Journal of Air Pollution and Health (Winter 2019); 4(1): 1-14

Original Article

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Effects of meteorological variables and holidays on the concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in Tehran (2014-2018)

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ARTICLE INFORMATION

Article Chronology:
Received 20 December 2018
Revised 1 February 2019
Accepted 13 February 2019
Published 29 March 2019

Keywords:
Particulate matter; Temporal variation; Trend; Outdoor; Ambient air pollution

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ABSTRACT:

Introduction: The aim of this study was to investigate the concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in Tehran during March 2014-March 2018, and evaluate the effects of holidays and meteorological parameters on the air pollution levels.

Materials and methods: Hourly concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in different air quality monitors of Tehran were acquired. The data from each air quality monitored were validated, and only high-quality monitors were included in this study.

Results: The 4-year averages of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations were 88.74 (µg/m^3), 31.02 (µg/m^3), 34.87 (ppb), 71.01 (ppb), 20.04 (ppb), and 3.78 (ppm), respectively. Higher concentrations of PM_{10} and O_3 were observed during summer. In case of $PM_{2.5}$ and CO, autumn and winter concentrations were higher than those in springer and summer. Lower concentrations of PM_{10} and NO_2 in Fridays were observed comparing to other days of week. Ozone had high concentrations in Fridays as the weekend in Iran. Except for O_3, all of the pollutants had higher concentrations in the working days, comparing to those in any type of vacation days. Concentrations of all pollutants rather that SO_2 and O_3 in Nowruz holidays were statistically lower than those in the working days. By controlling for the effects of meteorological variables, our results showed that the air pollution control policies and actions have been not effective for particulate matter.

Conclusion: These results determines the time periods in which the concentrations of criteria air pollutants are high. This can be very useful for announcing alarms for citizens, and designing the air pollution control plans. In addition, more effective actions should be designed and implemented for reducing ambient levels of particulate matter.

Introduction

Air pollution has been introduced as the fourth risk factor for human health [1]. In a report by World Health Organization (WHO), about 7 million annual deaths were attributed to indoor and outdoor air pollution [2]. There are several criteria air pollutants that can affect human health such as different fractions of particu-

Please cite this article as: Hadei M, Yarahmadi M, Jonidi Jafari A, Farhadi M, Hashemi Nazari S.S, Emam B, et al. Effects of meteorological variables and holidays on the concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in Tehran (2014-2018). Journal of Air Pollution and Health. 2019; 4(1): 1-14.

late matter, ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), etc. [3]. Particulate matter with a diameter of $PM_{2.5}$ μm or smaller ($PM_{2.5}$) is a fraction of particles that is able to enter the alveolar region in lung, as a place for blood exchange. $PM_{2.5}$ represents the high-risk fraction of particulate matter in air.

Many epidemiological studies have shown a positive relationship between short- or/and long-term exposure to $PM_{2.5}$ and different adverse health effects [4]. $PM_{2.5}$'s short-term exposure is associated with ischemic heart disease (IHD) and chronic obstructive pulmonary disease (COPD). Its long-term exposure is related to lung cancer, and respiratory and cardiovascular diseases. It is shown that lung cancer incidence increases per each 10 μg/m^3 $PM_{2.5}$ [5]. International Agency for Research on Cancer (IARC) has introduced particulate matter as Group 1 carcinogen (carcinogenic to humans) [6].

Several cities of Iran are experiencing high concentrations of air pollutants, especially $PM_{2.5}$ [7]. Southern and western cities are affected by Middle Eastern dust storm, which even reach Tehran in central Iran [8, 9]. Tehran as the capital of Iran is mainly affected by mobile sources of air pollution [10]. Annual concentrations $PM_{2.5}$ are reported to be 3-4 times higher than those in WHO's guideline. These extremely high concentrations cause large numbers of deaths and hospital admissions [11-16]. In addition, high concentrations of other criteria air pollutants such as O_3, NO_2, SO_2, and CO in different cities of Iran have been investigated in other studies [11, 17], and high levels of those pollutants have been reported.

Tehran is the capital of Iran, and have a population near 9 million people. There are about 3 million personal vehicles in Tehran, of which 25% are more than 10 years old and 75% have emissions with Euro-2 standard and less [18]. About 70% of particulate matter in Tehran during 2015 was emitted from mobile sources [19]. Mobile sources, energy production, and domestic sector are responsible for about 46%, 24%, and 23% of total NOx emission in Tehran [19]. The dominant source of emitted SOx in ambient air of Tehran is the energy production sector, which reflects the use of fossil fuels [19]. This situation has led to a severe condition of air pollution in this city [13]. Therefore, it is necessary to evaluate the concentrations of criteria air pollutants in Tehran during the recent years. It can provide information about the effectiveness of air pollution control strategies and actions. In addition, the temporal patterns of different air pollutions can be understood better. The aim of this study was to investigate the concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in Tehran during March 2014-March 2018, and evaluate the effects of holidays and meteorological parameters on the air pollution levels.

Materials and methods

Study design

This study investigated the concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in Tehran March 2014-March 2018. Tehran as the capital of Iran is located in Central areas of this country (35°41′21″N 51°23′20″E), and have a population about 9 million people [20, 21].

Air quality data

Hourly concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in different air quality monitoring stations of Tehran were acquired from Department of Environment (DoE) and Tehran's Air Quality Control Company (TAQCC). First, invalid concentrations of pollutants were removed from the dataset. Second, only stations were included in the study that contained at least 75% valid hourly concentrations. Third, the volumetric unit of gaseous pollutants i.e. ppbv or ppmv were converted to the mass unit i.e. μg/m^3. Then, appropriate averages for each pollutant were calculated. For PM_{10}, $PM_{2.5}$, and SO_2, 24-h averages were obtained. For NO_2 and CO, the maximum hourly concentration in each day was considered as the representative concentration for that day. For ozone, the maximum of 8-h moving averages in each day was calculated. This approach was taken from some previous studies [11, 12, 22].

Data analysis

The descriptive statistics of each air pollutant in each year were calculated. Daily concentrations of each pollutants during four seasons (in order of Persian calendar: spring, summer, autumn, and winter), twelve months (in order of Persian calendar: March, April, May, June, July, August, September, October, November, December, January, and February) and seven days of week (in order of Persian calendar: Saturday, Sunday, Monday, Tuesday, Wednesday, Thursday, and Friday) were averaged and compared statistically. In addition, days were divided into four categories: workdays, Fridays (weekend), formal holidays, and Nowruz holidays. Air pollutants' concentrations during each of these categories were averaged and compared.

For statistical analysis and comparing the concentrations between different years, seasons, months, days of week, and types of days, first, the normality of datasets was analyzed using the Kolmogorov-Smirnov test. Then, the equality of variances was analyzed by Levene's test. Third, based on the results of these steps, parametric (ANOVA) and non-parametric (Kruskal-Wallis) statistical tests were selected to compare the concentrations between groups. The effects of meteorological parameters on the concentrations of air pollutants were analyzed using multiple linear regression. Concentrations of each pollutant in each year and total of four years were considered as response variable. The values of all meteorological variables in the same time period were considered as predictor variables. All of the statistical analyses were performed using the R Programming Software.

Results and discussion

Temporal variations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations in Tehran were investigated. Table 1 shows the descriptive statistics of each air pollutant in each year during 2014-2018. Tables 2 shows the descriptive statistics of meteorological parameters including wind speed, air temperature, relative humidity, and dew point in Tehran during 2014-2018. The 4-year averages of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations were 888.74 (μg/m^3), 31.02 (μg/m^3), 34.87 (ppb), 71.01 (ppb), 20.04 (ppb), and 3.78 (ppm), respectively. $PM_{2.5}$, PM_{10}, NO_2 concentrations have increased gradually during the study period; however, SO_2 concentrations has decreased dramatically from 46.41 to 7.66 ppb. Some fluctuations were found in case of ozone, and no specific trend of ozone were observed. On the other hand, CO levels have been relatively constant. Statistical analyses showed that the concentrations of PM_{10}, $PM_{2.5}$, NO_2, and O_3 in the last year were significantly higher than those in the first year ($P<0.05$). However, the concentrations of SO_2, and CO in the last year were significantly lower than those in the first year of study ($P<0.05$).

In another study, the three-year average (± standard deviation) of PM_{10} and $PM_{2.5}$ concentrations were 80.21 (± 34.21) and 39.17 (± 17.26) μg/m^3, respectively [11, 23]. The three-year averages (± standard deviation) for ozone (O_3), nitrogen dioxide (NO_2), and sulphur dioxide (SO_2) were 54.88 (± 24.15), 103.97 (± 25.88) and 39.84 (± 11.17) μg/m^3, respectively [11]. In another study, the annual average of PM_{10}, SO_2, NO_2 and O_3 in Tehran were 90.58, 89.16, 85 and 68.82 μg/m^3, respectively [17].These results show some differences between those from our study.

In a report, TAQCC investigated the average concentrations of each pollutants in the individual monitoring stations in Tehran. The report showed that the number of stations with ozone concentrations higher than 70 ppb increased in the 2017-2018 year comparing to the 2015-2016 year [24]. This is consistent with our results. In addition, the report of TAQCC indicated that the concentrations of CO and SO_2 in different monitors have been reduced in the 2015-2018 period. The results of the present study was also indicative for a slight and dramatic decrease for CO and SO_2 concentrations in the whole city, respectively. The report showed that no increase and decrease was observed for NO_2. This is not consistent with our results that showed an increase in NO_2 concentrations over the study period. In case of $PM_{2.5}$, TAQCC reported that the annual average for the 2015-2016, 2016-2017, and 2017-2018 years were 28.8, 32.8, and 32.3 μg/m^3, respectively. The annual averages of PM2.5 during the same years in our study were 30.6, 31.6, and 33.4 μg/m^3, respectively. In total, some of their results were inconsistent with those in our study. It should be noted that a larger number of monitors were included in the present study, and the TAQCC report was based on a fewer number of monitors [24].

Another report by TAQCC indicated that there are about 3 million personal vehicles in Tehran, of which 25% are more than 10 years old and 75% have emissions with Euro-2 standard and less [18]. About 70% of particulate matter in Tehran during 2015 was emitted from mobile sources [19]. Mobile sources, energy production, and domestic sector are responsible for about 46%, 24%, and 23% of total NOx emission in Tehran. In addition, the major sources of SOx in Tehran is the energy production sector, which reflects the use of fossil fuels [19]. Several other studies also reported high concentrations of criteria air pollutants and volatile organic compounds (VOCs) in Tehran that indicates this city is highly polluted area in Iran [22, 25-29].

Table 1. Descriptive statistics of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations in Tehran during 2014-2018

Pollutant	Statistic	2014-2015	2015-2016	2016-2017	2017-2018	4-year average
PM_{10} (μg/m^3)	Mean	77.09	98.82	91.08	87.87	88.74
	SD	31.17	45.04	34.57	30.86	20.39
	Min	18.64	20.73	24.05	17.08	29.90
	Max	230.67	334.14	250.83	224.78	177.01
	98th p.	168.79	218.80	175.48	168.26	130.80
	99th p.	189.74	245.16	194.90	193.16	136.66
$PM_{2.5}$ (μg/m^3)	Mean	28.42	30.62	31.62	33.39	31.02
	SD	11.07	13.26	13.48	14.18	8.06
	Min	6.79	6.07	8.38	8.59	11.62
	Max	73.89	90.93	84.58	117.92	64.27
	98th p.	57.42	65.17	73.52	77.42	52.23
	99th p.	60.73	70.36	77.78	87.21	54.50

Table 1. Descriptive statistics of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations in Tehran during 2014-2018

Pollutant	Statistic	2014-2015	2015-2016	2016-2017	2017-2018	4-year average
O_3 (ppb)	Mean	31.01	39.40	32.93	39.85	34.87
	SD	10.40	15.47	15.89	20.49	13.99
	Min	10.44	7.77	5.79	5.40	10.76
	Max	64.97	77.31	83.57	82.64	66.45
	98^{th} p.	50.02	69.53	67.28	77.27	60.17
	99^{th} p.	52.62	71.21	71.39	78.80	61.38
NO_2 (ppb)	Mean	73.76	53.86	77.86	78.44	71.01
	SD	19.41	18.89	17.97	18.10	10.57
	Min	37.00	19.00	40.63	43.38	41.79
	Max	150.29	213.00	143.56	152.83	110.62
	98^{th} p.	122.15	94.10	121.06	123.94	95.27
	99^{th} p.	135.92	107.14	125.93	140.01	99.67
SO_2 (ppb)	Mean	46.41	16.57	11.20	7.66	20.04
	SD	25.26	3.30	4.25	1.97	6.39
	Min	12.70	10.07	4.58	3.10	8.16
	Max	197.67	27.05	29.04	15.33	57.09
	98^{th} p.	110.27	24.17	22.94	12.16	35.11
	99^{th} p.	147.65	24.88	24.89	13.29	44.25
CO (ppm)	Mean	3.83	3.41	4.44	3.47	3.78
	SD	0.95	0.77	1.35	0.75	0.61
	Min	2.05	1.99	1.71	1.83	1.99
	Max	8.21	6.09	9.49	7.10	5.52
	98^{th} p.	5.99	5.56	8.06	5.03	5.11
	99^{th} p.	6.48	5.92	8.51	5.31	5.27

Table 2. Descriptive statistics of meteorological parameters in Tehran during 2014-2018

Parameter	Statistic	2014-2015	2015-2016	2016-2017	2017-2018	4-year average
Wind speed (m/s)	Mean	3.21	3.14	3.17	2.99	3.13
	SD	1.44	1.53	1.45	1.34	1.44
	Min	0.75	0.50	0.38	0.75	0.38
	Max	9.38	10.13	9.38	9.13	10.13
Pressure (mbar)	Mean	880.69	881.86	880.94	881.62	881.51
	SD	4.68	4.38	4.24	4.05	4.35
	Min	866.93	866.64	870.66	871.55	866.64
	Max	894.85	896.26	893.05	894.73	896.26
Temperature (°C)	Mean	18.86	19.16	18.21	19.27	18.87
	SD	9.94	9.90	10.25	9.52	9.90
	Min	1.13	-0.91	-4.05	-4.10	-4.10
	Max	36.18	36.15	35.18	35.20	36.18

Table 2. Descriptive statistics of meteorological parameters in Tehran during 2014-2018

Parameter	Statistic	2014-2015	2015-2016	2016-2017	2017-2018	4-year average
R. Humidity (%)	Mean	33.11	33.20	33.73	31.26	32.83
	SD	16.03	17.52	16.92	16.04	16.65
	Min	8.00	9.64	9.38	8.13	8.00
	Max	83.63	85.38	90.50	94.00	94.00
Dew point (°C)	Mean	-0.43	-0.27	-0.75	-0.86	-0.58
	SD	4.26	4.92	5.10	4.54	4.72
	Min	-11.61	-15.56	-17.50	-12.44	-17.50
	Max	8.55	11.60	10.58	12.81	12.81

The percent of days with concentrations of PM_{10}, $PM_{2.5}$, O_3, and SO_2 within the air quality guidelines (AQG), and interim targets (IT) of WHO are presented in Fig. 1. According to this figure, only 12% and 34% of days in all the four years have met the AQG of WHO for daily concentrations of PM_{10} and $PM_{2.5}$, respectively. However, 80% and 19% of days were below the AQGs of O_3 and SO_2, respectively. For $PM_{2.5}$, 44%, 14%, and 7% of days had concentrations within AQG-IT3, IT3-IT2, and IT2-IT1, respectively. In addition, 1% of days in all the four years have had $PM_{2.5}$ concentration higher than IT1 of WHO. This situation is more worst in case of PM_{10}.

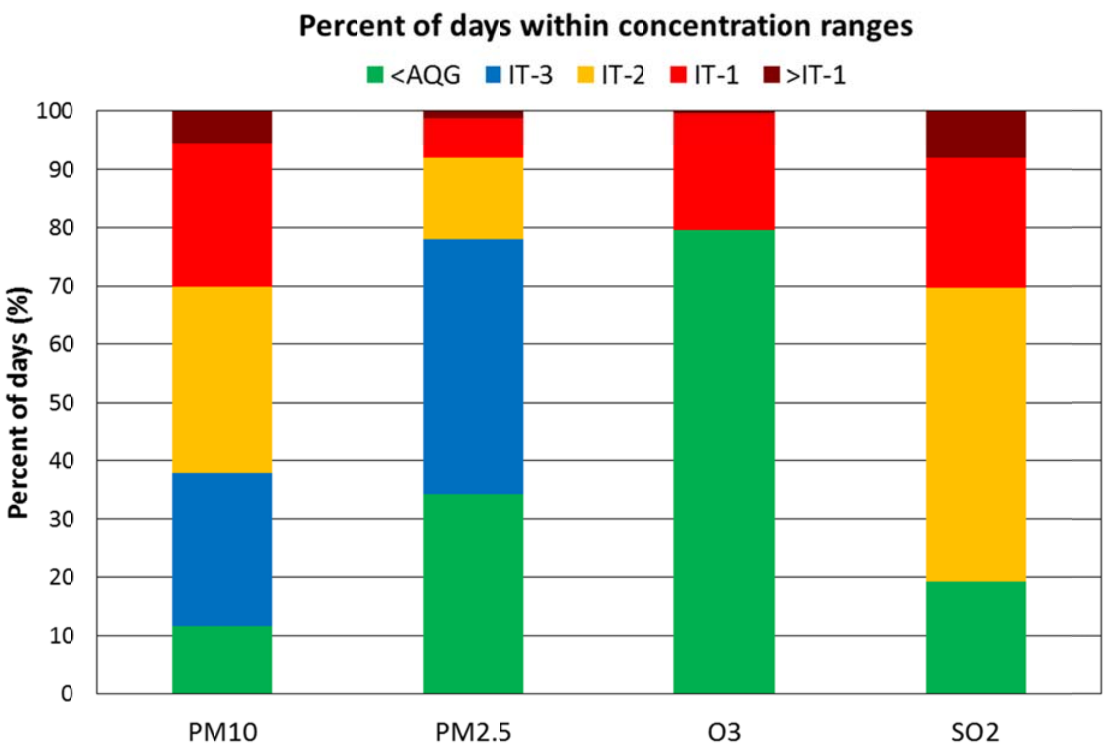

Fig. 1. Percentage of days with concentrations of PM_{10}, $PM_{2.5}$, O_3, and SO_2 within the air quality guidelines (AQG), and interim targets (IT) of WHO

Fig. 2 shows the seasonal averages (+standard deviation) of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO in Tehran during 2014-2018. According to this figure, higher concentrations of PM_{10} and O_3 were observed during summer (P<0.05). In case of $PM_{2.5}$ and CO, autumn and winter concentrations were higher than those in springer and summer (P<0.05). SO_2 concentrations were higher during the springs (P<0.05). In addition, summer and winter concentrations of NO_2 were higher than its spring and autumn levels (P<0.05). The same pattern can be seen in the Figure 3 that contains the monthly averages (+standard deviation) of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations in Tehran during 2014-2018.

In a study, the highest levels of CO in Tehran were observed in September, October, December, and January, respectively. The lowest levels of O_3 were in January, December, and November, respectively. The maximum NO_2 was in December, and the minimum is in March. The maximum SO_2 was in January and December, respectively. The concentration of PM_{10} was higher than the other pollutants in almost all months with no significant difference except in July, when the maximum amount of this pollutant was reported [30]. In another study, minimum and maximum concentration of $PM_{2.5}$ were observed in May (12.44 $\mu g/m^3$) and Jan (65.51 $\mu g/m^3$), respectively [31]. The results of another study indicated that meteorological and environmental parameters in winter season (71%) have a much higher ability to explain $PM_{2.5}$ concentration than summer season (40%). In winter, $PM_{2.5}$ concentration had a positive correlation with temperature, and a negative correlation with wind speed in the northeastern part of the study area. Precipitation has a positive correlation with $PM_{2.5}$ concentration in most parts of Tehran in both seasons. In summer, the air temperature parameter showed a high correlation with $PM_{2.5}$ concentration [31].

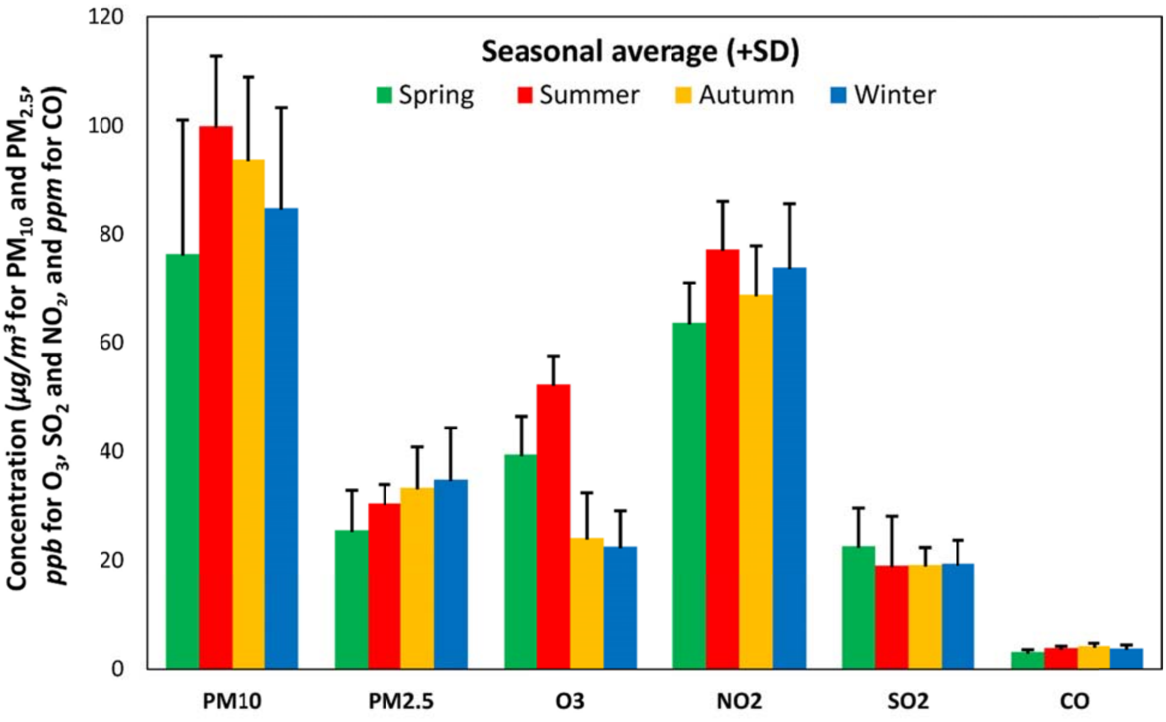

Fig. 2. Seasonal averages (+SD) of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations in Tehran during 2014-2018

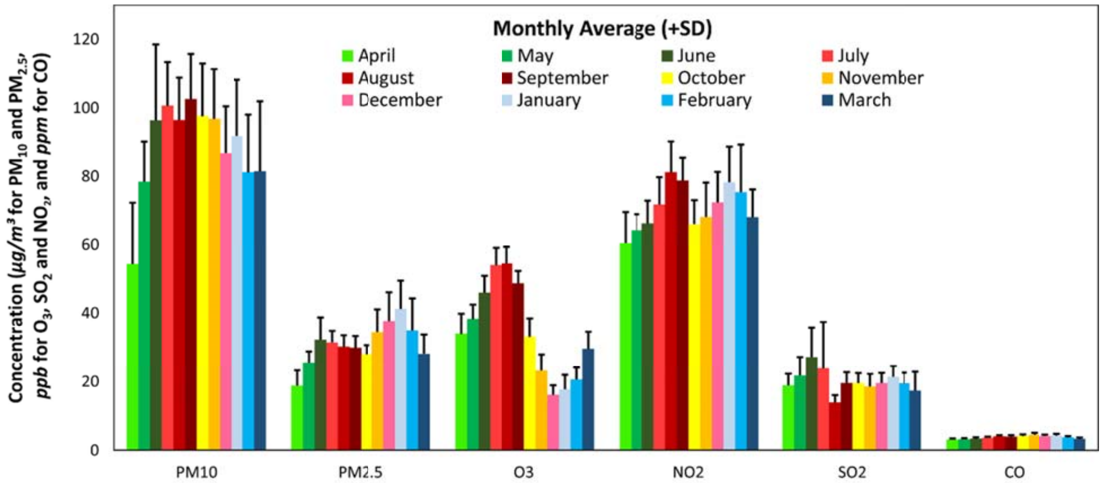

Fig. 3. Monthly averages (+SD) of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO concentrations in Tehran during 2014-2018

Fig. 4 illustrates the averages (+standard deviation) of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO based on the day of week. It should be noted that Fridays are weekend in Iran. Lower concentrations of PM_{10} and NO_2 in Fridays were observed comparing to other days of week. Friday concentrations of PM_{10} and NO_2 were statistically lower than those recorded in Wednesday and Tuesday, respectively ($P<0.05$). $PM_{2.5}$ concentrations were reduced in Fridays, but this was not statistically significant. Although no statistically significant differences were found were other air pollutants and other days, some variations can be seen in Fig. 4. For instance, ozone has high concentrations in Fridays. The reason for reduction in particulate matter and NO_2 concentrations in Fridays is the fewer people and vehicles moving within city. This increase in ozone levels during weekends is reported in other studies [32]. They stated that this can be due to several factors including: i) less NOx emission in weekends and less inhibition by NOx, ii) changes to the timing of NOx emissions, iii) recirculation of polluted air or overnight accumulation of emissions influences next-day O_3 formation and differs from weekdays to weekends, and iv) lower weekend aerosol levels and increase the amount of photolysis caused by solar radiation [32]. In Tehran, the higher concentrations of ozone in Fridays could be also due to the higher emission of hydrocarbons (as a precursors of ozone) from heavy vehicles that are free to enter the inner areas of Tehran in Fridays.

Table 3 presents the Pearson's correlation coefficients between PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, CO, temperature (°C), dew point (°C), relative humidity (%), wind speed (m/s), and barometric pressure (mbar). According to this Table, particulate matter (PM_{10} and $PM_{2.5}$) had significant correlations with all of the pollutants and meteorological variables, except for SO_2 and barometric pressure. On the other hand, SO_2 had only a significant negative correlation with ozone (r=-0.139) and relative humidity (r=-0.055). NO_2 had a high correlation with carbon monoxide (r=0.513). Ozone's correlation with all of the pollutant than PM_{10} was negative. Carbon monoxide showed to have positive significant correlations with particulates, NO_2, and pressure, and negative significant correlations with ozone, dew point, relative humidity, and wind speed. Surprisingly,

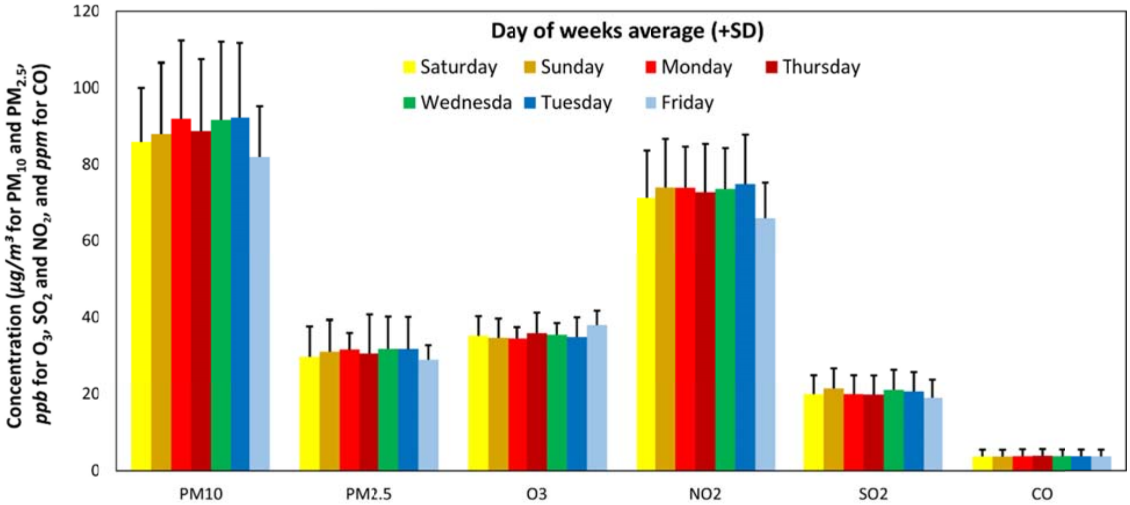

Fig. 4. PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO averages (+SD) in Tehran based on the day of the week

a negative correlation coefficient was observed between ozone and temperature. In addition, relative humidity had negative correlations with all other variables, except for $PM_{2.5}$. The correlation between wind speed and PM_{10}, $PM_{2.5}$, NO_2, and CO was negative and significant. This means that with increasing wind speed, the concentrations of these pollutants decreases.

In a study, a weak positive correlation was observed between $PM_{2.5}$ (µg/m³) and temperature ($r=0.42$, $P< 0.05$) and humidity ($r=0.37$, $P< 0.05$) in Tehran. In addition, a negative significant correlation was found between $PM_{2.5}$ daily average concentrations (µg/m³) and wind speed ($r=-0.686$, $P< 0.05$). However, no significant relationship ($P< 0.327$) was reported between total average precipitation and $PM_{2.5}$ daily average concentrations in Tehran during this study [31].

Table 3. Pearson's correlation coefficients between PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, CO, temperature (°C), dew point (°C), relative humidity (%), and pressure *

	PM_{10}	SO_2	NO_2	O_3	CO	Temp.	Dew.	RH	Wind S.	Pressure
$PM_{2.5}$	**0.767**	0.031	**0.438**	**-0.195**	**0.394**	**0.110**	**0.072**	**0.068**	**-0.367**	**0.233**
PM_{10}		-0.019	**0.244**	**0.075**	**0.268**	**0.225**	**0.115**	**-0.220**	**-0.152**	0.010
SO_2			0.019	**-0.139**	0.024	0.049	0.029	**-0.055**	0.010	-0.015
NO_2				0.014	**0.513**	**0.058**	**-0.140**	**-0.179**	**-0.296**	**0.073**
O_3					**-0.110**	**0.752**	**0.351**	**-0.638**	**0.101**	**-0.448**
CO						-0.035	**-0.139**	**-0.053**	**-0.417**	**0.198**
Temp.							0.530	**-0.787**	0.145	**-0.573**
Dew.								0.048	0.031	**-0.309**
RH									**-0.145**	**0.404**
Wind S.										**-0.429**

* Temp: temperature in °C; Dew: dew point in °C, RH: relative humidity in %, and Wind S: wind speed in m/s. In addition, significant correlation coefficients are presented as bold numbers.

The effects of meteorological parameters on the concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO during the study period were investigated using linear regression, and the results are presented in Table 4. In addition to yearly analyses, the concentrations of air pollutants in all the four years were modelled against the values of meteorological parameters in the same time period. All of the models were statistically significant. A wide range of adjusted R-squared values was observed in models (R^2=0.005-0.767). This means that depending on the situation, meteorological variables can explain a small or large variations of air pollutants. In addition, the R^2 values showed that there are other variables and confounders e.g. sources of air pollution that have a significant effect on air pollution variations. However, the fact that most of the models were significant indicates that meteorological variables in general affect the concentrations of air pollutants in Tehran, even if this effect is weak.

Positive coefficients mean that with increasing the meteorological parameter, the concentration of pollutant increases as well. The opposite relationship exist in case of negative coefficients. The total linear regression of air pollutants showed that PM_{10} concentrations were affected by wind speed (negatively), temperature (negatively), dew point (positively), and relative humidity (negatively). $PM_{2.5}$ was influenced by wind speed (negatively), dew point (negatively) and relative humidity (negatively). Ozone was affected by only temperature (positively) and relative humidity (negatively). In addition, wind speed, dew point, and relative humidity were related to NO_2 negatively. Temperature, dew point, and relative humidity influenced SO_2 concentrations negatively, positively, and negatively, respectively. And finally, CO were affected by wind speed (negatively), temperature (positively), and dew point (negatively), respectively.

The constant coefficient in the regression equation accounts for any other factors that are not included in model. In case of our study, other factors that are not included in the model are the sources and sinks of air pollutants. The constant is the basic concentration of the pollutant in ambient air when the effects of meteorological variables have been assumed to be zero. For $PM_{2.5}$, the constants in the first and last years were 56.83 and 67.69, meaning that the basic concentrations of $PM_{2.5}$ were 56.83 and 67.69 $\mu g/m^3$, respectively. This indicates that regardless of meteorological variables that potentially can reduce or increase air pollution concentrations, $PM_{2.5}$ concentrations have been increased during the study period. The same pattern can be observed for PM_{10}. These results show that the control policies for reduction of particulate matter have been not effective. However, the basic concentrations of NO_2, SO_2, O_3, and CO have decreased during the study period. In particular, SO_2's basic concentration has increased from 64.88 to 14.16 $\mu g/m^3$. This can be due to the performed air pollution control action, including the use of high-quality fuels in both mobile and industrial sector, and reducing industrial emissions of SO_2.

Fig. 5 shows the average concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO based on the working day and vacation type. Except for O_3, all of the pollutants had higher concentrations in the working days, comparing to those in any type of vacation days. Concentrations of all pollutants rather that SO_2 and O_3 in Nowruz vacations were statistically lower than those in the working days ($P<0.05$). $PM_{2.5}$ and PM_{10} concentrations in Nowruz were even lower than those in Fridays and formal vacations ($P<0.05$). In most cases, Fridays and formal vacations have not affected the concentrations of pollutants in comparison to work-

Table 4. Linear regression equations for the effects of meteorological parameters on air pollution in Tehran during 2014-2018 *

Pollutant	Linear regression equation	Adj. R^2
PM_{10}		
2014 -2015	PM_{10} = 101.902 + (-2.899×Wind speed) + (1.337×Dew point)+ (-0.450×RH)	0.084
2015 -2016	PM_{10} = 135.921 + (-3.716×Wind speed) + (1.985×Dew point)+ (-0.750×RH)	0.118
2016 -2017	PM_{10} = 133.731 + (-6.976×Wind speed) + (1.056×Dew point)+ (-0.582×RH)	0.147
2017-2018	PM_{10} = 203.266+ (-5.319×Wind speed) + (-2.394×Temperature) + (2.457×Dew point) + (-1.632×RH)	0.154
Total	PM_{10} = 164.084+ (-4.807×Wind speed) + (-1.165×Temperature) + (2.431×Dew point) + (-1.123×RH)	0.107
$PM_{2.5}$		
2014 -2015	$PM_{2.5}$ = 56.833 + (-2.591×Wind speed) + (-0.476×Temperature) + (0.756×Dew point) + (-2.591×RH)	0.106
2015-2016	$PM_{2.5}$ = 38.579 + (-2.533×Wind speed)	0.083
2016-2017	$PM_{2.5}$ = 47.87 + (-4.075×Wind speed) + (-0.181×Temperature)	0.232
2017-2018	$PM_{2.5}$ = 67.693 + (-4.083×RH) + (-0.734×RH) + (-0.253×RH)	0.274
Total	$PM_{2.5}$ = 46.543+ (-3.372×Wind speed) + (-0.156×Temperature) + (-0.061×RH)	0.145
O_3		
2014 -2015	O3 = 40.955 + (1.485×Wind speed) + (0.521×Dew point) + (-0.438×RH)	0.593
2015-2016	O3 = 63.933 + (-0.998×Wind speed) + (1.223×Dew point) + (-0.738×RH)	0.548
2016-2017	O3 = 34.031 + (0.571×Temperature) + (0.664×Dew point) + (-0.328×RH)	0.596
2017-2018	O_3 = 13.860 + (0.807×Wind speed) + (1.807×Temperature)	0.767
Total	O_3 = 18.503+ (1.098×Temperature) + (-0.131×RH)	0.571
NO_2		
2014 -2015	NO_2 = 128.184 + (-4.843×Wind speed) + (-1.100×Temperature) + (0.548×RH)	0.263
2015 -2016	NO_2 = 78.191 + (-3.291×Wind speed) + (-0.422×RH)	0.187
2016 -2017	NO_2 = 105.516 + (-4.648×Wind speed) + (-0.380×RH)	0.213
2017-2018	NO_2 = 87.121 + (-5.963×Wind speed) + (0.474×Temperature)+ (-1.187×Dew point)	0.247
Total	NO_2 = 94.624 + (-4.728×Wind speed) + (-0.532×Dew point) + (-0.279×RH)	0.150
SO_2		
2014 -2015	SO_2 = 64.882 + (0.837×Dew point) + (-0.531×RH)	0.128
2015-2016	SO_2 = 26.650 + (-0.915×Wind speed) + (-0.194×Temperature) + (0.250×Dew point) + (-0.103×RH)	0.185
2016-2017	SO_2 = 30.718 + (-1.153×Wind speed) + (-0.498×Temperature) + (0.326×Dew point) + (-0.193×RH)	0.398
2017-2018	SO_2 = 14.165 + (-0.680×Wind speed) + (-0.135×Temperature) + (-0.060×RH)	0.405
Total	SO_2 = 38.849 + (-0.464×Temperature) + (0.688×Dew point) + (-0.291×RH)	0.005
CO		
2014 -2015	CO = 5.460 + (-0.308×Wind speed) + (-0.017×Temperature) + (-0.010×RH)	0.233
2015-2016	CO = 5.291 + (-0.248×Wind speed) + (-0.028×Temperature) + (-0.017×RH)	0.267
2016-2017	CO = 5.477 + (-0.539×Wind speed) + (0.034×Temperature) + (-0.070×Dew point)	0.345
2017-2018	CO = 3.557 + (-0.232×Wind speed) + (0.029×Temperature) + (-0.049×Dew point)	0.251
Total	CO = 4.493 + (-0.318×Wind speed) + (0.014×Temperature) + (-0.044×Dew point)	0.142

* RH: relative humidity; Adj. R^2: adjusted R^2.

ing days, except for ozone (formal vacation), NO_2 (Friday), and PM_{10} (Friday) (P<0.05). These results are unique findings, and limited evidences are available in this regard until now.

Conclusion

Concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO during a 4-year period in Tehran were investigated, and the effects of season, month, day of week, and type of day (weekend, holiday and workday) on the air pollution levels were evaluated. The results showed that Tehran is affected by high concentrations of most of these pollutants. However, the annual trend for SO_2 was decreasing. Higher concentrations of PM_{10} and O_3 were observed during summer. In case of $PM_{2.5}$ and CO, autumn and winter concentrations were higher than those in springer and summer. Lower concentrations of PM_{10} and NO_2 and higher concentrations of ozone were observed in Fridays (as weekends in Iran) comparing to other days of week. In addition, except for O_3, all of the pollutants had higher concentrations in the working days, comparing to those in any type of vacation days. These results determines the time periods in which the concentrations of criteria air pollutants are high. This can be very useful for announcing alarms for citizens, and designing the air pollution control plans. For instance, the exact reason for higher concentrations of ozone during the weekends can be investigated by future studies, and lead to implement proper action plans. In addition, by controlling for the effects of meteorological variables, our results showed that the air pollution control policies and actions have been not effective for particulate matter. More effective actions should be designed and implemented for reducing ambient levels of particulate matter.

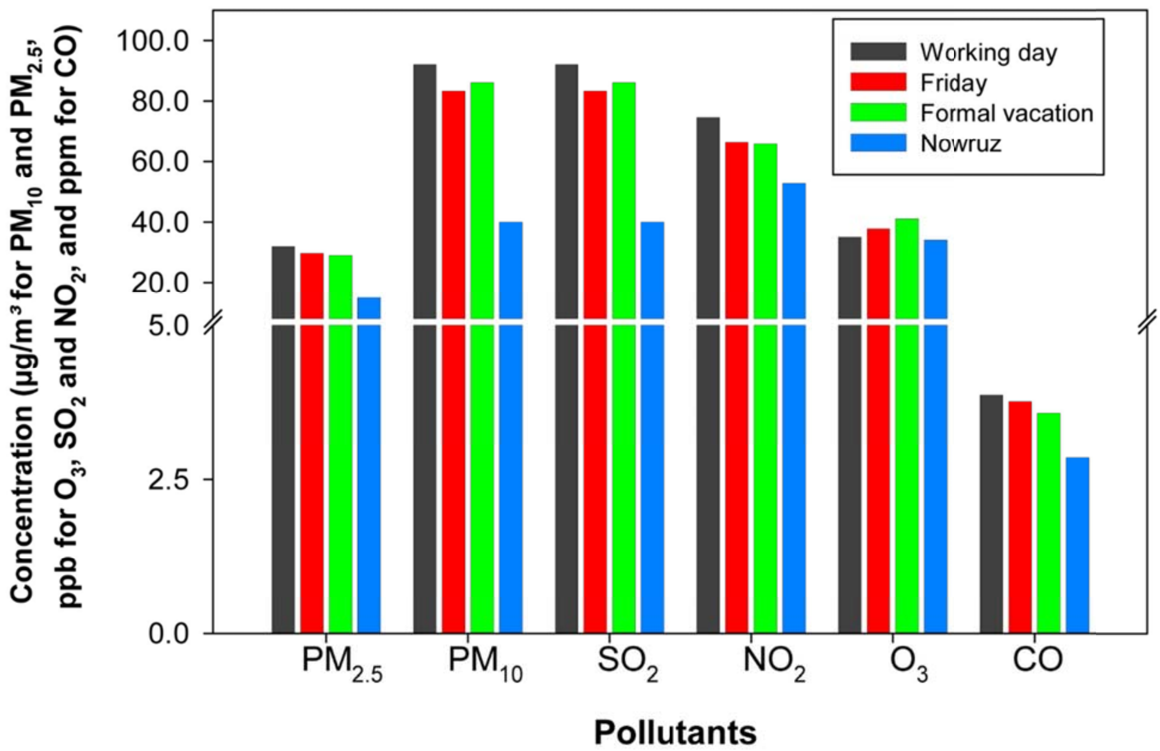

Fig. 5. PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2, and CO averages in Tehran based on the based on the workday and vacation type

Financial supports

This study was supported by the Shahid Beheshti University of Medical Sciences (grant number# 13846).

Competing interests

The authors declare that there are no competing interests.

Acknowledgements

The authors wish to thank Shahid Beheshti University of Medical Sciences. We thank the Environmental and Occupational Health Centre of the Ministry of Health and Medical Education & TAQQC, DOE for providing data.

Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors."

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