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Exposure to PM_{10}, NO_2, and O_3 and impacts on human health

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Abstract Air pollution is emerging as a risk factor for human health like cancer and other health outcomes in developing countries, especially Iran where air pollutant concentrations are elevated. Additionally, some of the crucial environmental problems are caused by air pollution. Nevertheless, the data on health effects of air pollution are limited. The main objective of this study was to assess the health impacts attributed to particulate matter less than 10 μg/m^3 (PM_{10}), nitrogen dioxide (NO_2), and ozone (O_3) in Kermanshah City (Iran). The diurnal averages of PM_{10} and NO_2 levels and 1-h averages of O_3 concentrations were applied to assess the cardiovascular mortality due to exposure to these pollutants during the years 2014 and 2015. The excess number of cardiovascular mortality was estimated by relative risk (RR) and baseline incidence (BI) defined by the World Health Organization (WHO). The excess in mortality risk for cardiovascular diseases is of 188 premature deaths related to PM_{10}, 33 related to NO_2, and 83 related to O_3, respectively. The results indicate that a 10-μg/m^3 change in PM_{10}, NO_2, and O_3 generates a relative risk of 1.066, 1.012, and 1.020, respectively. The excess of relative risk is of 6.6, 1.2, and 2.0%, respectively. Immediate policies and actions are needed to reduce the various sources of these pollutants from transport and energy manufacture facilities in Kermanshah.

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Introduction

Air pollution is emerging as a risk factor for, e.g., cancer and mortality due to cardiovascular diseases, particularly in developing countries including Iran where air pollutant concentrations are elevated (Daryanoosh et al. 2016; Geravandi et al. 2016; Ghozikali et al. 2016; Neisi et al. 2016; Nourmoradi et al. 2015). Tehran has cleaned up recently, with carbon monoxide levels no longer a problem, lead eliminated from gasoline, and sulfur levels dropping from a frightening 8000 parts per million (ppm) to less than 200 ppm (Mawer 2014). The increasing risk is associated with the presence of harmful pollutants like particulate matter (PM_{10}), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), and sulfur dioxide (SO_2) in the atmosphere (Borge et al. 2014; Dobaradaran et al. 2016; Nourmoradi et al. 2016; Raaschou-Nielsen et al. 2012). Exposure to air pollution is in relation to both acute and chronic effects on human health. The short-term endpoints of air pollution on human health were amply demonstrated in the twentieth century, when severe air pollution in Europe and in the USA caused mortality and morbidity in hundreds of thousands of people (Fattore et al. 2011; Nemery et al. 2001). These episodes have demonstrated that high levels of atmospheric pollutants caused an increase in mortality and

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morbidity rates. Among different atmospheric pollutants, particulate matter (PM) is a pollutant with the most undesired harmful impacts on the human health (Dominici et al. 2006; Goudarzi et al. 2015b; Schwartz et al. 1993; Weuve et al. 2012). Particulate matter with an aerodynamic diameter equal or less than 10 μm (PM_{10}) has the most adverse effects on the human health (Wang et al. 2009). Exposure to ambient PM_{10} can cause several health outcomes such as immune system reactions, lung irritation, damaged cells, coughing asthma, hospitalization due to respiratory and cardiovascular diseases, chronic bronchitis, cancer, and finally death (Jeong 2013). Nitrogen dioxide (NO_2) is a gas with oxidant properties capable to diminish air quality in many urban and industrial contexts, as well as indoor air in houses with combustion domestic devices. According to the results of epidemiological studies in Europe and over the world, approximately 5–7% of the lung cancers among ex-smokers and non-smokers can be associated with exposure to high levels of air pollutants containing NO_2 or vicinity to roads with heavy-traffic (Defense 1996; Fattore et al. 2011; Ghiyathoddin 2006). Tropospheric O_3 is known as the second critical pollutant of the atmosphere following the particulate matter that show increasing concentrations in the air, associated to human health impacts (Dehghani et al. 2014; Goudarzi et al. 2015a, Sicard et al. 2011; Yari et al. 2016). There is a relationship between exposure to O_3 and pulmonary function (Andersen et al. 2011; Sicard et al. 2010). Epidemiological studies showed that the exposure to O_3 levels ranging between 160 and 360 μg/m^3 for a duration of 1–8 h may cause reduction of different parameters of lung function (Zarandi et al. 2015). Around 0.7 million peoples per year die worldwide due to exposure to tropospheric O_3 (Anenberg et al. 2010). Ozone is a greenhouse gas and has an important role in climate change, global warming, chemistry of the air, and deteriorating of air quality (Mohnen et al. 1993; Sicard et al. 2016). Ozone annihilates the photosynthesis system of the plants and decreases the yields of the plants themselves (Van Dingenen et al. 2009). Nitrogen oxide (NO) is the main precursor of NO_2 in presence of atmospheric oxidants such as O_3 (Katsouyanni et al. 1995; Liang et al. 2009). In a polluted air, NO can quickly be oxidized by O_3 and then converted to NO_2 by a photochemical reaction (Defense 1996; Fattore et al. 2011; Ghiyathoddin 2006). Similar studies have been carried out, e.g., in France, Greece, and The Netherlands. The APHEA-2 project provides quantitative estimates of the short-term health effects of air pollution from 26 European cities. The average per 10 μg/m^3 increase (lag 0–1 days) in European and French regions, as well as the 95% confidence interval, for several health outcomes are obtained in some epidemiological studies (Sicard et al. 2011; Sicard et al. 2012).

In this study, the cardiovascular mortality due to exposure to air pollutants such as PM_{10}, NO_2, and O_3 were assessed on inhabitants of Kermanshah, Iran, during the years 2014 and 2015.

Materials and methods

Study area

This study was carried out in Kermanshah (34° 19′ N, 47° 3′ E) (Fig. 1). Kermanshah, the second largest megacity in western part of Iran, is the capital city of Kermanshah Province, with a population higher than 870,000 people and is among the most polluted cities of Iran. It is 1312 m above sea level and is located in the category semi-arid climate with the annual average precipitation and temperature of 447.7 mm and 14.3 °C, respectively. The vegetation cover is steppe with few trees in the ranges. The temperature may drop to 10 °C in the winter; however, it rises to 44 °C in the summer. Kermanshah is considered as one of the largest contaminated cities due to the presence of several huge industrial factories and the high number of automobiles. For measuring pollutants concentrations, an air monitoring station under responsibility of Kermanshah's Environmental Protection Agency (KEPA) was set. Hourly PM_{10}, NO_2, and O_3 data were achieved from KEPA and 24-h average were taken into account for PM_{10} and NO_2 evaluation of health endpoints, while 1-h averages were taken into account for O_3.

AirQ2.2.3 software

The Air Quality Health Impact Assessment (AirQ2.2.3 model) is a software provided by WHO to assess the health outcome of air pollutants (Nourmoradi et al. 2015; Shahsavani et al. 2012). The tools to model health impacts assessment combine the data of air quality and epidemiological parameters including relative risk (RR), attributed proportion (AP), and baseline incidence (BI) and present the results in the form of the mortality and morbidity rate (Fattore et al. 2011). In this study, the AirQ2.2.3 software tool developed by the WHO European Center for Environment and Health was applied in agreement with the approach proposed by the World Health Organization (WHO) (Fattore et al. 2011; Mohammadi et al. 2015b).

Before the input data to the model for calculation of health effects, there is need to convert volumetric levels of gases (NO_2 and O_3) into gravimetric units, according to Eq. (1), as the following:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_1} \tag{1}$$

where P is atmospheric pressure, V is volume of gas, and T is atmospheric temperature in Kelvin degree. AirQ calculates the potential effects of the exposure to atmospheric pollutants on health of human living in a given place and period (Zhou et al. 2014). The assessment was based on attributable proportion that is identified as the portion of the health effect in a particular population attributable to a certain air pollutant (Nourmoradi et al.
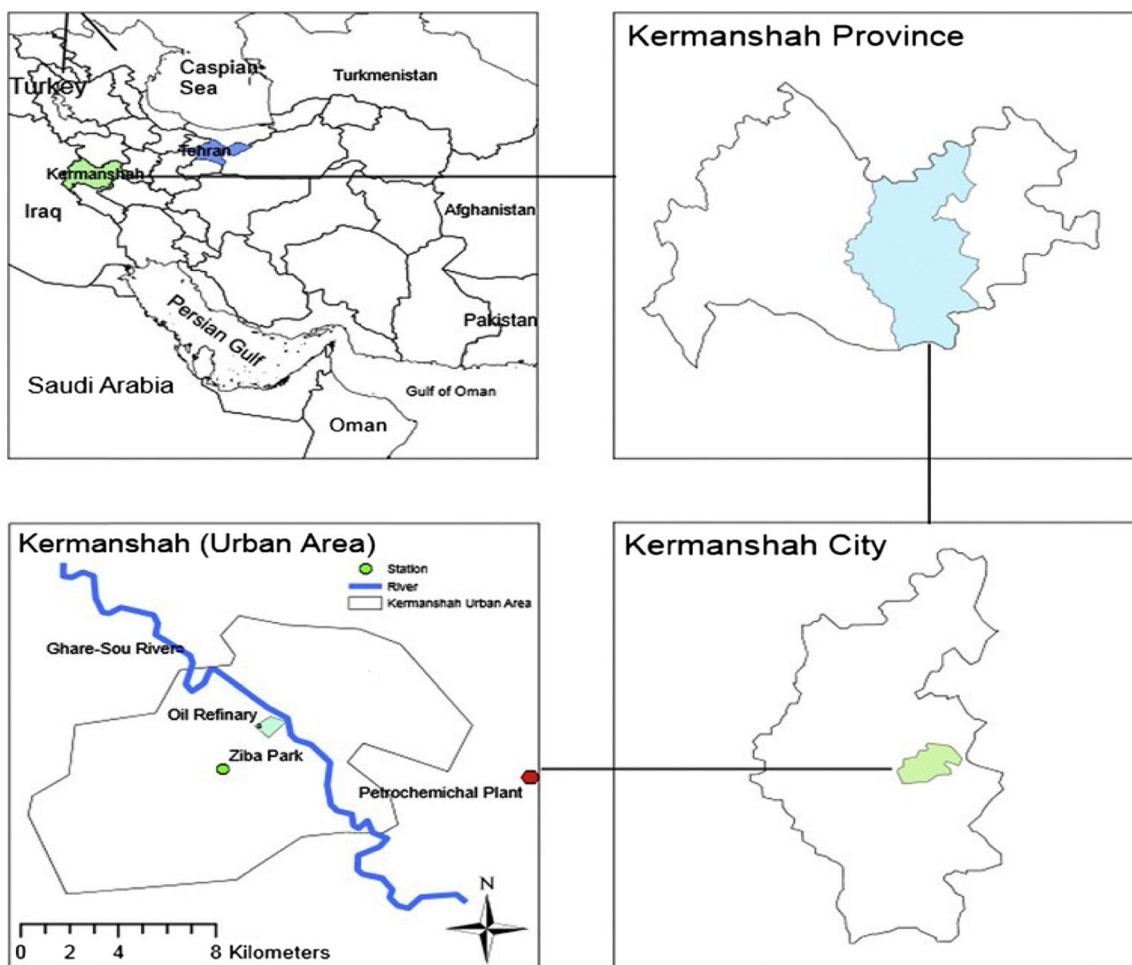
Fig. 1. Location of Kermanshah and the sampling station

2015; Shakour et al. 2011). The amount of AP can be calculated by using the Eq. (1).

$$AP = \sum \{[RR(c)-1] \times P(c)\} \Big/ \sum [RR(c) \times P(c)] \quad (2)$$

where AP is the attributable proportion of the health impacts, RR is the relative risk for a particular health effect and can be achieved from the dose-response functions. P(c) represents the exposed population (Lawrence et al. 2007; Nourmoradi et al. 2015).

Relative risk (RR) is the attributable health risk attributed to people who have defined exposures and can be simply estimated by means of Eq. (3).

$$RR = \frac{\text{Possibility of incident when exposed to air pollution}}{\text{Possibility of instance when non-exposed to air pollution}} \quad (3)$$

The quantity attributable to the population exposure can be estimated by Eq. (4), if the baseline incidence of the health impact in the population under study is known.

$$IE = I \times AP \quad (4)$$

where IE and I are the frequency of exposure and the baseline frequency of health effect in the studied population.

If the population size is known, the number of excess cases attributable to exposure can be calculated by the following equation:

$$NE = IE \times N \quad (5)$$

where NE and N are the number of cases attributable to exposure and the population size under study, respectively (Gurjar et al. 2010).

Input adjustment

In order to assess the occurrence of the cardiovascular diseases related to PM_{10}, NO_2, and O_3 by the AirQ2.2.3 tool, different concentrations of pollutants from 2014 to 2015 were taken from the monitoring station of KEPA. The obtained data were expressed on volumetric unit (ppm or ppb) for NO_2 and O_3, while the AirQ software tool requires the data based on gravimetric unit ($\mu g/m^3$). Thus, the data have been converted to gravimetric unit for the AirQ model. All the processing

mechanisms to convert the units from volumetric to gravimetric and other processes including the averaging, coding, modification of pressure and temperature, and data filtering were previously conducted. For filtering, the data were sorted into the average of diurnal concentration, were briefed by sorting the data amounts from lower to higher, and then identified the day's number in ranging of pollutants' concentration.

Exposure assessment

The values of RR and BI were considered according to the model's default to associating of health impacts in term of cardiovascular death. This model assumes that measured concentrations are representative of the mean exposure of the populations. As last step, cardiovascular mortality due to exposure to PM_{10}, NO_2, and O_3 was assessed through the AirQ2.2.3 model based on RR and BI defined by the WHO. The baseline incidence value for cardiovascular mortality is 497/100,000 people each year. Also, the RR values obtained from several epidemiological studies (Fattore et al. 2011; Jeong 2013; Touloumi 1997) for exposure to PM_{10}, NO_2, and O_3 are presented in Table 1.

Results

Pollutants concentration

Table 2 illustrates the annual average, annual maximum, summer and winter average, summer and winter maximum, and 98th percentile of PM_{10} and NO_2 concentrations which are taken from the processing of the KEPA data. The annual average concentration of PM_{10} and NO_2 in Kermanshah were equal to 85.7 and 75.76 µg/m³, respectively. The summer mean of PM_{10} concentration was 102.91 µg/m³, which was higher than during the winter with mean value of 68.17 µg/m³. As is described from Table 2, the summer mean of NO_2 level was 63.08 µg/m³ that is less than the winter with mean value of 77.34 µg/m³. The annual maximum of PM_{10} concentration was observed in summer with a level of 533.12 µg/m³ that was higher than the winter with maximum of 459.32 µg/m³. Also, the annual maximum of NO_2 concentration was observed in the winter with a concentration equal to 198.42 µg/m³, which was more than the summer with maximum of 142.93 µg/m³.

Table 2. PM_{10} and NO_2 concentrations (µg/m³) of 24 h in Kermanshah (2014–2015)

Parameter	PM_{10} (µg/m³)	NO_2 (µg/m³)
Annual average	85.7	75.76
Summer average	102.91	63.08
Winter average	68.17	77.34
Annual maximum	533.12	198.42
Summer maximum	533.12	142.93
Winter maximum	459.32	198.42
98th percentile	271	160.78

Table 3 illustrates the maximum annual 1-h average, summer and winter maximum 1-h averages, and 1-h 98th percentile of background O_3 levels. As can be seen, the maximum annual 1-h average was observed in winter with the amount of 328 µg/m³, whereas the maximum summer 1-h average in summer was 266 µg/m³. The 98th percentile 1-h has a concentration of about 261 µg/m³. The average concentration of ground-level O_3 was highest in winter.

Person-days

Figure 2 illustrates the percentage of time that people in Kermanshah were in contact with different levels of PM_{10}, NO_2, and O_3 during 2014 to 2015. Based on these figures, the highest percentage of person-days occurred in concentration interval of 100–109 µg/m³ for PM_{10} that led to the health effects among the inhabitants of Kermanshah. Also, the higher percentage of person-days associated with different levels of NO_2 and O_3 was detected in both the interval concentrations of 30–39 and 200–249 µg/m³, respectively, which resulted to mortality among the inhabitants.

Cardiovascular mortality

Estimated attributable proportion (AP) percentage and the number of excess cases of cardiovascular death due to exposure to PM_{10}, NO_2, and O_3 were calculated and the results are shown in Table 4. There were 95% confidence intervals that we considered; three of them in assessment process of the present study. As it was indicated, the number of excess of cases for cardiovascular mortality in the central RR for PM_{10}, NO_2, and O_3 was 188, 33, and 83 persons, respectively.

Table 1. Relative risk (RR) with confidence intervals (CI) of 95% used for investigating the cardiovascular mortality of PM_{10}, NO_2, and O_3 in baseline incidence (BI) of 497/100,000 people
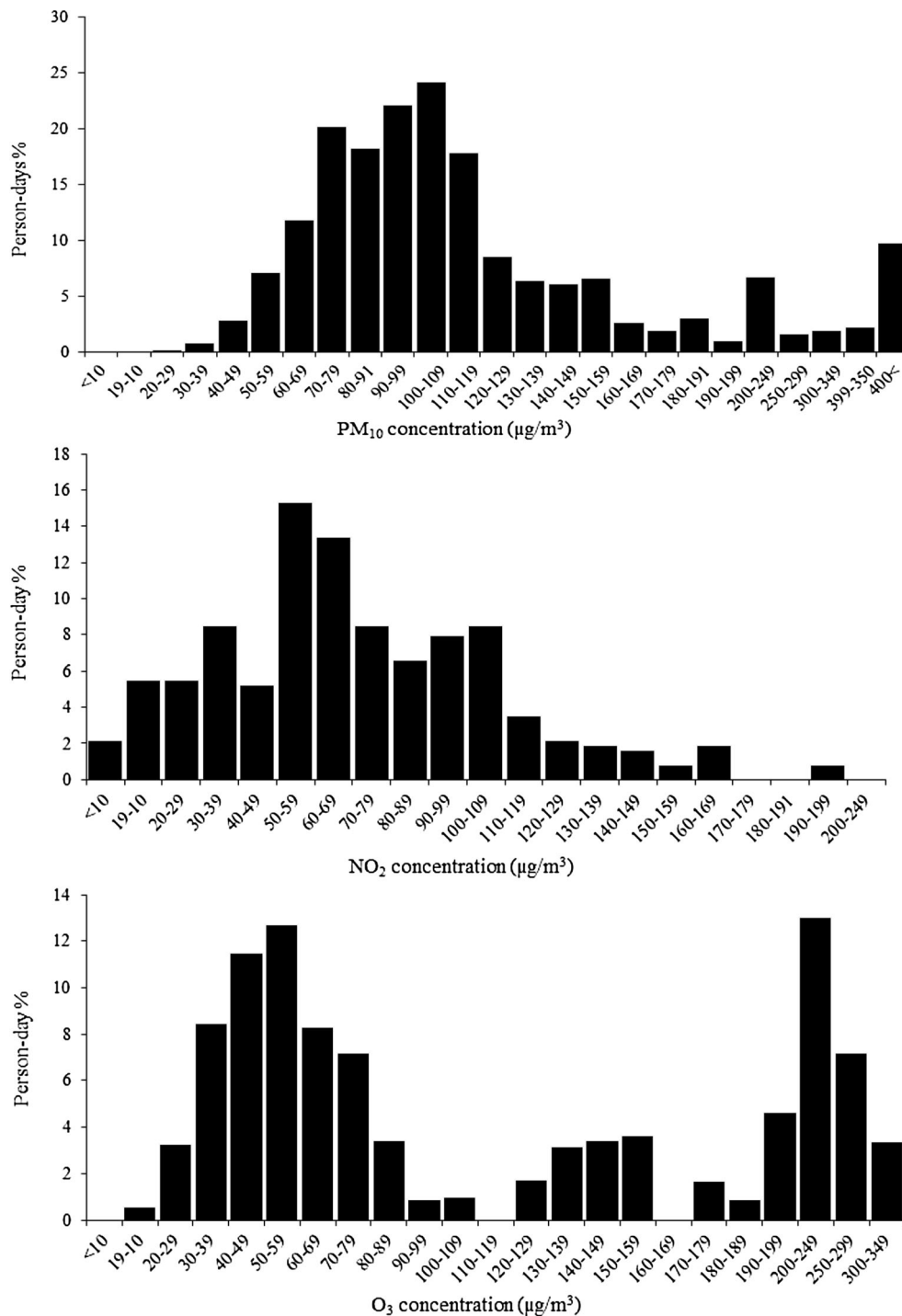
	PM_{10}	NO_2	O_3
RR (95% CI) per 10 µg/m³	1.0080 (1.0050–1.0180)	1.0020 (1.00–1.0040)	1.004 (1.000–1.006)

Table 3. O_3 concentrations ($\mu g/m^3$) of 1 h in Kermanshah (2014–2015)

Station parameters	Concentration ($\mu g/m^3$)
Maximum annual 1-h average	297
Maximum summer 1-h average	266
Maximum winter 1-h average	328
98th percentile 1-h average	261

Figure 3 shows the results of quantification the health outcomes due to exposure to PM_{10}, NO_2, and O_3 in Kermanshah obtained from the model explication versus hourly concentrations intervals. This figure illustrates diagrams based on the number of excess cases at 95% confidence interval. Moreover, the number of excess cases in upper, central, and lower of the relative risk versus different concentration interval is available. The number of 24, 33, and 83 cases of cardiovascular

Fig. 2. Percentage of times that people were exposed to different concentrations of air pollutant

Table 4. Estimated attributable proportion (AP) percentage and the number of excess cases of cardiovascular mortality

PM_{10}		NO_2		O_3	
AP (%)	Excess cases	AP (%)	Excess cases	AP (%)	Excess cases
6.621 (4.243–13.759)	188 (121–390)	1.2085 (0.000–2.3881)	33 (0.0–65)	1.960 (0–2.912)	83 (0–123)

death can be attributed to the PM_{10}, NO_2, and O_3 per 10 µg/m³ increase, respectively. The results also illustrated that about 6.6% (95% CI, 4.2–13.8%) of cardiovascular mortality is associated with PM_{10} per µg/m³ increase. In addition, 1.2% (95% CI, 0.00–2.4%) and 2% (95% CI, 0–2.9%) of cardiovascular mortality is attributed to NO_2 and O_3 levels per 10 µg/m³ increase, respectively.

Discussion

In this study, the WHO approach was used to investigate the health effects of particulate matter (PM_{10}), nitrogen dioxide (NO_2), and ozone (O_3) on human health for people living in Kermanshah, one of the most density populated city in the west of Iran. The impact of PM_{10}, NO_2, and O_3 was estimated as the

Fig. 3. Relationship between the number of cardiovascular mortality and concentration intervals of pollutants
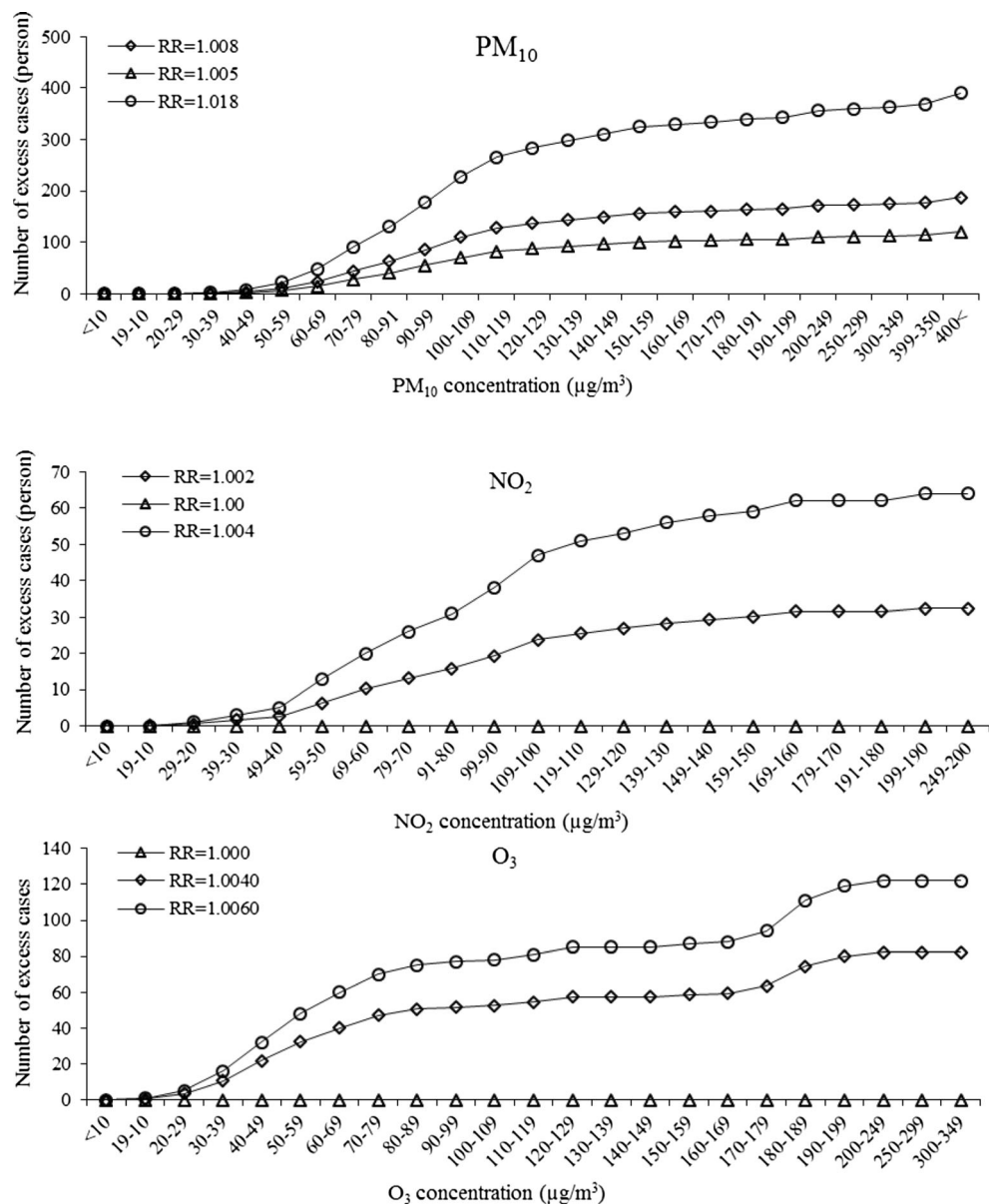
increase in cardiovascular death. The AirQ2.2.3 software has been used in several epidemiological studies in the world to assess the short-term health impacts of atmospheric pollutants on mortality cases (Fattore et al. 2011; Ghozikali et al. 2016; Goudarzi et al. 2015b). The annual average of 24 h, summer average, and winter average of PM_{10} concentrations were 85.7, 102.91, and 68.17 $\mu g/m^3$, respectively. These data were obtained in a study conducted in 2011 equal 90.03, 118.34, and 60.60 $\mu g/m^3$ in Kermanshah of Iran, respectively (Zallaghi et al. 2014). The comparison of these 2 years showed that winter average in 2014 was higher than 2011. The annual 24-h average, summer 24-h average, and winter 24-h average of NO_2 levels were assessed of 75.76, 63.08, and 77.34 $\mu g/m^3$, respectively. The standard of annual average of NO_2 is 80 $\mu g/m^3$ (Naddafi et al. 2012), which shows that the annual average of NO_2 during the years 2014 and 2015 is lower than the defined standard for this contaminant. The annual maximum of PM_{10} level was found in summer with amount of 533.12 $\mu g/m^3$, which is more than during the winter (459.32 $\mu g/m^3$). This showed a reduction in contrast with 2011 with annual maximum value of 1810.5 $\mu g/m^3$ (Zallaghi et al. 2014). The higher level of PM_{10} during summer is probably caused by high temperature and high wind speed, leading to an increase of atmospheric turbulent and resuspension of dust from the blowing sand particles of the Middle Eastern areas (Habeebullah 2013). The maximum annual 1-h average, maximum summer 1-h average, maximum winter 1-h average, and 98th percentile were calculated and equal to 297, 266, 328, and 261 $\mu g/m^3$, respectively. In Ahvaz, Iran, concentrations of 72.62, 84.38, 60.51, and 121.24 $\mu g/m^3$, respectively, were measured (Goudarzi et al. 2013). The number of excess cases for cardiovascular mortality was 188, 33, and 83 persons due to exposure to PM_{10}, NO_2, and O_3, respectively. While total cardiovascular death was 238 persons in 2011 in Kermanshah (Zallaghi et al. 2014), a reduction about 21 in rates of cardiovascular mortality because of lower PM_{10} in comparison with 2011 was observed. In an AP equal to 2.4, the excess number of cardiovascular mortality in Rezzato, Northern Italy, was obtained and about 2.4 persons for exposure to NO_2 during a year (Fattore et al. 2011). NO_2 is not highly soluble, and it is mostly retained in the small airways of lungs. Thus, it has a greater deposition and it remains a pollutant of current concern. In Suwon City, the number of cardiovascular mortality in BI value of 84.5 per 10^5 peoples in central relative risk (RR = 1.004) was estimated 23.9 persons (Jeong 2013). For population of more than 870,000 persons as it is in Kermanshah, about 13 cases of mortality due to cardiovascular diseases can be annually attributable to NO_2 levels higher than 100 $\mu g/m^3$. Approximately, 83 cases of death can be estimated annually due to O_3 levels above 10 $\mu g/m^3$. In a study, Martuzzi et al. (2006) investigated the health impacts of O_3 in 13 cities of Italy by a population approximately 9 million during the period of 2002–2004. It was informed that total mortality in relation to O_3 exposure was 516

persons as yearly (Martuzzi et al. 2006). In an attributable proportion (AP) of 2% (1–3.0%), the cardiovascular mortality was estimated 1.4 persons for Rezzato, due to exposure to O_3 levels above 10 $\mu g/m^3$ (Fattore et al. 2011). In Shiraz, Iran, the cumulative number of excess cases attributable to atmospheric O_3 was 218 persons for cardiovascular mortality (Mohammadi et al. 2015a), which is lower than the results of the present study. For each 10 $\mu g/m^3$ increasing in PM_{10} level, the cardiovascular mortality increase by 0.5%. In the USA, each 10 $\mu g/m^3$ increase of PM_{10} concentration up to 150 $\mu g/m^3$ caused to 0.12% increase in the risk rate of mortality among inhabitants of San Jose during 1980–1986 (Fairley 1990). For PM_{10} lower than 100 $\mu g/m^3$, each 10 $\mu g/m^3$ increase of PM_{10} level led to 1.1% increase in mortality risk in Los Angeles, USA (Shumway et al. 1988). In a cohort study in 25 cities of China, the researches indicated that 1.8% (0.8–2.9%) increase (mean and 95% CI) of mortality risk was relevant to 10 $\mu g/m^3$ increment of PM_{10} level for cardiovascular mortality (Zhou et al. 2014). With each increase of 10 $\mu g/m^3$ in NO_2 level, the risk of cardiovascular mortality rise about of 0.2%. Furthermore, for each 10 $\mu g/m^3$ increasing in O_3 level, the risk of cardiovascular mortality increased by 0.4%. The relative risk for a 50 $\mu g/m^3$ increase in diurnal average concentration of NO_2 was 1.02% (95% CI, 1.00–1.05%) (Anderson et al. 1997). In another study, an increase in NO_2 level was associated with an 11% increase in daily hospitalizations for cardiorespiratory diseases (Burnett et al. 1997). In another study in Sao Paulo, Brazil, exposure to O_3 has a significant correlation with the increase of hospital admissions (Gouveia et al. 2006).

In Ahvaz, 82% of cardiovascular death occurred in the days with atmospheric NO_2 level lower than 110 $\mu g/m^3$. While in present study, 87.12% of mortality occurred in NO_2 levels not exceeding 110 $\mu g/m^3$. The results of this study showed that 75.68% of the health endpoints occurred in PM_{10} concentration lower than 110 $\mu g/m^3$, and 96.72% of these impacts were attributed to PM_{10} concentrations not exceeding from 200 $\mu g/m^3$. In another study in Trieste, Italy, the results showed that 2.5% of respiratory death was related to PM_{10} levels over 20 $\mu g/m^3$ (Tominz et al. 2005). In a central RR equal to 1.0080 and AP of 3.18%, the number of cardiovascular mortality was estimated 43 persons among people of Ahvaz as 75% of these mortality occurred in days with ozone concentrations lower than 250 $\mu g/m^3$ (Goudarzi et al. 2015a). Higher than 92.1 and 55.3% of short-term health risks are in relation to the days where the background O_3 concentration was lower than 150 and 40 $\mu g/m^3$ and 55.3%, respectively. In a study in Tabriz, Iran, more than 97.6 and 79.2% of health outcomes were associated with NO_2 and O_3 levels under 100 and 60 $\mu g/m^3$, respectively (Ghozikali et al. 2016).

In Iran wherein countered with the Middle Eastern Dust events and the air quality is getting worse, and also the data of air pollution are not available, the use of the AirQ model for calculation of mortality among people is necessary. In general,

in assessing the health effects of air pollution, the interactions between different pollutants are not well considered, because these information are rarely available. In the approach used in this study, the health effect only focuses on single compounds without considering the simultaneous exposure to several pollutants that is what actually occurs. Also, this approach assumes that concentrations measured at the central monitoring station are representative of the exposure of all people settling on the whole city, and this appears as a limiting factor. Furthermore, RRs were generally based on epidemiological studies conducted on the European population that are not properly appropriated for other countries.

On the basis of our results, we can recommend to increase the number of quantification studies and regulate the use of undergrounds and fossil fuels, reduce the urban traffic, and improve its management. Furthermore, the use of this model and similar models to investigate the health effects attributed to air pollution is suggested. As a consequence, the application of effective strategies improves the air quality by implementing policies to reduce the emissions.

Conclusion

The results of this study showed that the further rate of mortality in Kermanshah was caused by the high levels of PM_{10}, NO_2, and O_3 or an increase in the number of days of people exposed to these pollutants. Although these results were in agreement with other studies conducted in throughout of the world, additional studies via specific RR and BI values based on climate change and geographical features are necessary. The results demonstrated that the importance of the Middle Eastern Dust (MED) events in Kermanshah is an increase of the health effects attributable to PM_{10}. In order to reduce the health endpoints of particulate matter, the attempt tried should be managed at the governmental scale. Possible solution to control air pollution can be driven by the use of urban forest as sink for pollutants (Nowak et al. 2006). The ozone concentrations are increasing in the cities (Sicard et al. 2016). Indeed, in urban areas, ground-level ozone can become an increased sanitary problem affecting trees, biodiversity, and well-being of citizens. Areas with high urban forest density, in fact, have lower PM than other sites (Irga et al. 2015). Such filtering capacity usually translate into little percent improvements of air quality, but such little values translate into significant savings in terms of human health (Nowak et al. 2013). There is the need to control various sources of emissions especially by cars to reduce NO_2 levels in the atmosphere, and transport and energy manufacture facilities and also health training should be conducted to people to increase public awareness. This is more important for individuals with chronic lung diseases and heart sickness, old, and children to pay attention to their activities in the days with unhealthy air quality.

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