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Evaluation of cardiovascular and respiratory mortality attributed to atmospheric SO_2 and CO using AirQ model

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Abstract

Background: Air pollutants have multiple adverse effects on human health. In this study, the health effects of exposure to carbon monoxide (CO) and SO_2 in the air of 6 Iranian metropolises in 2011-2012 were examined.

Methods: Raw data was collected from the Iranian Department of Environment and the Iran Meteorological Organization. After validation, the required statistical indices were calculated through programming and modifying temperature and pressure in Excel software. The output of Excel was given to the AirQ model, and the results were presented as the cases of death.

Results: The annual mean concentrations of SO_2 were 2.45, 1.55, 0.6, 0.55, 1.05, and 3.8 times higher than the guidelines of the World Health Organization (WHO) (20 μg/m^3) in Tehran, Mashhad, Isfahan, Shiraz, Tabriz, and Urmia, respectively. The concentrations of CO did not exceed the standard limit in any of the studied cities. The cumulative numbers of total deaths attributed to SO2 were 744, 122, 132, 44, 37, and 107 in Tehran, Mashhad, Isfahan, Shiraz, Tabriz, and Urmia, respectively. The highest mortality rate was found in Urmia at 2.9% followed by Tehran at 1.52%; the lowest rate of 0.46% was found in Tabriz.

Conclusion: The results show that of the 6 metropolises, the highest CO mortality rate of about 2.15% belonged to Isfahan followed by Arak with about 1.38%, and the lowest rate of 0.68% belonged to Mashhad. Because of the growing trend of air pollution and its mortality rate and adverse effects, practical solutions for the control and reduction of air pollution in Iranian metropolises are necessary.

Keywords: Air pollution, Software, Iran, Cities

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Introduction

The increases in technology and industrialization without consideration given to sustainable development and environmental pollution, particularly the pollution of air which is an important factor of life, need to be given more attention (1-8). Based on the annual estimates of the World Health Organization (WHO), 800 000 premature deaths occur; of that number, about 1 500 000 of these deaths occur in South Asia (9). Annually, deaths caused by air pollution in the United States about 60 000 number. Nevertheless mortality attributable to pollution appears to be low; however, due to the large population that is exposed to air pollution and the existence of sensitive groups in society, the burden of disease attributable to pollution will increase (10,11). The effects of air pollution on human health can be categorized as chronic or acute. In determining acute effects, one examines important events that occurred in the 20th century in some cities of Europe and America, such as Meuse Valley, Belgium; London, England; and Donora, Pennsylvania in the United States (11-13). Over the past 2 decades, studies on the health effects of air pollution have determined and demonstrated that the rate of mortality attributable to air pollution is rising (12,13). Research has shown that the global burden of air pollution-related disease estimated by the WHO is 89% of total deaths caused by heart and respiratory disease (13). In the past few decades, many studies have demonstrated that the current levels of SO_2 and carbon monoxide (CO) are associated with cardiopulmonary respiratory deaths, hospitalizations, and respiratory symptoms (14-17). CO is a colorless, odorless, poisonous, and tasteless gas. It is often mixed with other gases that do have an odor, though it has no detectable odor itself. When carbon monoxide is in haled, it displaces oxygen in the blood and deprives the heart, brain, and other vital organs of oxygen. The six main symptoms of CO poisoning are headaches, vertigo, nausea, breathlessness, heart palpitations, and a loss of consciousness. Large amounts of CO can overcome a person in just a few minutes without prior warning, cause a loss of consciousness and eventually suffocation. Carbon monoxide is relatively stable in air and is one of the major pollutants related to the burning of natural gas and internal combustion engines. If the appliances burning fuel are properly kept and used, the amount of CO produced is not usually dangerous. About 85%-90% of CO comes from automobile exhaust (18-20). When fossil fuels which contain sulfur, like coal, are burned, sulfur dioxide is released. Generally, there are 2 reasons why SO_2 is hazardous to humans: first, it is in gaseous form, and second, it oxidizes to form sulfate. Aerosol SO_2, in comparison with other pollutants, is more soluble in water, and when it is combined with suspended solids and moisture, it creates harmful effects that are relayed by air pollution. Many studies have shown that the number of hospitalizations increase on days with high levels of SO_2 in the air. Asthmatics are generally considered the group most sensitive to high concentrations of SO_2. Another sensitive group comprises those who exercise regularly. This is due to the fact that SO_2 is highly reactive; consequently, the distribution of SO_2 along the conductive airways of the respiratory tract is non-uniform, depending on breathing volumes and types (21,22). Information on the effects of exposure for long periods (e.g., 24 hours) is obtained from epidemiological studies, which are indicative of the relationships among contaminants such as SO_2 and the health impacts on communities. To evaluate the evidence of effects on health related to SO_2 exposure for the New Zealand ambient air quality guideline values, Dennison et al studied the correlations between SO_2 and other contaminants in the air. They determined that it would be quite difficult to confidently attribute the impacts observed in epidemiological studies to SO_2 alone (23). Experimental studies were therefore applied to derive the dose-response relationships underpinning the ambient air quality guideline values for SO_2 in New Zealand (24). In a study during the years 1996-2000 in 15 cities of Italy, with increasing concentrations of CO and SO_2, the number of mortalities due to cardiovascular disease rose 0.93% and 1.11%, respectively (24). In the 8 Iranian metropolises studied in the current research, several pollutants are discharged from motor vehicles, industries, and commercial and domestic resources, and the concentrations of most of these pollutants rise above standards levels during different hours of the day. The situation has attracted the attention of a group of officials and people. Therefore, to reduce air pollution and aid decision-making in this regard, there is a significant need to quantify the health effects of pollution. The main purpose of this study was to quantify the short-term health effects of air pollution, specifically regarding the pollutants CO and SO_2, in 2011-2012 in 6 cities of Iran (Isfahan, Shiraz, Tabriz, Mashhad, Tehran, and Urmia). This study employed the software AirQ2.2.3.

Materials and Methods

Data related to air pollution were taken from the Environmental Protection Department of 6 large cities in Iran (Figure 1).

There are 21 valid, general monitoring stations for SO_2 and 25 valid, general monitoring stations for CO in the 6 Iranian cities investigated in this study. All stations monitor SO_2 and other gaseous pollutants (NO_2, PM_{10}, $PM_{2.5}$, O_3, and CO) hourly. The data related to pressure and temperature were obtained from the cities' metrological offices. Data regarding the cities' populations were obtained for use in statistical analysis. The population static over 65 years

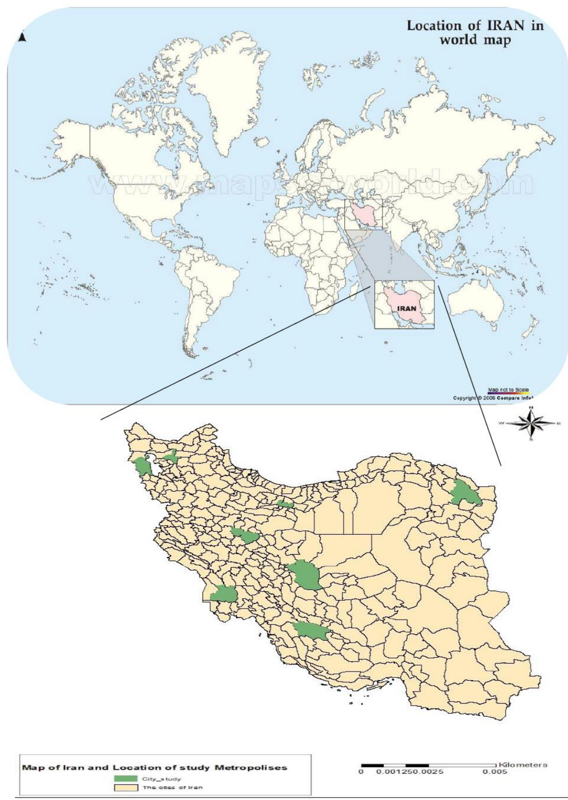

Figure 1. Map of Iran in world and location of study metropolises.

old were used for population that faced with CO. The data provided for consideration was volumetric base and needed to be gravimetric-based for entry into the selected software. Thus, by writing a program in Excel, new files were created with the model's required units. First, the raw data was changed based on temperature and measurement points. The following equation was used to correct the concentrations expressed in units.

$P_1V_1/T_1= P_2V_2/T_2$

Then, the raw data was analyzed and valid data was selected based on WHO, European, and European Union (EU) criteria. Zero values meant that disturbances were removed from calculating average that conducted with moving average. Data on SO_2 and CO was placed on separate sheets, because the files for entry into the software for SO_2 were daily averages and that for CO was based on an hourly average. Initial and secondary filtering was done in Excel. In this part, the required statistical parameters were calculated and prepared for entry into AirQ software. For the quantification of both pollutants in the air, the software AirQ2.2.3 presented by the European Environment Office and the WHO was employed. It was also used to quantify the health effects of air pollution. Using this model, a kind of statistical and epidemiological method, the health outcomes were estimated using pollutant concentration and epidemiological parameters like baseline incidence, relative risk, and exposed population of the studied cities. The results were shown as attributable proportion (AP) and the number of excess cases of mortality. Finally, the results were presented as tables and charts of base line incidence (BI) and relative risk (RR) with 95% CI for estimated health endpoints attributable to SO_2 and CO in the present study (Table 1). The populations of the studied cities are shown in Table 2 (25,26).

Results

Table 1. Baseline incidence and relative risk with 95% CI for health endpoints

Health endpoint		Baseline Incidence (per 105 inhabitants)	RR (95% CI) per 10 μg/m³	
			SO_2	CO
Mortality	Total	543.5	1.004 (1.003-1.0048)	-
	Cardiovascular	231	1.008 (1.002-1.012)	BI:497; 1.007 (1.002-1.012)
	Respiratory	48.4	1.01 (1.006-1.014)	-

Abbreviations: BI, baseline incidence; RR, relative risk; CO, carbon monoxide.
Source: AirQ 2.2. 3 software

Table 2. Population of studied cities from the census reports on Iran

City	Exposed population	The population used in the software	Population over 65 years	Latitude	Longitude
Mashhad	2749374	2750 × 1000	200 × 1000	36.31	59.58
Tabriz	1494998	1495 × 1000	143 × 1000	38.08	46.28
Isfahan	1987168	1987 × 1000	135 × 1000	32.68	51.64
Shiraz	1549453	1540 × 1000	90 × 1000	29.62	52.52
Tehran	9000000	9000 × 1000	550 × 1000	35.34	51.25
Urmia	1615000	680 × 1000	40 × 1000	37.55	45.07

Table 3. Statistical parameters required for import into the program- CO (mg/m³) in 6 megacities

Parameter	Mashhad	Tabriz	Isfahan	Shiraz	Tehran	Urmia
Annual mean	2	2	2	2	2	2
Winter mean	2	3	2	2	2	2
Summer mean	2	2	2	2	2	2
Annual 98 Percentile (P_{98})	4	5	10	5	5	7
No. of station	8	6	4	2	10	1

Table 4. Statistical parameters required for import into the program- SO_2 (μg/m³) in six Megacities

Parameter	Mashhad	Tabriz	Isfahan	Shiraz	Tehran	Urmia
Annual mean	31	21	12	11	49	76
Winter mean	34	29	10	9	54	82
Summer mean	28	13	13	14	43	71
Annual 98 Percentile (P_{98})	48	66	19	25	94	159
Annual maximum	61	118	26	33	118	188
Winter maximum	61	18	26	34	118	176
Summer maximum	41	34	20	32	88	188
No. of station	7	5	4	2	9	1

Table 5. Comparison annual average concentration of SO_2 with the Iran national standard in 6 metropolis of Iran

City	The average annual concentration Iran national standard (μg/m³)	The ratio annual average concentration SO2 (μg/m³)
Mashhad	20	1.55
Tabriz	20	1.05
Isfahan	20	0.6
Shiraz	20	0.55
Tehran	20	2.45
Urmia	20	3.8

Based on the WHO's criteria, the data related to SO_2 and CO pollutants was studied. The required statistical parameters (annual and seasonal means and annual 98th percentiles) for CO and SO_2 were obtained from each city and are shown in Tables 3 and 4, respectively.

Table 3 shows the results that indicate the 1-hour average concentration of CO in 6 metropolitan cities was not higher than the standard level, and the highest annual concentration of CO was related to the (mg/m³) concentration of Tehran city. Table 4 shows that the annual mean concentrations of SO_2 were higher than the standard level (20 μg/m³) in Mashhad, Tehran, and Urmia with the highest annual SO_2 concentration being related to Urmia (76 μg/m³). The annual mean concentration of SO_2 was compared with Iran's national standard for average annual concentration in six metropolises of Iran, and the results are given in Table 5.

As indicated in Table 5, the annual mean concentrations of SO_2 were higher in Tehran and Urmia than in the other cities; their average ratios were 2.45 and 3.8 times greater than the average standard concentration. The province of West Azerbaijan is located in western Iran and is affected by wet weather from the Atlantic Ocean and Mediterranean Sea. In Urmia, the capital city of the province, there are approximately 300 vehicles for every 1000 people. That is about 1.5 times the average of the country. In Urmia, the number of vehicles and expansion grows with no regard to environmental issues, and this is the main factor threatening the quality of Urmia's air in view of the quickly increasing population. In most months of the year, Mashhad has a great number of pilgrims. Thus, air pollution in this city is caused by the heavy traffic and increasing use of necessary fuels. Table 6 shows the number of times the SO_2 concentration of each city exceeds standard level in a 24-hour period and the comparison of SO_2 levels in these cities with the standard level.

Based on the results presented in Table 6, the city experiencing largest number of 24-hour periods that the SO_2 concentration was higher than that recommended by the WHO is Mashhad, where levels were higher 365 days. According to the National Quality Standards of the EPA (Environmental Production Agency) and the National Standard of Clean Air of Iran, the standard assigned to CO for an 8-hour average is 9 ppm. CO concentrations did not exceed this standard level in any of the studied cities. Based on indicators of estimated relative risk shown in Table 7, the highest death rate is related to respiratory mortality due to contact with SO_2 in Urmia. According to the results, the total number of respiratory deaths compared to all deaths in the study period for the 6 studied cities was 365 out of 10 641 persons per year. Based on indicators of estimated relative risk shown in Table 8, the highest number of deaths is related to cardiovascular mortality due to contact with CO in Isfahan. According to the results, the estimated number of cardiovascular cases resulting in death compared to all deaths in the 6 studied cities during the study period was 64 out of 6464 persons

Table 6. Comparison the average SO_2 concentration of 24 hours with guidelines and standards values in 6 metropolises

City	Guidelines and standards	Average 24-h	The No. of times that the SO_2 concentration of 24 h in each city is compared to a high standard
Mashhad	WHO Guidelines	20	365
	Iran national standard	100	0
	European standards	125	0
Tabriz	WHO Guidelines	20	128
	Iran national standard	100	1
	European standards	125	0
Isfahan	WHO Guidelines	20	267
	Iran national standard	100	17
	European standards	125	3
Shiraz	WHO Guidelines	20	153
	Iran national standard	100	0
	European standards	125	0
Tehran	WHO Guidelines	20	346
	Iran national standard	100	4
	European standards	125	0
Urmia	WHO Guidelines	20	351
	Iran national standard	100	109
	European standards	125	76

Table 7. Estimated attributable proportion expressed as percentage and number of excess cases in a year due to short-term exposure above 10 μg/m^3 for SO_2

Health endpoints	Study city	AP (uncertainty range)*	No. of excess cases (uncertainty range)
Total mortality	Mashhad	0.81 (0.61-0.997)	122 (92-146)
	Tabriz	0.46 (0.34-0.55)	37 (28-45)
	Isfahan	1.21 (0.92-1.45)	132 (99-158)
	Shiraz	0.55 (0.41-0.66)	44 (33-53)
	Tehran	1.52 (1.14-1.81)	744 (560-890)
	Urmia	2.19 (2.90-3.46)	107 (81-128)
Cardiovascular mortality	Mashhad	1.61 (0.40-2.40)	103 (26-153)
	Tabriz	0.91 (0.23-1.37)	32 (8-47)
	Isfahan	2.4 (0.61-3.56)	111 (28-164)
	Shiraz	1.10 (0.28-1.65)	37 (9-55)
	Tehran	2.99 (0.76-4.42)	623 (159-920)
	Urmia	5.64 (1.47-8.23)	89 (23-129)
Respiratory mortality	Mashhad	2.01 (1.22-2.8)	27 (16-38)
	Tabriz	1.14 (0.69-1.6)	8 (5-12)
	Isfahan	2.99 (1.8-4.13)	29 (18-40)
	Shiraz	1.38 (0.83-1.92)	10 (6-14)
	Tehran	3.72 (2.26-5.12)	162 (99-223)
	Urmia	6.95 (4.29-9.47)	23 (14-31)

Table 8. Estimated attributable proportion expressed as percentage and number of excess cases in a year due to short-term exposure above 10 μg/m^3 for CO

Health endpoints	Study city	AP (uncertainty range)	No. of excess cases (uncertainty range)
Cardiovascular mortality	Mashhad	0.68 (0.19-1.17)	9 (2-12)
	Tabriz	0.83 (0.24-1.42)	6 (2-10)
	Isfahan	2.15 (0.62-3.63)	14 (4-24)
	Shiraz	0.69 (0.19-1.17)	3 (1-5)
	Tehran	1.09 (0.31-1.86)	28 (8-48)
	Urmia	1.04 (0.3-1.77)	2 (1-4)

per year. According to the output charts obtained from the software, almost 50% of deaths attributed to contact with CO occurred in concentrations of less than 4 mg/m^3. The results from the AirQ software are shown in graph form in Figure 2. These figures show the cumulative excess cases of cardiovascular mortality due to CO concentration in the 6 studied cities in Iran: *a*) Mashhad; *b*) Tabriz; *c*) Isfahan; *d*) Shiraz; *e*) Urmia; *f*) Tehran.

Discussion

The results shown in Tables 4 and 5 indicate that the 2011 concentrations of SO_2 were 49, 31, 12, 11, 21, and 76 in Tehran, Mashhad, Isfahan, Shiraz, Tabriz, and Urmia, respectively. Those figures are 2.45, 1.55, 0.6, 0.55, 1.05, and 3.8 times higher than those set out in the WHO guidelines (20 μg/m^3). Therefore, the mean annual concentrations of SO_2 in Tehran, Mashhad, Tabriz, and Urmia were higher than the Iranian national standard and the EU standard, while it was reported as lower than the mentioned standards in Isfahan and Shiraz. As seen in Table 6, the mean annual concentration of SO_2 in Urmia was higher than the WHO standard for 96% of the days in a year. This rate was higher than the Iranian standard for 30% of days in a year (100 μg/m^3) and higher than the EU standard on 20% of days in a year (125 μg/m^3). In Tehran, the rates were 95% higher than the WHO standards, while it was only 2% higher than the Iranian standard and never exceeded the EU standard; this result indicates the deterioration of the situation of SO_2 in these cities. It should be noted that concentrations of SO_2 in Mashhad, Isfahan, Shiraz, and Tabriz were higher than the WHO standard on 100%, 73%, 42% and 35% of days in 2011, respectively. The results indicate that the status of SO_2 is critical in Urmia and Tehran. According to 2011 reports, there were about 300 cars for every 1000 individuals in Urmia; this rate is about 1.5 times the country's average (27). It seems that the high number of cars, the increased population, and the subsequent increased use of fossil fuels can be the causes for the increase in pollutants in the above-mentioned cities. On most days of the year in the studied cities, the distribution of the SO_2 concentration is in the range of 40-49 μg/m^3 in the studied cities. As seen in Figure 2, the highest percentage of exposure to the pollutant occurred in Shiraz, Isfahan, and Tabriz with concentration intervals of 10-19 μg/m^3, in Mashhad with 20-29 μg/m^3, in Urmia with 30-39 μg/m^3, and in Tehran with 40-49 μg/m^3. Based on these figures, it becomes clear that the largest number of mortalities from cardiovascular

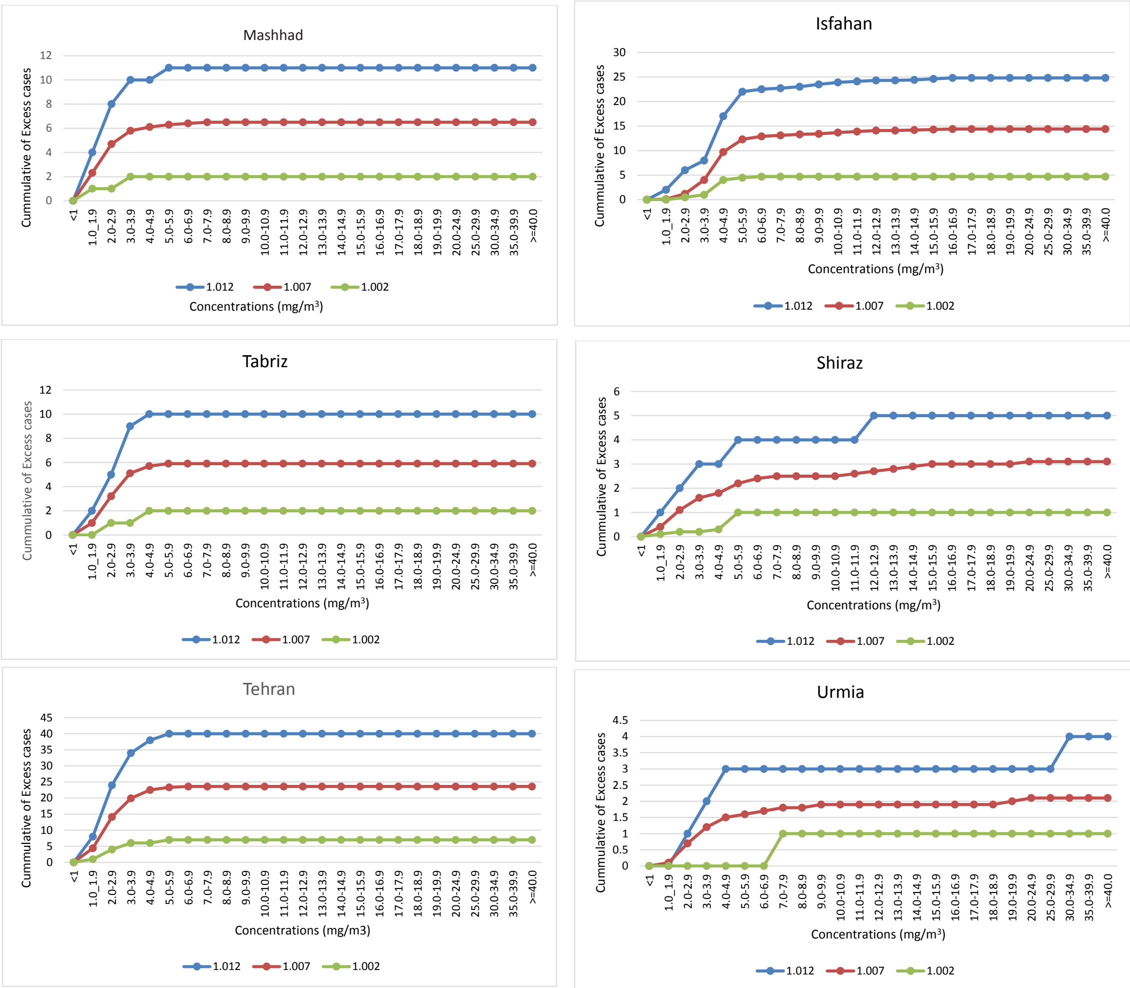

Figure 2. Cumulative of Excess cases for cardiovascular mortality of CO concentration in the six Iranian cities.

diseases have occurred at the same rate of concentration. In the case of CO, it was revealed that the concentration of the pollutant did not exceed the standard limits in any of the studied cities. According to Table 1 and considering RR and BI indices per 1000 population, the risk of cardiovascular deaths attributable to SO_2 and CO will increase 0.8% and 0.7% for each 10 μg/m³ concentration of SO_2 and 1 μg/m³ concentration of CO, respectively. Furthermore, it will increase the death rate 0.4% for each 10 μg/m³ increase in SO_2 concentration. In a study conducted in 8 cities of North America, it was found that per one unit of increase in concentration of carbon monoxide, a 2.79% increase in the number of cardiovascular patients was seen (28). As observed in Table 7, the cumulative total number of deaths attributed to SO_2 were 744, 122, 132, 44, 37, and 107 cases in Tehran, Mashhad, Isfahan, Shiraz, Tabriz, and Urmia, respectively. The results suggest that among the six studied metropolises, air pollution has caused the highest mortality rates in Urmia (about 2.19%) and Tehran (about 1.52%) and the lowest rate in Tabriz (0.46%). As is evident in Table 8, the cumulative numbers of cardiovascular deaths attributed to CO were 24, 7, 14, 3, 6, and 2 individuals in Tehran, Mashhad, Isfahan, Shiraz, Tabriz, and Urmia, respectively. The results suggest that among the six studied metropolises, air pollution caused the highest mortality rate in Isfahan (about 2.15%) and the lowest in Mashhad (0.68%). In a study examining 15 cities in Italy during the years 1996 to 2000, it was observed that the mortality rate caused by cardiovascular diseases increased with coefficients of 0.4%, 0.93%, 1.11%, and 0.54% in the concentration of NO_2, CO, SO_2 and PM_{10}, respectively (29). According to Figure 2, the largest and smallest cumulative numbers of deaths due to cardiovascular disease were 5.64% in Urmia and 0.9% in Tabriz for SO_2. For CO, the largest cumulative number was 2.15% in Isfahan. In a study carried out in Tucson (US) air pollutants, particles and carbon monoxide had significant and strong relationships with the referral rate of cardiovascular patients with coefficients of 2.75% and 2.79%, respectively, whereas other pollutants such as SO2, NO2, and O3 had weaker relationships with the referral rate of cardiovascular patients with coefficients of 0.14%, 0.69%, and 0.54%, respectively.

Conclusion

The current study, like other similar studies (30-41), showed that air pollution has a health effect on people. The results showed that in all calculated results attributed to SO_2, Tabriz had the lowest morality rate, while Tehran and Urmia had the highest mortality rates attributable to SO_2. Since the concentration of CO was not higher than the standard levels in the surveyed cities, the number of deaths from heart disease attributable to this pollutant was not high, while examination of the relationship between pollutant concentration and the number of deaths indicated that with increases in concentration, the number of deaths also increased. In general, statistics associated with the cumulative number of all deaths from cardiovascular disease extracted from the software clearly reflect the impacts of air pollution on human health. Thus, correct and effective planning is obviously required to control and reduce the harmful effects of air pollutants, especially SO_2 and CO. Thus, the adoption of effective methods to improve the quality of air and reduce the number of people exposed to air pollution should be considered by politicians.

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Ethical issues

The authors certify that all data collected during the study is presented in this manuscript, and no data from the study has been or will be published separately.

Competing interests

The authors hereby declare that in conducting this study, they had no competing interests.

Authors' contributions

All the authors contributed and participated equally in the collection, analysis, and interpretation of the data in this study. All authors critically reviewed, refined, and approved the manuscript.

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