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ORIGINAL PAPER

Evaluation of short-lived atmospheric fine particles in Tehran, Iran

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Abstract
Fine particles ($PM_{2.5}$) have adverse impacts and risks on air quality and human health. The present research focuses on the concentrations of $PM_{2.5}$, air quality index (AQI), and assessment of hospital admissions due to COPD attributed to $PM_{2.5}$ particle levels in Tehran during the last 10 years from 2011 to 2020. The effects of meteorological parameters (i.e., wind speed, humidity, and temperature) and AQI on $PM_{2.5}$ concentrations were examined using data from 21 active monitoring stations of the Air Quality Control Company (AQCC) and Mehrabad Meteorological Station. The health impact assessment of $PM_{2.5}$ in terms of hospital admissions due to chronic obstructive pulmonary disease (COPD) was obtained by the $AirQ_{2.2.3}$ model. Based on the results, the annual average $PM_{2.5}$ concentrations decreased from 2011 through 2020. The results also show a significant effect of meteorological data on the changes in $PM_{2.5}$ particle concentration. We also noticed that reduction of annual $PM_{2.5}$ concentration from 38.55 (AQI = 104.08) in 2011 to 28.59 μg m^{-3} (AQI = 83.87) in 2020 could prevent 779 (by about 70%) premature deaths, and the estimated number of excess cases human respiratory system attributed to $PM_{2.5}$ at central relative risk (RR) during the last decade was 6158 persons. Also, air quality got from unhealthy for sensitive groups of people to moderate air quality. Finally, any reduction in concentrations of $PM_{2.5}$ in Tehran can reduce the number of hospital admissions due to COPD significantly. The results of investigations on $PM_{2.5}$ particles have shown the need for the national clean air program policies and the necessity of urgent actions to improve the air quality to human health in Tehran.

Keywords Fine particles ($PM_{2.5}$) · Short-lived climate pollutants · Air pollution · Air quality · Health risk assessment · Human health

Introduction

Short-lived climate pollutants and their health effects are one of the most important challenges in Tehran, capital of Iran, as one of the hundred most polluted global cities (Atash 2007; Shahrabi et al. 2013; Borhani et al. 2017; Masoumi et al. 2017; Van Dingenen et al. 2018; Ansari and Ehrampoush 2019; Ghaffarpasand et al. 2020). Exposure to ambient air pollutants is a crucial global health risk factor estimated to cause over 7,000,000 people premature mortalities every year worldwide, predominantly from particulate matter 2.5 ($PM_{2.5}$) (Cohen et al. 2017; Boogaard et al. 2019). The increase of $PM_{2.5}$ particle concentration and AQI index is a health risk factor for humans (Li et al. 2018). $PM_{2.5}$ particle is composed of different aerosol species including nitrate, sulfate, black carbon, ammonium, dust, and organic carbon. These pollutants are collectively also referred to as the short-lived climate forcers (SLCFs). Also, they are known as subsets of short-lived climate pollutants (SLCP) (Shine et al. 2007; Randall 2008; Baker et al. 2015; Gao 2015; Retama et al. 2015; Rogelj et al. 2015; Stohl et al. 2015; Allen et al. 2016; Klimont and Shindell 2017; Scott et al. 2018; Kindbom et al. 2019; Kuylenstierna et al. 2020; Zheng and Unger 2021).

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Many studies have demonstrated the effects of air pollutants on human health and air quality (Borhani et al. 2014, 2019; Cheraghi and Borhani 2016a, b; Hoveidi et al. 2017; Borhani and Noorpoor 2020). Xing et al. (2016) investigated the effect of fine particulate matter concentrations on human respiratory system parts in China. They suggested to the citizens to limit exposure to air pollution and call to the authorities and communities to establish an index of pollution related to health impacts. Ghorbanian et al. (2020) estimated the mortality rate due to cause by air pollution agents (concentration of $PM_{2.5}$) by AirQ+software in Abadan from 2018 to 2019. Crouse et al. (2015) calculated the relationship between $PM_{2.5}$ concentration exposures and deaths directly rate over 16 Years. Their results show mortality from cardiovascular diseases increased by 10–20% due to an increase in $PM_{2.5}$ concentration. Also, Vahidi et al. (2020) found that $PM_{2.5}$ pollutants are one of the foremost causes of air pollution and their impact on human health is high. Borhani and Noorpoor (2017) studied and monitored the contribution of BTEX volatile organic compounds (i.e., benzene, toluene, ethylbenzene, and xylene) of bituminous production units on cancer risk for workers in Delijan city, Markazi province. In this study, the National Institute for Occupational Safety and Health (NIOSH)'s methods were used to monitor the concentrations of BTEX. Taghizadeh et al. (2019) studied the trend of changes in air quality index in Tehran city from 2011 to 2016. Their results showed among the index pollutants that $PM_{2.5}$ pollutant is the major cause of air quality decline which is the most important in terms of health effects. Faridi et al. (2018) calculated trends of $PM_{2.5}$ particle and ozone during 10 years on health effects of air pollution in Tehran city with the WHO Air Q software.

In this study, we examine the monthly and annual trends of $PM_{2.5}$ particle concentration, air quality index (AQI), and the relationship between $PM_{2.5}$ concentration in air, AQI, and weather parameters in Tehran city urban with an autoregressive integrated during 10 last years (2011–2020). Then, the effect of wind speed, relative humidity, temperature, and AQI on variations of $PM_{2.5}$ particle concentration based on Spearman's rank correlations was also analyzed. Finally, the relationship between $PM_{2.5}$ concentration, the number of attributable cases (NAC) and attributable proportions at central (AP), and growth rate was estimated, and the health impact assessment of fine particulate air pollution in terms of hospital admissions due to chronic obstructive pulmonary disease (HACOPD) cases was obtained by the $AirQ_{2.2.3}$ model.

Methodology

Study area

The study is located in Tehran (35.6892°N and 51.3890°E), the fastest growing city in Iran; according to the Statistical Center of Iran, Tehran's population growth rate in the study period (2011–2020) was respectively 0.89, 1.18, 1.31, 1.31, 1.31, 1.31, 1.32, 1.31, 1.33, and 1.34% (Table 3) (SCI 2020). Rapid population growth is leading to an increasing number of vehicles, city trips, and the consumption of fossil fuels, resulting in an increase in air pollution.

This city with around an area of 751 km^2 is located on the southern side of the Alborz Mountain to its north and the central desert to the south (Fig. 1). In this city, the annual maximum and minimum temperatures are 43℃ in the summer and − 15℃ in winter and the average relative humidity range is between 40 and 70% and the average annual wind speed is less than 3 m/s.

Field measurement

Measurements

In this study, $PM_{2.5}$ concentration values from 2011 to 2020 were taken from 21 active monitoring stations of Tehran Air Quality Control Company (AQCC; Iran) (Fig. 1) (AQCC 2020).

After validation and obtaining hourly and daily average values, the initial data were rounded to two digits after decimal point. Therefore, an approximate value was obtained with the desired accuracy and according to the data collection conditions. The WHO criteria were used to validate the data. Distorted information, including incorrect data (zero and negative data) and the data that were very inconsistent with other data due to local phenomena such as environmental issues (i.e., household waste, construction activities, or fire) in the vicinity of the station, was removed from the database. Stations with more than 75% available hourly concentration data were considered valid. Accordingly, all 21 stations were valid for data processing (Borhani et al., 2021b; USEPA 1997). In the United States Environmental Protection Agency Standard, a maximum concentration of $PM_{2.5}$ particle in the ambient air quality 24 h was used. Optical instruments used for measuring the concentration of $PM_{2.5}$ particles were continuous automatic analyzers made by Thermo Scientific Model (Inc., Waltham, MA, US EPA) and Teledyne API Model (T640 PM mass monitor, San Diego, CA, USA). The continuous particle monitors were commonly used to measure the concentrations of fine particles ($PM_{2.5}$) in outdoor air based on light scattering and beta rays measurement methods. Climate parameters (such as air temperature, wind speed, and relative humidity) are recorded by the weather station Tehran-Mehrabad (latitude 35° 68′ of north and longitude 51° 35′ of east) (refer to Fig. 1).

Air quality index (AQI)

The air quality index (AQI) is based on ground-level ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, and

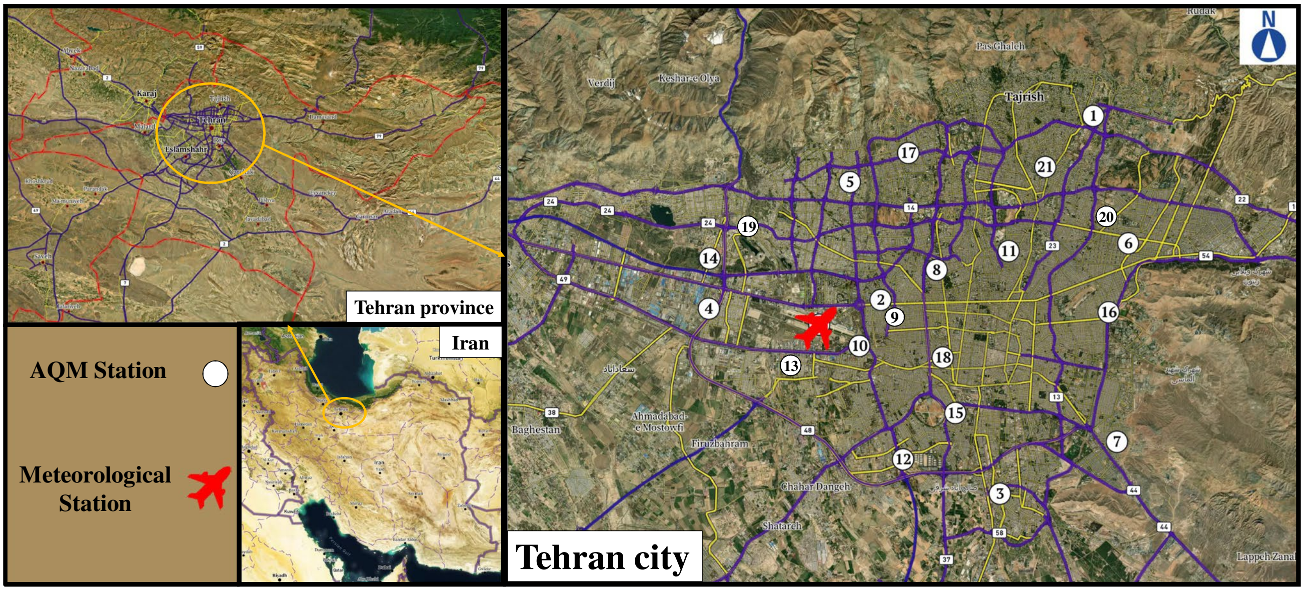

Fig. 1 The locations of the air quality monitoring (AQM) stations and the meteorological station in Tehran city (Source: WebGIS, https://www.mapbox.com/); 1, Aqdasiyeh; 2, Sharif University; 3, Ray; 4, District 21; 5, Punak; 6, Golbarg; 7, Masoudieh; 8, Tarbiat Modares University; 9, District 10; 10, Fath Sq.; 11, Setad Bohran; 12, District 19; 13, Shad Abad; 14, District 22; 15, District 16; 16, Piroozi; 17, District 2; 18, District 11; 19, Rose Park; 20, District 4; 21, Darous

emissions measurement of particle pollution (PM_{10} and $PM_{2.5}$). We extracted the AQI value from Air Quality Control Company in Tehran (AQCC 2020). The AQI was calculated as follows:

$$I_P = \frac{I_{Hi} - I_{LO}}{BP_{Hi} - BP_{LO}} \times \left(C_P - BP_{LO}\right) + I_{LO} \quad (1)$$

$$AQI = \max(I_{O_3}, I_{NO_2}, I_{SO_2}, I_{CO}, I_{PM_{10}}, I_{PM_{2.5}}) \quad (2)$$

where I_P is the index for pollutant p, the C_P is the rounded concentration of pollutant p, BP_{Hi} is the concentrations of pollutants that are higher than or equal to C_P, BP_{LO} is the concentrations of pollutants that are lower than or equal to C_P, I_{Hi} is the AQI value corresponding to BP_{Hi}, and I_{LO} is the AQI value corresponding to BP_{LO}. The AQI which ranges between 0 and 500 is a general indicator of the air quality. AQI ranges from 0 and 50 correspond to good air quality, between 51 and 100 to moderate, between 101 and 150 to unhealthy for sensitive groups, between 151 and 200 to unhealthy, between 201 and 300 to very unhealthy, and between 301 and 500 to hazardous conditions air quality (US EPA 2011).

Air $Q_{2.2.3}$ model

This study evaluates the health impacts of $PM_{2.5}$ on the population growth rate of Tehran with the Air Q software, version 2.2.3, recommended by the World Health Organization (WHO). The data entered included pollutant name ($PM_{2.5}$), area size (km^2), coordinates (latitude and longitude), study year, total population, number of stations used for profiling, and mean and maximum concentration of $PM_{2.5}$. The health risk assessment model correlates air quality data in various ranges of concentration with the WHO default values for epidemiological parameters including baseline incidence (I) per 100,000 per year, attributable proportion (AP), and relative risk (RR) (95% CI) at lower, central, and upper limits. The results of the model have been presents in terms of the number of attributable cases (NAC). For relative risk (RR) cases, the scientific uncertainty will be set to unknown by the program (Naddafi et al. 2012; Kamarehie et al. 2017). As shown, I, AP, and RR are calculated in this software using the following formulas:

$$RR_{IER} = \frac{\text{Probability of a health effect when exposed to air pollution}}{\text{Probability of a health effect when not exposed}} \quad (3)$$

$$AP = \frac{\sum([RR(c) - 1] \times P(c)])}{\sum [RR(c) \times P(c)]} \quad (4)$$

$$IE = I \times AP \quad (5)$$

$$NE = IE \times N \quad (6)$$

where RR, RR(c), AP, I, P(c), NE, IE, N, and IER are relative risk, the relative risk levels of pollutant for a given

Table 1 Monthly average $PM_{2.5}$ concentration, air quality index (AQI), and meteorological parameters (T, WS, and RH) from 2011 to 2020 in Tehran

Year	Parameters	January	February	March	April	May	June	July	August	September	October	November	December
2011	*$PM_{2.5}$ (μg m^{-3})	40.66	27.66	32.33	44.50	41.50	37.75	35.75	42.25	45.25	39.00	34.50	43.50
	AQI	116.07	86.53	84.03	106.67	108.03	128.07	109.35	108.29	105.50	93.58	82.07	120.81
	T (°C)	4.14	6.38	10.66	19.00	24.21	30.30	32.43	30.32	26.57	16.39	8.01	5.52
	WS (knot)	4.63	7.41	5.81	7.71	8.60	7.90	6.58	6.50	5.34	6.22	5.00	3.96
	RH (%)	58.95	48.36	45.58	26.74	27.62	19.17	17.10	26.87	23.90	45.00	66.28	52.88
2012	$PM_{2.5}$ (μg m^{-3})	34.33	33.33	34.00	33.00	41.56	32.90	38.64	31.15	32.36	36.50	35.14	44.50
	AQI	107.39	99.17	87.81	93.63	116.61	95.76	98.42	91.97	93.70	94.42	92.97	113.35
	T (°C)	4.30	3.59	9.32	18.22	24.37	28.25	30.77	31.02	26.25	19.85	12.70	6.11
	WS (knot)	5.88	6.08	8.69	6.54	8.59	6.31	6.15	5.48	5.51	5.23	4.22	4.27
	RH (%)	48.66	52.74	32.14	38.75	23.79	21.67	23.06	18.41	24.43	33.39	52.34	64.96
2013	$PM_{2.5}$ (μg m^{-3})	43.60	35.71	31.40	24.92	23.54	37.46	37.83	33.27	33.70	36.91	33.66	35.46
	AQI	111.13	94.46	86.22	75.03	73.13	104.50	99.90	95.03	99.37	109.90	98.67	109.48
	T (°C)	6.25	8.78	13.52	18.14	22.20	28.39	31.79	29.48	27.79	18.94	12.38	5.10
	WS (knot)	5.85	6.07	7.49	7.11	8.57	8.00	6.78	6.32	6.38	5.57	4.27	5.61
	RH (%)	45.63	44.34	35.15	30.54	28.37	20.77	21.93	24.08	18.67	31.50	53.52	50.79
2014	$PM_{2.5}$ (μg m^{-3})	38.61	35.85	24.85	21.90	22.80	34.33	36.00	29.00	34.45	32.09	29.50	37.91
	AQI	117.52	105.86	79.45	65.10	69.77	96.67	101.77	95.52	97.76	91.22	87.37	106.52
	T (°C)	5.45	5.18	12.52	18.20	24.45	29.56	32.21	31.72	28.06	18.34	9.89	7.33
	WS (knot)	5.26	5.07	8.18	7.44	7.72	8.00	6.78	6.16	6.21	6.57	4.58	4.39
	RH (%)	54.36	44.68	36.58	32.38	24.73	18.48	19.34	16.08	19.04	37.65	49.23	53.61
2015	$PM_{2.5}$ (μg m^{-3})	33.07	29.75	25.00	22.69	26.25	38.06	27.82	26.91	25.00	25.75	37.00	41.23
	AQI	102.77	89.36	76.10	71.40	81.97	108.37	89.42	84.93	82.87	86.29	94.30	116.93
	T (°C)	6.91	8.34	11.42	19.22	25.12	31.47	31.90	30.68	25.46	20.68	10.59	5.00
	WS (knot)	5.07	6.00	6.89	8.29	7.61	6.93	5.98	5.65	5.42	5.78	4.89	4.51
	RH (%)	42.41	47.34	41.90	23.20	20.51	16.02	18.96	21.18	26.18	38.57	50.11	61.62
2016	$PM_{2.5}$ (μg m^{-3})	27.71	32.07	23.38	22.43	25.50	30.14	35.20	35.21	31.33	29.50	42.00	42.00
	AQI	86.35	95.17	70.58	66.30	72.48	89.30	92.64	88.19	91.90	88.90	104.33	103.64
	T (°C)	7.02	9.83	13.66	17.64	24.85	28.64	31.58	30.14	27.24	19.45	9.80	6.28
	WS (knot)	5.76	6.04	8.75	7.57	8.47	8.14	7.03	5.19	6.66	4.71	4.61	5.14
	RH (%)	46.98	37.46	35.89	36.48	26.39	19.23	22.31	18.00	21.43	28.15	41.48	52.64
2017	$PM_{2.5}$ (μg m^{-3})	42.69	31.36	23.44	22.88	28.81	27.87	28.87	29.56	30.69	34.00	37.31	52.81
	AQI	107.00	88.25	69.58	69.70	83.19	80.40	83.19	85.87	86.23	88.97	100.53	114.84
	T (°C)	5.53	5.10	11.21	17.70	25.27	29.80	31.71	30.35	27.23	19.64	13.71	8.26
	WS (knot)	5.21	5.87	6.91	6.81	7.21	7.63	5.70	5.62	5.26	5.32	5.43	4.31
	RH (%)	49.88	47.25	46.32	37.73	24.26	16.87	18.65	19.12	20.41	27.98	32.39	40.00
2018	$PM_{2.5}$ (μg m^{-3})	40.33	43.47	30.60	25.06	25.00	26.14	32.26	25.86	25.07	24.57	29.93	33.80
	AQI	102.93	103.00	87.90	73.23	69.19	70.57	80.03	74.35	76.60	72.55	77.83	89.03
	T (°C)	6.11	8.44	17.07	16.80	21.22	28.86	34.10	31.73	27.15	19.30	10.91	8.99
	WS (knot)	5.34	5.15	8.38	6.25	7.18	6.30	5.65	6.00	5.58	5.69	4.29	4.71
	RH (%)	47.00	55.95	27.15	37.08	37.46	22.26	14.09	20.00	21.17	40.36	59.14	51.50
2019	$PM_{2.5}$ (μg m^{-3})	33.43	27.36	19.00	17.00	22.53	27.07	29.67	27.50	26.81	27.06	45.69	47.94
	AQI	89.26	72.89	57.03	50.77	64.26	76.40	86.13	79.71	79.70	81.42	108.03	108.90
	T (°C)	5.94	7.23	10.48	15.38	24.26	30.40	33.06	30.61	26.68	19.59	9.34	7.89
	WS (knot)	5.81	6.35	7.11	7.12	7.96	5.84	7.24	6.12	6.20	5.03	4.36	4.42
	RH (%)	51.86	44.44	43.09	34.07	25.34	18.13	18.42	20.52	24.53	40.02	57.45	56.81
2020	$PM_{2.5}$ (μg m^{-3})	38.75	26.44	21.56	18.62	22.75	26.25	27.75	24.37	24.50	31.62	30.94	49.50
	AQI	97.39	74.45	68.16	60.97	72.13	79.50	83.42	78.48	84.33	94.90	91.87	120.84
	T (°C)	4.02	7.25	13.00	15.09	24.14	29.67	31.20	28.87	25.98	18.27	11.48	5.01
	WS (knot)	5.11	7.90	6.21	6.86	7.47	7.65	6.27	6.78	5.27	4.42	4.42	4.08
	RH (%)	57.95	46.75	41.37	48.37	26.28	17.46	21.02	26.46	23.60	32.71	57.20	67.71

*Air quality monitoring stations with less than 75% valid hourly data available were excluded from the next analysis

AQI, air quality index; *T*, temperature; *WS*, wind speed; *RH*, relative humidity

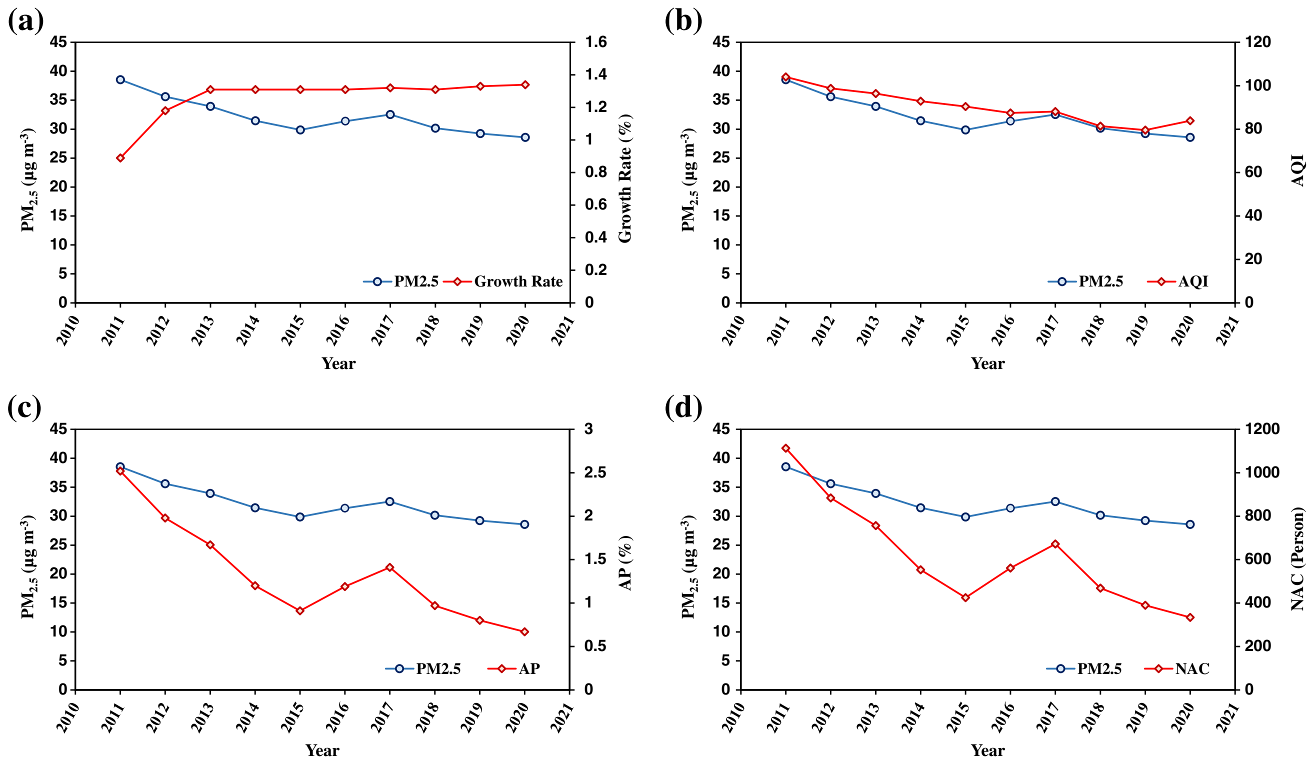

Fig. 2 Comparison of annual average of $PM_{2.5}$ from 2011 to 2020, **a** growth rate, **b** AQI, **c** AP, **d** NAC

health endpoint, in category "c" of exposure (e.g., industrial or residential), the exposed group of the population, the attributable proportion of the health effects, the rate of the health impact attributable to the short-term exposure, the baseline incidence of the health effect in the inhabitants under study, the number of excess cases related to the contact, the population size studied, and the integrated exposure–response function, respectively.

Analysis

Linear multivariate regression based on the LMV model is a common method in air pollution studies. This model was used in this study because of its capabilities to predict the participation of selected parameters in changing the concentration of $PM_{2.5}$ particle concentration (Abdul-Wahab et al. 2005). The general equation of multivariate linear regression is expressed as Eq. (7) (Gvozdić et al., 2011).

$$y = b_0 + \sum_{i=1}^{p} b_i x_i + \varepsilon \quad (7)$$

where b_0, b_i, x_i, and ε are the regression constant, regression coefficient, independent variable, and random error related to regression, respectively. Also, Spearman's correlation coefficient model was utilized to examine the statistical relationship among $PM_{2.5}$ particle and T, RH, WS, and AQI. Correlation coefficients significant (r) at the 0.05 level (where P value less than 0.05 is considered valid) are shown with a star-shaped symbol (*) (Özbay 2012). Statistical analysis was performed using SPSS software.

Result and discussion

Results of the effects of $PM_{2.5}$ emissions on air quality

Table 1 shows the monthly average of $PM_{2.5}$ concentration in Tehran. Average $PM_{2.5}$ particle concentrations in all the 21 air quality monitoring stations were about three times as high as the World Health Organization Air Quality Guidelines (AQGs) values (10 μg m^{-3}) for annual average $PM_{2.5}$ levels. The WHO (2003) showed that on most months (about 81.67%) of the decade (2011–2020), $PM_{2.5}$ particle concentration was higher than 25 μg m^{-3}.

Figure 2a shows the relationship between the population growth rate versus $PM_{2.5}$ concentration during 10

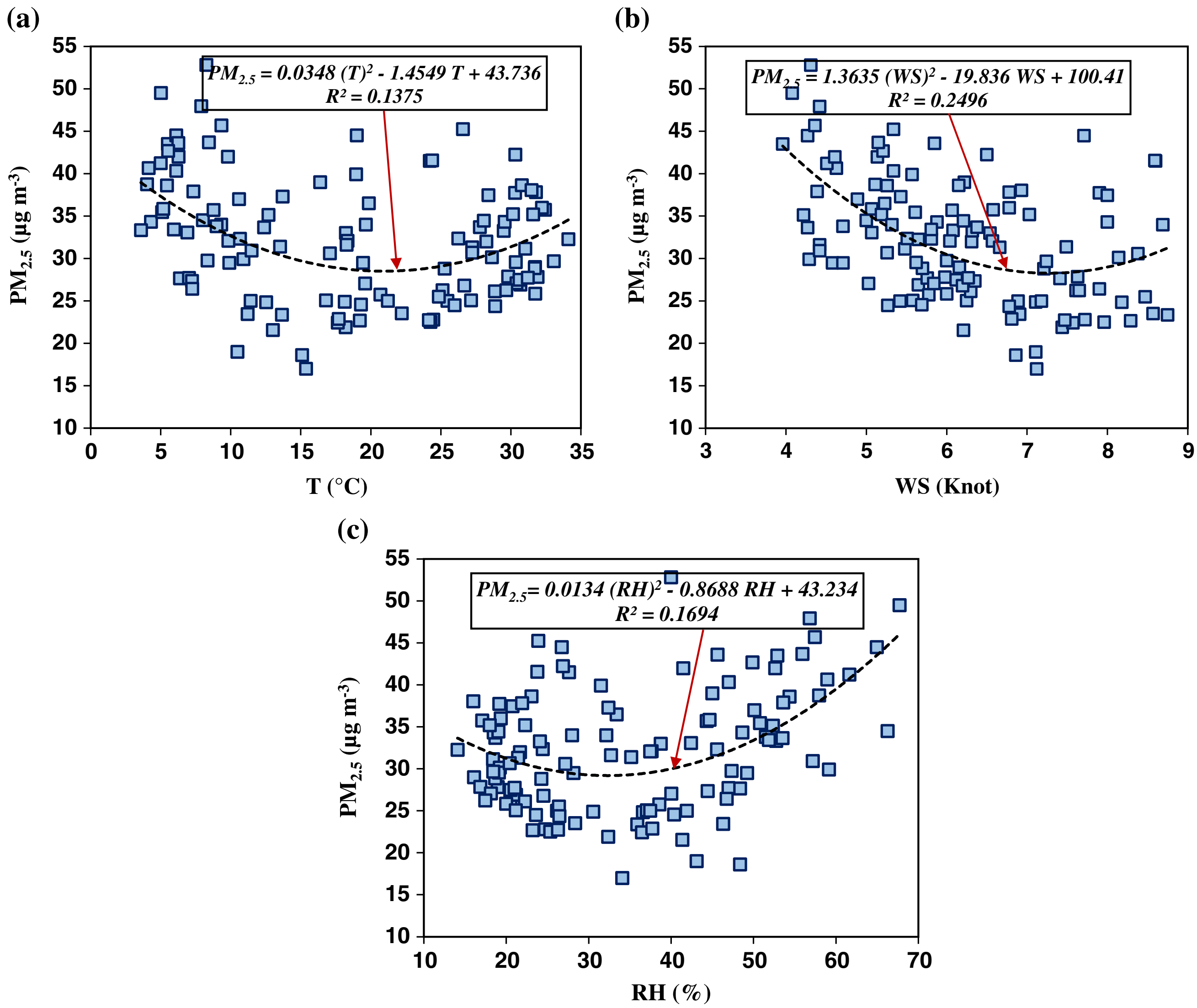

Fig. 3 Variation of $PM_{2.5}$ against **a** temperature (T), **b** wind speed (WS), **c** relative humidity (RH); the best fitted curve to data and related equation are also superimposed on the plot

successive years. Based on results, in the last 10 years, the speed of population growth has been much slower, and the annual average $PM_{2.5}$ concentrations and air quality index (AQI) decreased from 2011 through 2020 (Table 1). It was observed that the maximum $PM_{2.5}$ particle concentration for the studied decade was recorded in January and December (Table 1). These findings are consistent with other studies (i.e., Hien et al. 2002; DeGaetano and Doherty 2004; Meng et al. 2007; Yunesian et al. 2019; Barzeghar et al. 2020; Sidibe et al. 2022). The monthly unhealthy air quality (AQI > 100) was estimated about 26.67% during the last 10 years. The highest values of AQI were observed in December and January. Also, from January to March, the monthly average of AQI showed a decreasing trend.

Table 2 Spearman's rank correlations between $PM_{2.5}$ and T, RH, WS, and AQI data from 2011 to 2020

	$PM_{2.5}$ (µg m^{-3})	T (°C)	WS (knot)	RH (%)	AQI
$PM_{2.5}$ (µg m^{-3})	1				
T (°C)	−0.2122*	1			
WS (knot)	−0.4085*	0.3720	1		
RH (%)	0.2698	−0.9185*	−0.5136*	1	
AQI	0.8534	−0.2038*	−0.3976*	0.2283	1

*$P \leq 0.05$

Results of analysis

Table 1 shows the monthly average of meteorological parameters (wind speed, humidity, and temperature) from 2011

Table 3 Tehran historical population data and estimation of relative risk, attributable proportions, and number of attributable cases (persons)

Year	Dataset				Indicator		
	Population	Growth rate (%)	$PM_{2.5}$ (μg m^{-3})	AQI	RR	NAC	AP (%)
2011	8,131,000	0.89	38.55	104.08	1.00 (1.019–1.0402)	1113	2.52
2012	8,227,000	1.18	35.61	98.77	IER function	884	1.98
2013	8,335,000	1.31	33.95	96.40	IER function	757	1.67
2014	8,444,000	1.31	31.44	92.88	IER function	553	1.20
2015	8,555,000	1.31	29.88	90.39	IER function	425	0.91
2016	8,667,000	1.31	31.37	87.48	IER function	561	1.19
2017	8,781,000	1.32	32.53	88.14	IER function	672	1.41
2018	8,896,000	1.31	30.18	81.43	IER function	469	0.97
2019	9,014,000	1.33	29.25	79.54	IER function	390	0.80
2020	9,135,000	1.34	28.59	83.87	IER function	334	0.67

RR, relative risk (central); *AP*, attributable proportions at center (%); *NAC*, number of attributable cases (persons); *IER*, integrated exposure–response function

to 2020 in Tehran. There is a negative correlation between $PM_{2.5}$ particle, wind speed (WS), and temperature (T) (Fig. 3a, b, and Table 2). Maraziotis et al. (2008) investigated the concentration of fine particles ($PM_{2.5}$) in the urban region of Patras, Greece. They observed a negative correlation between $PM_{2.5}$ concentrations, wind speed, and temperature. Several investigations have reported negative correlation between wind speed and $PM_{2.5}$ concentration (e.g., Afghan and Patidar 2019; Hua et al. 2021; Borhani et al. 2022). In addition, there is a significant positive correlation between $PM_{2.5}$ particle concentration and relative humidity (RH) (Fig. 3c and Table 2). Previous studies show that geographic characteristics, aerosol types, and anthropogenic emissions have an important influence on the relationships between $PM_{2.5}$ concentration and meteorological factors (Zhao et al. 2014; Li et al. 2017; Yang et al. 2017). $PM_{2.5}$ concentration has a strong relationship with air quality index (AQI) (R square = 0.73) (e.g., How and Ling 2016; Navinya et al. 2020; Wang et al. 2020) (Fig. 2b).

Also, as can be seen in the regression model, the impact of attributable proportions (AP), number of attributable cases (NAC), growth rate (GR), and air quality index (AQI) on $PM_{2.5}$ concentration about was noticeable (Eq. 8). The wquation was estimated by linear multivariate regression based on the LMV model with machine learning algorithms in python.

$$PM_{2.5}\left(\mu g m^{-3}\right) = 5.1415\,AP + 0.0004\,NAC - 0.1650\,GR + 0.0045\,AQI + 24.8646 \quad (8)$$

Results of the effects of $PM_{2.5}$ emissions on human health

Using Air $Q_{2.2.3}$ software, health impacts from $PM_{2.5}$ concentration in Tehran during the last 10 years (2011–2020) were calculated. Table 3 shows relative risk (RR) per 10 μg m^{-3} increase and 95% confidence intervals (with 95% CIs), attributable percentage, and number of victims, per 100,000 person-years, from COPD chronic exposure to $PM_{2.5}$ particle. The number of cases of HACOPD related to $PM_{2.5}$ particle concentration is presented in Table 3. The estimated number of excess cases caused by $PM_{2.5}$ at central RR (1.019–1.0402) during the last decade was 6158 persons. The 2011 year showed the highest (NAC = 1113) and the 2020 year the lowest (NAC = 334) number of HACOPD per 100,000 people. As seen, percentages of attributable proportions at central RR were 2.52, 1.98, 1.67, 1.20, 0.91, 1.19, 1.41, 0.97, 0.80, and 0.67 during 2011 to 2020, respectively (Fig. 2c and Table 3). So, results showed that reduction of annual $PM_{2.5}$ concentration from 38.55 in 2011 to 28.59 μg m^{-3} in 2020 could prevent 779 (by about 70%) premature deaths (Fig. 2d and Table 3). The number of HACOPD was all correlated with the change of $PM_{2.5}$ and AQI value. Kermani et al. (2016) investigated in a study the $PM_{2.5}$ hygienic effects in eight industrialized cities of Iran. Based on their results, with increasing each 10 μg m^{-3} concentration of $PM_{2.5}$ particle 1.5% increase in the risk factor of mortality. Also, the total confirmed deaths due to mortality attributable to $PM_{2.5}$ pollutant in Shiraz and Isfahan were estimated 454 and 585 cases, and the rate is estimated 5.42% of all deaths in these eight industrialized cities (Kermani et al., 2016). Previous similar studies have shown that long-term exposure to $PM_{2.5}$ particle pollutants is related to a condition expanded risk of hospital admissions due to COPD infection (Hadei et al. 2017; Asgari et al. 2021; Mirzaei et al. 2021). Results of the similar studies also showed a significant relationship between COVID-19 pandemic lethality and exposure to air pollutants; exposure to $PM_{2.5}$ air concentration during this outbreak may increase the risk of pandemic of coronavirus disease in Tehran, Iran (Faridi et al. 2020; Borhani et al. 2021a; Czwojdzińska et al. 2021).

Conclusions

Air pollutants are considered one of the biggest threats to human health risks in Tehran, the capital of Iran. This study reports a detailed analysis of the variabilities and trends and meteorological conditions (wind speed, humidity, and temperature) in the $PM_{2.5}$ concentration measured on air quality and human health at 21 air pollution monitoring stations located in different districts of Tehran, in over 10 years (2011–2020). Annual mean of $PM_{2.5}$ particle concentration and AQI in 2020 compared to 2011 has decreased. The Pearson correlation method was used to indicate the effect of meteorological conditions on average concentration of $PM_{2.5}$. The results showed that $PM_{2.5}$ concentration had a relationship positive with relative humidity and a relationship negative with temperature and wind speed. Also, $PM_{2.5}$ concentration had a positive correlation with air quality index, indicating that fine particle pollution had a great impact on air quality. Then, we used the Air Q software to estimate the health impacts of air quality on human. The hospital admissions for respiratory and cardiovascular diseases that are attributable to relatively long period of time exposure to fine particles were estimated. As presented in this study, air quality affects the rates of hospital admissions due to COPD dramatically. Therefore, authorities must use the proper measures such as restriction of emissions from fossil fuel use for transportation, improving public vehicles, and increasing traffic management quality to control particulate matter emissions and improve the health effects upon human health.

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Data availability The database analyzed during the present study is available from the corresponding author on reasonable request.

Declarations

Ethics approval Not applicable.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors declare that they agree with the publication of this paper in this journal.

Conflict of interest The authors declare that they have no competing interests.

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