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Original Research

Quantification of Mortality Associated with Particulate Matter Using Air Q model in Ambient Air in Shiraz, Iran

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Abstract

Suspended particles of less than 10 µm (PM_{10}) are one of the most important pollutants that create irretrievable damage to human health and the environment. This study surveyed the death rate associated with cardiovascular and respiratory diseases related to PM_{10}. Three sampling stations were selected from various parts of Shiraz, Iran (Southwest of Iran). The concentration of PM_{10} particles was measured using a Grimm machine. The values of temperature and pressure were also obtained from the Metrological Organization of Shiraz. The data were initially processed in Excel, including pressure and temperature correction, programming, processing (calculating averages), and filtering. The input was entered into AirQ+ and Air Quality Health Impact Assessment model. This model consists of four input parameters (Parameter, Location, AQ data, Supplier) and produces two outputs in the format of tables and graphs. The results presented that the highest share of health impacts attribute to pollutants of air in Shiraz is due to PM_{10} pollution. The harmful health effects of PM_{10} significantly increases at concentrations exceeding 40 µg/m^3. The model revealed that the death number of respiratory and cardiovascular diseases attributed to the PM_{10} in Shiraz in 2019 was 92 and 22 respectively, which accounts for 2.4% of the total deaths in Shiraz. It should be concluded that the lack of management for particulate matter pollution can bring about more deaths and cause other health effects.

Keywords: mortality, respiratory disease, cardiovascular disease, suspended particles, Shiraz

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Introduction

Air pollution is considered a carcinogen agent which causes a serious problem for human health. In recent decades, some researchers have reported the adverse impacts of pollution of air on human beings all over the world [1-3]. Suspended particles are considered as an important air pollutants which can lead to irritation in the nose, throat, and eyes, nausea, headaches, respiratory infections, lung cancer, chronic respiratory diseases, allergic reactions, heart disease, and high mortality [4]. Particles especially what have less than 10 µm of aerodynamic diameter (PM_{10}) shows the maximum health effects because of their capability to penetrate the pulmonary alveoli. As a result, the International Cancer Research Agency considered the suspended particles as part of group 1 carcinogens in 2013 [5]. The particles chemical composition and size have a significant role in the health impacts of them. PM_{10} Exposure enlarges the heart and respiratory diseases rate based on the World Health Organization reports [6, 7]. The National Ambient Air Quality Standard (NAAQS) was set the primary daily standard for PM_{10} of outdoor air as value as 150 µg/m^3 [1]. In addition, WHO set the annual mean standard and average daily permissible airborne concentrations for PM_{10} particles as 20 µg/m^3 and 50 µg/m^3 because of the health impacts of these particles [6, 8]. It should be noted that these values should not occur more than 35 days per year. More evidence have been risen for the mortality associated to the pollutants of ambient air as long-term exposure [9, 10]. Comprehensive studies have been carried out for cardiovascular diseases related to the long-and short- term exposure to PM_{10} [11]. Recently, these researches have critically improved our perceptions of mechanisms that can clearly elucidate the attributions observed in experimental and epidemiological surveys related to mortality and air pollution [12]. Traffic emissions considered as main source of gaseous and particles pollutants like sulphur oxides (SO_2) and oxides of nitrogen in urban areas. Besides, exposure to these pollutant inconsistences associated to the traffic emissions could rarely presented by the amount of particulate matter due to the high regional background concentration of these pollutant associated to the other sources [13]. Nevertheless, more certain markers could be for the pollutants related to the traffic such as elemental carbon and ultrafine particle number [14]. Some approaches for control of emissions from the traffic sources could significantly decline these emissions, and therefore emissions of non-tailpipe sources such as emissions of engine crankcase (lubricating oil of combusted), brake wear, tire, and road have converted to be more important. Research related to the emissions of traffic in the Netherlands revealed that addition in the mount of pollutants in major roads related to tire and brake wear (Cu, Zn) as well as ultrafine particles and soot in comparison with urban background [15].

The city of Shiraz which the population of it estimate about 1.87 million people, considers as a metropolises city in Iran, placed in a semi-warm area of Iran (southwest of Iran). The industrial areas presence, the activity of a cement factory, a vegetable oil factory, and power plants, Shiraz is one of the industrialized cities in Iran. The geographical location of the city, prevailing local and regional winds and the effects of drought have made the city in terms of air pollution as a most polluted region. The results of a AQI study in Shiraz showed that PM_{10} was responsible for air pollution in Shiraz in 18% of days which had an AQI>50 (moderate air quality or worse). Due to the lack of a scientific and comprehensive study on the air pollution and its effects on human being in Shiraz, present work attempts to estimate the number of deaths from respiratory and cardiovascular diseases resulted in due to exposure of PM_{10} in Shiraz. Therefore, this study was sampled the suspended particles at 4 stations in 2019, and estimate the respiratory and cardiovascular mortality in Shiraz, and provided the necessary information for the city's municipal management and health department to control air pollution.

Materials and Methods

Study Area

Shiraz as a studied area is placed in the central part of Fars province with a total area of 178 square kilometers (29°36' north and 52°32' east, at an above sea altitude of 1486 meters). The average temperature of the warmest (July) and coldest months (January) are 30ºC, 5ºC, respectively. Shiraz contain a mild Mediterranean climate. The average annual temperature is 18ºC and annual rainfall in Shiraz is 337.8 mm. Suspended particle data were collected through the city's Department of Environment. The sampling points and characterization of studied area are shown in Fig. 1.

The characterizations of the population following age groups were collected from the national Center of Statistic of Iran. Besides, the deaths number that were categorized based on age were earned via the Office of Civil Registration in Shiraz. All mortalities and mortality rates of baseline incidence (BI) occurred due to COPD, IHD, ALRI, stroke, and LC were estimated through the information of the Office of Civil Registration of Shiraz as well as Shiraz University of Medical Sciences.

Modeling and Exposure Assessment

The present study was a quantitative study that was attributed to the impacts of PM_{10} on human health in Shiraz using a modeling approach. Modeling was developed using data that was collected via the Meteorological Organization and Department of Environment of Shiraz. The stations of sampling were

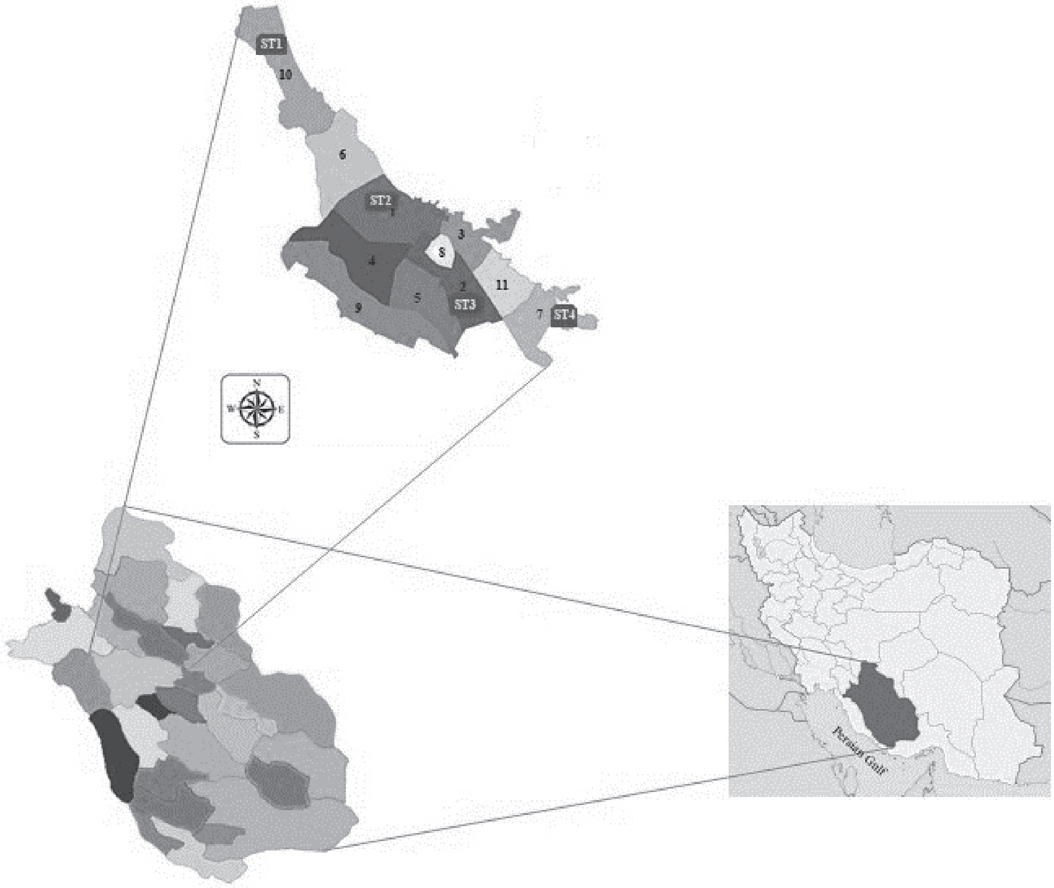

Fig. 1. Studied area location and sampling points.

chosen according to the EPA criteria and four sample points were chosen for sampling. The concentration of PM_{10} was measured using a Grim machine [16]. The Grim machine uses the air sheathing system and displays real-time aerosol mass readings. This device was equipped with software for transferring data to a PC with an RS232 cable and displayed data graphically as two numeric formats [17]. Since the pollution control stations lacked temperature sensors, meteorological data was collected for this purpose from the Meteorological Organization of Shiraz. After that, data were analyzed in Microsoft EXCEL and the result have input into the Air Q model. To prepare model input, different steps were taken to adjust temperature and pressure, adapt units to the model, perform primary and secondary processing, calculate daily averages, carry out condition correction, and perform primary and secondary filtering. Air Q requires four inputs (Parameter, Location, AQ data, Supplier) and generates two graphs. Features and advantages of the Air Q model include: encompassing features of other models such as CMAQ and ORAM, and the ability to make evaluation using all reference pollutants. One of the most important features of the Air Q model is its ability to generate risk of relative (RR, the likelihood ratio of a complication in the exposed population to the possibility of the same complication in the non-exposed group) [18]. The relative risk was calculated through the following equation.

$$RR = exp[\beta \ln (x - x_0)]$$

...where β is a confidence interval which was considered 95%, x and x_o refer to the concentration of pollutants and the value of the counterfactual, respectively.

Attributed proportion (AP, percentage of health consequences directly attributable to the pollutant) [1] and the baseline incidence (BI, the number of cases within one year), were calculated based on epidemiological studies conducted by the WHO and systematic reviews. The Air Q model is particularly suitable for industrialized cities such as Shiraz [4, 18]. AP is part of health outcomes that can be attributed to specific demographic exposures over a given time (on the assumption of a link between exposure and health outcome in the distorting influence absence) [19]. This component can be computed by the following equation:

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

RR (C) and P (C) represent the relative risk of health outcomes in target group or group C and population ratio of target group or group c, respectively.

Besides, the number of cases per population (BE) could be estimated with the following equation.

$$BE = B \times AP$$

...where B represents a certain baseline incidence. RR is reported in three forms; lower limit relative risk (having a positive and desirable effect in reducing complications), the middle limit relative risk, and the upper limit relative risk (having a negative and undesirable effect on increasing the incidence of complications) [20]. Based on the confidence intervals (CI: 95%) of the estimation of relative risk in the calculations, it can determine the number range of the expected cases and the lower and upper limits of the estimated component.

Results and Discussion

In 2019, the annual average concentration, mean concentration in summer and winter, and 98th percentile for PM_{10} were 43.8, 53, 31, and 140 μg/m^3, respectively. The average amount of suspended particles at warm seasons (spring and summer) was lower than the cold seasons (autumn and winter). Dust storms in the western areas of the Middle East and human activities were the main source of pollutants [21]. The amount of cardiovascular deaths because of PM_{10} was calculated to be 92 people in 2019, with a baseline incidence (BI) of 216 per one thousand individuals (Table 1).

In Table 2, relative risk indicators, attributable component, baseline incidence, and the amount of cases associated to particulate matter (PM_{10}) pollution for respiratory disease deaths are presented. Baseline incidence was assumed to be 36 cases per one hundred thousand individuals. According to the findings presented in Table 2, the cumulative incidence of respiratory death in Shiraz was 22 individuals.

Fig. 2 and 3 are plotted according to the quantitative analysis and cumulative number of health outcomes impacted by the concentration of pollutant. As can be observed in these Figs, the three lines attributed to the relative risk (RR) associated with PM_{10} at the lower, middle, and upper limits. Fig. 1 presents that the cumulative mortality rate related to the cardiovascular disease due to PM_{10} was 92 individuals in 2019. Besides, an increasing trend in cumulative mortality of people in Shiraz was emerged less steep for concentrations higher than 60 μg/m^3 (Fig. 1) for concentration of PM_{10} between 10 to 60 μg/m^3. Fig. 2 shows the death number related to the respiratory diseases in the various concentrations of PM_{10} at the three limits. As shown in Fig. 2, the cumulative death number due to respiratory illness enlarged with an increase in the concentration of PM_{10}. The death number rose sharply for concentrations between 10 to 40 μg/m^3 and somewhat plateaus later. It can be seen that about 50% of mortality occurred per day with a PM_{10} concentration of less than 50 μg/m^3 (Fig. 2).

The results showed that the cardiovascular death number associated to particles less than 10μm in Shiraz was 92 based on the BI=216 (per one hundred thousand individuals). It reflected that the risk of cardiovascular death enhanced with 4% per 1 μg/m^3 addition in the concentration of PM_{10}. It is worth to note that about 70% of cardiovascular deaths per day have been carried out during the concentration of PM_{10} was less than 60 μg/m^3.

The death number due to respiratory diseases was 22 which 53% of them occurred at concentrations below 40 μg/m^3. The large attributable factor in number of death due to pulmonary problems represented an elevated relative risk (64 individuals). Despite the presence of some relative risk, the health impacts of PM_{10} exposure at concentrations of less than 10 μg/m^3 was zero due to the population didn't expose to these concentrations. It should be mentioned that the PM_{10}

Table 1. Estimation of total cardiovascular mortality based on relative risk, attributable cases and attributable component due to PM_{10} pollution in 2019, in Shiraz (BI = 216).

Relative Risk (upper limit)	Attributable proportion (percent)	Total count (individuals)
Lower limit (1.005)	1.66	58
Middle limit (1.008)	2.63	92
Upper limit (1.018)	5.74	200

Table 2. Estimation of total mortality of pulmonary based on the relative risk, total attributable individuals and attributable proportion (%) due to PM_{10} pollution in 2019, in Shiraz (BI = 36).

Relative Risk (upper limit)	Attributable proportion (percent)	Total count (individuals)
Lower limit (1.008)	2.63	15
Middle limit (1.012)	3.90	22
Upper limit (1.037)	11.12	64

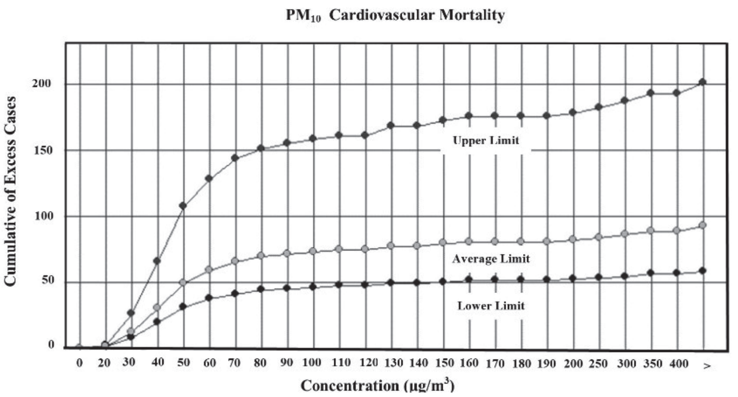

Fig. 2. Correlation of the cumulative mortality rate of cardiovascular diseases attributed to PM_{10} versus concentration of PM_{10}.

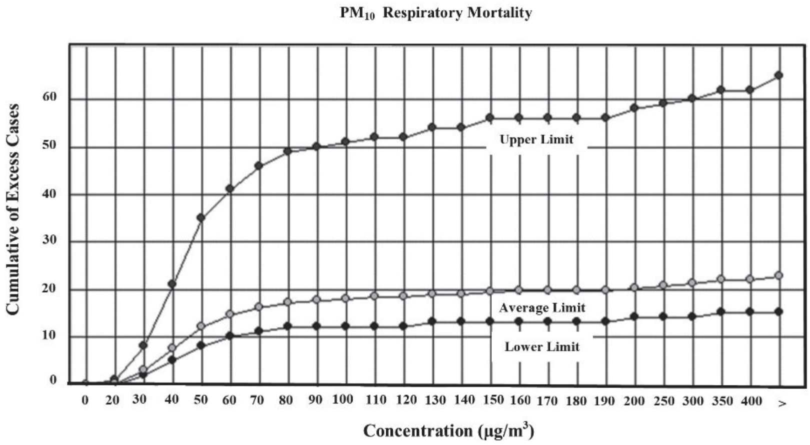

Fig. 3. Correlation of cumulative mortality rate of respiratory diseases associated to PM_{10} versus concentration of PM_{10}.

concentration less than 10 μg/m^3 has never occurred for 2019. Based on the results, the annual average of PM_{10} in Shiraz in 2019 was 43.8 μg/m^3. The concentration of this pollutant exceeded the WHO limit in 18% of days in this year. The high levels of PM_{10} in Shiraz were created by high levels of fossil fuel consumption due to the region's cold climate, high per capita car ownership, the tropospheric inversion, and the dust caused by neighboring countries. The number of deaths and diseases attributed to the different concentrations of pollutants was linked to the relative risk and the number of days was exposed to a given concentration. According to the Air Q evaluation, the highest total deaths from cardiovascular and pulmonary diseases associated with PM_{10} pollution occurred at concentrations between 49-40 μg/m^3. However, only 5% of the days in 2019 had concentrations in this range.

Besides, the death number in Shiraz city attributed to the suspended particles due to the various disease is shown in Table 3. According to the obtained results, suspended particles could increase the number of deaths related to heart ischemia more than other diseases. The findings of air pollution study in Mashhad city (northeast of Iran) were in line with this study [22].

Table 4 shows the average number of total deaths in Shiraz attributed to PM_{10} in 2019 in a population of higher than 30 years. As can be seen, there are about 531 total deaths might be attributed to the long-term exposure to PM_{10} in the average concentration of 27.7 μg/m^3 during the studied time. In other words, there were 31 deaths per 100000 people in Shiraz which were related to the exposure of long-term to this pollutant. It should be mentioned that this number of death was less than the average death number in the world (53 per person) attributed to the PM_{10} exposures [23]. There is a finding that showed the Exposure of long-term to $PM_{2.5}$ in Tehran causes 128 deaths per 100000 people (in 2018) which was much more than the world average and this study calculated [24]. In addition, the results of another study showed that total death in Tehran related to the $PM_{2.5}$ in a 10-year study was between 3755 to 5895 per year [25]. According to the results, the maximum death is associated with brain stroke. It merits to note that many studies reported that the correlation between stroke and exposure the air pollutants is significant [26, 27]. Based on the previous study, the maximum occurrence of stroke was occurred in winter, as the amount of air pollutants is high [26].

Table 3. The base death rate in Shiraz (2019) (Total population: 1712745 and total death: 8291).

Parameter	Basic	COPD	Lung cancer	Heart ischemia	Brain stroke
Number of deaths for population between 25 to 60	7739	19	36	138	110
Total population between 25 to 60	773459	773459	773459	956436	956436
Total number of deaths in the population between 25 to 60	246	3.4	4.6	14.4	11.05
Total number of deaths in the population over 60 years without an accident	4797	158	97	597	393
Total number of populations over 60 years	171612	171612	171612	171612	171612
Total death in the population of over 60 year	279	92	56.52	347.8	229
Total death in the population of over 60 years without accident per 100000 persons	709	19.57	14.7	65.15	44.59

Also, the large-scale study suggested that there is a correlation between the stroke rate related to air pollution and racial differences and geographic characteristics [28]. It was found that a high amount of particulate matter in the air could lead to an increase in the admitted persons to the hospital due to hemorrhagic and ischemic stroke [29]. According to the previous study, it was shown that the highest association between particulate matters and death rate related to them could be attributed to the stroke in Tehran [25]. It was found that the binding protein of lipopolysaccharide prevented the induction of cytokine through $PM_{2.5-10}$ and this suggests bacteria of gram-negative is a component of $PM_{2.5-10}$. Besides, the synergetic effect of the suspended matter and endotoxin proinflammatory related to the macrophages could cause the homeostasis of lung tissue [30]. In addition, it was reported that high rate of respiratory disease caused by air pollution may be due to pneumonia [31, 32].

It was apperceived that there was an increase (0.25%) in total mortality of ischemic heart disease due to an addition in each 10 μg/m^3 of particulate matter with size of less than 2.5μm ($PM_{2.5}$) in Tehran [24]. The average death attributed to disease of ischemic heart because of exposure of long-term to PM_{10} in Shiraz was 380 persons. Therefore, the results of this study were lower than the mortality obtained from a previous study in Tehran [25].

Particulate matter could cause epigenetic variations in LC like rising in cytokines and some cells of inflammatory, small, and non-small cell lung cancer [24]. The high values of PM_{10} in the air could lead to oxidative stress and release of cytokine which could be remarked as the primary mechanism for improving asthma, COPD, and LC. Besides, an increase in autophagocytosis and tumor cells might be attributed to the increment in amount of PM_{10} in air and then LC [33]. It was found that there is a significant correlation between LC mortality and exposure of long-term to PM_{10} in various regions of the world [34, 35].

The related deaths from COPD attributed to the PM_{10} in this study were 21. While the number of deaths associated with the $PM_{2.5}$ due to COPD in Tehran was 158 persons which much more than the present study. These differences may be due to the concentration of $PM_{2.5}$ in Tehran [36].

Table 5 shows the health effects of PM_{10} in 2018 and 2019. Based on the results, the death associated with PM_{10} in 2019 was less than in 2018. It was reported that the total deaths associated with cardiovascular disease

Table 4. Long-term (chronic) health effects attributed to suspended particles PM_{10} in Shiraz in 2019.

Demographical characteristics	Total Population	Population (higher than 30 years)	Average concentration (μg/m^3)
No.	1712745	945071	27.7
Chronic health effect associated with PM_{10}			
Parameters	Average	Upper limit	Lower limit
Total deaths	531	694	351
Death associated with COPD	21	33	8
Death associated with lung cancer	18	30	4
Death associated with heart ischemia	380	463	278
Death associated with Brain stroke	248	340	112

Table 5. Air pollution effects attributed to PM_{10}.

Effects	Number		Attributed component (%)	Decrease/increase than 2018
	2018	2019		
Total deaths	278	249	2.44	-10
Death due to cardiovascular disease	102	92	2.63	-9.8
Death due to respiratory disease	25	22	3.9	-12
Hospitalization due to respiratory disease	599	538	2.63	-10.18
Hospitalization due to cardiovascular disease	232	208	2.95	-10.34

in Baja California, southeast Texas, and Southwest US increased by 3.1% for PM_{10} and 2.8% for $PM_{10-2.5}$ [32].

A large amount of researches were carried out for estimating the impacts of health due to pollution of air using the Air Q 2.2.3 and Air Q+ models in Iran [37, 38]. These studies represented that air pollution has negatively influenced on health in the first three years because of extremely dusty storms. Studies in many cities in Europe, America, and Asian countries revealed that the short-term exposure of PM_{10} had the similar health effects. It was reported that the risk of death increases with daily concentration of PM_{10} by 0.5 percent per 10 μg/m^3 [39-41]. The health impacts of airborne pollutants, in particular PM_{10} were evaluated in Ukraine. The results showed that total deaths was about 46,000 which more than half of them was associated to the cardiovascular disease and lung cancer [41].

It is worth mentioning that this study had some limitations such as pollutants were studied in isolation and it was considered that the obtained concentrations at the sampling points indicate the average exposure of the people living in Shiraz. Therefore, the results of this study should be taken into consideration with caution by experts [6].

Conclusion

The present study represented that mortality related to the PM_{10} pollution in Shiraz due to heart attack and respiratory problem were about 2.6% and 3.9%, respectively. The death number related to the respiratory disease as well as cardiovascular problems were calculated by the Air Q model clearly illustrated the effects of PM_{10} on the health of exposed individuals in Shiraz. The results underscored the importance of a management plan for air pollution and the necessity of sustainable development in the city. Pollution reduction measures such as mulching and reduction of emissions from the main sources of particulate matter pollution, it is possible to mitigate the health effects of this pollutant and lower the current risk level (the upper limit) to a more favorable situation (the lower limit). Lack of management for particulate matter pollution can bring about more deaths and cause other health effects. Further epidemiological studies are needed to estimate the actual impacts of air pollutants by calculating some statistical components such as the attributable component and relative risk (RR) index and baseline incidence (BI).

On the other hand, air pollution considered as the challenges of urbanization and industrialization that could influence the human lives all over the world. Numerous epidemiological studies revealed the correlation between mortality and air pollutants. There is also a famine in the studies that show the general air pollutant health impacts in the region. It was reported by WHO that missing data could significantly have carried out during the maintenance periods or times as measuring devices are turned off. Therefore, the results of epidemiological studies could be influenced by the data obtained from these situations and devices. Thus, the new, credible and scientific standard of air quality must be set for Iran. According to the geographical characteristics of the country, frequent dust storms and low precipitation, the standards of PM_{10} pollutants require to be revised.

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Conflict of Interest

The authors declare no conflict of interest.

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