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Estimation of Mortality and Hospital Admissions Attributed to Criteria Air Pollutants in Tehran Metropolis, Iran (2013–2016)

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ABSTRACT

Health impact assessments are useful for governmental authorities and decision-makers to determine the need for action and address potential public health problems arising from exposure to air pollution. The present study was conducted to assess the short-term health impacts of ambient air pollution in Tehran using the AirQ 2.2.3 model for March 2013–March 2016. Hourly concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2 were acquired from the Department of Environment (DOE) and Tehran Air Quality Control Company (TAQCC). Air pollution data was validated according to the USEPA criteria, and only valid monitoring stations for each of the three years were entered to the AirQ 2.2.3 model. The pollutant concentrations were lower in the March 2015-March 2016 period compared to the previous years. 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. 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. The total estimated number of deaths attributed to PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2 over these three years were 4192, 4336, 1363, 2830, and 1216, respectively. The health impacts attributed to all pollutants except for PM_{10} were estimated to decrease in 2016, compared to the prior years. However, the air quality in Tehran still poses significant risks to public health. In conclusion, urgent efforts are needed such as mandating the replacing of old and poorly functioning vehicles from the roadways in order to reduce the health burden that air pollution is currently imposing on this city.

Keywords: Quantification; Air pollution; Short-term effect; Particulate matter; Ozone.

INTRODUCTION

The World Health Organization (WHO) reported that in 2012 about 7 million deaths could be attributed to exposure to air pollution, of which 3.7 million could be the result of exposure to ambient air pollution (WHO, 2014). Epidemiological studies have shown positive associations between air pollutants such as particulate matter of aerodynamic diameter less than 10 µm (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3) and carbon monoxide (CO) and adverse health outcomes (Goldberg *et al.*, 2013; Crouse *et al.*, 2015; Fischer *et al.*, 2015; Liu *et al.*, 2015; Wong *et al.*, 2015; Yorifuji *et al.*, 2016). Many studies have been conducted to assess the health impacts of air pollution in various cities of the world (Boldo *et al.*, 2006; Fattore *et al.*, 2011; Orru *et al.*, 2012; Allen *et al.*, 2013), including Iranian cities (Naddafi *et al.*, 2012a; Gholampour *et al.*, 2014; Ghozikali *et al.*, 2016; Mohammadi *et al.*, 2016). These results could be of interest to authorities and decision-makers (Fattore *et al.*, 2011; Likhvar *et al.*, 2015).

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The World Bank reported that the economic cost of air pollution has increased significantly from 1990 to 2013, in which the total welfare losses due to premature deaths from exposure to air pollution increased by 94 percent. The welfare losses due to air pollution in the Middle East and North Africa in 2013 were reported to be 154 billion USD, an increase of 108% compared to 1990. In addition, the costs due to exposure to $PM_{2.5}$ in the Middle East and North Africa have increased from 62 to 141 billion USD in the same period (World Bank, 2016). Due to the contribution of air pollution to decreased public health and its economic impact on the country, quantification of possible mortality and hospitalizations is useful in assessing the likely damages.

BACKGROUND

The AirQ 2.2.3 model has been developed by the WHO European Centre for Environment and Health, Bilthoven Division, and estimates the health effects of air pollutants such as mortality and hospital admission among people within a specific area and over a given time period (Fattore *et al.*, 2011).

Approximately 1.5 million tons of pollutants especially particulate matter are produced in Tehran annually (Madanipour, 2006; Atash, 2007). Tehran's population is about 9 million people (about 13% of population of Iran) (Naddafi *et al.*, 2012b). Studies have been conducted on the physicochemical characteristics and genotoxic effects of particulate matter in Tehran (Mohseni Bandpi *et al.*, 2016; Mohseni Bandpi *et al.*, 2017).

Multiple studies have been conducted to estimate the health impacts of various air pollutants using the AirQ 2.2.3 model. Kermani *et al.* (2016a) investigated $PM_{2.5}$ concentrations and its health effect in Tehran during 2005–2014. The annual mean concentrations of $PM_{2.5}$ during these 10 years were 34.92, 30.29, 33.09, 41.40, 38.38, 47.02, 47.31, 40.75, 43.26 and 36.15, respectively. All the annual concentrations were higher than the WHO's guideline. In addition, the total attributable deaths during the whole period were estimated to be 20015 cases (Kermani *et al.*, 2016a). In another study in Tehran, the number of cardiovascular and respiratory hospital admissions due to exposure to PM_{10} during 2005–2014 was estimated using the AirQ 2.2.3 model. The total cases of cardiovascular and respiratory hospital admissions in the whole period were reported 20990 and 54352, respectively (Kermani *et al.*, 2016b). Naddafi *et al.* (2012a) assessed the health impacts of PM_{10}, NO_2, SO_2, and O_3 in Tehran during 2010. The number of all-cause, cardiovascular, and respiratory deaths, and cardiovascular, respiratory, and chronic obstruction pulmonary disease hospital admissions, and acute myocardial infarctions were estimated. They concluded that the magnitude of the health impacts estimated for Tehran underscores the need for urgent action to reduce the health burden of air pollution (Naddafi *et al.*, 2012a).

Another study estimated health outcomes for cardiovascular and respiratory mortality attributable to O_3 and NO_2 using the AirQ program. The results showed that the total cumulative number of mortalities attributed to NO_2 and O_3 were 1593 and 946, respectively, that represents about 2.66% and 1.58% of total non-accidental mortality in Tehran (Kermani *et al.*, 2016c). In general, few studies exist about the health impacts of particulate air pollution, especially $PM_{2.5}$. However, the majority of these studies have a serious weakness in methodology because they used the old WHO criteria for validating monitoring stations.

The numbers of hospital admissions and mortality related to NO_2 in five Iranian cities (Mashhad, Tabriz, Shiraz, Isfahan and Arak) in 2011–2012 were estimated using the AirQ model. The highest numbers of estimated adverse health outcomes were in Mashhad and Isfahan. These values likely result from the increasing number of vehicles with related traffic, fuel usage, and high levels of temporary and permanent population in religious and tourist sites (Asl *et al.*, 2015).

Miri *et al.* (2016) estimated the mortality and morbidity resulting from exposure to ambient air pollution in Mashhad metropolis using AirQ model. The attributable proportion of total mortality values attributed to exposure to PM_{10}, $PM_{2.5}$, SO_2, NO_2 and O_3 were, respectively, 4.24%, 4.57%, 0.99%, 2.21%, 2.08%, and 1.61% of the total deaths occurring in the year of study (Miri *et al.*, 2016). Goudarzi *et al.* (2015) estimated the all-cause and respiratory mortality attributable to PM_{10} in Ahvaz city during 2009. Their analysis predicted 1165 all-cause deaths and 115 respiratory deaths annually for each 10 µg m^{-3} increase in PM_{10}. They concluded that the high number of deaths could be the result of higher PM_{10} average or because of sustained high-concentration days in Ahvaz (Goudarzi *et al.*, 2015). There are other studies about the application of AirQ 2.2.3 for a variety of air pollutants in different Iranian cities (Goudarzi, 2014; Geravandi *et al.*, 2015; Nourmoradi *et al.*, 2015; Ghozikali *et al.*, 2016; Mohammadi *et al.*, 2016; Nourmoradi *et al.*, 2016; Khaniabadi *et al.*, 2017). However, there has not been a recent analysis of the impacts of each of the criteria pollutants on health outcomes in Tehran, Iran’s most populous city.

The present study was conducted to assess the short-term health impacts of outdoor air pollution in Tehran using the AirQ model for the March 2013–March 2016 period.

METHODS

Location and Time

Tehran is the capital of Iran located at latitude and longitude of 35° 41'N, 51° 25'E. It has about 9 million inhabitants and 3 million personal vehicles (Shahbazi, 2015). Three one-year periods were considered in this study. The first period is from 21 March 2013 to 20 March 2014. The second period is from 21 March 2014 to 20 March 2015. Also, the third period is between 21 March 2015 and 19 March 2016.

Data Collection

Hourly concentrations of PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2 from 21 March 2013 to 19 March 2016 (three years in the Persian calendar) were acquired from the Department of

Environment (DOE), and Tehran Air Quality Control Company (TAQCC). The locations of monitoring stations are illustrated in Fig. 1. Relative risk values were adopted from several European meta-analyses that have been used in previous studies regarding health impact quantification in Iran (WHO, 2000; Anderson *et al.*, 2004; Gryparis *et al.*, 2004; Samoli *et al.*, 2006). The number of deaths for all mortality was obtained from National Organization for Civil Registration of Iran. Baseline incidence (BI) for non-accidental mortality was calculated using the ratio of accidental deaths given by Ministry of Health and Medical Education of Iran (Khosravi, 2016). In addition, BI values for cardiovascular and respiratory mortality were calculated by multiplying the reported non-accidental mortality value by the ratio of cardiovascular and respiratory deaths given by Ministry of Health and Medical Education. BI values for cause-specific hospital admission were taken as the default values in AirQ 2.2.3. The populations of Tehran during these three periods were obtained from Statistical Centre of Iran. The city population in March 2013–March 2014, March 2014–March 2015, and March 2015–March 2016 periods were 8209730, 8652820, and 8866500, respectively.

Data Validation

The initial filtering of the data included the deletion of zero and negative data. The concentrations of the gaseous pollutants were converted to $\mu g\ m^{-3}$ (Boguski, 2006). Then, EPA's criteria for data completeness requirements was used to determine valid stations for entering the model (USEPA, 2015). After assessment of the data from each station, only qualified data sets were selected. Finally, 24-hour average values were calculated for PM_{10}, $PM_{2.5}$, and SO_2. In addition, eight-hour moving average and one-hour average were calculated for O_3 and NO_2, respectively. Only valid stations common in all the three years were selected to enter the model, and the others were excluded. The overall 24-h city-wide averages were calculated from the 24-h averages of all of the included stations on each day. The frequency of days within the AirQ-defined concentration ranges was calculated for the model.

AirQ Software 2.2.3

WHO has developed and released AirQ 2.2.3 to assess the short- and long-term health effects of ambient air pollution. This program calculated the attributable proportion, the attributable cases, the attributable cases per 100,000 persons, and the proportion of cases in each concentration range. Epidemiological studies are the sources of the relative risk values and the concentration-response functions used in the model. The required model inputs include the annual and seasonal mean and maximum, the 98th percentile, the number of days within each specified concentration range, demographical information, baseline incidence, and relative risk values.

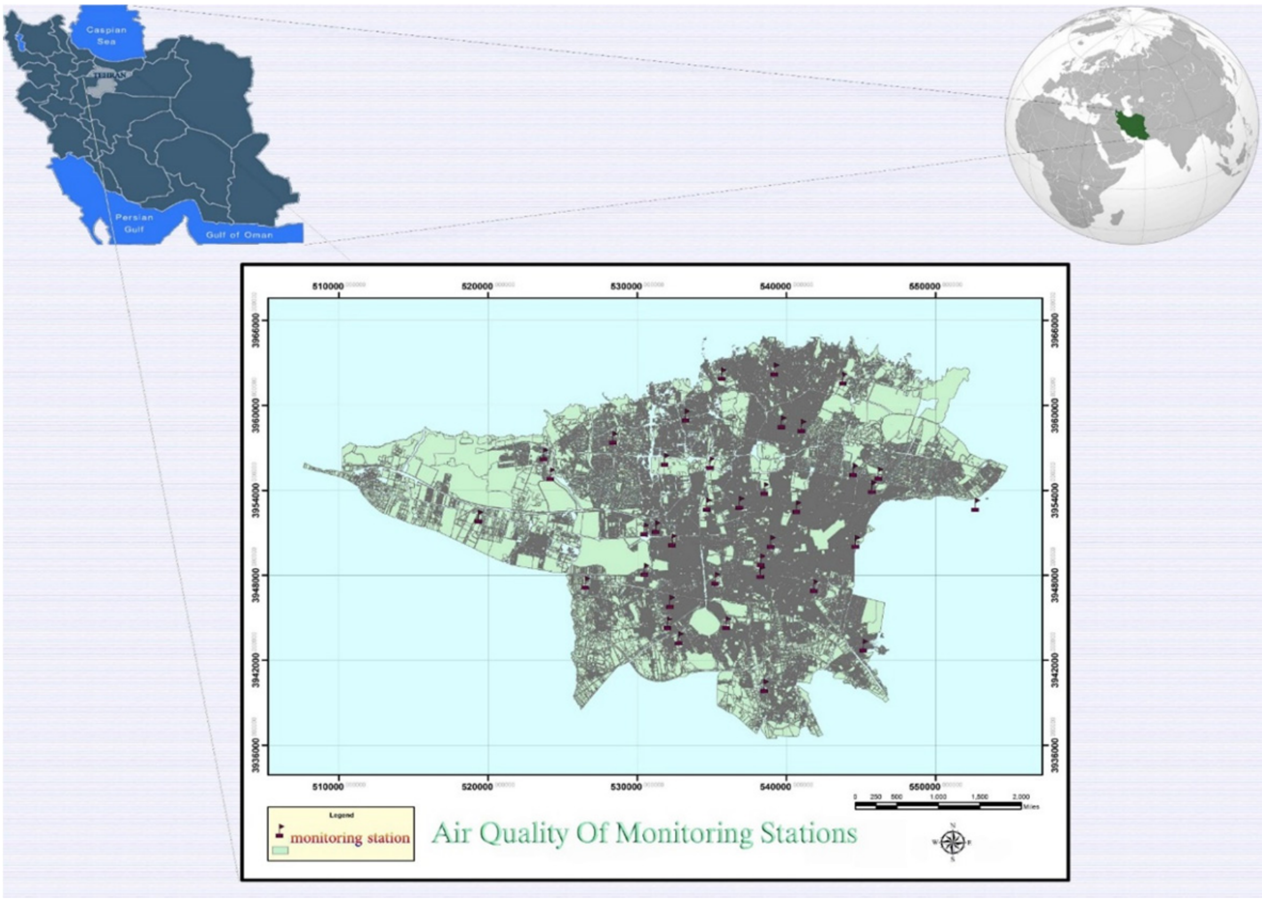

Fig. 1. Location of ambient air monitoring stations of Tehran.

RESULTS AND DISCUSSION

The Concentration of Pollutants

The descriptive statistics of air pollutant concentrations including PM_{10}, $PM_{2.5}$, O_3, NO_2, and SO_2 are illustrated in Fig. 2. The average (± SD), maximum, 98th percentile, and seasonal mean (± SD) and maximum values of PM_{10}, $PM_{2.5}$, O_3, NO_2, and SO_2 are presented in Table 1. The three-year mean values (± standard deviation) of PM_{10} and $PM_{2.5}$ were 80.21 (± 34.21) and 39.17 (± 17.26) µg m^{-3}, respectively. By comparing the mean concentrations from Table 1, it can be seen that the PM_{10} concentrations have decreased during the three-year period. In addition, $PM_{2.5}$ concentrations have decreased over these three years. Naddafi *et al.* (2012a) reported that the average concentration of PM_{10} in Tehran during 2010 was 90.6 µg m^{-3}. The annual average of PM_{10} values were 1.3 and 4.5 times higher than the world-wide average (71 µg m^{-3}) for 2011 (WHO, 2011), and the WHO guideline values (Naddafi *et al.*, 2012a), respectively. The high PM concentrations in Tehran are accounted by TAQCC. They 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 (Shahbazi, 2015). About 70% of particulate matter in Tehran during 2015 was emitted from mobile sources (Ahadi, 2016). In addition, dust from Middle Eastern dust storms affects the particulate concentrations in Tehran (Sowlat *et al.*, 2012; Sowlat *et al.*, 2013).

The three-year mean values (± standard deviation) for O_3, NO_2 and SO_2 were 54.88 (± 24.15), 103.97 (± 25.88) and 39.84 (± 11.17) µg m^{-3}, respectively. The average concentration of O_3 in the third year decreased substantially compared to the other years by 36% and 24% reduction from year 2 and year 1, respectively. The mean NO_2 concentration during the third year was lower than the similar periods in previous years. Mobile sources, energy production, and domestic sector are responsible for about 46%, 24%, and 23% of total NO_x emission in Tehran (Ahadi, 2016). Also the results indicated that the March 2015–March 2016 year had a lower SO_2 concentration compared to the first (24% lower) and second year (9% lower). The dominant source of emitted SO_x in ambient air of Tehran is the energy production sector, which reflects the use of fossil fuels (Ahadi, 2016). Naddafi *et al.* (2012a) reported that the average concentration of O_3, NO_2, and SO_2 were in Tehran in 2010 were 68.82, 85.00 and 89.16 µg m^{-3}, respectively (Naddafi *et al.*, 2012a).

Since AirQ model estimates the health effects based on the number of days in concentration ranges, the related charts (Figs. S1 and S2) are provided in Supplementary file.

Health Impacts

The number of total, cardiovascular and respiratory mortality and cardiovascular and respiratory hospitalization attributed to short-term exposure to PM_{10} in concentrations above 10 µg m^{-3} is presented in Table 2. The total number of deaths attributed to PM_{10} over these three years was 4192. The PM_{10} health effects in March 2015–March 2016

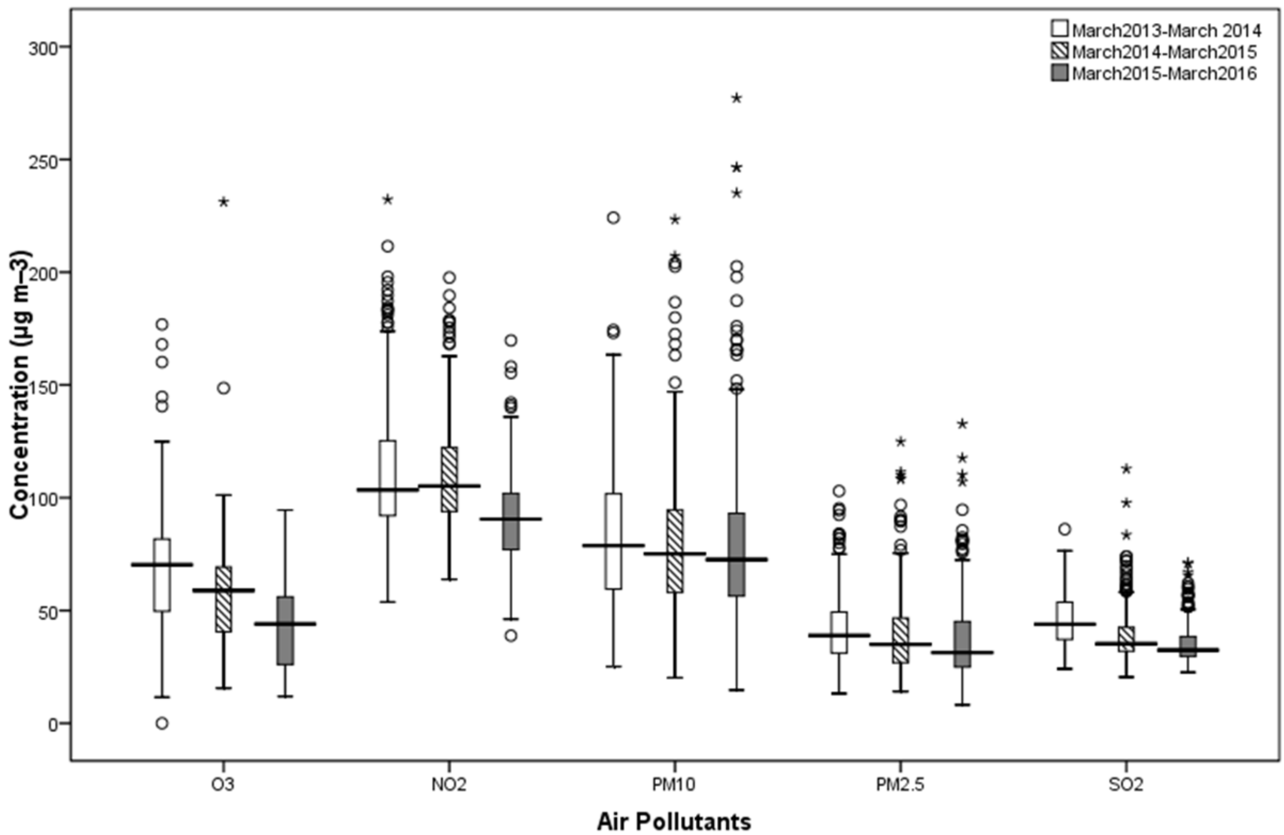

Fig. 2. Descriptive statistics of air pollutants' concentrations, Tehran (2013–2016).

Table 1. Summary of air pollutants' concentrations, Tehran (2013–2016).

Year	Pollutant	Annual mean (± SD), μg m^{-3}	Conc./WHO[a]	Summer, μg m^{-3}		Winter, μg m^{-3}		98th percentile, μg m^{-3}	Stations: total (valid)
				Mean (± SD)	Max.	Mean (± SD)	Max.		
1th year	PM_{10}	82.19 (± 30.84)	4.2	81.3 (± 31.46)	173.08	83.11 (± 30.25)	224.15	150.7	25 (5)
	$PM_{2.5}$	41.9 (± 15.46)	4.2	38.65 (± 11.87)	94.38	45.27 (± 17.88)	102.95	82.97	30 (7)
	O_3	66.14 (± 26.88)	-	78.32 (± 13.13)	124.92	53.48 (± 31.34)	176.82	116.49	24 (3)
	NO_2	111.78 (± 28.79)	2.75	95.25 (± 14.54)	134.62	128.97 (± 29.88)	232.25	184.09	34 (8)
	SO_2	45.93 (± 11.14)	-	44.46 (± 10.77)	76.47	47.45 (± 11.34)	86.04	69.46	27 (4)
	Temp. (°C)	18.15 (± 9.94)	-	25.68 (± 5.62)	42.6	10.34 (± 6.98)	33.2	33.54	-
	Pressure (mbar)	880.58 (± 5.09)	-	877.22 (± 3.5)	886.49	884.07 (± 4.02)	894.03	891.36	-
2nd Year	PM_{10}	79.59 (± 33.76)	3.98	81.1 (± 37.69)	322.12	78.03 (± 29.15)	207.19	171.31	25 (5)
	$PM_{2.5}$	39.17 (± 17.81)	3.92	38.81 (± 19.32)	124.87	39.56 (± 16.14)	111.44	90.22	31 (7)
	O_3	56.1 (± 21.15)	-	68.84 (± 9.86)	99.5	42.87 (± 21.63)	231.19	88.21	25 (3)
	NO_2	109.73 (± 22.73)	2.74	105.52 (± 16.7)	168.55	114.09 (± 27.34)	197.6	172.72	35 (8)
	SO_2	38.6 (± 10.78)	-	34.62 (± 5.38)	66.4	42.72 (± 13.19)	112.81	69.23	30 (4)
	Temp. (°C)	18.88 (± 9.94)	-	26.57 (± 6.52)	41.6	10.89 (± 5.66)	33.2	34.77	-
	Pressure (mbar)	881.18 (± 4.68)	-	878.49 (± 3.37)	887.46	883.96 (± 4.21)	894.85	890.93	-
3rd year	PM_{10}	78.86 (± 37.68)	3.94	85.06 (± 40.81)	277.22	72.41 (± 33.03)	235.1	175.44	25 (5)
	$PM_{2.5}$	36.43 (± 17.99)	3.64	33.34 (± 17.05)	132.75	39.64 (± 18.42)	110.24	81.27	33 (7)
	O_3	42.41 (± 17.27)	-	55.16 (± 11.07)	94.52	29.16 (± 11.66)	67.07	75.04	27 (3)
	NO_2	90.39 (± 19.46)	2.26	92.64 (± 15.67)	140.96	88.05 (± 22.54)	169.75	134.3	35 (8)
	SO_2	34.98 (± 8.5)	-	32.12 (± 4.89)	67.02	37.96 (± 10.27)	71.2	59.07	31 (4)
	Temp. (°C)	23.93 (± 3.26)	-	26.01 (± 3.15)	34.57	22.47 (± 2.22)	28.95	31.10	-
	Pressure (mbar)	850.59 (± 1.65)	-	851.60 (± 1.6)	855.75	849.84 (± 1.14)	853.07	854.11	-

[a] The ratio of annual mean concentration to WHO guideline value (WHO, 2006).

Table 2. The number of cases attributable to short-term exposure to air pollutants above 10 μg m^{-3}, Tehran (2013–2016).

Health Endpoint	Pollutant	Relative risk	Attributable cases (CI 95%)		
			March 2013–March 2014	March 2014–March 2015	March 2015–March 2016
Total mortality (BI = 402.09) 4336	PM_{10}	1.006 (1.004–1.008)	1371 (927–1803)	1403 (948–1845)	1418 (958–1866)
	$PM_{2.5}$	1.015 (1.011–1.019)	1500 (1114–1878)	1471 (1093–1843)	1365 (1011–1712)
	O_3	1.003 (1.002–1.005)	548 (367–903)	474 (317–783)	341 (228–565)
	NO_2	1.003 (1.002–1.004)	981 (661–1296)	1010 (680–1334)	839 (564–1110)
	SO_2	1.004 (1.003–1.0048)	467 (351–558)	397 (298–475)	352 (264–421)
Cardiovascular mortality (BI = 214.46)	PM_{10}	1.009 (1.005–1.013)	1075 (614–1511)	1100 (628–1548)	1113 (635–1566)
	O_3	1.005 (1.002–1.007)	435 (196–667)	377 (169–579)	272 (122–419)
	NO_2	1.004 (1.003–1.005)	691 (523–855)	712 (539–881)	592 (447–734)
	SO_2	1.008 (1.002–1.1012)	491 (125–726)	418 (106–621)	372 (94–552)
Respiratory mortality (BI = 34.64)	PM_{10}	1.013 (1.005–1.02)	244 (99–359)	250 (101–368)	253 (102–371)
	O_3	1.013 (1.007–1.015)	194 (108–221)	169 (94–194)	123 (68–142)
	SO_2	1.01 (1.006–1.014)	98 (60–136)	84 (51–116)	75 (45–103)
Cardiovascular hospitalization (BI = 436)	PM_{10}	1.009 (1.006–1.013)	2185 (1487–3073)	2236 (1521–3147)	2262 (1538–3184)
Respiratory hospitalization (BI = 1260)	PM_{10}	1.008(1.0048–1.0112)	5651 (3466–7742)	5783 (3545–7928)	5848 (3584–8020)
COPD hospitalization (BI = 101.4)	O_3	1.0058 (1.0022–1.0094)	263 (102–418)	228 (88–364)	165 (63–264)
	NO_2	1.0026 (1.0006–1.0044)	215 (51–358)	222 (52–369)	184 (43–307)
	SO_2	1.0044 (1–1.011)	129 (0–316)	110 (0–270)	97 (0–240)
Acute myocardial infarction (BI = 132)	SO_2	1.0064 (1.0026–1.0101)	243 (100–379)	207 (85–323)	184 (75–287)

have increased compared to its previous years. This is due to the increase in Population, which has neutralized the effect of reduction in PM_{10} concentration. In case of $PM_{2.5}$, the attributable total number of deaths is 4336 cases. The total mortality decreased constantly from 2013 to 2016. The mortality in March 2015–March 2016 showed a reduction of 9% in comparison to March 2013–March 2014. Particulate matter has been implicated as the seventh leading risk factor for premature death and disability in Iran (Forouzanfar *et al.*, 2016).

The total number of deaths attributable to O_3 for the 3-year period was 1363. Total mortality in the March 2015–March 2016 period decreased 38% and 28% compared to the March 2013–March 2014 and March 2014–March 2015 periods, respectively. The same pattern can be detected in other related health effects of O_3 concentrations. The total cases of mortality attributable to NO_2 were 2830. The increase in health impacts of NO_2 is related to the population increase in March 2014-March 2015 comparing to its previous year. The total number of deaths attributable to SO_2 was 1216 cases. The SO_2's health effects have decreased constantly from 2013 to 2016.

For total mortality, $PM_{2.5}$ and PM_{10} have shown the highest health impacts in the March 2013–March 2014, March 2014–March 2015, and March 2015–March 2016 periods. In addition, PM_{10} was responsible for most of the cardiovascular and respiratory deaths in each of the three years. For COPD hospital admissions, O_3 and NO_2 have the highest values for March 2013–March 2014, March 2014–March 2015, and March 2015–March 2016. The health impacts attributed to all pollutants except for PM_{10} have decreased for March 2015–March 2016 compared to the previous year. The reduction in concentration and health effects of air pollutants may be different from national reports regarding Tehran's air pollution (Ahadi, 2016). This can be due to the use of valid monitoring stations' datasets in this study.

Naddafi *et al.* (2012a) conducted a similar study on the health impacts of Tehran's ambient air pollutants (PM_{10}, O_3, NO_2 and SO_2) for concentrations above 10 µg m^{-3} in 2010 using AirQ 2.2.3. The results indicated that the total mortality attributable to PM_{10}, O_3, NO_2 and SO_2 was 2194, 819, 1050 and 1458, respectively. The cardiovascular mortality attributable to PM_{10}, O_3, NO_2 and SO_2 was 1367, 574, 591 and 1202, respectively. The excess respiratory deaths attributable to PM_{10}, O_3 and SO_2 were 402, 299 and 310, respectively. They also reported that PM_{10} caused 2580 and 6677 cases of cardiovascular and respiratory hospital admissions, respectively. The number of hospital admissions attributed to O_3, NO_2 and SO_2 was reported 424, 247 and 298, respectively. Furthermore, about 305 and 556 excess cases of acute myocardial infarction were attributed to NO_2 and SO_2 concentrations, respectively (Naddafi *et al.*, 2012a). Air pollution in Mashhad, the second largest metropolis in Iran was estimated to cause total mortality due to PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO about 557, 600, 130, 290 and 274 cases per year, respectively. $PM_{2.5}$ showed the highest attributable deaths (Miri *et al.*, 2016), mainly due to the higher relative risk value and a high $PM_{2.5}/PM_{10}$ ratio (0.49).

Boldo *et al.* (2006) assessed the health impacts of long-term exposure to $PM_{2.5}$ in 23 European cities. About 16,926 premature deaths from all causes, including 11,612 cardiopulmonary deaths and 1901 lung-cancer deaths, could be prevented annually if long-term exposure to $PM_{2.5}$ levels were reduced to 15 µg m^{-3} in each city (Boldo *et al.*, 2006). Fattore *et al.* (2011) estimated short- and long-term effects of air pollution in two municipalities in an industrialized area of Northern Italy using AirQ 2.2.3. They reported that in case of short-term exposure, $PM_{2.5}$ showed the highest health impact on the 24,000 inhabitants, causing an excess of eight deaths out of 177 annually. O_3 and NO_2 each caused about three excess cases of total mortality. The results on long-term effects showed 433, 180, and 72 years of life lost (YLL) for mortality for all-cause, cardiopulmonary diseases and lung cancer, respectively in a year (Fattore *et al.*, 2011). In a study in 13 Italian cities with about 13 million inhabitants, the health impacts of PM_{10} and O_3 were estimated. The authors reported that chronic exposure to PM_{10} in adults older than 30 years caused about 8220 excess non-accidental deaths in concentrations above the reference value of 20 µg m^{-3}. In addition, 1372 deaths are attributed to short-term exposure to PM_{10}. Furthermore, a total of 516 premature deaths from all causes (0.6% of total acute mortality), excluding accidents are attributable every year to O_3 (Martuzzi, 2006).

WHO has estimated that the total mortality attributed to $PM_{2.5}$ concentrations in Iran were 26267 during 2014. In addition, the years of lost life (YLLs) and disability adjusted life years (DALY) were 703207 and 726027 years, respectively. However, that study had serious limitations such as considering a constant value of concentration for all the cities and populations (WHO, 2016). The World Bank announced that the total deaths due to air pollution in Iran in 1990 and 2013 were 17035 and 21680 cases, respectively. The related total welfare losses and the contribution in GDP were estimated to be 30.6 billion USD and 2.48% in 2013, respectively. Furthermore, the total lost labor output and its contribution in Iran's GDP were 1471 billion USD and 0.12%, respectively (World Bank, 2016).

About 85% of the total mass of pollutants are emitted from mobile sources (Shahbazi, 2015). Thus, improvement in policies, regulations, traffic plans, fuel substitution, etc., and consequence reduction in emitted pollutants can show a significant effect on decreasing health impacts and economic costs of air pollution in Tehran.

CONCLUSIONS

Short-term health impacts of Tehran's air pollutants (PM_{10}, $PM_{2.5}$, O_3, NO_2, and SO_2) in concentrations above 10 µg m^{-3} were assessed using AirQ 2.2.3 model in the period of 21 March 2013 to 19 March 2016. Only monitoring stations with all three years of valid data were included in the study. The results showed that the health impacts of $PM_{2.5}$, O_3, NO_2 and SO_2 have decreased in March 2015–March 2016 in comparison to the previous year. There were likely to be significant public health impacts from exposure to high concentrations of air pollutants in Tehran, and urgent efforts are required such as mandating the removal of old and poorly functioning vehicles from the roadways in order to reduce the burden of air pollution is currently placing on this city.

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SUPPLEMENTARY MATERIAL

Supplementary data associated with this article can be found in the online version at http://www.aaqr.org.

REFERENCES

Ahadi, S., Roshani, M., Tadari, M. and Torbatian, S. (2016). Annual report on the ambient air quality of Tehran, 2015-2016 (1394), Tehran Air Quality Control Company (TAQCC), Tehran, Iran.

Allen, R.W., Gombojav, E., Barkhasragchaa, B., Byambaa, T., Lkhasuren, O., Amram, O., Takaro, T.K. and Janes, C.R. (2013). An assessment of air pollution and its attributable mortality in Ulaanbaatar, Mongolia. *Air Qual. Atmos. Health* 6: 137–150.

Anderson, H.R., Atkinson, R.W., Peacock, J.L., Marston, L. and Konstantinou, K. (2004). Meta-analysis of time-series studies and panel studies of particulate matter (PM) and ozone (O_3): Report of a WHO task group. Department of Community Health Sciences, Epidemiology, St. George's Hospital Medical School, London, United Kingdom as part of the WHO project "Systemic Review of Health Aspects of Air Quality in Europe"

Asl, F.B., Kermani, M., Aghaei, M., Karimzadeh, S., Arian, S.S., Shahsavani, A. and Goudarzi, G. (2015). Estimation of diseases and mortality attributed to NO_2 pollutant in five metropolises of iran using airq model in 2011-2012. *J. Mazandaran Univ. Med. Sci.* 25: 239–249.

Atash, F. (2007). The deterioration of urban environments in developing countries: Mitigating the air pollution crisis in Tehran, Iran. *Cities* 24: 399–409.

Boguski, T.K. (2006). Understanding units of measurement, In *Environmental Science and Technology Briefs for Citizens*, Center for Hazardous Substance Research, Kansas State University.

Boldo, E., Medina, S., Le Tertre, A., Hurley, F., Mücke, H.G., Ballester, F. and Aguilera, I. (2006). Apheis: Health impact assessment of long-term exposure to $PM_{2.5}$ in 23 european cities. *Eur. J. Epidemiol.* 21: 449–458.

Crouse, D.L., Peters, P.A., Hystad, P., Brook, J.R., van Donkelaar, A., Martin, R.V., Villeneuve, P.J., Jerrett, M., Goldberg, M.S., Pope, C.A., 3rd, Brauer, M., Brook, R.D., Robichaud, A., Menard, R. and Burnett, R.T. (2015). Ambient $PM_{2.5}$, O_3, and NO_2 exposures and associations with mortality over 16 years of follow-up in the Canadian Census Health and Environment Cohort (CanCHEC). *Environ. Health Perspect.* 123: 1180–1186.

Fattore, E., Paiano, V., Borgini, A., Tittarelli, A., Bertoldi, M., Crosignani, P. and Fanelli, R. (2011). Human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy. *Environ. Res.* 111: 1321–1327.

Fischer, P.H., Marra, M., Ameling, C.B., Hoek, G., Beelen, R., de Hoogh, K., Breugelmans, O., Kruize, H., Janssen, N.A. and Houthuijs, D. (2015). Air pollution and mortality in seven million adults: The Dutch environmental longitudinal study (DUELS). *Environ. Health Perspect.* 123: 697–704.

Forouzanfar, M.H., Afshin, A., Alexander, L.T., Anderson, H.R., Bhutta ,Z.A., Biryukov, S., Brauer, M., Burnett, R., Cercy, K. and Charlson, F.J. (2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: A systematic analysis for the global burden of disease study 2015. *The Lancet* 388: 1659–1724.

Geravandi, S., Neisi, A.K., Goudarzi, G., Vousoghi Niri, M. and Mohammadi, M.J. (2015). Estimation of cardiovascular and respiratory deaths related to ozone exposure in Ahvaz, during 2011. *J. Rafsanjan Univ. Med. Sci.* 13: 1073–1082.

Gholampour, A., Nabizadeh, R., Naseri, S., Yunesian, M., Taghipour, H., Rastkari, N., Nazmara, S., Faridi, S. and Mahvi, A.H. (2014). Exposure and health impacts of outdoor particulate matter in two urban and industrialized area of Tabriz, Iran. *J. Environ. Health Sci. Eng.* 12: 27.

Ghozikali, M.G., Heibati, B., Naddafi, K., Kloog, I., Conti, G.O., Polosa, R. and Ferrante, M. (2016). Evaluation of Chronic Obstructive Pulmonary Disease (COPD) attributed to atmospheric O_3, NO_2, and SO_2 using Air Q Model (2011-2012 year). *Environ. Res.* 144: 99–105.

Goldberg, M.S., Burnett, R.T., Stieb, D.M., Brophy, J.M., Daskalopoulou, S.S., Valois, M.F. and Brook, J.R. (2013). Associations between ambient air pollution and daily mortality among elderly persons in Montreal, Quebec. *Sci. Total Environ.* 463: 931–942.

Goudarzi, G., Geravandi, S., Salmanzadeh, S., Mohammadi, M. and Zallaghi, E. (2014). The number of myocardial infarction and cardiovascular death cases associated with sulfur dioxide exposure in Ahvaz, Iran. *Arch. Hyg. Sci.* 3: 112–119.

Goudarzi, G., Geravandi, S., Mohammadi, M.J., Vosoughi, M., Angali, K.A., Zallaghi, E., Neisi, A.K., Saeidimehr, S. and Mohammadi, B. (2015). Total number of deaths and respiratory mortality attributed to particulate matter (PM_{10}) in Ahvaz, Iran during 2009. *Int. J. Environ. Health Eng.* 4: 33.

Gryparis, A., Forsberg ,B., Katsouyanni, K., Analitis, A., Touloumi, G., Schwartz, J., Samoli, E., Medina, S., Anderson, H.R. and Niciu, E.M. (2004). Acute effects of ozone on mortality from the "air pollution and health: A european approach" project. *Am. J. Respir. Crit. Care Med.* 170: 1080–1087.

Kermani, M., Dowlati, M., Jafari, A.J. and Kalantari, R.R. (2016a). Health risks attributed to particulate matter of 2.5 microns or less in Tehran air 2005-2015. *J. Kermanshah Univ. Me. Sci.* 20: 99–105.

Kermani, M., Dowlati, M., Jonidi Jafari, A., Rezaei Kalantari, R. and Sadat Sakhaei, F. (2016b). Effect of air pollution on the emergency admissions of cardiovascular and respiratory patients, using the air quality model: A study in Tehran, 2005-2014. *Health Emergencies Disasters Q.* 1: 137–146.

Kermani, M., Aghaei, M. and Dolati, M. (2016c). Estimation the number of mortality due to cardiovascular and respiratory disease, attributed to pollutants O_3, and NO_2 in the air of Tehran. *J. Health Res. Community* 1: 1–11.

Khaniabadi, Y.O., Goudarzi, G., Daryanoosh, S.M., Borgini, A., Tittarelli, A. and De Marco, A. (2017). Exposure to PM_{10}, NO_2, and O_3 and impacts on human health. *Environ. Sci. Pollut. Res.* 24: 2781–2789.

Khosravi, A., Aghamohamadi, S., Kazemi, E. and Kalantari, N. (2016). The outlook of mortality in 30 provinces of iran during 2011-2012, Ministry of Health and Medical Education, Tehran, Iran.

Likhvar, V.N., Pascal, M., Markakis, K., Colette, A., Hauglustaine, D., Valari, M., Klimont, Z., Medina, S. and Kinney, P. (2015). A multi-scale health impact assessment of air pollution over the 21st century. *Sci. Total Environ.* 514: 439–449.

Liu, Y., Chen, X., Huang, S., Tian, L., Lu, Y.A., Mei, Y., Ren, M., Li, N., Liu, L. and Xiang, H. (2015). Association between air pollutants and cardiovascular disease mortality in Wuhan, China. *Int. J. Environ. Res. Public Health* 12: 3506–3516.

Madanipour, A. (2006). Urban planning and development in tehran. *Cities* 23: 433–438.

Martuzzi, M.M., Mitis, F., Iavarone, I. and Serinelli, M. (2006). *Health impact of PM_{10} and ozone in 13 italian cities*. WHO Regional Office for Europe.

Miri, M., Derakhshan, Z., Allahabadi, A., Ahmadi, E., Conti, G.O., Ferrante, M. and Aval, H.E. (2016). Mortality and morbidity due to exposure to outdoor air pollution in mashhad metropolis, Iran. The AirQ model approach. *Environ. Res.* 151: 451–457.

Mohammadi, A., Azhdarpoor, A., Shahsavani, A. and Tabatabaee, H. (2016). Investigating the health effects of exposure to criteria pollutants using AirQ2.2.3 in Shiraz, Iran. *Aerosol Air Qual. Res.* 16: 1035–1043.

Mohseni Bandpi, A., Eslami, A., Shahsavani, A., Khodagholi, F., Aliaghaei, A. and Alinejad, A. (2016). Water-soluble and organic extracts of ambient $PM_{2.5}$ in Tehran air: Assessment of genotoxic effects on human lung epithelial cells (A549) by the Comet assay. *Toxin Rev.* 36: 116–124.

Mohseni Bandpi, A., Eslami, A., Shahsavani, A., Khodagholi, F. and Alinejad, A. (2017). Physicochemical characterization of ambient $PM_{2.5}$ in Tehran air and its potential cytotoxicity in human lung epithelial cells (A549). *Sci. Total Environ.* 593–594: 182–190.

Naddafi, K., Hassanvand, M.S., Yunesian, M., Momeniha, F., Nabizadeh, R., Faridi, S. and Gholampour, A. (2012). Health impact assessment of air pollution in megacity of Tehran, Iran. *Iranian J. Environ. Health Sci. Eng.* 9: 28.

Naddafi, K., Sowlat, M. and Safari, M. (2012b). Integrated assessment of air pollution in Tehran, over the period from september 2008 to september 2009. *Iran J. Public Health* 41: 77.

Nourmoradi, H., Goudarzi, G., Daryanoosh, S.M. and Omidi-Khaniabadi, F. (2015). Health impacts of particulate matter in air using airq model in Khorramabad city, Iran. *J. Basic Res. Med. Sci.* 2: 52–44.

Nourmoradi, H., Omidi Khaniabadi, Y., Goudarzi, G., Daryanoosh, S.M., Khoshgoftar, M., Omidi, F. and Armin, H. (2016). Air quality and health risks associated with exposure to particulate matter: A cross-sectional study in Khorramabad, Iran. *Health Scope* 5: e31766.

Orru, H., Laukaitiene, A. and Zurlyte, I. (2012). Particulate air pollution and its impact on health in Vilnius and Kaunas. *Medicina (Kaunas)* 48: 472–477.

Samoli, E., Aga, E., Touloumi, G., Nisiotis, K., Forsberg, B., Lefranc, A., Pekkanen, J., Wojtyniak, B., Schindler, C. and Niciu, E. (2006). Short-term effects of nitrogen dioxide on mortality: An analysis within the aphea project. *Eur. Respir. J.* 27: 1129–1138.

Shahbazi, H., Babaee, M., Afshin, H. and Hosseini, V. (2015). Tehran's air pollution emission inventory for the year 2013- volume ii: Mobile sources [in Persian], Tehran Air Quality Control Company, Tehran, Iran.

Sowlat, M.H., Naddafi, K., Yunesian, M., Jackson, P.L. and Shahsavani, A. (2012). Source apportionment of total suspended particulates in an arid area in southwestern Iran using positive matrix factorization. *Bull. Environ. Contam. Toxicol.* 88: 735–740.

Sowlat, M.H., Naddafi, K., Yunesian, M., Jackson, P.L., Lotfi, S. and Shahsavani, A. (2013). PM_{10} source apportionment in Ahvaz, Iran, using positive matrix factorization. *Clean Soil Air Water* 41: 1143–1151.

USEPA (2015). Chapter 11: Valid data and completeness requirements, Agency, U.S.E.P. (Ed.), USA.

WHO (2000). Air quality guidelines for Europe. World Health Organization, Geneva, Switzerland.

WHO (2011). Urban outdoor air pollution database. World Health Organization, Geneva, Switzerland.

WHO (2014). 7 million premature deaths annually linked to air pollution. World Health Organization, Geneva, Switzerland.

WHO (2016). Ambient air pollution: A global assessment of exposure and burden of disease. World Health Organization, Geneva, Switzerland.

Wong, C.M., Lai, H.K., Tsang, H., Thach, T.Q., Thomas, G.N., Lam, K.B.H., Chan, K.P ,.Yang, L., Lau, A.K. and Ayres, J.G. (2015). Satellite-based estimates of long-term exposure to fine particles and association with mortality in elderly Hong Kong residents. *Environ. Health Perspect.* 123: 1167.

World Bank (2016). The cost of air pollution: Strengthening the economic case for action. World Bank Group, Washington, D.C.

Yorifuji, T., Kashima, S. and Doi, H. (2016). Acute exposure to fine and coarse particulate matter and infant mortality in Tokyo, Japan (2002–2013). *Sci. Total Environ.* 551: 66–72.

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