Original Article

Health risks caused by exposure to sulfur dioxide in the ambient air of three main cities of South Western of Iran during 2011

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ABSTRACT

Aims: In this study, the health impacts of SO2 in three cities, including Ahvaz, Kermanshah and Boushehr was quantified and compared based on modeling using data from Department of Environment (DoE) in 2011.

Materials and Methods: Required data were collected from DoE and Meteorological Organization. Later, data were processed by Excel software and entered into AirQ Model; this model is identified by the World Health Organization. The processes include: Correction of temperature and pressure, matching the unit with the model.

Results: Results from three study areas showed that SO_2 concentration in Kermanshah city with the annual average of 103 $\mu g/m^3$ and in Boushehr city with 44 $\mu g/m^3$ was the highest and lowest in 2011, respectively. In all three cities, 8% and 1% increase in risk of cardiovascular and respiratory mortality was observed, respectively, per 10 $\mu g/m^3$ increased in concentration of SO_2.

Conclusion: About 60% of cardiovascular deaths attributed to SO_2 in ambient air of Ahvaz occurred in days with pollutant not exceeding 90 $\mu g/m^3$, whereas 46% and 41% of this health end point occurred in days with sulfur dioxide concentration not exceeding 190 $\mu g/m^3$ and 100 $\mu g/m^3$ in ambient air of Kermanshah and Boushehr, respectively. In comparison, Kermanshah and Boushehr were the highest and lowest in view of cardiovascular and respiratory mortality attributed to SO_2 concentration in 2011, respectively.

Key words: Ahvaz, Boushehr, cardiovascular mortality, Kermanshah, respiratory mortality, sulfur dioxide

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INTRODUCTION

According to World Health Organization (WHO), 800,000 people die prematurely due to cardiovascular and respiratory diseases and lung cancer resulting from air pollution throughout the world every year. Nearly, 150,000 of these deaths occur in South Asia.[1,2] Models estimating health impacts are often of statistical-epidemiological type, which combine air quality data in concentration intervals with

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epidemiological parameters such as relative risk (RR), baseline incidence (BI) and attributed proportion and display output in the form of the death toll.[3] >80% of sulfur dioxide in the air is mainly caused by fossil fuels consumption by human of which about 85% is from power plant and only 2% is caused by vehicles. SO_2 is a nonexplosive; colorless gas with a suffocating odor which reacts on the surface of many solids and air particles, and has twice the weight of air. It dissolves in water and rain droplets and eventually converts to sulfuric acid. Furthermore, it is estimated that SO_2 remains 2-4 days in the atmosphere. Some of the noncombustion sources for SO_2 production are oil refineries, copper melting plants and cement factories. The United States, Russia and China emit half of all man-made sulfur dioxide into the northern hemisphere atmosphere through the power plants. Di-methyl Sulfide produced by phytoplankton as the most important natural source and converting it to sulfur dioxide in the northern hemisphere atmosphere suggests a geographic split between man-made and natural sources of this pollutant on Earth.[4,5]

Health impacts of SO_2

Among the overall impacts of SO_2 we can pointed to the narrowing of the airways, bronchospasm, eye and respiratory tract irritation, reduced breathing efficiency and shortness of breath (dyspnea), shallow breathing, decreased lung defenses, and ultimately worsen the cardiovascular and respiratory side effects. Exposure of some asthmatics to SO_2 concentration of 1-5 ppm for 10 min leads to specific symptoms of shortness of breath, which will require the treatment bronchodilatasion. Exposure to 0.5-1 ppm of SO_2 for 10 min can cause difficulty in breathing. However, no pulmonary symptoms were observed in concentration of 0.3 ppm of SO_2 for 120 min.[6] Studies conducted at the University of Arizona on blood showed that amount of DNA is reduced by SO_2 and changes have occurred in chromosomes. It also found that lymphocytes are destroyed and body's resistance to infectious diseases is reduced.[7] The WHO air quality guideline values for sulfur dioxide as the average of 24-h (daily) is given 20 $\mu g/m^3$.[8] Ahvaz, Kermanshah and Boushehr cities with a population of approximately 969,843, 843,117, and 181,674 people, respectively, are located in southwest of Iran, and currently considered as Iran's industrial centers and as a result they are among most polluted cities in Iran. The main objective of this study was to estimate health effects of sulfur dioxide as an air pollutant in three main city of southwestern of Iran.

MATERIALS AND METHODS

This study encompasses three cities in Iran. Ahvaz, capital city of Khuzestan province, with approximately one million people is located in south west of Iran. It has encountered many environmental concerns such as drinking water salinity, failure in wastewater collection system as well as air pollution due to existing many industries and factories inside the city. Kermanshah is located in the west of Iran with a population of 850,000 persons, approximately. Bushehr port in south of Iran play an important role in marine transportation through Persian Gulf. Air pollution data in these three cities were gathered by using Air Quality Monitoring Networks which are established by Department of Environment (DoE). Measured concentration of SO_2 as hourly interval at all stations was used to estimate health outcomes during 2011. Air Quality Health Impact Assessment (AirQ 2.2.3) model developed by WHO European Centre for Environment Health, Bilthoven Division. Air pollution modeling studies are categorized into four most common types of models. They are physical, Gaussian, numerical and statistical models. Epidemiologists and environmentalists use statistical methods to determine whether the differences they see are real or due to chance fluctuations. In general, epidemiologic indices reflect the likelihood that someone will get a particular disease if exposed to a particular risk factor compared to the likelihood of getting the disease without the exposure.[9-11] RR can be calculated by cohort study, but here we applied AirQ software for estimating health effects of sulfur dioxide as an air pollutant.

In this study, we quantified and compared the health impacts of SO_2 in three cities; Ahvaz, Kermanshah and Boushehr based on modeling using data from DoE in 2011. Thus, the raw data were collected from the DoE and the Meteorological organization at the first stage, in the next stage; the data were processed by Microsoft Office Excel 2007 and then entered into the AirQ Model. This model is identified by the WHO as a valid and reliable tool to estimate the short-term impacts of air pollutants.

Determine the health impact based on the hypothesis of the relative risk attributed to the SO_2 pollutant

Attributable proportion (AP) is part of health outcomes that may be related to exposure of a specific population (given the relationship between exposure and health outcomes without major confounding effect on the relationship) during a specific time period. It can be calculated using the following formula:

$$AP = SUM([RR(c) - 1] \times p(c))/SUM(RR[c] \times p[c])$$

Where,

RR(c) is RR of health outcome in the group (c) or considered group;

P(c) is population ratio of group (c) or considered group;

The RR of selective health outcome can be obtained using the exposure-response functions.

$$RR = \frac{\text{Probability of event when exposed}}{\text{Probability of event when non-exposed}}$$

Knowing the BI of selective health outcomes (I) in the target population, the amount attributable to population exposure (or number of cases per unit) (IE) can be calculated as follows:

$$IE = I \times AP$$

In a population with the size of N, this amount can be transformed into the estimated number of cases attributable to exposure (NE):

$$N \times NE = IE$$

The user can use of local statistics instead determining the amount of BI of health outcomes. Consequently, the amount of the incidence of outcomes in a population that is not exposed (INE) can be estimated:

$$INE = I - IE - 1 \times (1 - AP)$$

In addition to all attributed cases, the distribution of the number of attributed cases can be estimated in terms of concentration intervals of the pollutant. Knowing the RR in a certain level of the pollutant concentration and the incidence in nonexposed population, the additional incidence (I+ (c)) and the number of additional cases (N+ (c)) in an exposed group (c) will be calculated from following relationships.

$$I + (c) = (RR\,[c - 1])\,P\,(c) \times INE$$

All the above formulas are based on the assumption that the estimates used in the analysis has been controlled in terms of all possible confounding effects. We can obtain upper and lower limits of estimation of the AP and the range of the number of the expected attributable exposure by placing confidence intervals (CIs) of RR into the formula. In practice, however, uncertainty of the effects (and the range of estimated effects) is larger due to errors in exposure assessment and nonstatistical uncertainties of the concentration-response function.

Study areas

Ahvaz city

Ahvaz city, the capital of Khuzestan province (southwestern Iran), with an area of 8152 km^2 is located between 48° to 49° and 29′ E and between 30° to 32°and 45′ N. Its height from sea level is 22.5 m. It has a semi-humid and hot climate.[12]

Kermanshah city

This city, the capital of Kermanshah province (western Iran) is located on 47° and 4′ E and 19° and 34′ N.[13] Its climate is semi-arid and cold steppe (temperate mountainous). Its physiographic is plain-foothill. Its height from sea level is 1200 m.

Boushehr city

Boushehr port is the center of Boushehr province. Its area is 1441 km^2 and is located between 71° and 83° and 50′ E and between 76° and 95° and 28′ N according Figure 1.[14]

The procedures are as follows

Data collecting: Data related to SO_2 in 2011 were obtained from Ahvaz, Boushehr and Kermanshah DoE in the form of Excel file.

Preparation of the model input file from raw data: To create this file, following steps were conducted, including: Correction of temperature and pressure, matching the unit with the model, primary processing, secondary processing, coding, calculating daily average based on coding, condition modifying, primary filtering and secondary filtering.

RESULTS AND FINDINGS

SO_2 concentration in three study areas (Ahvaz, Boushehr and Kermanshah)

Mean and maximum of SO_2 as μg/m^{3}in two seasons and annual in 2011 shown in Table 1. The concentration of SO_2 in three cities showed that SO_2 concentration in Kermanshah and Boushehr with the annual average of 103 μg/m^3 and 44 μg/m^3 in 2011 was highest and lowest, respectively. The number of cardiovascular mortality cases attributed

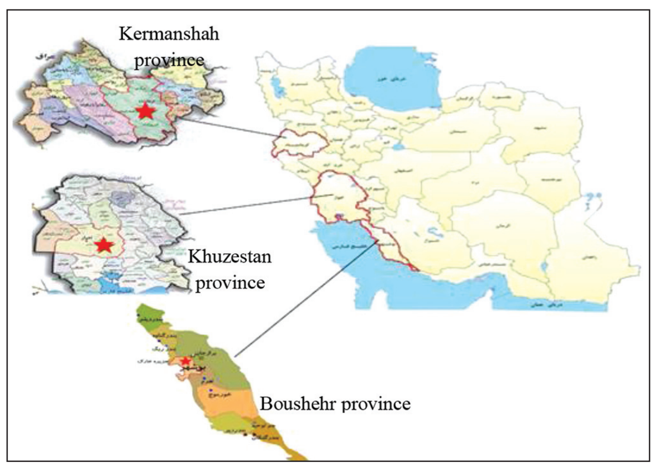

Figure 1: Study areas locations

Table 1: SO_2 concentration in μg/m^3 for using in the model (Ahvaz, Boushehr and Kermanshah-2011)

Parameter (SO_2)	Boushehr city	Kermanshah city	Ahvaz city
Annual average	44.10	103.02	56.30
Summer average	36.51	46.64	39.19
Winter average	51.99	161.60	74.09
Annual 98 percentile	106.28	401.17	142.66
Annual maximum	163.74	625.18	210.09
Summer maximum	137.17	157.10	114.33
Winter maximum	163.74	625.18	210.09

to SO_2 according to Table 2 in BI of 497/100,000 persons was approximately 173 persons in Ahvaz in 2011, while it was approximately 295 and 24 persons in Kermanshah and Boushehr in 2011, respectively.

According to Table 2 the percentage of attributed proportion consistent with three estimated limits of RR, cumulative number of respiratory death cases in Ahvaz city was 28 persons (17 persons in RR = 1.006 and 39 persons in RR = 1.014). Cumulative number of respiratory death cases in Kermanshah city in 2011 was 48 person (30 persons in RR = 1.006 and 65 persons in RR = 1.014). According to the percentage of AP consistent with three estimated limits of RR, cumulative number of respiratory death cases in Boushehr city in 2011 was 4 persons (2 persons in RR = 1.006 and 5 persons in RR = 1.014) [See Table 3].

Results of quantifying (displaying the number of outcomes against pollutant concentration for limits of relative risk) in studied cities (Ahvaz, Boushehr and Kermanshah-2011)

Figures 2 and 3 according to cumulative numbers of a health outcome affected by related pollutant concentration in quantifying discussion are drawn and displayed as follow. There are three curves in each figure, which are corresponding to central RR attributable to SO_2 for each side-effect.

Figure 2 shows that the rising rate of the mortality resulted from cardiovascular diseases in Ahvaz with increased in SO_2

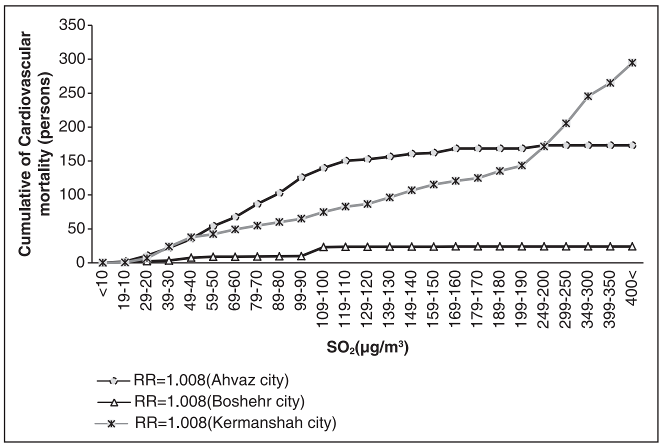

Figure 2: Cumulative number of mortality of cardiovascular death cases due to SO_2 against concentration intervals (Ahvaz, Boushehr and Kermanshah-2011)

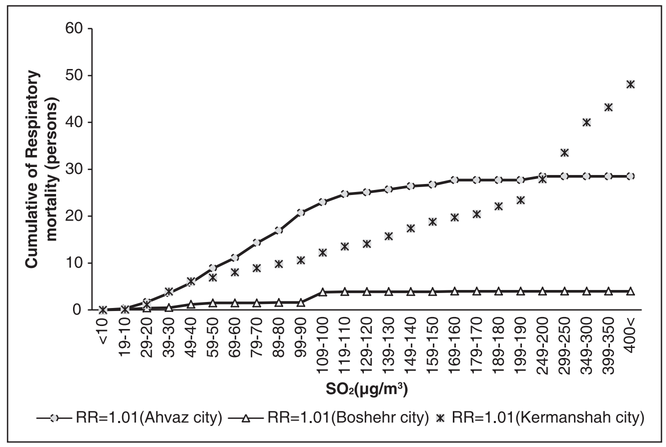

Figure 3: Cumulative number of mortality of respiratory death cases due to SO_2 against concentration intervals (Ahvaz, Boushehr and Kermanshah-2011)

Table 2: Estimation of indices for relative risk, attributable proportion and attributed cases to SO_2 for mortality caused by cardiovascular diseases in Ahvaz-2011 (BI=497*)

Index estimation	Relative risk (Ahvaz-2011)	Attributable proportion percentage (Ahvaz-2011)	Cumulative number of cases (person) (Ahvaz-2011)	Attributable proportion percentage (Kermanshah-2011)	Cumulative number of cases (person) (Kermanshah-2011)	Attributable proportion percentage (Boushehr-2011)	Cumulative number of cases (person) (Boushehr-2011)
Low	1.002 (CI=0/05)	0.9234	44.5	1.8572	77.8	0.6846	6.2
Middle	1.008	3.5942	173.1	7.0367	294.8	2.6832	24.1
High	1.012 (CI=0/95)	5.2962	255.1	10.1963	427.2	3.9715	35.7

*Baseline Incidence is a value representing a normal background level or an initial level of a measurable quantity and used for comparison with values representing response to an environmental stimulus or intervention. CI: Confidence interval

Table 3: Estimation of indices for relative risk, attributable proportion and attributed cases to SO_2 for mortality caused by respiratory diseases in Ahvaz-2011 (BI=66*)

Index estimation	Relative risk	Attributable proportion percentage (Ahvaz-2011)	Cumulative number of cases (person) (Ahvaz-2011)	Attributable proportion percentage (Kermanshah-2011)	Cumulative number of cases (person) (Kermanshah-2011)	Attributable proportion percentage (Boushehr-2011)	Cumulative number of cases (person) (Boushehr-2011)
Low	1.006 (CI=0/05)	2.7201	17.4	5.3720	29.9	2.0260	2.4
Middle	1.01	4.4528	28.5	8.6438	48.1	3.3316	4.0
High	1.014 (CI=0/95)	6.1248	39.2	11.6969	65.1	4.6029	5.5

*Baseline Incidence is a value representing a normal background level or an initial level of a measurable quantity and used for comparison with values representing response to an environmental stimulus or intervention. CI: Confidence interval in concentrations of 20-80 μg/m³ is of a steady trend and in concentrations >90 μg/m³ it suddenly increases and in concentrations >120 μg/m³ it increases in a steady manner, again. In Kermanshah city, the rising rate of the mortality caused by cardiovascular diseases with increased in SO_2 in concentrations of 30-190 μg/m³ has a steady manner and in concentrations >200 μg/m³ it suddenly increases and in concentrations >350 μg/m³ it again increases in a steady manner. In Boushehr city, the rising rate of the mortality caused by cardiovascular diseases with increased in SO_2 in concentrations of 10-30 μg/m³ has a steady trend and in concentrations from 40 to 50 μg/m³ it suddenly increases and in concentrations from 100 to 110 μg/m³ it again suddenly increases and in concentrations >110 μg/m³ it is constant.

Figure 3 shows that the rising rate of the mortality resulted from respiratory diseases in Ahvaz with increased in SO_2 in concentrations from 10 to 50 μg/m³ is of a steady trend and in concentrations >50 μg/m³ it suddenly increases and in concentrations >110 μg/m³ it increases in a steady trend, again. Furthermore, in Kermanshah city, the rising rate of the mortality caused by respiratory diseases with increased in SO_2 in concentrations from 30 to 190 μg/m³ has a steady manner and in concentrations >200 μg/m³ it suddenly increases and in concentrations >350 μg/m³ it again increases in a steady trend. In Boushehr city, the rising rate of the mortality caused by respiratory diseases with increased in SO_2 in concentrations of 10-30 μg/m³ has a steady trend and in concentrations from 40 to 50 μg/m³ it suddenly increases and in concentrations from 100 to 110 μg/m³ it again suddenly increases and in concentrations >110 μg/m³ it is constant.

Interpretation of quantifying the health impact of SO_2

Quantifying the health impact of SO_2 in Ahvaz city

Results showed that in Ahvaz city, the number of cardiovascular death cases attributable to SO_2 in BI of 497/100,000 persons is estimated approximately 173 persons (that is an increase of 16 persons over year 2010, i.e., 0.3% increase) [Table 2]. Risk of cardiovascular death increases 8% with every 10 μg/m³ increased in SO_2 concentration. Steep slope corresponding to increase in cardiovascular death cases in concentration range from 90 to 100 μg/m³ of SO_2 is well visible in Figure 2 in RR = 1.008. It is worth noting that 60% of cardiac death cases attributable to SO_2 were occurred in days in which the concentration of SO_2 doesn't exceed 90 μg/m³. RR of estimated middle limit with low certainty equal to 4.45 (2.72 in CI = 0.05 and 6.12 in CI = 0.95) means a percent increase in respiratory death risk with every 10 μg/m³ increase in SO_2 concentration. Respiratory death estimated in year 2011 attributed to SO_2 in Ahvaz city is 28 persons that shows a 0.42% (approximately equal to 2 persons) increase over year 2010. Although the RR of this health endpoint is higher than that of cardiovascular death, reduction in cumulative number of this health consequence compared with cardiovascular death is not unexpected due to the low BI for respiratory deaths.

Quantifying the health impact of SO_2 in Kermanshah city

The number of cardiovascular death cases attributable to SO_2 in BI = 497/100,000 persons is estimated approximately 295 persons in Kermanshah city in 2011. Risk of cardiovascular death increases 8% with every 10 μg/m³ increased in SO_2 concentration. Steep slope corresponding to increase in cardiovascular death cases in concentration range from 300 to 350 μg/m³ of SO_2 is well visible in Figure 2 in RR = 1.008. It is worth noting that 46% of cardiac death cases were occurred in days in which the concentration of SO_2 doesn't exceed 190 μg/m³. RR of estimated middle limit with low certainty equal to 8.64 (5.37 in CI = 0.05 and 11.69 in CI = 0.95) means a percent increase in respiratory death risk with every 10 μg/m³ increase in SO_2 concentration. Respiratory death estimated in year 2011 attributed to SO_2 in Kermanshah city is 48 persons. As observed from [Figure 3 and Table3], there is a sudden increase in slope (jump) in RR in concentration range 300-350 μg/m³.

Quantifying the health impact of SO_2 in Boushehr city

The number of cardiovascular death cases attributable to SO_2 in BI = 497/100,000 persons is estimated approximately 24 persons in Boushehr city. Risk of cardiovascular death increases 8% with every 10 μg/m³ increased in SO_2 concentration. Steep slope corresponding to increase in cardiovascular death cases in concentration range from 100 to 110 μg/m³ of SO_2 is well visible in Figure 2 in RR = 1.008; that is consistent with increase in percentage of person-exposure day in this concentrate range. It is worth noting that 41% of cardiac death cases attributable to SO_2 were occurred in days in which the concentration of SO_2 doesn't exceed 100 μg/m³. RR of estimated middle limit with low certainty equal to 3.33 (2.02 in CI = 0.05 and 4.60 in CI = 0.95) means a percent increase in respiratory death risk with every 10 μg/m³ increase in SO_2 concentration. Respiratory death estimated in year 2011 attributed to SO_2 in Boushehr city is 4 persons [Table 3]. As observed in Figure 3, there is a sudden increase in slope in RR in concentration range 100-110 μg/m³.

DISCUSSION

Results from three cities showed that SO_2 concentration in Kermanshah and Boushehr with the annual average of 103 μg/m³ and 44 μg/m³ in 2011 was highest and lowest, respectively, which can be due to further fossil fuel consumption and more heating appliances used in Kermanshah compared with Ahvaz and Boushehr. Furthermore, studies showed that SO_2 concentration in winter is higher than summer, because of increasing in fossil fuel consumption in winter compared to summer. It should be noted that existing PM_{10} with sulfur dioxide simultaneously can exacerbate health of citizens. Studies in 29 European cities, 20 American cities and some cities of the Asian countries, represent the fact that the hygienic effects related to the short-term contact with PM_{10} appear to be identical in the different cities of the developed countries and developing ones, furthermore, in lieu of each

10 μg/m³ increase of daily PM_{10} concentration the rate of death risk rises up to 5%. Thus, 150 μg/m³ concentrations are interpreted as 0.5% increase of daily death toll.[15,16] The AirQ software has been used by other investigators to evaluate the human health impact of various pollutants in the world. For example in Tehran the annual mean of PM_{10}, SO_2, NO_2 and O_3 was 90.58, 89.16, 85 and 68.82 μg/m³, respectively. PM_{10} had the highest health impact on the 8,700,000 inhabitants of Tehran city, causing an excess of total mortality of 2194 out of 47,284 in a year. Sulfur dioxide, nitrogen dioxide and ozone caused about, respectively, 1458, 1050 and 819 excess cases of total mortality.[11] In Ahvaz Sum of accumulative cases of mortalities attributed to ozone was 358 cases in 2010 and 276 cases in 2011. Cardiovascular and respiratory mortality attributed to ozone were 118 and 31 persons, respectively; which revealed a considerable reduction compared to those values in 2010. Number of cases for hospital admissions due to Chronic Obstructive Pulmonary Disease (COPD) was 35 in 2011, while it was 45 cases in 2010.[17]

By adopting the WHO guideline concentrations for the air pollutants SO_2, NO_2 and total suspended particles (TSP), concentration-response relationships and a population attributable-risk proportion concept are employed. Results suggest that some megacities such as Los Angeles, New York, Osaka Kobe, Sao Paulo and Tokyo have very low excess cases in total mortality from these pollutants. In contrast, the approximate numbers of cases is highest in Karachi (15,000/year) characterized by a very high concentration of total TSP (670 μg/m³). Dhaka (7000/year), Beijing (5500/year), Karachi (5200/year), Cairo (5000/year) and Delhi (3500/year) rank highest with cardiovascular mortality. The morbidity (hospital admissions) due to COPD follows the tendency of cardiovascular mortality.[18]

Mohammadi *et al*. (2011) suggested that in Ahvaz city, out of total mortalities in 2010, 3.25% (157 persons) were due to cardiac death attributed to SO_2 and 4.03% (26 persons) were caused by respiratory death attributed to SO_2, and estimated COPD attributed to SO_2 equal to 18 persons with AP 1.81%.[19] In an investigation in Tehran in year 2008, Goudarzi *et al*. (2008) estimated APs for attributed cardiac deaths (6.35%), for attributed respiratory deaths (7.82%) and for attributed COPD (3.60%) in SO_2 concentration above 10 μg/m³.[20] Thus, of total mortalities in year 2011 in three studied cities, 7.03% were due to cardiac death attributed to SO_2 and 8.64% were due to respiratory death attributed to SO_2 in Kermanshah. In Ahvaz city, out of total mortalities in 2011, 3.5% were due to cardiac death attributed to SO_2 and 4.4% were due to respiratory death attributed to SO_2. In Boushehr city, 2.68% of total mortalities in 2011 were due to cardiac death attributed to SO_2 and 3.33% were due to respiratory death attributed to SO_2. Comparison of three studied area shows that Kermanshah city and Boushehr city had highest and lowest cardiopulmonary death cases attributed to SO_2 in 2011, respectively, and it can be justified by high concentration of SO_2 in Kermanshah city. For all cities in this study, RRs of SO_2 attributed to cardiovascular deaths at upper, central and lower limits were 1.012, 1.008 and 1.002, respectively. AP percentages of cardiovascular deaths in Ahvaz, Kermanshah, and Boushehr were 3.5, 7.03 and 2.68, respectively. For all cities in the present study, RRs of respiratory deaths attributed to SO_2 at upper, central and lower limits were 1.014, 1.01 and 1.006, respectively. AP percentages of respiratory deaths in Ahvaz, Kermanshah, and Boushehr were 4.4, 8.6 and 3.3, respectively.

CONCLUSION

By considering central RR (1.008) and BI = 497/10⁵, health effects attributed to SO_2 in term of cardiovascular mortalities in 2011 were 175, 295 and 24 persons in Ahvaz, Kermanshah and Boushehr, respectively. At the same concentration of SO_2 in 2011, respiratory mortalities (RR = 1.01 and BI = 66/10⁵) were estimated 28, 48 and 4 persons in Ahvaz, Kermanshah and Boushehr, respectively. As a result, the annual concentration of SO_2 in ambient air of Kermanshah was so high (103 μg/m³) and this was why we observed more individuals in Kermanshah whether in terms of cardiovascular or respiratory mortality than in Ahvaz and Boushehr based on AirQ model in 2011.

Limitations of study

The outputs of thisstudy in terms of cardiovascular and respiratory deaths were obtained on basis of BI and RR, which were extracted from model defaults. We recommend checking the response of model according to regional, national and local values of these epidemiological indices.

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