Original Article

Investigating Air Pollutant Trends Based on Temporal Air Quality Indexes in Karaj, Iran, during 2012 – 2018

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Abstract

Aim: Due to the importance of the relationship between air pollutants and the incidence of many diseases in polluted cities, in this study, we collected the data related to yearly, seasonally, monthly, daily, and hourly concentrations of particulate matter $(PM)_{2.5}$, PM_{10}, sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3) recorded at four monitoring stations across Karaj city, Iran, to investigate the air pollutant trends based on air quality indexes (AQIs) in the city during 2012–2018. **Materials and Methods:** The correlations between PMs and gaseous pollutants were analyzed using the Pearson correlation coefficient. The concentrations of air pollutants indexes including O_3, NO_2, SO_2, CO, PM_{10}, and $PM_{2.5}$ were recorded in four air pollution monitoring stations in Karaj obtained from the monitoring system of the environment department. Then, the data were analyzed using SPSS and Graph pad softwares. **Results:** The findings showed that in 20%–40% and 1%–5% of days during 2012–2018, higher concentrations of $PM_{2.5}$ and PM_{10} were experienced than the national standard (NS) concentration, respectively. Furthermore, during this time, 0.3%–0.9% of days indicated the higher concentrations of CO and SO_2 than the NS, respectively. Although the daily concentration of NO_2 was lower than NS, 0.5%–5% of days were exposed to the higher concentration of O_3 than NS. SO_2 concentration showed a negative and positive correlation with PM_{10} ($r = -0.69$, $P = 0.013$) and O_3($r = 0.58$, $P = 0.03$), respectively. **Conclusion:** These results indicated that Karaj AQI was moderate and the most problem with air quality in Karaj city was attributed to the $PM_{2.5}$ concentrations. To reduce health disorders related to this pollutant, it is necessary to control $PM_{2.5}$ sources and sensitive groups should reduce outdoor activities.

Keywords: Air pollution, air quality index, Karaj, temporal changes

Introduction

Industrialization and urbanization over the last decades, along with rapid global economic growth, have resulted in an increase in ambient air pollution, which is a serious threat to human health.[1] Ambient air pollutants include complex mixtures of particles and gases such as carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matters (PMs).[2-5] Exposure to $PM_{2.5}$ and PM_{10} can aggravate chronic respiratory and cardiovascular diseases, alter host defenses, and damage lung tissue.[4,6] It can also lead to premature death and cancer. Ground-level O_3 can exacerbate chronic respiratory diseases and cause short-term reductions in lung function. The health effects of exposure to CO, SO_2, and NO_2 gases can include reduced work capacity, aggravation of existing cardiovascular diseases, negative effects on pulmonary function, respiratory illnesses, lung irritation, and alteration to lung defense systems.[7,8] Estimations of the magnitude of risk have been based on the factors related to the air pollutant mixture, personal exposure, study methods, evaluation models, and monitoring network characteristics.[9,10]

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Atmospheric aerosol particles are known as PMs, which is a mixture of extremely small solid and liquid droplets, including acids, organic chemicals, metals, soil particles, dust, and some biological elements such as pollen and fungal spores.[10] The size of this suspended PM varies from a few nanometers to 10 μm, which has the ability to penetrate unfiltered deep into the lungs and bloodstream, potentially causing asthma, DNA mutations, and heart disease with other respiratory diseases.[11,12] PM_{10} and $PM_{2.5}$ originate primarily from motor vehicle-related emissions, biomass burning, combustion-derived carbon with ultrafine nitrates, sulfates and air dust, and endotoxins associated with many biological particles.[13] The World Health Organization established the standard levels for $PM_{2.5}$ and PM_{10} as: (i) maximum 24-h average $PM_{2.5}$ exposures: 25 μg/m^3; maximum annual average exposure: 10 μg/m^3 and (ii) maximum 24-h average PM_{10} exposure: 50 μg/m^3; maximum annual average PM_{10} exposure: 20 μg/m^3.[12]

Currently, tropospheric O_3 is one of the most important atmospheric pollutants in China, the US, and Europe, and it is primarily generated from auto emissions. Breathing O_3 can trigger a variety of health problems, such as chest pain, coughing, throat irritation, eye irritation, reduced lung function, and damaged lung tissue. O_3 also harms ecosystems and damages sensitive vegetation during the growing season.[12,14] The standard value of O_3 is 100 μg/m^3 for an 8-h averaging time.[15] CO is another toxic gas in the atmosphere that is primarily produced from the incomplete combustion of carbon-containing fuels such as gasoline, natural gas, oil, coal, and wood. Breathing high concentrations of CO can reduce O_2 transport in hemoglobin and cause health effects, including headaches, chest pain, heart disease, etc.[16] To minimize health effects, an appropriate level of CO must be below 10.5 μg/m^3 for an 8-h averaging time, and possibly as low as 4.6–5.8 μg/m^3. The primary source for the anthropogenic emission of NO_2 and SO_2 into the atmosphere is a combination of the burning of fossil fuels, biomass, and emissions from cars, trucks, buses, power plants, and off-road equipment. The standard value of NO_2 is 40 μg/m^3 annual averaging time and 200 μg/m^3 1 h averaging time, and for SO_2 the standard values are 20 μg/m^3 24-h averaging time and 500 μg/m^{3}10 min averaging time. Most of the atmospheric NO_2 is emitted by NO, which is then rapidly oxidized by O_3 to become NO_2. Both NO_2 and SO_2 greatly impact the environment and human health because atmospheric NO_2 and SO_2 easily mix with rainwater, creating acid rain, which is very harmful to animals and plant life. Breathing with a high concentration of NO_2 and SO_2 can cause some respiratory illnesses such as asthma, coughing, and wheezing.[17,18]

Up to now, the study of air pollutions has been done based on air quality index (AQI) in many cities of Iran. For example, Kermani *et al*. found that AQI in Tehran, Tabriz, Mashhad, Urmia, Ahvaz, and Irak in 341, 139, 347, 28, 162, and 81 days of the year was over the Environment Protection Agency of Iran's standard, respectively.[19] Furthermore, in all of the cities, PM was the main responsible pollutant. In another study, Ashtari *et al*. showed that an increase in AQI levels in Isfahan city was associated with a higher expanded disability status scale among multiple sclerosis patients.[20] With respect to air pollution studied conducted in Karaj city, it was cleared that several studies.[21-26] have been investigated the importance of the relationship between air pollutants and the incidence of many diseases in Karaj city. However, there is no study that has surveyed the importance of the temporal variations and profiles of AQI in this city during a long time. Therefore, for air quality monitoring in this city, we decided to study the pollutants trends in yearly, seasonally, monthly, daily, and hourly concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and O_3 recorded from 2012 to 2018 at four monitoring stations across Karaj city, Iran. Furthermore, the correlations between PM and gaseous pollutants were analyzed using the Pearson correlation coefficient.

Materials and Methods

Study area

Karaj, a bustling metropolis in the center of Alborz Province with a population of nearly 3 million people is located 48 km northwest of Tehran (The capital of Iran). The city has 16 km in length and is 1300 m above the sea level, with a total area of 175.5 km^2. It is located at the latitude of 35.4845 and longitude of 51.030 in the northern hemisphere. Karaj population in 2018 has been estimated 1,585,000. In general, its climate is similar to other parts of Alborz Province so that, in cold seasons, the weather is influenced by the north, northwest, and west, especially southwest climates, with atmospheric rainfall from November and August continuing until May. It experiences a huge volume of public and personal transportation daily due to its communication path with more than 15 provinces of Iran and suffers from severe air pollution where the emission by cars contributes to almost 75% of the pollution.[25]

Data collection and analysis

Concentrations of standard air pollutants (O_3, NO_2, SO_2, CO, PM_{10}, and $PM_{2.5}$) in four air pollution monitoring stations in Karaj city (Farhangsara, Metro, Faculty of Environment, and District 6 Municipality) have been online recorded in the monitoring system of the Environment Department) [Figure 1]. In 2018, after referring to Alborz Environment Organization, it was obtained as an Excel file from 2012 to 2018. Then, data were analyzed by SPSS software. First, the normality of the data was measured using the Kolmogorov–Smirnov test, then descriptive data were expressed as average, standard deviation, maximum, and minimum. The analysis of variance test was also used to compare the concentrations of pollutants at different times (year, season, month, day, and hour). AQI, as an indicator for daily air quality, is divided into six categories and alerts people to air quality (clean or polluted) and provides related health effects.

Results

Particulate matter$_{10}$ and particulate matter$_{2.5}$ concentration

In this study, in Table 1, the results of yearly average concentrations of $PM_{2.5}$ and PM_{10} have been shown during

2012–2018. The highest yearly average PM_{10} and $PM_{2.5}$ concentrations were obtained in 2014 (94.55 ± 46.6 μgm^{-3}) and 2012 (34.48 ± 23.2 μg/m^3), respectively. PM_{10} and $PM_{2.5}$ concentrations during these 7 years had a significant difference ($P < 0.001$). In regard to seasonal distribution, the highest PM_{10} and $PM_{2.5}$ values showed in summer (76.26 ± 88.7 μg/m^3) and winter (31.56 ± 12.2 μg/m^3), respectively [Table 2]. The seasonal average distribution of PM_{10} and $PM_{2.5}$ concentrations during 2012–2018 showed a statistically significant difference ($P < 0.001$). The trend analysis of the monthly average of PM_{10} and $PM_{2.5}$ at this time could be observed in Table 3. The highest monthly average concentrations of PM_{10} and $PM_{2.5}$ (88.98 and 35.14 μg/m^3) obtained in June and January, respectively. Furthermore, the daily maximum averages of both PM_{10} and $PM_{2.5}$ have been reported on Monday in the range of 72.69 ± 12.3 and 30.02 ± 24.3 μg/m^3, respectively [Table 4]. Monthly and daily trends in PM_{10} and $PM_{2.5}$ concentrations showed a significant difference ($P < 0.001$). During this time, remarkable changes were not observed at hourly tends of PM_{10} and $PM_{2.5}$ (Data not shown). Figure 2 indicates day's percentage with a higher concentration than national standards (NSs) of PM_{10} and $PM_{2.5}$ during 2012–2018. Based on these results, the worst days with the higher $PM_{2.5}$ and PM_{10} concentrations were found in 2012 and 2014, respectively.

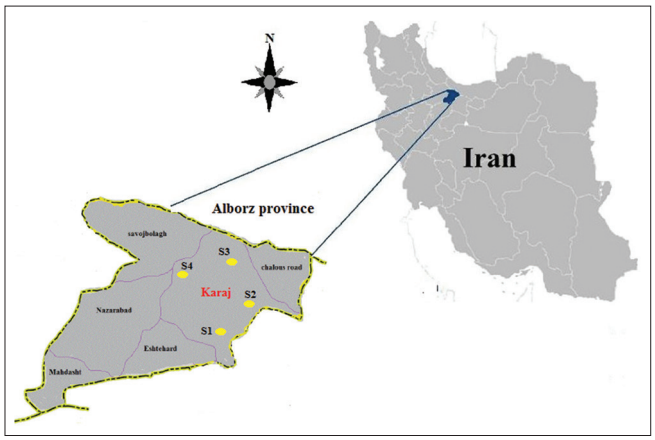

Figure 1: Location of the study area and sampling stations in Karaj city (Yellow circles are monitoring air stations)

Carbon monoxide concentration

Table 1 indicates the results of CO concentration during 2012–2018. Based on these results, the maximum and minimum yearly

Table 1: Annual average concentration trend of the pollutants

Year/pollutants	PM_{10} (μg/m^3)	$PM_{2.5}$ (μg/m^3)	CO (ppm)	NO_2 (ppmV)	SO_2 (ppm)	O^3 (ppm)
2012						
Mean±SD	76.54±104.5	34.48±23.2	2.35±1.2	0.031±0.01	0.019±0.006	0.028±0.01
Maximum	9177.8	354.4	22.80	0.083	0.22	0.13
Minimum	0.1	0.17	0.01	0.0003	0.009	0.00001
2013						
Mean±SD	74.05±50.06	30.34±28.7	1.43±1.03	0.026±0.01	0.01±0.003	0.017±0.00006
Maximum	648.56	911.71	8.02	0.067	0.032	0.017
Minimum	0.3	0.06	0.03	0.001	0.001	0.016
2014						
Mean±SD	94.55±46.6	29.83±25	1.37±0.8	0.026±0.008	0.011±0.01	0.029±0.01
Maximum	217	808	9.14	0.071	0.047	0.049
Minimum	17	1	0.1	0.009	0.0001	0.016
2015						
Mean±SD	77.74±66.1	20.63±37.9	1.61±1.01	0.019±0.01	0.013±0.007	0.022±0.02
Maximum	981	14.38	27.05	0.074	0.22	0.136
Minimum	1	1	0.03	0.001	0.002	0.002
2016						
Mean±SD	68.66±49.1	29.87±20.8	1.43±0.9	0.006±0.005	0.017±0.01	0.018±0.01
Maximum	1437.5	213	16.28	0.038	0.145	0.116
Minimum	0.4	0.38	0.02	0.0001	0.000001	0.0004
2017						
Mean±SD	66.14±38.4	26.48±16.7	1.72±1.3	0.026±0.02	0.011±0.01	0.017±0.1
Maximum	513.05	150	9.36	0.098	0.05	0.071
Minimum	0.02	0.02	0.03	0.00001	0.000001	0.0004
2018						
Mean±SD	56.24±33.7	23.18±15.8	2.32±1.09	0.007±0.005	0.029±0.02	0.02±0.01
Maximum	435.2	150	9.35	0.065	0.08	0.075
Minimum	1.02	0.1	0.04	0.00001	0.005	0.003
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SD: Standard deviation, CO: Carbon monoxide, NO_2: Nitrogen dioxide, O_3: Ozone, SO_2: Sulfur dioxide, PM: Particulate matter

Table 2: Seasonal average concentration trend of the pollutants

Season/pollutants	PM_{10} (μg/m³)	$PM_{2.5}$ (μg/m³)	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	O_3 (ppm)
Spring						
Mean±SD	72.42±63.5	24.49±21.6	1.65±1	0.020±0.01	0.017±0.009	0.021±0.01
Maximum	1437.5	882.41	22.08	0.094	0.0229	0.113
Minimum	0.03	0.02	0.02	0.0004	0.003	0.00001
Summer						
Mean±SD	76.26±88.7	28.99±31.7	1.43±1.01	0.021±0.01	0.017±0.009	0.026±0.019
Maximum	9177.89	1438	9.62	0.098	0.225	0.0136
Minimum	0.3	0.05	0.01	0.00001	0.00001	0.0001
Autumn						
Mean±SD	63.92±42.2	30.67±25.8	1.98±1.3	0.019±0.01	0.015±0.01	0.019±0.01
Maximum	961.3	1232	17.87	0.083	0.145	0.0947
Minimum	0.1	0.19	0.04	0.00001	0.00001	0.0002
Winter						
Mean±SD	60.61±40.4	31.56±12.2	1.89±1.01	0.022±0.01	0.014±0.01	0.022±0.01
Maximum	440.05	238	27.05	0.074	0.095	0.132
Minimum	0.02	0.06	0.03	0.00001	0.00001	0.0003
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SD: Standard deviation, CO: Carbon monoxide, NO_2: Nitrogen dioxide, O_3: Ozone, SO_2: Sulfur dioxide, PM: Particulate matter

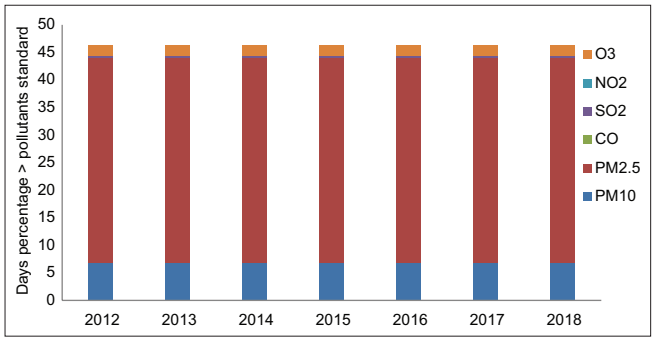

Figure 2: Days percentages with pollutants concentration higher than national standard

average concentration of CO occurred in 2012 (2.35 ± 1.2 ppm) and 2014 (1.37 ± 0.8 ppm), respectively [Table 1]. Furthermore, the maximum and minimum average seasonally concentration of CO was obtained from autumn (1.98 ± 1.3 ppm) and summer (1.43 ± 1.01 ppm), respectively [Table 2]. The monthly average concentration of CO showed that the worst and best CO concentrations could be attributed to Noveber (2.21 ± 1.5 ppm) and September (0.001 ± 0.001 ppm) [Table 3], respectively. Furthermore, Tuesday (1.78 ± 1.1 ppm) and Friday (1.67 ± 1.09 ppm) showed the highest and lowest daily concentration of CO, respectively [Table 4]. However in hour 22 (2.33 ± 1.4 ppm) and hours 13 and 14 (1.39 ± 0.9 ppm) was reported the maximum and minimum hourly average concentration of CO, respectively (Data not shown). During 2012–2018, 0.3% of days had CO concentration higher than standard (9 ppm) [Figure 2].

Nitrogen dioxide concentration

Annually, seasonally, monthly, daily, and hourly averages of NO_2 concentration during 7 years are observable in the following tables. These results show that the highest and lowest yearly average concentration of NO_2 occurred in 2012 (0.031 ± 0.01 ppm) and 2016 (0.006 ± 0.005 ppm), respectively [Table 1]. Furthermore, the highest and lowest average seasonally concentration of NO_2 was reported in winter (0.022 ± 0.01 ppm) and autumn (0.019 ± 0.01 ppm), respectively [Table 2]. January (0.028 ± 0.01 ppm) and November (0.01 ± 0.01 ppm) indicated the highest and lowest monthly average concentrations of NO_2, respectively [Table 3]. However, there is not any remarkable difference between daily and hourly NO_2 concentration [Table 4]. Based on obtained results, during 2012-2018, all daily averages (%) of NO_2 were lower than the national NO_2 standard (100 ppb) [Figure 2].

Sulfur dioxide concentration

The change of average SO_2 during 2012-2018 is observed in Table 1. The maximum and minimum yearly average concentrations of SO_2 occurred in 2018 (0.029 ± 0.02 ppm) and 2013 (0.01 ± 0.003 ppm), respectively [Table 1]. Furthermore, the maximum and minimum average seasonally concentration of SO_2 was obtained from spring and summer (0.017 ± 0.009 ppm) and winter (0.014 ± 0.01 ppm), respectively [Table 2]. September (0.02 ± 0.009 ppm) and October (0.01 ± 0.008 ppm) have been related to the highest and lowest monthly average concentration of SO_2, respectively [Table 3]. It was clear that there was not any remarkable difference between daily and hourly SO_2 concentrations [Table 4]. However in 2018, SO_2 concentration of 0.8% days was higher than the NS [Figure 2].

Ozone concentration

The worst and best yearly average concentrations of O_3 occurred in 2014 (0.029 ± 0.01 ppm) and 2017 (0.017 ± 0.1 ppm), respectively [Table 1]. Furthermore, seasonally concentration of O_3 was observed in the summer (0.026 ± 0.019 ppm) and autumn (0.019 ± 0.01 ppm), respectively [Table 2]. In

Table 3: Monthly average concentration trend of the pollutants

Month/pollutants	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	O_3 (ppm)
April						
Mean±SD	54.91±56.7	21.01±12.7	1.8±0.9	0.015±0.01	0.016±0.03	0.017±0.01
Maximum	1437.5	137	13.91	0.046	0.073	0.079
Minimum	0.03	0.15	0.07	0.0004	0.0038	0.0006
May						
Mean±SD	67.14±53.9	24.15±22.2	1.74±1.09	0.022±0.01	0.018±0.01	0.018±0.01
Maximum	68.56	882.41	22.8	0.069	0.051	0.086
Minimum	1.05	0.18	0.02	0.0007	0.0059	0.000001
June						
Mean±SD	88.89±0.1	28.86±27.4	1.48±0.9	0.024±0.02	0.017±0.007	0.027±0.02
Maximum	876.01	853.77	8.02	0.094	0.2229	0.113
Minimum	1	0.02	0.03	0.0012	0.0074	0.0022
July						
Mean±SD	81.91±125.6	30.88±35.8	1.331±0.9	0.021±0.01	0.014±0.009	0.028±0.02
Maximum	9177.89	906	9.62	0.098	0.225	0.136
Minimum	0.3	0.05	0.09	0.000001	0.000001	0.0011
August						
Mean±SD	71.66±38.5	28.9±32.2	1.41±0.9	0.022±0.01	0.017±0.009	0.014±0.0009
Maximum	625.88	1438	0.009	0.096	0.062	0.0091
Minimum	0.39	0.08	0.02	0.001	0.000001	0.0001
September						
Mean±SD	72.04±42.6	27.33±26.5	0.001±0.001	0.019±0.01	0.02±0.009	0.025±0.01
Maximum	1049.69	1438	9.41	0.076	0.07	0.109
Minimum	2.56	0.08	0.01	0.00001	0.0014	0.0003
October						
Mean±SD	68.7±43.3	27.29±29.2	1.85±1.34	0.02±0.01	0.017±0.01	0.022±0.01
Maximum	96.13	1232	17.87	0.083	0.077	0.0970
Minimum	0.12	0.22	0.04	0.00001	0.000001	0.0002
November						
Mean±SD	61.7±41.5	32.66±23.4	2.21±1.5	0.01±0.01	0.01±0.008	0.016±0.01
Maximum	686	911.71	9.30	0.064	0.057	0.067
Minimum	0.10	1	0.08	0.00001	0.00005	0.0003
December						
Mean±SD	57.9±39.8	32.32±23.8	1.94±1.1	0.023±0.01	0.011±0.01	0.016±0.01
Maximum	237	167.74	9.35	0.055	0.145	0.044
Minimum	2.99	0.19	0.26	0.0009	0.002	0.0003
January						
Mean±SD	69.97±40.06	35.14±23.8	1.62±0.8	0.028±0.01	0.01±0.009	0.021±0.01
Maximum	333	169	7.27	0.074	0.067	0.073
Minimum	0.12	0.13	0.23	0.00001	0.000001	0.0003
February						
Mean±SD	55.06±37.6	31.29±20.09	2.17±1.07	0.019±0.01	0.018±0.02	0.022±0.01
Maximum	366	238	8.54	0.057	0.095	0.089
Minimum	0.07	0.06	0.32	0.00001	0.000001	0.0029
March						
Mean±SD	56.38±41.09	27.67±17.1	1.8±1	0.02±0.01	0.015±0.008	0.023±0.01
Maximum	440.55	161	27.05	0.056	0.063	0.132
Minimum	2.33	0.17	0.03	0.0013	0.0001	0.0029
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SD: Standard deviation, CO: Carbon monoxide, NO_2: Nitrogen dioxide, O_3: Ozone, SO_2: Sulfur dioxide, PM: Particulate matter

July (0.028 ± 0.02 ppm) and August (0.014 ± 0.0009 ppm), we observed the worst and best monthly average concentrations of O_3, respectively [Table 3]. The highest and the lowest daily concentration of O_3 was showed on Friday (0.023 ± 0.01 ppm) [Table 4]. The highest and lowest hourly average concentration of O_3 was reported in hours 15 and 16 (0.034 ± 0.02 ppm) and hours 7 (0.015 ± 0.012 ppm), respectively (Data not shown). During 2012–2018, days

Table 4: Daily average concentration trend of the pollutants

Day/pollutants	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	CO (ppm)	NO_2 (ppm)	SO_2 (ppm)	O_3 (ppm)
Saturday						
Mean±SD	66.85±46.3	28.72±20.4	1.76±1.1	0.02±0.01	0.015±0.01	0.022±0.02
Maximum	981	471	16.28	0.086	0.076	0.109
Minimum	0.21	0.06	0.08	0.00001	0.00001	0.0003
Sunday						
Mean±SD	69.17±45.1	29.63±29.3	1.73±1.1	0.02±0.01	0.016±0.01	0.022±0.01
Maximum	1049.69	1438	22.8	0.096	0.094	0.106
Minimum	0.2	0.11	0.03	0.00001	0.00001	0.0001
Monday						
Mean±SD	72.69±12.3	30.02±24.3	1.75±1.1	0.02±0.01	0.016±0.01	0.022±0.01
Maximum	9177.89	808	17.2	0.095	0.225	0.136
Minimum	0.21	0.09	0.01	0.00001	0.00001	0.0003
Tuesday						
Mean±SD	70.16±49.6	29.37±22.9	1.78±1.1	0.021±0.01	0.016±0.01	0.022±0.01
Maximum	670.9	892.48	17.78	0.098	0.229	0.12
Minimum	0.02	0.05	0.02	0.00001	0.00001	0.0003
Wednesday						
Mean±SD	69.63±47.4	29.54±28.6	1.77±1.1	0.021±0.01	0.016±0.01	0.022±0.01
Maximum	734.72	1438	13.91	0.093	0.125	0.131
Minimum	0.10	0.02	0.02	0.00001	0.00001	0.0001
Thursday						
Mean±SD	68.47±47.5	28.63±22.2	1.74±1.1	0.02±0.01	0.016±0.01	0.022±0.01
Maximum	961.3	911.71	27.05	0.09	0.145	0.132
Minimum	0.03	0.1	0.03	0.00001	0.00001	0.0003
Friday						
Mean±SD	64.75±51.4	27.54±28	1.67±1.09	0.02±0.01	0.015±0.01	0.023±0.01
Maximum	1075.9	1232	9.35	0.089	0.08	0.1
Minimum	0.1	0.06	0.02	0.00001	0.00001	0.00001
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

SD: Standard deviation, CO: Carbon monoxide, NO_2: Nitrogen dioxide, O_3: Ozone, SO_2: Sulfur dioxide, PM: Particulate matter

Table 5: Pearson correlation coefficients between particulate matter and gaseous pollutants

Pollutants	PM_{10}	$PM_{2.5}$	CO	NO_2	SO_2	O_3
PM_{10}	1					
$PM_{2.5}$	−0.57	1				
CO	−0.29	0.32	1			
NO_2	0.37	0.36	0.01	1		
SO_2	−0.69*	0.32	0.49	−0.09	1	
O_3	−0.53	0.57*	0.07	−0.49	0.58*	1

*P<0.05. CO: Carbon monoxide, NO_2: Nitrogen dioxide, O_3: Ozone, SO_2: Sulfur dioxide, PM: Particulate matter

percentage with O_3 higher than the national O_3 standard (0.007 ppb) are shown in Figure 2.

Correlation between particulate matters and gaseous pollutants

Pearson correlation coefficient was used to examine the correlation between the average concentrations of pollutants during the 7 years of the study [Table 5]. Pearson correlation coefficient showed that there is a significant negative relationship between PM_{10} and SO_2 ($r = -0.69$, $P = 0.013$). This averages that with the increase of PM_{10} pollutants, the amount of SO_2 has decreased and vice versa. Also, a significant positive relationship was observed between $PM_{2.5}$ and O_3 ($r = 0.57$, $P = 0.03$). This averages that as the amount of $PM_{2.5}$ pollutants increases, so does the amount of O_3 pollutants. There was a significant positive relationship between SO_2 and O_3 pollutants ($r = 0.58$, $P = 0.03$).

Air quality index trends in Karaj city during 2012-2018

During the study from 2012 to 2018, a one-way analysis of the variance test showed a significant difference between the average concentrations of pollutants ($P < 0.001$). Results obtained from this study showed that long-term trend of AQI during this time at four monitoring stations is directed to clean. At this time, only 2012 indicated an unhealthy AQI (102.47) [Figure 3]. It was observed that Karaj's AQI was moderate.

Discussion

Air pollution trends based on hourly, monthly, seasonal, and annual changes are important. The pattern of the temporal distribution of air pollutants is a suitable tool to assess air quality in comparison with national and international air standards. Overview of data indicated that the highest

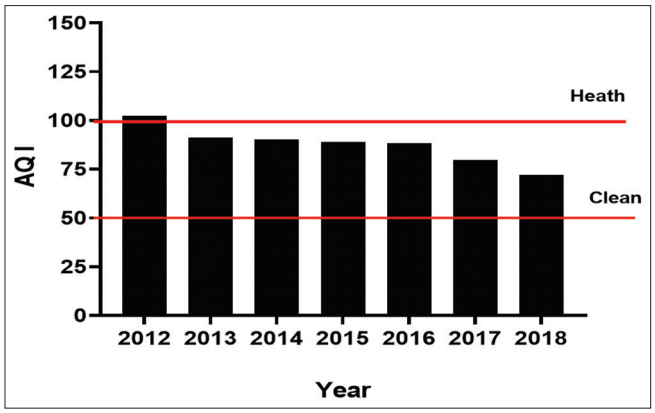

Figure 3: AQI trends in Karaj city during 2012–2018. AQI: Air quality index

concentrations of PM_{10} (88.89 ± 0.1 μg/m³) in June, $PM_{2.5}$ (35.14 ± 23.80 μg/m³) in January, SO_2 (0.02 ± 0.009 ppm) in September, and O_3 (0.028 ± 0.020 ppm) in July. However, the highest concentrations of CO (2.21 ± 1.5 ppm) in November and NO_2 (0.028 ± 0.01 ppm) in January were reported. In this study, a quick look at Tables shows that some types of pollutants are worse in the summer, while others are worse in cold winter, it can be due to changes in air humidity and wind direction. Totally, due to nonrainy days in summer and combustion of more fuel in winter, PMs are the most part of air pollution, due to heat and sunlight, O_3, NOx, and Volatile organic carbons (VOCs) are higher than other pollutants. Because of the falling and decay of leaves, VOCs can pose the highest threat to human health. In winter, smog and inversion cause that CO, NO_x, PM_{10}, $PM_{2.5,}$ and VOCs are trapped in the ground until the temperature change.[27]

The increasing temporal concentration of PM_{10} and $PM_{2.5}$ can be due to agricultural activities during spring. In winter, smog and inversion cause that CO, NO_x, PM_{10}, $PM_{2.5,}$ and VOCs are trapped in the ground until the temperature change.[27] According to the results of Baltaci *et al*.,[28] three highest monthly average PM_{10} concentrations are found during March, February, and April months with average values of 55.8, 53.5, and 53.3 μg/m³, respectively. PM_{10} concentration exceeded the European (EU) threshold limit (50 μg/m³) in a total of 54% of days in March. In regard to seasonal distribution, the highest PM_{10} values in spring (53.8 μg/m³) are followed by winter, fall, and summer seasons with average values of 49.7, 43.2, and 42.8 μg/m³, respectively. Based on the results of Zhang *et al*. (2017),[29] extreme $PM_{2.5}$ days usually occurred when the speed of wind is under 2 m/s. It is cleared this difference in PM concentration obtained from different studies is due to differences in geographical and atmospheric conditions, and distance from city centers. Furthermore, Goudarzi *et al*. found the maximum concentration of PM_{10} in Ahvaz in the cold season than in the hot season in Ahvaz city in Iran.[30] In our neighboring country, Ozel et al. showed that the average of daily total PM10 concentration in Turkey is 148 μg/m³, the average of monthly total PM10 concentration is 4 437 μg/m³, and the average of yearly total PM10 concentrations is 53 984 μg/m³.[25] In another study conducted by Kermani *et al*., it was observed that maximum and minimum annual concentrations of $PM_{2.5}$ have happened in the autumn and spring seasons with a value of 67.48 and 19.85 μg/m³, respectively.[19] Furthermore, the citizens of Karaj are exposed to $PM_{2.5}$ pollutants four times more than the US-EPA standard (10 μg/m³).[23] Moreover, Barzeghar *et al*. result in Tabriz showed the highest monthly average concentrations of PM_{10} and $PM_{2.5}$ were observed in May (80.4 μg/m³) and December (42.5 μg/m³), respectively.[31] In this study, although the PMs trend has decreased and the air quality of Karaj improved, almost 20% of days in 2018 involved $PM_{2.5}$ with a higher concentration than NS [Figure 2].

Despite our results that showed the low concentrations for CO and NO_2, in the study of Xiao *et al*.(2018) in the Basin City of Chengdu, China, CO had concentration between 95.1 and 99.7 ppm. Also, in this study, it was cleared that in the city of Chengdu in China, reported the annually concentration of NO_2 between 20 and 69 μg/m³ (37.6–129.77 ppb).[32] Furthermore, Hewitt[33] has investigated the concentrations of NO_2 in a city and their results showed that the concentration of NO_2 decreased with increasing the distance from the main road. Both low temperature and heating cause an increase in NOx concentrations. The low temperatures in winter are not conducive to the conversion of NO_2, resulting in the accumulation of NOx. Heating increases the amount of coal used and increases the concentration of NO_2. The results of Wang *et al*.(2020) showed that the maximum monthly average concentration of NO_x and NO was reached in October, and the maximum monthly average concentration of NO_2 was reached in March. The spatial distribution characteristics and annual average spatial distribution were the same. They found that the average daily variation in NOx concentration occurred at 07:00–08:00 in the morning, and the second peak occurred between 20:00 and 22:00 at night.[34]

In the present study, during 2012–2018, pollution during the cold season was higher than warm season. Another reason for these results can be due to the difference in topography, and meteorology of locations.[5] The highest days' percentage with SO_2 higher than the national SO_2 standard was 0.8%. The study of Krochmal and Kalina showed that the average of SO_2 concentration.[35] In Tabriz, Barzeghar *et al*.(2020) found the highest monthly average concentration of O_3 in June (78.4 μg/m³ or 156.8 × 10^{-3} ppm).[30]

The generation and distribution of O_3 depend on ground air temperature, wind speed and direction, relative humidity, and precipitation associated with climate change have the potential to affect, and deposition of O_3.[36] In the present study, in 2016, 5% of days had O_3 higher than standards. According to the results of Faridi *et al*., O_3 seasonal behavior shows higher concentrations during summer months, certainly due to the more intensive photochemical reactions, than in other months.[37] The amount of photochemical reactions conducted during time can affect O_3 production in a region.[27] Surface O_3 concentrations may be affected by many factors such as UV

radiation, cloud cover, temperature, wind direction and speed, precipitation, and position of fronts, but in general, temporal O_3 concentration (annually, seasonally, monthly, daily, and hourly) in the air all of them are highly positively correlated with the temperature.[38] In the present study, the correlation between PM_{10} and SO_2 can be due to the adsorption of SO_2 on dust particles. Ghaderi *et al*.(2018) in Ahvaz city showed that SO_2 and PM_{10} variables are correlated with each other ($P < 0.05$) due to the absorption of PMs on SO_2. The correlation between O_3 and $PM_{2.5}$ could be because O_3 is related to secondary aerosols and not primary aerosols.[38] Wang *et al*. (2020) reported that the NOx concentration in Changchun was positively correlated with NO_2, NO, $PM_{2.5}$, PM_{10}, and CO, and it had a significant negative correlation with O_3. The NOx concentration had a significant positive correlation with the $PM_{2.5}$ concentration because the secondary conversion of NOx had a significant effect on $PM_{2.5}$. There was a significant negative correlation between NOx and O_3 because the precursors were consumed and produced by photochemical reactions.[34]

Conclusion

In the present study, temporal profiles of air quality in Karaj were characterized by AQI during 2012–2018. Totally, AQI in Karaj during this time had a moderate range. Among six pollutants, $PM_{2.5}$ was the major contributor to the AQI, and the annual average $PM_{2.5}$ concentrations at all stations exceeded the NS. These results show that, for Karaj, $PM_{2.5}$ is a major issue to be considered in improving air quality. In Karaj, the AQI profile and its pattern showed an unhealthy for sensitive groups who should reduce their activities in the outdoor air. Consequently, to better understand the long-term trend of air quality variation in Karaj, $PM_{2.5}$ concentrations must be taken into account, and its resources should be considered and controlled. Furthermore, air pollution research with respect to epidemiological studies is recommended.

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Conflicts of interest

There are no conflicts of interest.

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