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ESTIMATING HEALTH IMPACT OF EXPOSURE TO $PM_{2.5}$, NO_2 AND O_3 USING AIRQ+ MODEL IN KERMAN, IRAN

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Abstract

Air pollutants have harmful effects on the human health and exacerbate morbidity and mortality. The aim of this study is to assess the short-and long-term effects of the suspended particulate matter with the diameter of smaller than 2.5 μm ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) on the mortality cases in city of Kerman in 2016 and 2017. In this study, AirQ+ software presented by European Center for Environment and Health and World Health Organization (WHO) was employed. Daily mean concentration of $PM_{2.5}$, mean hourly concentration of NO_2, and maximum 8-h O_3 concentration were used to assess the health impact of human exposure to these pollutants. The mean concentration of $PM_{2.5}$, NO_2, and O_3 in the studied years was higher than the WHO guideline and the mean concentration of NO_2 and O_3 was less than the WHO guideline. In the short-term health impact assessment, the death caused by stroke in individuals above 25 years old due to O_3 had the highest attributable proportion with 2.48% in 2016 and 2.39% in 2017.Also, in the long-term health impact assessment, the highest attributable proportion for natural death caused by $PM_{2.5}$ was 15.24% in 2016 and 15.15% in 2017. In general, exposure to air pollutants is a risk factor; therefore, the implementation of sustainable control policies including population growth, urbanization, and traffic control is suggested to avoid the health impacts and economic damages.

Key words: air pollution, health outcomes, long-term impact, meteorological, mortality, short-term impact

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1. Introduction

Nowadays, air pollution has been one of the most important environmental problems affecting human health in the developed and developing countries and the fourth leading cause of death in the world (Cohen et al., 2017; Gakidou et al., 2017; West et al., 2016). Air pollution is composed of particulate matter and gases such as ozone, carbon monoxide, nitrogen oxides, and sulfur dioxide (Borge et al., 2014; Geravandi et al., 2015). As estimated by World Health Organization (WHO), 800,000 deaths caused by the respiratory and heart diseases related to air pollution occur every year worldwide and, approximately, 150000 of these deaths occur in southern Asia (Borge et al., 2014; Mohammadi et al., 2016).

Many studies have shown the relationship of air pollutants with increased incidence of disease and death (Bloemsma et al., 2019; Dobaradaran et al., 2016; Hadei et al., 2020; Karimi et al., 2019; Khaefi et al., 2017; Klepac et al., 2018; Mohammadi et al., 2015; Mohammadi et al., 2016; Rovira et al., 2020; Sówka et al., 2019). Research has demonstrated the effect of pollutants such as $PM_{2.5}$, O_3, and NO_2 on the health of residents in the metropolises such as Los Angeles (Hasheminassab et al., 2014), Delhi (Amann et al., 2017), Mexico City (Calderon-Garciduenas et al., 2015), Tehran (Faridi et al., 2018), and Rome (Fattore et al., 2011).

Although, many air pollution health effect evaluation studies have been done based on the WHO's AirQ model so far (Bahrami Asl et al., 2018;

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Miri et al., 2016; Oliveri Conti et al., 2017), however, there have been few studies carried out using the AirQ+ software (Faridi et al., 2018; Yarahmadi et al., 2018). For example Faridi et al. (2018) evaluated $PM_{2.5}$ and O_3 3years health effects including all-cause and cause-specific mortality in Tehran by using AirQ+. In another study, Yarahmadi et al. (2018) estimated total and some other mortality attributed to exposure to $PM_{2.5}$ among in Tehran.

Kerman, capital city of Kerman Province in southwestern Iran, is one of the metropolises in Iran with the population 537718. It is located at latitude 30.29 north and longitude 57.06 east (Fig. 1) (Atapour, 2015) which has high levels of air pollution due to hosting various industries, population growth, urbanization, and increased traffic, as well as proximity to the desert, prolonged drought, and loss of rangelands and natural resources increasing the air pollutants and worsening the weather. The pollutants such as PM_{10}, $PM_{2.5}$, SO_2, NO_2, HC, O_3, and CO are the major air pollutants in city of Kerman (Malakootian et al., 2013).

The AirQ model or health impact assessment of air quality is the method proposed by WHO to assess the potential effects caused by short- and long-term exposure of a particular pollutant on humans in a certain urban area over a specific period. Although the health impact assessment of air quality has been conducted in many studies using AirQ software, it has been utilized in a few studies using AirQ+ software. In this work, AirQ+ model is used to evaluate the short- and long-term impacts of $PM_{2.5}$, NO_2, and O_3 pollutants on the residents in Kerman in 2016 and 2017, which has been rarely performed in similar studies.

2. Material and methods

2.1. Air pollution data

In this study, the data on air pollutants such as $PM_{2.5}$, NO_2, and O_3 was collected from Environmental Protection Agency of Kerman, Iran, as one-hour average in 2016 and 2017.

2.2. Population data

The population of Kerman by age groups was obtained from Statistical Center of Iran. The baseline incidence per 100,000 people was calculated based on the data such as the total number of mortality, death of people over 30 years old, and death caused by cardiovascular disease (CVD), ischemic heart disease (IHD), stroke, respiratory diseases, and chronic obstructive pulmonary disease (COPD) provided by Vice Chancellor for Health, Kerman University of Medical Sciences.

2.3. AirQ+ software

In this study, the software for health impact assessment of air quality (AirQ+) proposed by European Center for Environment and Health and World Health Organization (WHO) was selected. This software is designed for health impact assessment of air pollution on human health over a certain time and place. All the calculations conducted by the AirQ+ model are based on concentration-response functions and methods obtained from epidemiological studies (WHO, 2017).

AirQ+ estimates attributable proportion, attributable cases per 100,000 population at risk, and proportion of cases in a range of air pollutants concentration (according to the baseline incidence of health outcomes, cut-off values of desired concentration, and relative risk (RR)).

The following data are required for quantifying the short- and long-term effects: the data of air quality (frequency of days with specified pollutant concentration values), data of population at risk, health data such as baseline incidence of health outcomes, cut-off values of desired concentration, and values of relative risks if different from the default values provided by WHO (WHO, 2017).

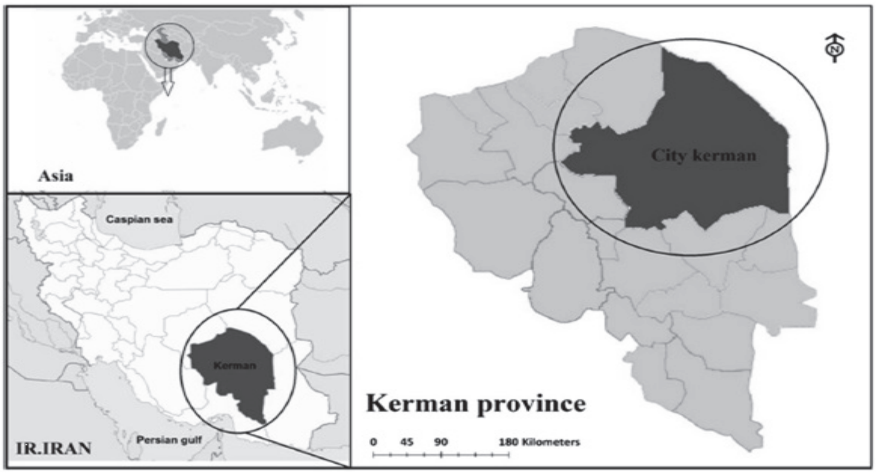

Fig. 1. Map of the study area

In this study, the air pollution data were validated based on WHO criteria and over 75% of days had valid values. To calculate the annual and daily concentrations of $PM_{2.5}$, NO_2, and O_3, the hourly concentration was used. The maximum 8-h O_3 concentration was also calculated based on hourly O_3 concentration. SOMO35 (annual sum of maximum daily 8-h ozone means over 70 µg m^{-3}) metric is an important indicator to estimate the mortality caused by exposure to O_3 in the computations of health impact assessment. SOMO35 (µgm^{-3}) was calculated in the research period as follows (Faridi et al., 2018; WHO, 2017) (Eq. 1):

$$SOMO35_{uncorrected} = \sum_{i=1}^{N_{total}} \max\left[0, \left(\mathrm{Ci} - 70\right)\right]$$

$$SOMO35 = SOMO35_{uncorrected} \left(N_{total} / N_{valid}\right) \quad (1)$$

where: Ci refers to maximum 8-h daily mean O_3 concentration, N_{total} refers to total days of the year (365 or 366 days for a year), and N_{Valid} refers to the number of days with valid concentrations.

AP can be calculated using the following formula (Ansari and Ehrampoush, 2019; WHO, 2017) (Eq. 2):

$$AP = SUM\{[RR(C)-1]\times P(C)\} / SUM[RR(C)\times P(C)] \quad (2)$$

where: *AP* refers to the attributable proportion of health outcome, *RR* refers to the relative risk of health outcome of group c in exposure that is obtained from exposure-response functions resulting from epidemiological studies, and *P(C)* refers to population ratio of group c in exposure. Knowing the baseline incidence of the selected health outcome, the attributable rate to population exposure in the desired population will be calculated as follows (Eq. 3):

$$IE = B \times AP \quad (3)$$

where: *IE* is the health outcome attributable to exposure and *B* is the baseline incidence of health outcome in the studied population. Finally, knowing the population size, the number of cases attributed to the exposure can be calculated as follows (Eq. 4):

$$NE = IE \times N \quad (4)$$

where: *NE* refers to the number of cases attributed to exposure and *N* refers to the size of the studied population.

2.4. Statistical analysis

Spearman correlation was used to analyze the relationship between concentration of $PM_{2.5}$, NO_2, and O_3 pollutants and the meteorological parameters of temperature, pressure, precipitation, and humidity. Values of $P<0.01$ and $P<0.05$ were considered as significant levels. Statistical calculations were carried out using SPSS 22 software.

3. Results and discussion

3.1. Descriptive statistics of $PM_{2.5}$, NO_2, and O_3

In Table 1, the statistical data of air quality of Kerman are shown during 2016 and 2017. The mean annual concentration of $PM_{2.5}$ was 24.04 and 24.05 µg m^{-3} in 2016 and 2017, respectively. The mean NO_2 in 2017 was obtained equal to 33.36 µg m^{-3}, which was higher than the mean value in 2016. Moreover, O_3 with concentration of 70.68 µg m^{-3} in 2017 was higher than that of 2016. The results showed that the mean $PM_{2.5}$ in 2016 and 2017 was almost 2.4 times of the level in the guideline proposed by WHO. According to Table 1, the maximum concentration of $PM_{2.5}$ was 328.27 µg m^{-3} in 2016, while it was 135.28 µg m^{-3} in 2017. The maximum concentration of NO_2 and O_3 was 102.09 and 119.91 µg m^{-3} in 2016 as well as 70.20 and 131.48 µg m^{-3} in 2017, respectively.

3.2. Relationship between pollutants and meteorological factors

Meteorological parameters such as temperature, pressure, humidity, and precipitation can influence the amount of air pollutants (Cichowicz et al., 2017; Nakhlé et al., 2015). Further, Rabee (2015) found that some variables such as traffic density, private generators, and chemical processes in the atmosphere are associated with O_3, SO_2, NO, NO_2, CO concentration (Rabee, 2015). In Table 2, the correlations between mean concentration of $PM_{2.5}$, NO_2, and O_3 (µg m^{-3}) and meteorological data (temperature, pressure, humidity, and atmospheric precipitation) are shown during 2016 and 2017 in Kerman. According to Table 2, $PM_{2.5}$ showed a positively significant correlation with NO_2 and O_3, while no significant relationship was found between NO_2 and O_3. According to Table 2, a negatively weak correlation was observed between $PM_{2.5}$ (µg m^{-3}) and precipitation ($r=-0.075$ and $P<0.05$) in Kerman, and there was no significant relationship between the pollutant, mean temperature, and humidity.

Table 1. Annual average and maximum concentrations of $PM_{2.5}$, NO_2 and O_3 in Kerman during 2016 and 2017

Pollutant	***Unit***	***Average ± standard deviation***		***Maximum***	
		year 2016	***year 2017***	***year 2016***	***year 2017***
$PM_{2.5}$[a]	µg m^{-3}	24.04±21.05	24.05±15.77	328.27	135.28
NO_2[a]	µg m^{-3}	26.36±25.25	33.36±16.04	102.09	70.20
O_3[b]	µg m^{-3}	63.86±25.25	70.68±35.47	119.91	131.84

[a] *Annual 24 hr;* [b] *Annual 8 hr.*

Table 2. Spearman's rank correlations between of $PM_{2.5}$, NO_2 and O_3 and meteorological data from 2016-2017

	$PM_{2.5}$	NO_2	O_3	Temperature	pressure	Rain	moisture
$PM_{2.5}$	1.000						
NO_2	0.321**	1.000					
O_3	0.198**	0.047	1.000				
Temperature	0.012	-0.361**	0.268**	1.000			
pressure	0.024	0.400**	-0.249**	-0.550**	1.000		
Rain	-0.075*	-0.069	-0.078*	-0.134**	-0.011	1.000	
moisture	-0.024	0.075*	-0.179**	-0.611**	0.271**	0.462**	1.000

** * Note: Correlation is significant at P value< 0.01; * Note: Correlation is significant at P value< 0.05*

Moreover, the mean daily concentration of NO_2 (μg m^{-3}) had a negative correlation with temperature (r = -0.361 and P<0.01), and a positively weak correlation with humidity (r = 0.075 and P<0.05). The mean daily O_3 concentration (μg m^{-3}) also had a positive correlation with mean temperature (r = 0.268 and P<0.01) and a negative correlation with mean precipitation (r = -0.078 and P<0.05) and humidity (r=-0.179 and P<0.01). In contrast to the results of this study, temperature and humidity had a positively weak correlation with $PM_{2.5}$ in Ansari and Ehrampoush (2019). In the study by Faridi et al. (2018), a significantly positive correlation was found between $PM_{2.5}$ and humidity and temperature, and a negative correlation was found between $PM_{2.5}$ and precipitation. Also, a positive correlation was found between O_3 and temperature and a negative correlation was found between O_3 and precipitation (Faridi et al., 2018), which were consistent with some of the results of the present study, such as negative correlation of $PM_{2.5}$ and O_3 with mean precipitation and positive correlation of O_3 with mean temperature.

3.3. Health impacts of exposure to $PM_{2.5}$, NO_2, and O_3

This paper represents a case study using the WHO method for health impact assessment of atmospheric pollution on the residents in city of Kerman. In this research, the short- and long-term impacts of $PM_{2.5}$, NO_2, and O_3 pollutants on a number of health effects, including total cases of mortality, total cases of mortality for people over 30 years old, and mortality caused by respiratory diseases, cardiovascular diseases, IHD, stroke, and chronic obstructive pulmonary disease, were quantified using AirQ+ model during 2016 and 2017. Table 3 shows the attributable proportion percentage, Table 4 shows the attributable cases and Table 5 demonstrates the number of attributable cases per 100,000 people for mortality outcomes caused by short- and long-term exposure to $PM_{2.5}$, NO_2, and O_3 in 2016 and 2017.

3.3.1. Short-term health impacts

According to the estimates of AirQ+ model in Table 3, the attributable proportion of total mortality of individuals over 30 years associated with $PM_{2.5}$ in 2016 and 2017 was 1.96% and 2.01% of total cases of this outcome, respectively. The highest attributable proportion percentage was related to cardiovascular death caused by exposure to O_3 with the value of 4.16 and 4.01 in 2016 and 2017, respectively. As shown in Table 4, 60 cases of mortality for people over 30 in 2016 and 62 cases of mortality in 2017 could be caused by short-term exposure to the concentration of $PM_{2.5}$ above 10 μg m^{-3}. Also, the total number of mortality attributable to NO_2 in 2016 and 2017 was estimated to be 21 and 27, respectively. According to Table 4, the highest impacts estimated in 2016 and 2017 were related to all cases of mortality attributable to O_3 with almost 92 and 89 cases from the total cases of this outcome.

In a large number of studies worldwide, AirQ software has been used for short-term health impact assessment of air pollution on mortality and hospital visits caused by cardiovascular and respiratory diseases in Iran (Faridi et al., 2018; Hadei et al., 2017a, 2017b, Hopke et al., 2018; Karimi et al., 2019; Mohammadi et al., 2016), 23 European cities (Boldo et al., 2006), South Korea (Jeong, 2013). For example, the human health hazards related to air quality of two cities was estimated in an industrial area in Italy. The authors found that $PM_{2.5}$ had the highest health impacts on 24,000 residents in two small cities of Mazzano and Rezzato with 8 additional cases from total of 177 deaths over a year. PM_{10} also caused 4 additional cases, and NO_2 and O_3 caused 3 additional cases from the total cases of mortality (Fattore et al., 2011). In the short-term health impact assessment caused by exposure to $PM_{2.5}$ in 10 cities of Iran over 3 years using AirQ+ software, the highest mortality rate was estimated to be on average 548 cases in 3 years for Tehran (Hopke et al., 2018). In the work by Hadi et al., the number of deaths caused by IHD for exposure to $PM_{2.5}$ was 4851 and 4876 cases during 2013-2014 and 2014-2015, respectively, and the number of deaths caused by stroke was 2411 and 2396 cases during 2013-2014 and 2014-2015, respectively (Hadei et al., 2017a). The lower number of health outcomes attributed to the studied pollutants in Kerman compared to the other similar studies could be due to the smaller population of this city and as a result the differences in baseline mortalities.

3.3.2. Long-term health impacts

According to Table 3, the attributable proportions of total cases of mortality of people over 30 caused by prolonged exposure to $PM_{2.5}$ in 2016 and 2017 were 9.5% and 9.29% of total cases of this outcome, respectively, and attributable proportion of total cases of mortality for prolonged exposure to NO_2 was about 8.11% in 2016 and 10.31% in 2017, respectively. According to Table 4, the number of deaths related to $PM_{2.5}$ for people above 30 was 284 and 289 in 2016 and 2017, respectively, and the highest number of outcomes related to the number of mortality cases attributable to NO_2 was 301 and 382 cases in 2016 and 2017, respectively, which could be due to the higher baseline incidence of this outcome than other outcomes. According to the results in Table 5, $PM_{2.5}$ with values of 52.81 and 53.68 cases of total mortality rate of people above 30 in 2016 and 2017, and NO_2 with values of 55.92 and 71.08 cases in 2016 and 2017, had the highest number of health outcomes per 100000 people, respectively. For example, Yarahmadi et al. (2018) reported 5073 deaths caused by exposure to $PM_{2.5}$ in Tehran. Faridi et al. (2018) studied the health outcomes caused by prolonged exposure to $PM_{2.5}$ and O_3 in Tehran from 2006 to 2015, where the number of deaths caused by IHD and stroke for exposure to $PM_{2.5}$ was reduced from 1558 and 825 in 2006 to 1286 and 604 in 2015, respectively, while the deaths caused by COPD was increased from 53 to 123. The number of respiratory deaths caused by O_3 was also reduced from 85 in 2006 to 54 in 2015 (Faridi et al., 2018). Guo et al. (2018) also carried out a study entitled "Effect of prolonged exposure to particulate matter on reduced pulmonary function and risk of chronic obstructive pulmonary disease" in Taiwan.

Table 3. Attributable proportion (%) of mortality outcomes due to $PM_{2.5}$, NO_2 and O_3 exposure in 2016 and 2017

	short-term effect		***long-term effect***	
	2016	***2017***	***2016***	***2017***
$PM_{2.5}$				
Mortality, all-cause (age≥30)	2.01(0.74-3.25)	1.96(0.73-3.17)	9.5(6.3-12.4)	9.29(6.16-12.12)
Mortality, IHD[a] (age≥25)	-	-	15.04(14.82-15.27)	14.98(14.76-15.21)
Mortality, Stroke (age≥25)	-	-	15.24(14.82-15.65)	15.15(14.73-15.56)
Mortality, COPD[b] (age≥30)	-	-	4.47(3.68-5.35)	4.4(3.63-5.27)
NO_2				
Mortality, all-cause	0.57(0.34-0.8)	0.74(0.44-1.04)	8.11(3.88-12.24)	10.31(4.97-15.49)
O_3				
Mortality, all cause	2.48(1.21-3.66)	2.39(1.16-3.52)	-	-
Mortality, respiratory diseases	2.48(-0.96-5.88)	2.39(-0.92-5.67)	11.38(4.24-18.62)	10.98(4.09-17.99)
Mortality, CVD[c]	4.16(1.12-7.09)	4.01(1.08-6.83)	-	-

[a] Ischemic heart disease; [b] Chronic obstructive pulmonary disease; [c] Cardiovascular diseases.

Table 4. Number of attributable cases death outcomes due to $PM_{2.5}$, NO_2 and O_3 exposure in 2016 and 2017

	short-term effect		***long-term effect***	
	2016	***2017***	***2016***	***2017***
$PM_{2.5}$				
Mortality, all-cause (age≥30)	60(22-97)	61(23-99)	284(188-370)	289(191-377)
Mortality, IHD[a] (age≥25)	-	-	115(113-117)	96(95-98)
Mortality, Stroke (age≥25)	-	-	28(28-29)	40(39-41)
Mortality, COPD[b] (age≥30)	-	-	13(10-15)	14(12-17)
NO_2				
Mortality, all-cause	21(12-29)	27(16-38)	301(144-454)	382(184-573)
O_3				
Mortality, all causes	92(45-136)	89(43-131)	-	-
Mortality, respiratory diseases	16(-6-38)	15(-6-37)	73(27-120)	71(26-117)
Mortality, CVD[c]	51(14-87)	50(13-58)	-	-

[a] Ischemic heart disease; [b] Chronic obstructive pulmonary disease; [c] Cardiovascular disease.

Table 5. Number of attributable cases per 100,000 population death outcomes due to $PM_{2.5}$, NO_2 and O_3 exposure in 2016 and 2017

	short-term effect		***long-term effect***	
	2016	***2017***	***2016***	***2017***
$PM_{2.5}$				
Mortality, all-cause (age≥30)	11.16(4.13-18.06)	11.34(4.19-18.35)	52.81(35.03-68.89)	53.68(35.59-70.06)
Mortality, IHD[a] (age≥25)	-	-	21.40(21.09-21.73)	17.91(17.65-18.19)
Mortality, Stroke (age≥25)	-	-	5.30(5.15-5.44)	7.49(7.28-7.70)
Mortality, COPD[b] (age≥30)	-	-	2.43(1.93-2.80)	2.68(2.21-3.21)
NO_2				
Mortality, all-cause	3.9(2.31-5.48)	5.09(3.02-7.14	55.92(26.78-84.41)	71.08(34.26-106.61)
O_3				
Mortality, all causes	17.11(8.32-25.20)	16.50(8.02-24.31)	-	-
Mortality, respiratory diseases	2.98(-1.15-7.06)	2.88(-1.11-6.83)	13.66(5.09-22.36)	13.22(4.92-21.97)
Mortality, CVD[c]	9.54(2.57-16.26)	9.28(2.50-15.83)	-	-

[a] Ischemic heart disease; [b] Chronic obstructive pulmonary disease; [c] Cardiovascular disease.

In this study, the exposure to $PM_{2.5}$ was associated with reduced pulmonary function and increased risk of COPD. This study emphasized the use of global urgent strategies to reduce air pollution and improve the pulmonary health and prevent COPD (Guo et al., 2018). The lower long-term health impacts in city of Kerman compared to similar studies could be due to the differences in baseline mortalities.

This approach had limitations, including the study of air pollutant concentration to measure the exposure of population using the model and overlooking the scenario of exposure to several pollutants in model calculations due to the limitations of epidemiological studies, as well as estimating the results of exposure based on health outcomes obtained from epidemiological studies in other areas with different population, socioeconomic status, and exposure to different particulate mixtures (WHO, 2016).

4. Conclusions

Although there were limitations for health impact assessment of air pollutants in this study, such as assuming a causal relationship between the studied pollutants and health outcomes caused by exposure to them and lack of effect caused by interfering factors on the relationship, such studies are very beneficial for providing valuable data on the importance of air pollutants and their considerable effects on humans. Moreover, according to the results of this study, the average annual concentration of $PM_{2.5}$ in city of Kerman was much higher than the WHO guideline, which could be due to the existence of various industries near the city, proximity to desert, prolonged drought, as well as loss of rangelands and natural resources, population growth, urbanization, and increased traffic. Therefore, controlling $PM_{2.5}$ and other air pollutants is essential to preserve the health of citizens and reduce their health impacts.

In total, air pollutants can be modified as a risk factor by adopting air quality and emission standards; therefore, sustainable control policies are suggested to prevent the health impacts and economic damages.

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