ORIGINAL PAPER

Quantification of health effects related to SO_2 and NO_2 pollutants using Air quality model

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Date of submission: 22 Dec 2016, ***Date of acceptance:*** 08 Mar 2017

ABSTRACT

In the past few decades, the results of epidemiological studies have shown that there is a significant relationship between human health and air pollution. The aim of this study was to quantify the health effects, the estimated number of cases of death, cardiovascular and respiratory deaths attributed to NO_2 and SO_2 pollutants in Bukan city by Air Quality software. Bukan city has a population of 224,628 persons and an area of 2541.306 square kilometer. Raw data of SO_2 and NO_2 concentrations were received from the Department of Environment of Bukan city. To analyze the data, the Excel and Air quality 2.2.3 softwares were employed. The annual average of SO_2 concentration was 85.61 µg m^{-3} which is higher than the WHO AQGs and Iranian National Standard. Air Quality model predicted that with every 10 µg m^{-3} increase in gaseous SO_2, total, respiratory and cardiovascular mortality related to SO_2 was 36.2, 7.8 and 29.9 deaths, respectively. The average concentration of NO_2 was almost constant throughout the year. NO_2 concentration in summer and winter seasons was 25.23 and 25.95 µg m^{-3}, respectively. Consequently, 0.64 and 0.36% of the total and cardiovascular mortality was due to NO_2, respectively. In conclusion, Air Quality software can be used for health risk assessment of SO_2 and NO_2 pollutants.

Keywords: Air pollution, Bukan, Nitrogen dioxide, Sulfur dioxide, Air Quality software.

Introduction

Today, air pollution is one of the most important environmental problems in world cities.[1] In the past few decades, the findings of epidemiological studies have shown that there is a significant relationship between human health and air pollution.[2, 3] Air pollution is a serious challenge for human health which causes various diseases and deaths globally each year.[4, 5]

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Citation: Kamarehie B, Ghaderpoori M, Jafari A, Karami M, Mohammadi A, Azarshab Kh, et al. Quantification of health effects related to SO2 and NO2 pollutants using Air quality model. J Adv. Environ Health Res 2017; 5(1): 44-50

The health effects of air pollution is divided into short-term and long-term effects.[6] According to the estimate of World Health Organization (WHO), 800,000 persons have encountered premature death worldwide each year due to cardiovascular, respiratory diseases and lung cancer. Approximately, 150,000 deaths occur in South Asia.[7] Also, it is estimated that 1.4% deaths in the world is attributed to air pollution.[8] According to WHO Air Quality Guidelines (AQGs), criteria pollutants are nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), carbon monoxide (CO) and lead (Pb).[9] The results to estimate the disease burden by WHO show that 89% of all air pollution has been associated with cardiovascular and respiratory diseases.[10, 11] Therefore, because each person inhales 10 m^3 of air every day, investigating the effects of air pollutants on human health is very crucial. Nitrogen compounds are chemically different, but the most important form from the perspective of health is NO_2.[12] NO_2 is one of the criteria pollutants that has various effects on human health. The health effects of NO_2 is divided into short-term and long-term effects. Health effects include hospital admissions, upper and lower respiratory illness, bronchitis, chronic cough, and increasing infant mortality.[13] In addition to health effects on humans, NO_2 can adsorb sunlight and reduce visibility.[14] According to studies, the main effects of NO_2 occur as pulmonary and Chronic Obstructive Pulmonary Disease (COPD).[1] The WHO AQGs value is 40 μg m^{-3} (annual mean) that is set to protect the public from the health effects of NO_2[9]. NO_2 has natural and anthropological sources. Natural sources include lighting, volcanic activity, bacterial activity and oxidation of NO to NO_2 in the atmosphere.[9] Anthropological sources include combustion processes, power stations, transportation systems, heating plants and industries. The main sources of NO_2 in urban air include motor vehicles (transportation system) and the combustion of fossil fuels that are responsible for the production of more than 70% of NO_2.[9, 15] Health effects of NO_2 can occur at high and low concentrations. Epidemiological studies have shown that 5-7% of lung cancer in smoker and non-smoker can attributed to the existence of NO_2 in the atmosphere.[16, 17] Some studies have shown that short-term exposure to NO_2 can cause cardiovascular death of exposed people.[2, 18] SO_2 is one of the criteria pollutants of the atmosphere. Natural resources emitting SO_2 into the atmosphere are volcanic eruptions and forest fires. Anthropological sources of SO_2 include motor vehicles, burning of oil and coal at power stations. Health effects of SO_2 on human can be associated with these cases: constriction of airways, bronchitis, irritation of the eyes, nose, throat and airways, low depth of breathing, cardiovascular complications, breathing problems and COPD.[17, 19] Studies have shown that there is a significant relationship between SO_2 concentration and increasing hospital admissions due to asthma and other respiratory problems.[20] The findings of an epidemiological studies in Europe show that low concentration of SO_2 (less than 10 ppb) was related to increased mortality due to heart and respiratory illnesses. In other words, for every 10 ppb increase in SO_2 concentration, the risk of death increased by 0.2-2%.[21] Therefore, as ealier mentioned, the aim of this study was to quantify the health effects, the estimated number of cases of death, cardiovascular and respiratory death attributed to NO_2 and SO_2 in Bukan city by Air Quality (Air Q) software.

Materials and Methods

Location data

West Azerbaijan province is located in northwestern Iran. Also, Bukan is located to the south of this province (36°32'N, 46°13'E). Based on the latest population census, Bukan has a population of 224,628 persons. Its height is 1370 meters above sea level with an area of 2541.306 square kilometer. The location of the Bukan city and its air quality monitoring station is shown in Fig.1. As shown in Fig.1, at present, Bukan city has only an air quality monitoring station which is located almost at the center of the town.

Data collection and processing

In this study, raw data of SO_2 and NO_2 concentrations were received from the Department of Environment of Bukan city. Data processing steps are shown in Fig.2. As shown in Fig.2, data processing is divided into four stages. In stage 1 (SO_2 and NO_2), concentration data were received from Department of Environment of Bukan city as Microsoft office excel spread sheet format. SO_2 and NO_2 concentrations (hourly) data were received from 2015 to 2016. Also, temperature and pressure data (for unit conversion) were received from the Meteorological Agency of Bukan city. In stage 2, SO_2 and NO_2 data were processed by MS excel 2013 software. SO_2 and NO_2 data in excel software were processed according to the following stages: Primary processing (removing, sheeting, integration time, corrections for temperature and pressure), secondary processing (code writing in excel, the calculation of SO_2 and NO_2 means, primary and secondary filtering of data). For data analysis on short-term health impact assessment, interval of 10 μg m^{-3} was selected. Therefore, it is necessary to know the number of days the daily average falls within: Interval of 10 μg m^{-3} : <10, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, 90-99, 100-109, 110-119, 120-129, 130-139, 140-149, 150-159, 160-169, 170-179, 180-189, 190-199, 200-249, 250-299, 300-349, 350-399, >400. Finally, after data classification according to interval of 10 μg m^{-3}, the results were entered into Air Q software.

WHO criteria for quality health assessment

The received data of SO_2 and NO_2 should have the following criteria: I. data related to one year (1 January to 31 December), II. The data are divided into two seasons (winter: from January to March and from October to December inclusive and summer: from April to September inclusive), also, the ratio between the number of valid data for the two seasons of the year considered cannot be greater than 2. III. To obtain one-hour average values from data with a smaller averaging time,at least 75% of valid data should be used. IV. To obtain average values of 8-hour 'moving' from hourly measures, the number of hours where valid measures have been performed must be for at least 18 hours (75%). V. To obtain 24-hour average values from data, at least 50% of time should be available. VI. To obtain seasonal and annual average values, at least 50% of valid data for the reported period should be used.[1]

Air Quality software

For data analysis, Air Q software version 2.2.3was used. To use the Air Q software, the following information were reqiured: latitude and longitude, city population, mean and maximum concentration (annual, winter and summer) of SO_2 and NO_2, annual 98 percentile, baseline incidence (BI) per 100,000 per year, relative risk (RR). In this study, BI and RR values were selected based on similar studies.[19, 22]

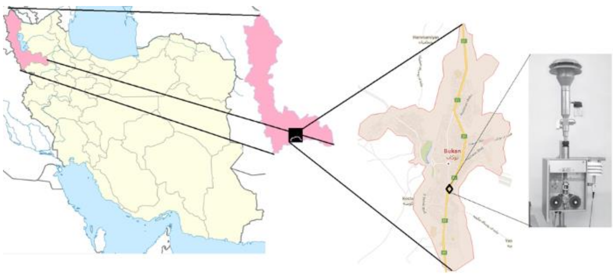

Fig.1 Location of the study area in Bukan city, West Azerbaijan, Iran.

Fig.2 Data processing with use of Air Q 2.2.3 software

Results and Discussion

This study investigated the health effects of SO2 and NO2 pollutants onto inhabitants in Bukan city by WHO approach. Table 1 shows descriptive analysis of SO2 and NO2 concentrations in various seasons of 2015-2106. WHO AQGs and Iranian National Standard have recommended an average concentration of 20 µg m-3 for SO2.9 According to Table 1, the annual-average concentration of SO2 was 85.61 µg m-3 which was higher than the WHO AQGs and Iranian National Standard. The average concentration of SO2 was more in winter than in summer. SO2 concentration in summer and winter was 79.51 and 92.35 µg m-3, respectively. Table 2 shows hourly-average concentration of SO2 from 2014 to 2015. WHO AQGs for SO2 was recommended as 20 µg m-3 (24-hour mean).9 In all months of the year, 24-hour concentration of SO2 is higher than the WHO AQGs and Iranian National Standard. Table 3 presents RR with 95% CI which was used for estimating the health effects of SO2 and NO2. The values of Table 3 have been extracted from previous studies.23 As shown in Table 3, health effects of SO2 can be used to calculate mortality such as total mortality (except for deaths from traffic accidents), cardiovascular, respiratory mortality and morbidity such as Hospital Admissions (H.A), COPD disease and acute myocardial infarction. Table 4 shows the relationship between SO2 concentration and the percentage of estimated AP % (attributed proportion), RR and estimated number of excess cases (persons). As shown in Table 4, Air Q model predicted that with 10 µg m-3 increase in every gaseous SO2, total, respiratory and cardiovascular mortality in relation to SO2 was 36.2, 7.8 and 29.9 deaths (mean), respectively. From 2015-2016 in Bukan city, there had been 935 deaths, and 57 deaths were attributed to driving accidents. In other words, 878 persons encountered non-accidental deaths. Consequently, 4.12, 0.889 and 3.4% of the total,

Table 1 SO_2 and NO_2 concentrations in different seasons

			SO_2 (µg m^{-3})			
Average			**Maximum**			**Percentile of 98%**
Annual	Summer	Winter	Annual	Summer	Winter	
85.61	79.51	92.35	365	199.62	365	189.88
			NO_2 (µg m^{-3})			
Average			**Maximum**			**Percentile of 98 %**
Annual	Summer	Winter	Annual	Summer	Winter	
25.58	25.23	25.95	42.09	32	42.09	33.9

respiratory and cardiovascular mortality were due to SO_2, respectively. The findings of Mohammadi et al showed that the number of deaths related to total and respiratory mortality with SO2 was 157 (3.25%) and 26 (4.03%) persons, respectively, at Ahvaz in 2010.24
WHO AQGs has recommended a concentration of 40 µg m-3 to protect the public from the health effects of gaseous NO2.9, 15 Iranian National Standard also recommended 40 µg m-3.

According to Table 1, the annual-average concentration of NO2 was 25.58 µg m-3 which was less than the WHO AQGs and Iranian National Standard. The average concentration of NO2 was almost constant throughout the year. NO2 concentration in summer and winter was 25.23 and 25.95 µg m-3, respectively. Table 2 shows hourly-average concentration of NO2 from 2014 to 2015. WHO AQGs for NO2 was recommended as 40 µg m-3 (1-hour mean).9 In all months of the year,

Table 2 SO_2 and NO_2 hourly-average concentrations (µg m^{-3}) at Bukan city from 2014 to 2015.

		Maximum	**Minimum**	**Mean**
January	SO_2	174.98	17.33	118.04
	NO_2	31.93	22.09	25.24
February	SO_2	155.91	26.1	63.68
	NO_2	29.75	22.81	25.32
March	SO_2	161.19	14.21	113.14
	NO_2	42.09	23.33	26.73
April	SO_2	155.07	22.99	84.4
	NO_2	27.52	22.35	24.57
May	SO_2	132.11	20.25	91.36
	NO_2	28.16	22.35	24.83
June	SO_2	138.46	13.68	95.02
	NO_2	29.22	22.10	25.35
July	SO_2	110.82	0.26	36.54
	NO_2	28.59	18.65	24.82
August	SO_2	104.07	15.12	72.09
	NO_2	32	22.28	26.03
September	SO_2	199.62	10.02	70.57
	NO_2	29.42	20.5	25.78
October	SO_2	237.27	6.4	149.17
	NO_2	29.29	19.07	25
November	SO_2	202.81	0.07	51.93
	NO_2	25.55	21.09	23.44
December	SO_2	136.43	0.02	43.87
	NO_2	32.87	21.04	27.93

Table 3 Relative risk with 95% CI and corresponding reference, implemented by Air quality software and used for the estimate of health effects of SO_2 and NO_2

	Health effects		**Baseline Incidence**	**Relative risk per 10 µg m^{-3}**		
				Low	**Medium**	**High**
SO_2	**Mortality**	Total	543.5	1.003	1.008	1.0048
		Cardiovascular	231	1.002	1.008	1.012
		Respiratory	48.8	1.006	1.01	1.014
	Morbidity	H.A. COPD	101.4	1	1.0044	1.011
		Acute myocardial infraction	132	1.0026	1.0064	1.0101
NO_2	**Mortality**	Total	543.5	1.002	1.003	1.004
		Cardiovascular	231	1.003	1.004	1.005
	Morbidity	H.A. COPD	101.4	1.0006	1.0026	1.0044

hourly-NO2 concentration was lower than the WHO AQGs.
The findings of Kermani et al revealed that the average-annual concentration of ozone and nitrogen dioxide was 130 and 64 $\mu g/m^3$ in Tehran, respectively.[1] In addition, Naddafi et al study showed that annual-average concentration of PM_{10}, SO_2, NO_2 and O_3 were 90.58, 89.16, 85 and 68.82 $\mu g/m^3$ in Tehran, respectively.[22] Table 3 presents RR with 95% CI which was used to estimate the health effects of NO_2. The values of Table 3 have been extracted from similar studies in Iran.[15, 17, 25] As shown in Table 3, health effects of NO_2 can be used to calculate mortality

Table 4. Health effects, relative risks, estimated AP % and estimated number of excess case due to short term exposure to SO_2 concentration above 10 μg m^{-3}

Health effects	RR (Medium)	Estimated AP (%)	Estimated number of excess cases (Persons)
Total mortality	Central	2.9606	36.2
	Lower	2.237	27.3
	Upper	3.5318	43.1
Cardiovascular mortality	Central	5.7509	29.9
	Lower	1.5025	7.8
	Upper	8.3853	43.6
Respiratory mortality	Central	7.0868	7.8
	Lower	4.3761	4.8
	Upper	9.648	10.6
H.A. COPD	Central	3.2471	7.4
	Lower	0	9
	Upper	7.7406	17.7
Acute myocardial infarction	Central	4.6543	13.8
	Lower	1.9445	5.8
	Upper	7.1526	21.2

such as total mortality (except for deaths from traffic accidents), cardiovascular mortality and morbidity such as H.A. COPD. Table 5 shows the relationship between NO_2 concentration with the percentage of estimated AP % (attributed proportion), RR and estimated number of excess cases (persons). According to Table 5, Air Q model predicted that with every 10 μg m^{-3} increase in gaseous NO_2, total and cardiovascular mortality was 5.6 and 3.2 deaths (mean), respectively. From 2015-2016 in Bukan city, there had been 935 deaths, and 57 deaths were attributed to driving accidents. In other words, 878 persons encountered non-driving-accidental deaths. Consequently, 0.64 and 0.36 % of the total and cardiovascular mortality was due to NO_2, respectively. Motalleby et al showed the number of deaths due to NO_2, SO_2, and O_3 as 22, 82 and 54 persons, respectively, and that the highest health effect was due to SO_2.[26] The findings of Omidi et al showed that for every 10 μg/m^3 increase in the NO_2 level, the risk of CM, MI, and HACOPD increased to about 0.2, 0.36, and 0.38%, respectively.[17] The modeling results of zallaghi et al showed that in 2011, 13 cases of respiratory deaths in Tabriz city were due to SO_2. Also, the cumulative number of COPD related to SO_2 was 9.[18] Jeong study showed that among studied pollutants, PM_{10} had the highest health effect on the 1118000 persons of Suwon city, causing an excess of total mortality of 105 out of 4254 in a year and SO_2 had the least health effect. Also, O_3 and NO_2 each caused 42.7 and 81.3 excess cases of total mortality in a year, respectively.[27] The results of Ghozikali et al at

Table 5. Health effects, relative risks, estimated AP % and estimated number of excess case due to short term exposure to NO_2 concentration above 10 μg m^{-3}

Health effects	RR (Medium)	Estimated AP (%)	Estimated number of excess cases (Persons)
Total mortality	Central	0.46	5.6
	Lower	0.3072	3.8
	Upper	0.6124	7.4
Cardiovascular mortality	Central	0.6124	3.2
	Lower	0.46	2.4
	Upper	0.7644	4
H.A. COPD	Central	0.3989	0.9
	Lower	0.0923	0.2
	Upper	0.6733	1.5

Tabriz in 2014 showed that 0.9 and 0.4% of H.A. COPD were related to SO_2 and NO_2 at a concentration of over 10 μg/m^3, respectively.[28] In another study by Ghozikali et al, the findings showed that 0.5 and 0.7% of H.A. COPD were related to SO_2 and NO_2 at a concentration of over 10 μg/m^3, respectively.[29] For monitoring of public health, continuous survey of criteria pollutants in air pollution, modeling and simulation can be very useful.

Conclusion

The findings of this study showed that concentration of gaseous SO_2 and NO_2 were higher and less than WHO AQGs and Iranian National Standard, respectively. Annual-average concentration of SO_2 and NO_2 were 85.61 and 25.58 µg m^{-3}, respectively. Quantification of the health effects of nitrogen dioxide and sulfur dioxide pollutants were performed with Air Quality software. The use of this software for health-risk assessment is very simple and it can give useful information on the field.

Acknowledgement

This work was supported by Students Research Committee of Shahid Beheshti University of Medical Science, Iran (Grant no. 2571).

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