Environmental Research 156 (2017) 683–687

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Acute myocardial infarction and COPD attributed to ambient SO2 in Iran

Yusef Omidi Khaniabadi[a], Seyed Mohammad Daryanoosh[b], Philip K. Hopke[c,d], Margherita Ferrante[e,*], Alessandra De Marco[f], Pierre Sicard[g], Gea Oliveri Conti[e], Gholamreza Goudarzi[h], Hassan Basiri[i], Mohammad Javad Mohammadi[j], Fariba Keishams[k]

[a] Health Care System of Karoon, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[b] Health Center of Hendijan, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[c] Center for Air Resources Engineering and Science, Clarkson University, Potsdam, NY 13699, USA
[d] Department of Public Health Sciences, University of Rochester School of Medicine and Dentistry, Rochester, NY 14619, USA
[e] Environmental and Food Hygiene Laboratories (LIAA) of Department of Medical Sciences, Surgical and Advanced Technologies "G.F. Ingrassia", Hygiene and Public Health. University of Catania, Italy
[f] Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Lungotevere Thaon de Revel, Rome, Italy
[g] ACRI-HE, route du Pin Montard, Sophia Antipolis, France
[h] Air Pollution and Respiratory Diseases Research Center, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran
[i] Department of Environmental Health Engineering, School of Health, Lorestan University of Medical Sciences, Khorramabad, Iran
[j] Abadan School of Medical Sciences, Abadan, Iran
[k] Department of Environmental Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran

A R T I C L E I N F O

Keywords:
Myocardial Infarction
COPD
SO_2
Relative Risk
AirQ software

A B S T R A C T

Acute myocardial infarction (MI) and chronic obstructive pulmonary disease (COPD) are important diseases worldwide. Inhalation is the major route of short-term exposure to air sulfur dioxide (SO_2) that negatively affect human health. The objective of this study was to estimate the health effects of short-term exposure to SO_2 in Khorramabad, Iran using the AirQ software developed by the World Health Organization (WHO). Daily mean SO_2 concentrations were used as the estimates of human short-term exposure and allow calculation of the attributable excess relative risk of an acute MI and hospital admissions due to COPD (HACOPD). The annual mean SO_2 concentration in Khorramabad was 51.33 μg/m^3. Based on the relative risk (RR) and baseline incidence (BI) approach of WHO, an increased risk of 2.7% (95% CI: 1.1–4.2%) of acute MI and 2.0% (95% CI: 0–4.6%) of HACOPD, respectively, were attributed to a 10 μg/m^3 SO_2 increase. Since the geographic, demographic, and climatic characteristics are different from the areas in which the risk relationships were developed and not evaluated here, further investigations will be needed to fully quantify other health impacts of SO_2. A decreased risk for MIs and COPD attributable to SO_2 could be achieved if mitigation strategies and measures are implemented to reduce the exposure.

1. Introduction

Urban air pollution is characterized by presence of more than 200 pollutants or classes of pollutants with varying risks of adverse outcomes for the exposed individuals (Sicard et al., 2011; Oliveri Conti et al., 2017a). Extensive research has demonstrated the associations between short-term exposure to the air pollutants (e.g., ozone, sulfur dioxide, pollens and particulate matter) and adverse respiratory and cardiovascular diseases and mortality (Miri et al., 2016; Sicard et al., 2012; Dehghani et al., 2017). Health, life expectancy, and welfare effects will occur if air pollution decreases. According to the World Health Organization about 7 million deaths occurs per year in the world due to air pollution (WHO, 2011, 2013). Among the common air pollutants, sulfur dioxide (SO_2) is a colorless gas, non-explosive, pungent, soluble in water and rain droplets, acid odor and taste and, producing irritation. It has many emission sources and it is mainly produced by combustion of sulfur-containing fossil fuels such as coal and petroleum (about 80%) and, as by-product of non-ferrous metal smelting and converting processes (Zallaghi et al., 2015).

Road traffic is the dominant source of SO_2 in urban zones. Although air quality has improved in recent years, increasing road traffic remains an issue. There are serious fuel quality issues in Iran with Iran-made gasoline with SO_2 averaging from 180 to 1000 ppm (ppm), while diesel fuel ranging between from 7000 to 8000 ppm (Khatinoglu, 2013). In

* Corresponding author.
E-mail address: marfer@unict.it (M. Ferrante).

http://dx.doi.org/10.1016/j.envres.2017.04.028
Received 27 December 2016; Received in revised form 15 April 2017; Accepted 21 April 2017

western countries instead, the energy production and distribution and energy use in industry represent the dominant sources of SO_2 for 58% and 20% of total emissions respectively (EEA, 2015).

A range of chronic and acute health impacts may result from human exposure to SO_2 or related species (Rosenlund et al., 2006; Sicard et al., 2011; Ghozikali et al., 2016). In a gaseous form, SO_2 can irritate the respiratory system, in case of short-term high exposure, a reversible effect on lung functioning may occur, according to individual sensitivity (WHO, 2000). SO_2 can cause mainly reduction of visibility, several respiratory problems, cardiopulmonary diseases and chronic obstructive pulmonary diseases (COPD) with an increase of related mortality (Naddafi et al., 2012; Rahila and Siddiqui, 2014). Some epidemiological studies have ascribed to the outdoor air pollution a correlation to cardiovascular diseases, especially with the myocardial infarction (EPA, 2016). Acute myocardial infarction (MI) is a typical severe disease with severe outcomes that cause many deaths and increases the costs of population health (Goudarzi et al., 2014, 2017; Khaefi et al., 2017). Most of the epidemiological studies have focused on the impacts of SO_2 using the hospital admission due to respiratory illness and on pulmonary function for its health impact assessment (Barnett et al., 2006). Several studies illustrated that COPD influences 329 million people or nearly 4.4% of the entire world population. It ranked as the fourth cause of death killing more than 3 million people only in 2011 (WHO, 2013). A better quantification of the impacts of SO_2 short-term exposure in terms of public health, i.e. risk assessment, has an important policy implication to define proper local, regional or global policies to decrease the extent of SO_2 pollution. The aim of this study was to evaluate the short-term effects of SO_2 concentrations on the MI and hospital admissions due to COPD in Iranian Khorramabad City during the 2014–2015 year using WHO's AirQ software.

2. Materials and methods

2.1. Study area

Khorramabad, is located in the southwestern of Iran. Khorramabad is the capital city of Lorestan province (Fig. 1). This city is enclosed by Zagros Mountains at an altitude of about 1170 m above sea level. Based on the latest census report by Iran's Statistical Center on 2014, the population of Khorramabad is 540,000 inhabitants. During the recent years, due to the growth of urban vehicular traffic and increase of new heavy industries such as fuels refinery, the outdoor air pollutants levels are increasing continually (Mirhosseini et al., 2013).

2.2. AirQ software

In this study we applied the approach developed by the World Health Organization (WHO) for assessing the health impacts of air pollution by applying the Air Quality Health Impact Assessment model (AirQ software 2.2.3) (Fattore et al., 2011; Omidi et al., 2016, Khaniabadi et al., 2017a,b,c; Nourmoradi et al., 2016). Air Q software is a tool developed to estimate the health endpoints of short-term exposure to air pollutants on a residential population in a given area who are exposed over one year (Oliveri Conti et al., 2017b). Quantifying the impacts of exposure to air pollution in terms of public health has become a critical component of air quality management policy discussions. In epidemiological studies, the relative risk (RR) value, for a given health endpoint, associated with a 10 $\mu g\, m^{-3}$ increase of air pollutant concentration, is obtained from the published exposure-response relative risk functions. The exposure-response relationship is defined in using a probability function for the occurrence of the specified health outcome with the assumption that there are no threshold concentrations that are safe for health (a risk-based approach).

The amounts of relative risk and baseline incidence (BI) per 100,000 inhabitants associated with acute MI and HACOPD have been illustrated in Table 1. The values of RR and related BI have been accepted from data files of the AirQ2.2.3 software based on various conducted peer-reviewed studies (Atkinson and Anderson, 1997; Burnett and Doles, 1997; Touloumi, 1997). To illustrate, regarding the acute MI and HACOPD, the results indicate that a 10 $\mu g\, m^{-3}$ change in SO_2 generates a relative risk of 1.0064 and 1.0044, respectively. Therefore,

Fig. 1. Location of Khorramabad in Iran's map.

Table 1
The average Relative risk per 10 μg/m^3 increase and 95% confidence intervals (95% CI), attributable proportion and number of persons suffering, per 100,000 inhabitants, from acute MI and HACOPD owing to SO_2 exposure (5% and 95% of confidence intervals).

Health effect	BI[a]	Estimated AP[b] (%)	Nb. of excess cases (person)	RR[c] (95% CI) per 10 μg/m^3
Acute MI[d]	132.0	2.73 (1.13–4.25)	20 (8–31)	1.0064 (1.0026–1.0101) (Goudarzi et al., 2014)
HACOPD[e]	101.4	1.90 (0–4.61)	11 (0–26)	1.0044 (1.000–1.011) (Ghozikali et al., 2016)

[a] Baseline incidence.
[b] Attributable proportion.
[c] Relative risk.
[d] Myocardial infarction.
[e] Hospital admissions due to chronic obstructive pulmonary disease.

the excess relative risk is of 0.64% and 0.44%, respectively. For example, at a 24 h averaged SO_2 concentration of 50 μg m^{-3}, the daily HACOPD relative risk is 1.022 i.e. an increased risk of 2.2% (RR_{SO2} = 1.0044). A relative risk of 1 indicates there is no increase in risk. The assessment is built on the attributable proportion (AP), defined as the fraction of the health effect in a certain population, attributable to specific air pollutant's short-term exposure. Therefore, AP can be calculated as Eq. (1):

$$AP = \sum([RR(c) - 1]*P(c)]) / \sum[RR(c)*P(c)] \quad (1)$$

where AP is the attributable proportion of the health effects, RR(c) is the relative risk values of SO_2 for a given health endpoint, in category "c" of exposure (e.g., residential or industrial). P(c) is the exposed group of the population (Fattore et al., 2011; Gurjar et al., 2010).

Relative risk (RR) is the attributable health risk associated with people who have defined exposures and can be calculated by means of Eq. (2):

$$RR = \frac{\text{Probability of a health effect when exposed to air pollution}}{\text{Probability of a health effect when not exposed}} \quad (2)$$

The rate attributable to the exposure can be estimated by following equation, if the baseline incidence of the health effect in the population under evaluation is determined.

$$IE = I*AP \quad (3)$$

where IE and I are the rate of the health impact attributable to the short-term exposure and the baseline incidence of the health effect in the inhabitants under study, respectively. If the population rate is known, the number of estimated excess cases associated with the exposure can be calculated by Eq. (4):

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

where NE is the number of excess cases attributed to the contact and N is the ~~rate~~ size of the population studied (in our case N was 540,000 inhabitants).

2.3. Exposure assessment

In this study, we used fixed air-monitoring stations located in Khorramabad according to Mirhosseini monitoring's description, The Khorramabad's Environmental Protection Agency (KEPA) was responsible for the measurement of SO_2 concentrations using Environ Tech model M200 continuous monitoring systems. One year of hourly SO_2 concentrations data (from 21st March 2014 to 21st March 2015) were obtained from KEPA. For each day when more than 75% of validated hourly data were available, 24-h mean concentrations were calculated. All data were collected on a basis of volumetric unit (ppm or ppb), while the model requires the concentrations on a gravimetric basis (μg/m^3). Thus, all the collected data were converted to gravimetric units for their use in the AirQ software. All the data were processed to convert the volumetric units to gravimetric units and, other processes including the averaging, coding, modification of pressure and temperature to standard conditions and data filtering were processed in Excel. The different parameters require for the modal (include annual and seasonal average, annual and seasonal maximum, and 98th percentile) were considered and concentration intervals of SO_2 were recorded into 10 μg/m^3 categories, corresponding to equivalent exposure categories. Exposure was assessed considering a residential population of 540,000 inhabitants in Khorramabad. Finally, the number of excess cases for acute MI and HACOPD were estimated for three ranges (lower, central and upper) of RR using AirQ 2.2.3 software.

3. Results

The annual mean SO_2 concentration in Khorramabad was 51.33 μg/m^3, which is below the National Ambient Air Quality Standard (NAAQS) value (80 μg/m^3). The summer mean (56.28 μg/m^3) is slightly higher than the winter mean (47.14 μg/m^3). The annual maximum was observed in summer (431 μg/m^3) while the winter maximum reached 302 μg/m^3. Table 1 shows the short-term health impacts through the estimated percentages of attributable proportion (AP) and the number of excess cases, per 100,000 inhabitants, attributable to the SO_2 exposure in Khorramabad. The minimum and maximum values were computed from the RR and BI at 5% and 95% of confidence intervals, respectively.

The measures of the health effect of acute MI and hospital admission for COPD by SO_2 exposure in Khorramabad are reported as 5%, 50%, and 95% relative risk, respectively. The cumulative numbers of excess cases of acute MI and HACOPD due to SO_2 exposure, based on RR5 = 1.0026 and 1.0, RR50 = 1.0064 and 1.0044, and RR95 = 1.0101 and 1.011 were 8 and 0, 20 and 11, and 31 and 26 persons, respectively. The number of excess cases for acute MI and HACOD for the average RR were 20 and 11 persons, respectively (Table 1). A cumulative number of 5.4 and 2.9 acute MI and HACOPD cases can be associated with exposure to SO_2 concentrations higher than 150 μg/m^3, respectively.

The findings showed that 96% of the health endpoints from SO_2 exposure occurred on days with the mean concentration exceeded 150 μg/m^3. In addition, 0.71% of health cases occurred when the daily mean concentration was lower than 20 μg/m^3.

The average RR and cumulative number of excess cases for acute MI and COPD was 20 and 11 persons, respectively (Table 1). The results showed that about 2.7% (95% CI: 1.1–4.2%) of acute MI and 2% (95% CI: 0–4.6%) of HACOPD were attributed to SO_2 levels over 10 μg/m^3, respectively (Table 1).

4. Discussion

With the increase in energy consumption, urbanization and with the rapid increase in the number of motor vehicles in recent years, the increase of outdoor air pollution is inevitable (Omidi et al., 2016). Health effects have been found to be associated with lower levels of SO_2 than previously reported (Angle et al., 2006; WHO, 2011). In our study, the numbers of acute MI and HACOPD due to short-term exposure to SO_2 have been estimated using AirQ2.2.3 model, a tool for the health impact assessment (HIA) of the air pollutants. Three ranges of relative risk (RR), including lower, central, and upper values were considered for each endpoint based on the AirQ model to assess the short-term exposure to SO_2. The cumulative numbers of acute MIs and HACOPD were estimated in relation to SO_2 concentrations in Khorramabad. Indicators of relative risk (RR) and the attributable proportion (AP) for acute MI and HACOPD to SO_2 are defined using baseline incidence (BI) values of 132 and 101.4 per 10^5 inhabitants.

In this study, we used the SO_2 values measured between 21st March 2014 and 21st March 2015. The annual mean, summer mean, winter mean, and 98 percentile values for SO_2 were 51.3, 56.3, 47.1, and 231.1 μg/m^3 in Khorramabad, Iran. The recorded concentrations were lower than observations made in Ahvaz, Iran where values of 160, 46, 173 and 171 μg/m^3, respectively, were measured during 2014 (Goudarzi et al., 2014). The annual maximum of SO_2 level was found to be in summer with a concentration of 431 μg/m^3 that was higher than winter (302.1 μg/m^3). In a similar study, the annual mean, summer mean, winter mean, annual maximum, winter maximum, and annual 98 percentile of SO_2 was 21, 15, 31, 116, 37, 116 and 71 μg/m^3 were found in Tabriz (Iran) over the period of 2001–2012 (Ghozikali et al., 2016). The National Ambient Air Quality Standard (NAAQS) annual mean SO_2 concentration is 80 μg/m^3. In this study, the annual mean SO_2 was lower than the standard.

A time-series studies of hospital admissions for cardiac diseases in Hong-Kong and London produced no evidence of a threshold for health impacts at 24-h SO_2 levels in the range of 5–40 μg/m^3 (Wong et al., 2002). In the American Cancer Society (ACS) study, a significant association between SO_2 and mortality was observed during 1928–1998, in which the mean SO_2 level was 18 μg/m^3, with the higher annual mean being 85 μg/m^3 (Pope et al., 2002). The researchers found a high risk of morbidity (i.e. hospital admissions) from acute MI associated with an increase in SO_2 concentration (Rahila and Siddiqui, 2014). The BIs for health outcomes of SO_2 were 132.0 and 101.4 per 10^5 inhabitants, so the total annual acute MI and HACOPD cases were estimated to be 20 (95% CI: 1.13 − 4.25) and 11 (95% CI: 0–4.61) for the central RR. In Ahvaz (Iran), based on an average RR of 1.0044, the number of hospital admissions for COPD was 24 in 2012 which 3.2% (95% CI) of HACOPD attributable to SO_2 concentrations higher than 10 μg/m^3 (Geravandi et al., 2015).

In Europe, the average RR values are 1.008 for the daily mortality for cardiovascular causes, and 1.010 for respiratory diseases per 10 μg m^{-3} change in SO_2. Regarding the daily hospital admissions, RR = 1.0018 and 1.004 for respiratory diseases (15–64 and more than 65 years old, respectively), RR = 1.015 and 1.0 for asthma exacerbation (less and more than 15 years old, respectively) and RR = 1.0044 for COPD (Sicard et al., 2011, 2012; WHO, 2001; WHO, 2008). In Detroit (USA), the health impact of air pollution was studied and the results showed that a 10 μg/m^3 increase in daily mean of SO_2, the number of hospital admissions increased by 2%, i.e. RR = 1.020 (Lippmann et al., 2000). In a similar study conducted in Tehran, capital of Iran in 2009, almost 3.6% of hospital admissions were attributed to SO_2 (Goudarzi, 2007). In Ahvaz (Iran), the number of acute MI associated with exposure to SO_2 was estimated at 37 persons (Goudarzi et al., 2014), which are lower than the present study. These results are due to lower registered levels of SO_2 and difference in the geographic, demographic, and climate characteristics of Khorramabad compared to Tehran and Ahvaz (two megacities in Iran with 8.5 and 1.2 million of inhabitants, respectively). An Italian study, based on data from 6 Italian cities, showed that the increase in the diurnal average pollutant levels of 10 μg/m^3 of SO_2 is linked to 2.8% increase in cardiovascular diseases (Biggeri et al., 2001). A study conducted in Valencia (Spain) has demonstrated that a 10 μg/m^3 increase in daily SO_2 mean led to an increase of 3% in all circulatory diseases (Ballester et al., 2001). In Tabriz (Iran), the number of HACOPD was 8.2 in 2011–2012 (Ghozikali et al., 2016), i.e. lower than the calculated HACOPD in our study, due to lower SO_2 mean concentrations in Tabriz compared to Khorramabad. Also, 0.5% (95% CI: 0–1.0%) of HACOPD were associated with daily SO_2 levels exceeding 10 μg/m^3 (Ghozikali et al., 2016), while in Khorramabad about 1.90% (95% CI: 0–4.61%) of HACOPD was attributed to daily SO_2 concentrations above 10 μg/m^3.

In European cities, in Hong-Kong (China) or in Sao Paulo (Brazil), there are significant correlations between SO_2 and HACOPD (Anderson et al., 1997; Ko et al., 2008). Increases in SO_2 was related to an 11% rise in daily hospitalizations in Canada (Burnett et al., 1997). In Ahvaz, 74% of the acute MI occurred on days with SO_2 levels lower than 100 μg/m^3 (Goudarzi et al., 2014). In Tabriz, 79% of HACOPD occurred in days with SO_2 concentrations lower than 60 μg/m^3 in 2011 (Ghozikali et al., 2016).

Our study has weaknesses because the AirQ 2.2.3 approach is applied on only single compounds without considering the simultaneous exposure to multiple pollutants. In quantitative risk assessment, the interactions between different pollutants are generally not well evaluated. In fact, this information is still rarely available. Another weakness is due to the RR values being derived from studies outside the study region. In addition, this model is an ecological-based approach and not an epidemiological approach, so the model does not consider intra-individual differences related to the different behaviors within the studied population. Finally, another limitation but accepted by all authors on the topic, is that the method assumes that levels measured at the central sampling site are representative of the mean exposure of all inhabitants of Khorramabad.

5. Conclusions

The present study has assessed acute MI and COPD attributed to SO_2 in Khorramabad, Iran. This study was the first attempt to the investigation the health effects of SO_2 in west of Iran for which direct health data are not available. The results showed that 2.7% of MI and 2.0% of HACOPD were correlated to SO_2 concentrations over 10 μg/m^3. Since the geographic, demographic and climate characteristics are different and not well evaluated, further studies are needed for quantification of other health impacts of SO_2 and assessment the health endpoints of exposure to other pollutants in urban area's atmosphere. The results of our study are in line with those of other studies, and despite of the limitations, show that this approach offers an effective and easy tool, helpful in decision-making.

The vulnerable people can modify their behavior, in line with their physicians' recommendations for controlling symptoms. To reduce the adverse effects of SO_2, the reduction of source of air pollution and a careful monitoring of air pollution will continue to have an important role g. Environmental health training by healthcare systems should be applied to all general population especially to elderly and children but also to the people with chronic cardiac and lung diseases. Other actions will be needed such as raise the level of eco-friendly urban public transport systems, the reduction of the high traffic urban both finalized to reduce the negative health outcomes caused by air pollution and so to obtain a lower RR value.

Acknowledgments

The authors wish to thanks to the local agency of Khorramabad's Environment for measuring and providing data.

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