO_2, and CO. The study findings proved the relationship of CO concentration with precipitation. Despite the high mean of precipitation in Mashhad, the concentration of CO is high in this city. This can be attributed to rainfalls of less than 5 mm which

cause more filth of the air. Considering the relationship between meteorological parameters and air pollutants in the city of Mashhad during the study period, high concentration of dust in the sky of this city, and the resulting unfavorable weather conditions, increased number of days with an unhealthy air quality in this city is expected which can cause many problems in people's lives and health. Therefore, this issue requires more attention of authorities and urban planners and managers, because the unpredictability of meteorological parameters and lack of numerical estimation of them may reduce our control over the air pollution. The neglect or lack of attention of humans to air pollutants can deprive the next generation of breathing in a clean air that is the absolute right of every human being. Hence, in addition to the identification of various sources of pollution, it is necessary to continuously monitor the air quality indicators and take the appropriate measures to modify them.

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Persian Abstract

چکیده

امروزه آلودگی هوا بعنوان یکی از معضلات مهم شهرنشینی و زندگی صنعتی مطرح بوده و پیامدهای مختلف و اثرات بهداشتی آن باعث شده است که کنترل کیفیت هوا به صورت امری گریز ناپذیر در رأس مسائل ملی مطرح شود. لذا جهت کاهش اثرات ناشی از آن باید پارامترهای موثر بر این پدیده را به خوبی شناسایی نمود. از آنجا که آلودگی هوای تنفسی شهر مشهد در اکثر موارد فراتر از حد استاندارد می‌باشد، لذا این تحقیق با هدف تعیین شاخص کیفیت هوا (AQI) و بررسی ارتباط آن با پارامترهای هواشناسی شهر مشهد در سال ۱۳۹۳، انجام شد. در این مطالعه توصیفی- تحلیلی، غلظت های لحظه ای آلاینده‌های شاخص هوای شهر مشهد در سال ۱۳۹۳ با مراجعه به مرکز پایش آلاینده‌های زیست محیطی تهیه گردید و میزان AQI نیز محاسبه شده و کیفیت هوا مشخص گردید. سپس تجزیه و تحلیل داده‌ها با استفاده با آزمون‌های ناپارامتریک Kruskal-Wallis و Mann-Whitney در سطح معناداری ۵٪ در نرم افزار آماری SPSSV.23 انجام شد. در نهایت داده‌های مربوط به به عناصر اقلیمی همچون دما، فشار، رطوبت، سرعت باد و بارندگی در طول دورۀ آماری سال ۱۳۹۳ با مراجعه به سازمان هواشناسی مشهد تهیه و از مدل سری زمانی محض ARIMA و نرم افزار آماری R (3.3.0) به منظور بررسی ارتباط آن با آلاینده‌های شاخص هوا در حالت‌های بدون تأخیر و با تأخیر یک روز استفاده گردید. نتایج این مطالعه نشان داد که کیفیت هوای شهر مشهد در وضعیت بسیار وخیمی از نظر حفظ سلامتی اعضای جامعه به ویژه گروه‌های حساس قرار داشته به طوری که ۲۴۵ روز از مدت مورد مطالعه در آن، بالاتر از حد استاندارد ایران (۱۰۰) بود. همچنین ساختار فیزیکی معادلات در اثر بر هم کنش جو با آلاینده‌ها در بررسی ارتباط میان عناصر جوی و آلاینده‌های معیار شهر مشهد در سال۱۳۹۳ بدست آمد و بر این اساس مشخص شد که از میان پارامترهای اقلیمی، دما و فشار بیشترین تأثیر را بصورت مستقیم بر غلظت اکثر آلاینده‌های شاخص هوا دارند. علاوه بر این نتایج مطالعه حاضر، نشان‌دهنده تأثیر آنی دما بر غلظت آلاینده‌های هوا بود، هر چند سایر عناصر جوی با گذشت زمان و با تأخیر زمانی (در این مطالعه بصورت ۱ روز) قادر به اثرگذاری معنادار بر پیامد می‌باشند. نتایج این مطالعه نشان داد که کیفیت محاسبه مدل به طور گسترده به تغییرات پارامترهای جوی وابسته است، به طوری که می‌توان به معادلات آلودگی متفاوت و در نتیجه به یک سنجش کمی برای هر آلاینده با توجه به داده‌های هواشناسی و در شرایط جوی متفاوت دست یافت. بنابراین به نظر می‌رسد که با توجه به اثرات سوء آلاینده‌ها بر سلامتی انسان، آگاهی از روند تغییرات آن‌ها به همراه برنامه‌ریزی‌های کوتاه مدت و بلند مدت ملی و منطقه‌ای می‌تواند در جهت رفع این مشکل موثر واقع گردد.