How to Cite:
Neisi, A., Goudarzi, G., Angali, K. A., Dastoorpoor, M., Fadaei, A., & Naghan, D. J. (2022). Comparison between evaluation of PM2.5, NO2 and O3 concentrations and attributed short-term and long-term effects as determined by AirQ + software for residents of Shahrekord and Ahvaz-Ira (2012-2018). *International Journal of Health Sciences*, *6*(S3), 9266–9281. https://doi.org/10.53730/ijhs.v6nS3.8153

Comparison between evaluation of PM2.5, NO2 and O3 concentrations and attributed short-term and long-term effects as determined by AirQ + software for residents of Shahrekord and Ahvaz-Ira (2012-2018)

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***Abstract*---**Background and objectives: Air pollution has been reported to contribute to respiratory and cardiovascular diseases, asthma attacks, acute bronchitis and decreased lung function, which can increase hospitalization rate. Premature mortality is another consequence of exposure to polluted air. Procedure: From the

Manuscript submitted: 27 March 2022, Manuscript revised: 9 April 2022, Accepted for publication: 18 May 2022

Environment Department (DOE) of Ahvaz and Shahrekord cities, the average hourly concentrations of PM2.5, O3 and NO2 recorded in different stations of the monitoring network of these two cities were obtained. Then, for different air quality monitoring stations, through soft Excel 2010 maximum 8-hour daily O3 concentration, one-hour average NO2 concentration and 24-hour average PM2.5 concentration were calculated and then SOMO35 indicator was calculated for cases where ozone level was more than 35. Data validation according to Aphekom methods And WHO was determined and demographic statistics and baseline incidence were also obtained. Results: In Shahrekord, the number of deaths from IHD, COPD, lung cancer, ALRI and stroke attributed to PM2.5 was 176, 7, 0, 10, and 105, respectively. in Ahvaz, the number of deaths from IHD, COPD, lung cancer, ALRI, and stroke attributed to PM2.5 was 2023, 128, 110, 23, and 802. Conclusion: by devising and implementing strategies and measures to control air pollution, both health effects and economic losses can be prevented. Therefore, policymakers and experts in the field should put air pollution reduction at their agenda.

***Keywords*---**air pollutants, cardiovascular diseases, respiratory diseases, mortality, Shahrekord, Ahvaz.

Introduction

Ambient air quality has deteriorated in different parts of the world in the last few decades (Faridi et al. 206-2015). Many Middle Eastern cities, including Iranian cities, experience high concentrations of air pollutants, especially particulate matter(Hopke et al.2018; WHO, 2016) . As a developing country, Iran is facing severe air quality problems, which in turn are exacerbated by frequent desert dust storms from inland and abroad (Dastoorpoor et al. 2018a; Dastoorpoor et al. 2018b). These events have had significant health effects on the affected areas such as the northwest, southwest, southeast, and west of Iran (Khaniabadi et al. 2017; Mohammadi et al.2019). In fact, desert dust events and major anthropogenic resources disrupt air quality in different parts of the country (Farsani et al. 2018). Air pollution has been reported to contribute to respiratory and cardiovascular diseases, asthma attacks, acute bronchitis and decreased lung function, which can increase hospitalization rate (Sinuraya RK, et. al., 2021; Alzahrani S, et. al., 2019; Berezin AA, et. al., 2021). Premature mortality is another consequence of exposure to polluted air (Anenberg et al. 2010; Puett et al. 2014; Silva et al. 2013; Lepeule et al. 2012; Almeida et al. 2014). In 2011, for instance, long-term exposure to PM2.5 caused approximately 458,000 premature deaths in 40 European countries (EPA. 2014). According to the World Health Organization (WHO), air pollution accounts for 800,000 annual deaths worldwide (Krzyzanowski and Cohen. 2008).

Because air pollution imposes a significant number of deaths and morbidities on society, it is important to conduct research to determine the extent to which it affects health in any society. In addition to health-related objectives, results of such research will provide a rationale for legislators and officials to set new air pollution standard constraints in order to increase funding for strategic plans and hygienic measures aimed at reduction of ambient air pollution (Jo, C. 2014). Determining the frequency of health effects attributed to air pollution can be useful for management purposes. One of the most obvious reasons that officials and policymakers benefit more significantly from these results in allocating funds is that every death, hospitalization, or medication imposes a financial burden on health care systems(Clabaugh and Ward. 2008; Byford et al. 2000). Numerous tools with varying complexity have been developed and used to estimate the public health effects resulting from changes in air quality. These effects include both premature deaths and related diseases along with their associated economic value(Gauderman et al. 2015; Requia et al. 2018; Adam et al. 2015). Among these tools, AirQ$^+$ (developed by World Health Organization and US Environmental Protection Agency (EPA), and the U.S. environmental protection agency's benefits mapping and analysis program—community edition (BenMAP-CE) are most commonly used.

Assessing the effects of air pollution on health can not only determine the adverse effects of air quality on public health, but also be useful when considering the potential implementation of various air quality policies. In fact, assessing potential health impacts is a reliable source for public health and environmental professionals. Therefore, the aim of this study was to conduct a comparative evaluation of the relationship between $PM_{2.5}$, NO_2 and O_3 concentrations and their attributed short- and long-term health effects as determined by AirQ$^+$ for residents of Shahrekord and Ahvaz, Iran during the 2012-2018 period.

Method

Study, period, and estimation method

Shahrekord city, the capital of Chaharmahal and Bakhtiari province in Iran, has an area of 70 square kilometers and is located in the plains of Chaharmahal and Bakhtiari province at 42°22 / E and 32°20 / N. Ahvaz with an area of 185 square kilometers is the capital of Khuzestan province in Iran and is located in plains of this province at 31°20 ′ N and 48 ° 40 ′ E. The main purpose of this study was to estimate the disease burden and mortality caused by short-term and long-term effects of PM2.5, NO2, and O3 in Ahvaz and Shahrekord, Iran from March 21, 2012 to March 20, 2018. According to the population statistics obtained from health centers, which are the most reliable source of population statistics, the total population of Shahrekord in the first, second, third, fourth, fifth, sixth and seventh intervals, was 82450, 95632, 132450, 170198, 222198, 275549, and 288199, respectively, and Ahvaz for the same intervals were 886576, 900853, 999720, 1110420, 1192439, 1278627, 1393144, respectively. Due to paucity of comprehensive studies in Iran and the lack of sufficient information on the health consequences attributed to pollutants, new findings of meta-analysis studies obtained by AirQ$^+$ software in other countries were used in the present study, and this was one of its major limitations. The health consequences discussed included the following: natural mortality in the population over 30 years of age, mortality from acute lower respiratory infections (ALRI) in people under 5 years of age, chronic respiratory disease (COPD), heart disease, lung cancer in the population over 30 years of age, and stroke and ischemic heart disease (IHD) in the population over 25 years.

Air quality data

This study was a time series and ecological research. Data on hospital admissions, total mortality, and mortality from cardiovascular and respiratory diseases from 2012 to 2018 (7 years) were collected on a daily basis from the main and referral hospitals in Shahrekord and Ahvaz and also from the health deputies of Shahrekord University of Medical Sciences and Ahvaz Jundishapur University of Medical Sciences. Daily concentrations of pollutants were collected on a daily basis from the Department of Environmental Protection of Chaharmahal and Bakhtiari and Khuzestan provinces for 7 years. These data included ozone, nitrogen dioxide and particles smaller than or equal to 2.5 microns that were measured in three monitoring stations installed in Jahad Square, Ostandari Square, and Chaharmahal Square in Shahrekord, and stations of the General Directorate of Environmental Protection Organization, Naderi Square, University Square, and Ahvaz Meteorological Organization in Ahvaz. In these stations, outdoor air pollutants and particles smaller than or equal to 2.5 microns were measured separately in different ways. To measure suspended particles, air is first pumped into the measuring devices. The device then measures the particle concentration based on the intensity of adsorption and records it every one hour. In this method, stations that have 75% of the complete data are selected according to Aphekom and WHO methods (Gauderman et al. 2015; Requia et al. 2018). The method for determining the average concentration of each pollutant was as follows.

- PM2.5: the 24-hour average (24-hour)
- NO2: the maximum average of 1 hour
- O3: the total ozone i.e., more than 35 ppb (SOMO35) (Byford et al. 2000).

For PM2.5, the 24-hour average for each station was first calculated and then, using the 24-hour average of different stations, the 24-hour average of the whole city was calculated. For NO2, in order to calculate the maximum of 1 hour, the average was taken only from the days that had data for at least 18 hours (0.75) and finally, the maximum hourly concentration for each day was selected and considered as the average of that day. To calculate SOMO35, an average concentration of a maximum of 8 hours per day was calculated in ppb for all stations, which is attributable to SOMO35. That is, values below 35 ppb were not considered to have health effects.

$$SOMO35 = \frac{\sum_i \max\{0, C_i - 35ppb\}}{SOMO35_{uncorrected}} . \frac{N_{total}}{\mathrm{N}_{Va;id}}$$

where $SOMO35_{uncorrected}$ is uncorrected form of SOMO35. Ntotal is the total number of days in a year, and Nvalid is the number of days for which valid data is available.

Air pollution standards for PM2.5, NO2 and O3 are set by the World Health Organization at 10, 40 and 100 micrograms per cubic meter, respectively (average annual concentration) (WHO. 2006).

Demographic information

In Iran, population statistics are monitored and recorded daily by health centers under the auspices of medical universities, and thus it is the most reliable source of population statistics. The statistics used in this study were annually collected from health centers under the auspices of Shahrekord University of Medical Sciences and Ahvaz Jundishapur University of Medical Sciences.

Baseline incidence

The rate of baseline incidence (BI) related to each health effect (number of basic health consequences per population (100,000)) for each city was obtained separately from the Deputy of Health of Shahrekord University of Medical Sciences and Ahvaz Jundishapur University of Medical Sciences.
BI is obtained according to the following formula:

$$BI = AP \times B \qquad (1)$$

where B is the initial rate of beneficial health outcome per 100,000 people, and AP is the attributable ratio (AP) of the health effects of air pollution.

Relative Risk (RRs)

In this study, due to limitations such as insufficient previous studies determining the RR index for the target areas, the default values of relative RR risk in the AirQ + model were used for this study. These values are obtained from meta-analysis studies (Pierpaolo and Maria Dunbar. 2016). In this study, RR values for the total mortality and respiratory mortality were 1.065 (1.04-1.083) and 1.014 (1.005-1.024), respectively. The rate of ALRI, COPD, lung cancer, IHD, and stroke were also estimated using IER. The relative risk index for different concentrations was obtained according to the following formula (Pierpaolo and Maria Dunbar. 2016).

$$RR(X) = e^{\beta(X - X_0)} \qquad (2)$$

X, X0 and β on average represent the concentration of a contaminant in the target city, the amount of cut and the change in RR for a unit of change in concentration X.

Statistical analyses

The concentrations of all three pollutants were analyzed separately in different years. Since the data had normal distribution and equal variance, Kolmogorov-Smirnov and Levene test (equality of variance and normal distribution) and Kruskal-Wallis test (inequality of variance) were used.

Results and Discussion

In this study, the health effects attributed to PM2.5 and NO2 for concentrations higher than those set by WHO guidelines and those attributed to O3 concentrations above 35 ppb were estimated by AirQ + software. The average 7-year concentrations and standard deviation of PM2.5, NO2 and O3 in Shahrekord were 49.94 (287.48%) and 59.42 (86.75%) micrograms per cubic meter, and 15.98 (35.71%) ppb, respectively. SOMO35 ozone levels were zero in all years of the study period. For Ahvaz, the obtained values were 68.21 (135.86%), 24.46 (22.79%) micrograms per cubic meter, and 24.48 (13.77%) ppb, respectively. SOMO35 ozone values in this city were 1203.45, 1792.56, 544.38, 457.75, 619.04, 0 and 0, respectively. The annual average and standard deviation of pollutants are shown in Figures1and 2.

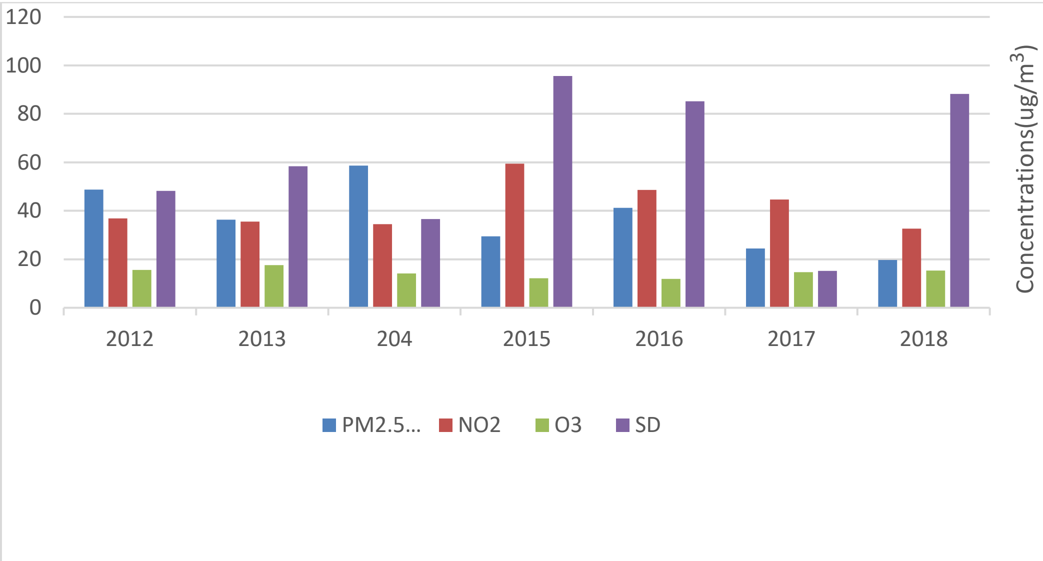

Fig. 1. Annual averages and standard deviations of the $PM_{2.5}$, NO_2, and O_3 during the study period in ambient air of Shahrekord

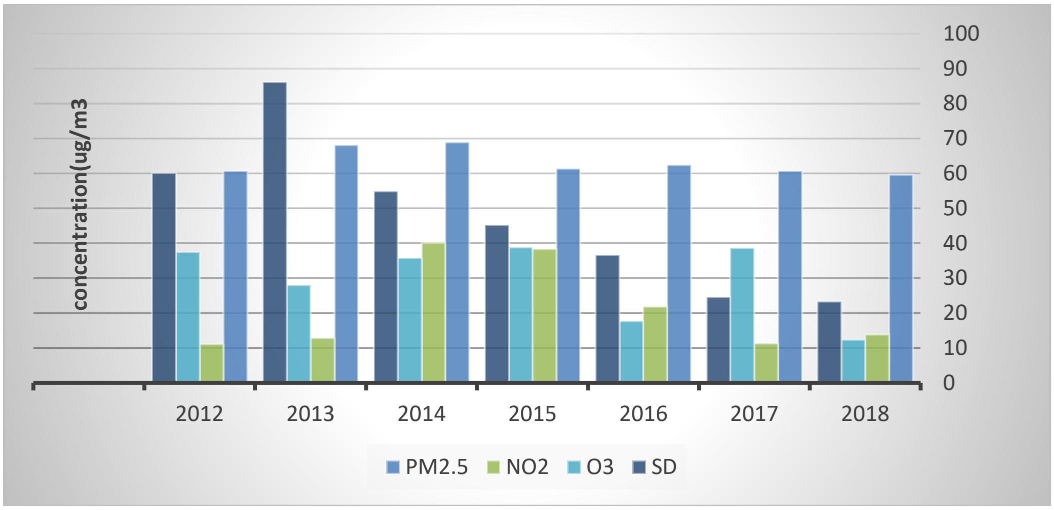

Fig 2. Annual averages and standard deviations of the $PM_{2.5}$, NO_2, and O_3 during the study period in ambient air of Ahvaz Cit

Table 1 shows the average annual concentration of pollutants for the two cities in the studied years. The average annual concentration of PM2.5 during the years 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018 and 2018-2019 in Shahrekord were respectively 4.8, 3.63, 5.86, 2.95, 4.12 , 2.45, 1.97 times and in Ahvaz 60.6, 68.1, 68.9, 61.4, 62.4, 60.6 and 59.6 times the values recommended by the guidelines of the World Health Organization (10 micrograms per cubic meter)(Adam et al. 2015). These results are consistent with those of other studies(Goudarzi et al.2020).

Table 1
Concentration of pollutants in Ahvaz and Shahrekord

City	Pollutant	Concentrations content			
		2012	2013		2014
		2015	2016		2017
	$PM_{2.5}$	2018			
Shahrekord					
	NO_2	48.8	36.37	58.6	29.5
	O_3	41.2	24.5	19.7	
		36.9	35.5		34.5
		59.42	48.6		44.7
	$PM_{2.5}$	32.7			
Ahvaz	NO_2	15.6	17.56		14.22
	O_3	12.23	11.85	14.75	15.3
		60.6	68.1		68.9
		61.4	62.4	60.6	59.6
		11.1	12.8		40.1
		38.3	21.8		11.3
		13.8			
		37.4	28		35.8

38.8 17.7 38.6 12.4

2012(2012-2013) 2013(2013-2014) 2014(2014-2015) 2015(2015-2016) 2016(2016-2017) 2017(2017-2018) 2018(2018-2019)

According to our results, the trend of pollutant concentrations in both cities during the study period was irregular and did not follow any specific pattern. The rate of ozone in both cities in all intervals was less than that recommended by guidelines of the World Health Organization. The rate of NO2 in Shahrekord from the fourth to sixth intervals and in Ahvaz only in the third interval was higher than that indicated in the guidelines of the World Health Organization (Adam et al. 2015). PM2.5 and ozone were higher in Ahvaz compared with Shahrekord, but NO2 concentration was higher in Shahrekord than that in Ahvaz. In general, Ahvaz is in a more threatening situation than Shahrekord, which can be due to the proximity of Ahvaz to the Persian Gulf countries such as Iraq and Kuwait, the existence of large industries and petrochemicals in Khuzestan province and the suburbs of Ahvaz, and the droughts in recent years.

In 2018, Dastoorpour et al. examined cardiovascular mortality attributable to ambient air pollutants in Ahvaz, Iran, and found that the average daily concentrations of ozone and NO2 in the period 2008-2015 were 62 micrograms per cubic meter and 44.20 micrograms per cubic meter, respectively(Dastoorpoor et al. 2018a; Dastoorpoor et al. 2018b). which is consistent with the results of this study. Tables 2 and 3 show the rate of natural and respiratory deaths due to short-term exposure, and Tables 4 and 5 show the rate of natural and respiratory deaths due to long-term exposure to PM2.5, NO2 and O3 for Shahrekord and Ahvaz, respectively.

Table 2
Attributable cases due to short-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period (Shahrekord)

Pollutant	Health outcome	Attributable cases						
		2012	2013	2014	2015	2016	2017	2018
$PM_{2.5}$	Natural mortality	16	10	35	6	28	0	0
NO_2	Natural mortality	6	7	0	22	23	25	17
O_3	Natural mortality	0	0	0	0	0	0	0
		0	0	0	0	0	0	0
	Respiratory mortality	0	0	0	0	0	0	0

	Cardiovascular mortality	

Table 3
Attributable cases due to short-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period (Ahvaz)

Pollutant	Health outcome	Attributable cases
		2012 2013 2014 2015 2016 2017 2018
$PM_{2.5}$	Natural mortality	87 257 310 305 379 342 320
NO_2	Natural mortality	3 7 80 84 119 4 12
O_3	Natural mortality	10 16 3 5 7 0 0
	Respiratory mortality	1 1 3 0 0 0 0
	Cardiovascular mortality	9 13 4 4 5 0 0

Regarding natural mortality, the highest and lowest natural mortality rates were related to NO2 and O3 for Shahrekord and PM2.5 and O3 for Ahvaz, respectively. In Shahrekord, no health effects attributed to ozone were identified and with this level of ozone concentration, there is no concern about health outcomes in this city. In Ahvaz, in the last two intervals, health effects attributed to ozone were zero. In both cities, the most short term effects are determined in the fifth period.

Table 4
Attributable cases due to long-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period (Shahrekord)

Pollutant	Health outcome	Attributable cases
		2012 2013 2014 2015 2016 2017 2018
$PM_{2.5}$	Natural mortality	117 109 217 117 200 118 101
	ALRI	

	COPD mortality	0	0	0	0	0	0	0
	LC mortality	1	1	1	1	1	1	1
NO_2	IHD mortality	1	1	2	1	2	1	2
O_3	Stroke	23	22	25	21	24	22	39
		7	8	17	13	23	19	18
	Natural mortality	86	95	124	303	322	351	250
	Respiratory mortality	0	0	0	0	0	0	0

Table 5
Attributable cases due to long-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period (Ahvaz)

Pollutant	Health outcome	Attributable cases						
		2012	2013	2014	2015	2016	2017	2018
$PM_{2.5}$	Natural mortality							
	ALRI	534	1807	1770	1997	2246	2103	1991
	COPD mortality	0	1	2	8	3	4	5
	LC mortality	10	18	27	17	18	21	17
	IHD mortality	13	19	23	13	3	18	21
NO_2	*Stroke*	234	243	272	255	279	324	416
O_3		81	84	109	106	122	132	168
	Natural mortality	40	101	1126	1190	517	59	173
	Respiratory mortality	3	55	2	1	2	0	0

In Shahrekord, the most long-term health effects attributed to PM2.5 and NO2 were observed in the third and sixth years, respectively, and in Ahvaz, they were respectively observed in the fifth and fourth year. On average, 12%, 7.7%, 13.8%, 4.8% and 12.28% of natural mortality in Shahrekord were due to short-term exposure to PM2.5 in the first, second, third, fourth and fifth years, respectively, and no natural deaths due to short-term exposure to this pollutant was reported in the sixth and seventh years. These findings are slightly different from those of previous studies. In Ahvaz, on average, 15%, 8.8% and 43.75% of deaths during the studied seven years were due to short-term exposure to PM2.5, NO 2 and O3, respectively, and the rest were due to long-term exposure. Also, the percentage of mortality due to short-term exposure to ozone was higher than that of $PM_{2.5}$ and NO_2 combined.

Hopke et al. reported that about 3.60 to5.02% of natural deaths in Ahvaz are due to $PM_{2.5}$ exposure(Hopke et al.2018). Overall, in the whole study period in Shahrekord, the number of natural mortality due to long-term and short-term exposure to PM2.5 was 1278 and 95, respectively, and the same figures for NO2 were 1531 and 100, respectively. Therefore, NO2 was more threatening than PM2.5, and it can be identified as the responsible pollutant, while no death was reported in relation to exposure to ozone. In Ahvaz, the number of natural mortality due to long-term and short-term exposure to PM2.5 was 11291 and 2000, respectively, and the same figures for NO2 were 3206 and 309. Unlike Shahrekord, exposure to O3 in Ahvaz in the short- and long-term led to the natural death of 81 and 63 individuals, respectively. In this city, PM2.5 was the responsible pollutant.

Nadafi et al. conducted a study in Tehran (capital of Iran) aimed at determining the health effects of air pollutants in this city. According to their results, the majority of health effects were attributed to $PM_{2.5}$ and PM_{10}(Naddafi et al. 2012). which is completely similar to the results of Ahvaz city. In a study in Ahvaz, Iran, air pollution and the total number of respiratory deaths due to ozone exposure were calculated to be 6.17% and 173, respectively, which is different from the results of the present study. This difference may be due to the differences in the geographical distribution of the populations at risk (population census by taking into account the growth rate) or the difference in the average daily recording of pollutants(Goudarzi et al.2020).

In Shahrekord, the number of deaths from IHD, COPD, lung cancer, ALRI and stroke attributed to PM2.5 was 176, 7, 0, 10, and 105, respectively. The effect of ozone on respiratory mortality was zero. No ozone-induced respiratory mortality and acute lower respiratory tract infection (ALRI) were observed during the study period. However, in Ahvaz, the number of deaths from IHD, COPD, lung cancer, ALRI, and stroke attributed to PM2.5 was 2023, 128, 110, 23, and 802, respectively, and the number of respiratory deaths attributed to ozone was 68, while no respiratory mortality due to ozone was reported for the intervals 2017-2018 and 2018-2019. According to a study conducted in Sao Paulo, Brazil during 1998-2008, the rate of mortality resulting from cardiovascular and respiratory diseases was 55.9 and 15.6 per 100,000, respectively(De Araujo Pinheiro et al. 2014). which is significantly higher than that of Shahrekord but completely consistent with the results obtained in Ahvaz.

No studies have been performed to investigate the health effects of long-term exposure to gaseous pollutants in Shahrekord while a very small number of such studies have been conducted in Ahvaz. Therefore, the present study is one of the first studies to investigate the health effects of pollutants in Shahrekord and Ahvaz. Hadei et al. (2017) estimated that the average annual AP and the number of deaths due to lung cancer caused by PM2.5 in Ahvaz were about 25% and 23 cases, respectively(Hadei et al. 2017). In another study, Hadei et al. (2018) reported that the number of deaths from IHD and stroke due to long-term exposure to PM2.5 was around 660 and 338 cases, respectively. The number of deaths due to IHD and stroke per 100,000 people was 93 and 47, respectively. These results are not consistent with those obtained in our study, which is probably due to different approaches used to estimate population exposure, as well as differences in the conditions of the two populations and the study area(Hadei et al. 2018). We only considered monitors with more than 75% data completeness, which increases the validity of the concentration in actual human contact.

Air pollution imposes direct and indirect financial burdens upon governments. According to the World Bank Group report, the health effects of ambient air pollution in Iran led to a decrease in total welfare and GDP of $ 30.6 million and 2.48%, respectively in 2013. In addition, the lost labor productivity cost and its share in Iran's GDP was $ 1471 million and 0.12 percent, respectively(World Bank, 2016). Therefore, air pollution in Ahvaz and Shahrekord, as two important cities of Iran, is a serious problem which requires policy makers to take preventive and control measures in this regard. By devising and implementing strategies and measures to control air pollution, including continuous monitoring of air pollution indicators and identifying influential factors, both health effects and economic losses caused by air pollution could be prevented. Motor vehicles and the Middle East dust storms are the main source of air pollution in Shahrekord, and in addition to these factors, Ahvaz suffers from large and small industries as sources of air pollution. In order to reduce the effects of these pollutants in these two cities, development of plans and collaboration between organizations and even neighboring countries, as well as improvements in the efficiency of motor vehicles will certainly have a significant impact. The results of this study will be useful if supported by political and economic regulations.

This study has a number of strengths. First, all data related to air pollutants and the baseline incidences were collected from governmental and trusted organizations in the capitals of Khuzestan (Ahvaz) and Chaharmahal and Bakhtiari (Shahrekord), and from the Ministry of Health (Iran), which resulted in a relatively large amount of data. Second, compared to previous similar studies, the 7-year period investigated in this study yielded a large amount of data which allowed us to examine relationships at a higher level of reliability and validity. Also, inclusion of 4 air pollution monitoring sites in Ahvaz and 3 sites in Shahrekord contributed to a more detailed analysis of the effects of air pollution compared with other studies. Finally, this study was one of the few studies conducted on one of the most polluted cities in the world (Ahvaz) and included all gender and age groups (total population).

However, this study has its own limitations. First, as in other studies, the results and outcomes of the effects of air pollutants on health and well-being need to be interpreted with caution, and the relationship between pollutants and health effects (mortality and hospital admissions) should be inferred according to the specific conditions of the study area. Secondly, fixed monitoring stations in specific urban areas represent the total exposure of people to pollutants for all residents of the region, but this generalization cannot always be true and represent the contact of each member of the population with pollutants. Exposure of people to pollutants depends on many factors such as indoor or outdoor activities, place of residence, job exposure, etc. Third, other potential contributing factors, such as BMI, education and income, smoking, physical activity, and medical history, were not included in this study, which may have a potential impact on the relationship between air pollutants and hospitalization, mortality, and other effects. Fourth, the relative risks (RR) used to estimate the effects of pollutants on health are based on the default configuration of the software programs and studies conducted in other countries. Finally, the main limitation of this study is its ecological nature, which does not allow us to control potentially disruptive factors at the individual level. These include respiratory habits, age, diet, genetic diseases, socioeconomic status, etc.

Conclusion

In the present study, we examined the short- and long-term health effects attributed to $PM_{2.5}$, NO_2 and O_3 exposure in Shahrekord and Ahvaz over a seven-year period using the AirQ$^+$ model. In both cities, the concentrations of pollutants were often higher than the values indicated in WHO guideline. In Shahrekord, while the short-term effects of PM2.5 on health were greater than those of NO2, the long-term effects of NO2 were more than those of PM2.5. In general, the effects of NO2 were more than those of PM2.5, and the total number of natural deaths due to PM2.5 and NO2 in all the studied years were 1074 and 1631, respectively. The total number of deaths from IHD, COPD, lung cancer, ALRI and stroke attributed to PM2.5 were 176, 7, 10, 0, and 105, respectively. In Ahvaz, both long-term and short-term effects of PM2.5 on health were greater than those of NO2 and ozone. The total number of natural deaths due to $PM_{2.5}$, NO2, and ozone in all studied years were 13291, 3515 and 144, respectively. The death rates of IHD, COPD, lung cancer, ALRI, and stroke attributed to PM2.5 were 2023, 128, 110, 23, and 802, respectively. Finally, the number of respiratory deaths attributed to ozone in this city was 68. Other studies have shown that the health effects of air pollution impose direct and indirect costs on countries. Therefore, by devising and implementing strategies and measures to control air pollution, both health effects and economic losses can be prevented. Therefore, policymakers and experts in the field should put air pollution reduction at their agenda.

Acknowledgements

The authors would like to express their gratitude to the departments of environmental protection of Ahvaz and Shahrekord, and deputies of health of Ahvaz Jundishapur University of Medical Sciences and Shahrekord University of Medical Sciences for providing the relevant data.

Conflict of interest

We have no conflict of interest to declare. This statement is to certify that all Authors have seen and approved the manuscript being submitted. We warrant that the article is the Authors' original work. We warrant that the article has not received prior publication and is not under consideration for publication elsewhere. On behalf of all Co-Authors, the corresponding Author shall bear full responsibility for the submission. This research has not been submitted for publication nor has it been published in whole or in part elsewhere. We attest to the fact that all Authors listed on the title page have contributed significantly to the work, have read the manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission to the International Journal of Health Sciences (IJHS). All authors agree that author list is correct in its content and order and that no modification to the author list can be made without the formal approval of the Editor-in-Chief, and all authors accept that the Editor-in-Chief's decisions over acceptance or rejection or in the event of any breach of the Principles of Ethical Publishing in the International Journal of Health Sciences (IJHS) being discovered of retraction are final. No funding was received to assist with the preparation of this manuscript. No additional authors will be added post submission, unless editors receive agreement from all authors and detailed information is supplied as to why the author list should be amended.

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