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Evaluation of ozone, $PM_{2.5}$ and NO_2 concentrations and estimation of attributed health effects based on AirQ+ on residents of Ahvaz, Iran (2012-2018)

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ABSTRACT

Introduction: Inadequate air quality is one of the environmental hazards factors imposing a significant number of deaths and complications of diseases on society. Therefore, it is highly important to determine the extent of its effects on health in communities. This study sought to assessment the concentration and additional short- and long-term mortality attributed to Particulate Matter less than 2.5 µm ($PM_{2.5}$), Nitrogen Dioxide (NO_2) and Ozone (O_3) were observed in Ahwaz from 2012 to 2018 using AirQ+.

Materials and methods: Daily and hourly concentrations of $PM_{2.5}$, ozone and NO_2 were obtained from Department of Environment in Ahvaz. Then, the mean concentration of 2.5 $PM_{2.5}$ for 24 h, the mean concentration of NO_2 for 1 h and the maximum concentration of O_3 for 8 h daily were calculated using Excel 2010. Finally, to calculate the annual sum of maximum daily 8-h ozone means over 35 ppb (SOMO35) index, concentrations above 35 were collected and entered into the software.

Results: The mean seven-year concentrations of $PM_{2.5}$, NO_2 and O_3 were 68.21 (±135.86%), 24.46 (±22.79%) µg/m^3 and 24.48 (±13.77%) ppb, respectively. The death rates of Ischemic Heart Disease (IHD), Chronic Obstructive Pulmonary Disease (COPD), lung cancer and Acute Lower Respiratory tract Infections (ALRI) and stroke related to $PM_{2.5}$ were 2023, 128, 110, 23, 802, respectively. The number of respiratory deaths attributed to ozone was 68.

Conclusion: The results show a high number of deaths due to bad weather in Ahvaz. It can be concluded that by designing and implementing appropriate and correct solutions and decisions, both health and economic losses are prevented.

Introduction

Inadequate air quality is one of the environmental hazards factors that can lead to premature death and disability-adjusted life year [1, 2]. Reducing air pollution has been shown to increase significant health benefits, such as reducing premature mortality and exacerbating

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or developing a number of respiratory and cardiovascular diseases [3]. Evidence and experience show that exposure to air pollution has many acute and chronic effects on human health, from minor problems to associated death [4-7]. The expansion of urbanization and industrialization, and the reduction of air quality are one of the major and growing concerns of developed and developing countries [8, 9]. Today, many cities in Iran face unhealthy air quality and dust [10-14]. In 2011, long-term exposure to $PM_{2.5}$ caused approximately 458,000 premature deaths in 40 European countries [15]. According to the World Health Organization (WHO), air pollution causes 800,000 deaths worldwide annually [15, 16].

There is no doubt that environmental damages such as air pollution, devastated cities and the other environmental pollution will cost not only economically, but also in terms of healthy and the quality of life [17]. Determining the number of health effects attributed to air pollution can be useful for managing this area. One of the most obvious reasons that officials and policymakers use these results to allocate funds more significantly is that every death, hospitalization, or drug imposes a financial burden on health care systems [18, 19].

Numerous instruments have been used to estimate the health impact of changes in air quality (including premature deaths and related diseases and their associated economic value) [20]. These tools include $AirQ^+$ and the environmental Benefits Mapping and Analysis Program-Community Edition (BenMAP-CE).

This software considers the complications and mortality caused by the mentioned air pollution in the short and long term. In addition, it evaluates the health effects of domestic air pollution related to the use of Solid Fuel Use (SFU) [21, 22]. Air pollution management programs in big cities are one of the most important strategies that use real-world environmental information to estimate all the effects of air pollution on human health [23]. Assessing the effects of air pollution on health cannot only determine the adverse effects of air quality on public health. However, it will also be useful when considering the potential implementation of various air quality policies. Therefore, assessing potential health effects is a reliable point for public health and environmental professionals. The present study aims to evaluate the concentration and short-term and long-term health effects attributed to standard pollutants on residents of Ahvaz (Iran) during the years 2012-2018.

Materials and methods

Study, course and estimation method

The city of Ahvaz with an area of 185 km2 is the capital of Khuzestan Province in Iran. Ahvaz is located at 31 º20 ′ N and 48 ° 40 ′ E in the plains of Khuzestan Province. The main purpose of this study was to estimate the disease burden and mortality caused by short-term and long-term effects of ozone, $PM_{2.5}$ and NO_2 in Ahvaz, Iran from 2012 to 2018. According to the population statistics obtained from health centers, which are the most reliable source of population statistics, the total population of Ahvaz in the first, second, third, fourth, fifth, sixth and seventh intervals, was 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 $AirQ^+$ 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. The health results used in this study are presented in Tables 2 and 1.

Table 1. Health outcomes and population studied

Pollutant	Health outcome	At-risk population						
		2012	2013	2014	2015	2016	2017	2018
$PM_{2.5}$	Natural mortality	501005	610124	660019	703225	881882	901533	941040
	ALRI	16725	20952	32111	43910	57659	71500	88655
	COPD mortality	501005	610124	660019	703225	881882	901533	94104
	LC mortality	501005	610124	660019	703225	881882	901533	941040
	IHD mortality	581211	690133	722219	773225	911882	981533	1098564
	Stroke mortality	581211	690133	722219	773225	911882	981533	1098564
NO_2	Natural mortality	501005	610124	660019	703225	881882	901533	941040
O_3	Respiratory mortality	501005	610124	660019	703225	881882	901533	941040

All natural mortality for adults >30 years old; Acute lower respiratory infection for children <5 years; Chronic obstructive pulmonary disease mortality for adults >30 years; lung cancer mortality for adults >30 years; e: Ischemic heart disease mortality for adults >25 years; f: Stroke mortality for adults >25; All natural mortality for adults > 30 years old; All natural mortality for adults > 30 years old

Table 2. Health outcomes and population baseline incidence studied

Pollutant	Health outcome	Baseline incidence (per 100,000)						
		2012	2013	2014	2015	2016	2017	2018
$PM_{2.5}$	Natural mortality	1013	1004	989	997	961	890	820
	ALRI	18	17	20	19	19	20	21
	COPD mortality	10	10.3	9	9.6	8.5	9.8	8.1
	LC mortality	12.5	11.5	9.5	8	8.8	9.1	11.2
	IHD mortality	165	161	145	135	124	135.7	157.4
	Stroke mortality	62.4	60.4	58	56	54.2	55.5	63.5
NO_2	Natural mortality	1013	1004	989	997	961	890	820
O_3	Respiratory mortality	66	69	61.1	62.3	58.4	55.8	13.8

In this study, we tried to estimate the impact assessment criteria for all pollutants. However, due to the fact that in this software, the effects of carbon monoxide and sulfur dioxide pollutants could not be calculated from the standard pollutants, unfortunately, it has not been possible to estimate the health effects of these two pollutants.

Air quality data

This study is a time series study. Hospitalization data, total mortality and mortality due to cardiovascular and respiratory diseases during (7 years) were collected daily from the main hospitals of Ahvaz Ahvaz Jundishapur University of Medical Sciences. Concentrations of pollutants were collected on a daily basis from the Department of Environment of Khuzestan provinces for 7 years. These data included ozone, nitrogen dioxide and particles smaller than or equal to 2.5 µm that were measured in three monitoring stations installed in 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 µm were measured separately in different ways. To measure suspended particles, air is first pumped into the measuring devices. The device measures the particle concentration based on the intensity of adsorption and records it every 1 h. In this method, stations that have 75% of the complete data are selected according to Aphekom and WHO methods [10].

The method for determining the average concentration of each pollutant was as follows:

$PM_{2.5}$: the 24-h average (24 h)

NO_2: the maximum average of 1 h

O_3: the total ozone i.e., more than 35 ppb [18].

For $PM_{2.5}$, the 24-h average for each station was first calculated and then, using the 24 (h) average of different stations, the 24 (h) average of the whole city was calculated. For NO_2, in order to calculate the maximum of 1(h), the average was taken only from the days that had data for at least 18 h (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 h/day was calculated in ppb for all stations, which is attributable to SOMO35. Values less than 35 ppb were not considered for health effects.

$$\text{SOMO35}= \sum_i \left(\frac{\max\{0, Ci-35\text{ppb}\}}{SOMO35uncorrected} * \frac{Ntotal}{Nvalid}\right) \quad (1)$$

Where SOMO35uncorrected 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 $PM_{2.5}$, NO_2 and O_3 are set by the World Health Organization at 10, 40 and 100 (ug/m^3), respectively (average annual concentration) [25,26].

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 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, Shahrekord University of Medical Sciences and Ahvaz Jundishapur University of Medical Sciences.

BI is obtained according to the following Equatation:

$$BI = AP \times B \quad (2)$$

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 risks (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. 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 Equatation [20].

$$RR(X)=e^{\beta(X-Xo)} \quad (3)$$

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 $PM_{2.5}$ and NO_2 for concentrations higher than those set by WHO guidelines and those attributed to O_3 concentrations above 35 ppb were estimated by $AirQ^+$ software. To achieve accurate results, it should be noted that the health effects attributed to $PM_{2.5}$ and NO_2 were calculated only for concentrations higher than the WHO guidelines. In addition, the health effects of O_3 were estimated for concentrations above 35 ppb. The mean seven-year concentrations of $PM_{2.5}$, NO_2 and O_3 were 68.21 (±135.86%), 24.46 (±22.79%) $\mu g/m^3$ and 24.48 (±13.77%) ppb, respectively. SOMO35 ozone levels during the periods 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018 and 2018-2019 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 Fig. 1.

The average annual concentrations of $PM_{2.5}$ pollutants during the years 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018 and 2018-2019 are 60.6, 68.1, 68.9, 61.4, 62.4, 60.6, and 59.6, respectively. Thjs was 6.06, 6.81, 6.89, 6.14, 6.24, 6.06, 5.96 times the amount of the WHO guideline (10 µg/m3) (24). These results are consistent with other studies [25]. The average annual concentrations of NO_2 pollutants during the years 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018 and 2018-

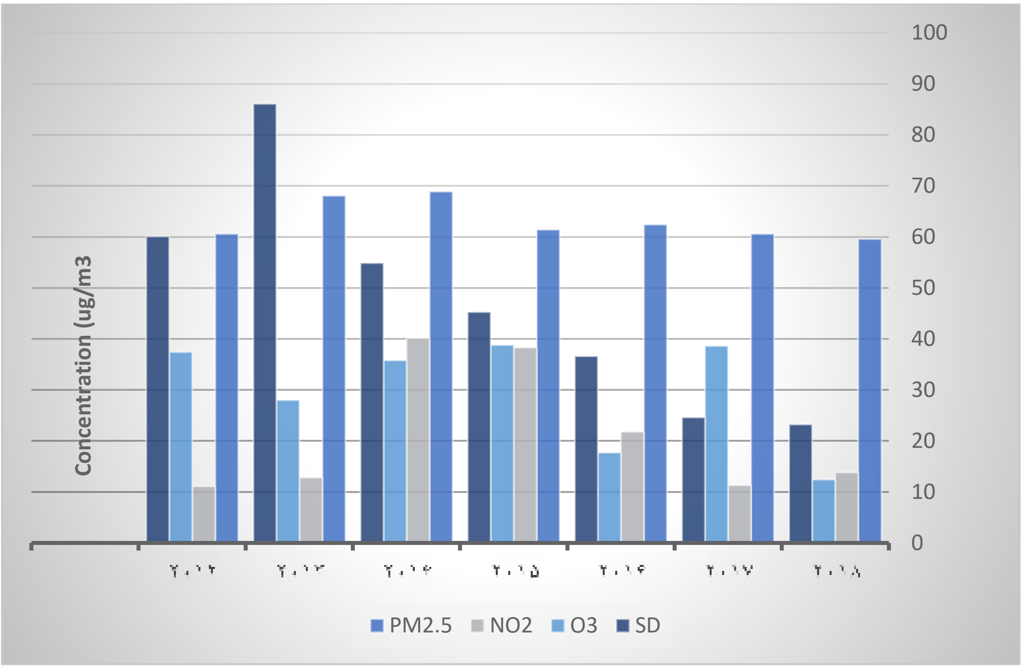

Fig. 1. Annual averages and standard deviations of the $PM_{2.5}$, NO_2, and O_3 during the study period in ambient air of Ahvaz city

2019 are 11.1, 12.8, 40.1, 38.3, 21.8, 11.3 and 13.8, respectively. This was higher only in the period 2014-2015 and less in the rest of the periods than the guidelines of the World Health Organization (40 µg/m^3).

The average annual concentrations of O_3 pollutants during the years 2012-2013, 2013-2014, 2014-2015, 2015-2016, 2016-2017, 2017-2018 and 2018-2019 are 37.4, 28, 35.8, 38.8, 17.7, 38.6 and 12.4, respectively. For all years, it has been less than the guideline of the World Health Organization (100 µg/m^3) [26]. These results are consistent with other studies.

In this study, it was found that the trend of pollutant concentrations in Ahvaz during the study period was irregular and did not follow a specific rule. Cardiovascular mortality attributed to ambient air pollutants in Ahvaz, Iran was studied and found that the average daily concentration of ozone and nitrogen dioxide in the period from 1387 to 1394 was 62 (31.07 ppb) and 44.20 µg/m3 [27].

Tables 4 and 3 attributable ratio (AP) and number of natural and respiratory deaths due to short-term contact and Tables 6 and 5 AP and number of natural and respiratory deaths due to long-term contact with $PM_{2.5}$, NO_2 and O_3 Reported. The attribution ratio represents the percentage of health outcomes in a population due to a given pollutant. In the case of natural death, the highest and lowest natural mortality were related to $PM_{2.5}$ and O_3, respectively. The highest long-term health effects of $PM_{2.5}$ and NO_2 were observed in the fifth and fourth years, respectively.

Table 3. Attributable proportion due to short-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period

Pollutant	Health outcome	Attributable proportion (%)						
		2012	2013	2014	2015	2016	2017	2018
$PM_{2.5}$	Natural mortality	4.26	4.26	5.23	4.35	4.47	4.26	4.26
NO_2	Naural mortality	0.03	0.08	0.81	0.76	1.04	1.04	1.04
O_3	Natural mortality	0.12	0.17	0.06	0.05	0.06	0	0
	Respiratory mortality	0.12	0.17	0.06	0.05	0.06	0	0
	cardiovascular mortality	0.19	0.29	0.09	0.08	0.11	0	0

Table 4. Attributable cases due to short-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period

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

Table 5. Attributable proportion due to long-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period

Pollutant	Health outcome	Attributable proportion (%)						
		2012	2013	2014	2015	2016	2017	2018
$PM_{2.5}$	Natural mortality	26.24	29.5	29.83	26.6	26.51	26.24	25.67
	ALRI	0	30.92	31.14	28.97	29.27	28.72	28.41
	COPD mortality	23.81	25.07	25.89	25.89	24.28	23.81	23.52
	LC mortality	21.53	23.54	23.57	21.76	24.28	21.53	21.28
	IHD mortality	24.29	25.8	25.95	24.46	24.67	24.29	24.07
	Stroke	22.28	23.89	25.95	24.46	24.67	24.29	24.07
NO_2	Natural mortality	0.44	1.12	11.39	10.57	4.52	0.52	1.52
O_3	Respiratory mortality	0.52	0.77	0.25	0.25	0.28	0	0

Table 6. Attributable cases due to short-term exposure to $PM_{2.5}$, NO_2, and O_3 during the study period

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

On average, 15%, 8.8% and 43.75% of deaths during the seven years were due to the short-term exposure to $PM_{2.5}$, NO_2 and O_3, respectively, and the rest were due to long-term exposure. Mortality from short-term exposure to ozone is higher than total mortality from $PM_{2.5}$, NO_2. For example, about 3.60 to 5.02% of natural deaths in Ahvaz were due to exposure to $PM_{2.5}$ [16], which is lower than the results of this study.

In total, in the whole study period, the number of natural mortality due to long-term contact with $PM_{2.5}$ was 11291 individuals; for short-term contact, it was 2000 individuals; the number of natural mortality due to long-term contact with NO_2 was 3206 individuals; and short-term contact was 309 individuals. The number of natural deaths due to long-term exposure to O_3 is 81 and short-term exposure is 63 $PM_{2.5}$ was in a worse position than the other two pollutants and was identified as the responsible pollutant. Researchers in a study in Tehran (Iran), entitled "Determining the effects of air pollutants in Tehran in 2012 on health" found that the largest share of health effects was attributed to suspended particles of 2.5 and 10 μm [24]. Which is exactly consistent with the results of this study. In Ahvaz, Iran AP, the total number of respiratory deaths due to ozone exposure was examined, which was determined to be 6.17% and 173 people, respectively, which is more than the present study. This difference may be due to a numerical difference in geographical distribution, the population at risk (recording the population census, taking into account the growth rate), or the difference in the average daily recording of pollutants [29]. The death rates of IHD, COPD, lung cancer and ALRI and stroke related to $PM_{2.5}$ were 2023, 128, 110, 23, 802, respectively. The number of respiratory deaths attributed to ozone was 68. In Ahvaz in the periods 2017-2018 and 2018-2019, no respiratory mortality due to ozone has been determined. Research conducted in São Paulo, Brazil during 1998-2008 showed that cardiovascular mortality was 55.9 per 100,000 and respiratory mortality was 15.6 per 100,000 [29]. This mortality rate is almost similar to the mortality rates and ratios determined in this study.

In Ahvaz, no study has been conducted to investigate the effects of gas particles. This study is one of the few studies that investigates the health effects of pollutants in Ahvaz. In a study, it was estimated that the average annual AP and the number of deaths due to lung cancer caused by $PM_{2.5}$ in Ahvaz were about 25% and 23 cases, respectively [6]. Which is closely similar to the results of this study.

WHO health impact reports, number of deaths, Missing Years (YLL) and Disability-Adjusted Life Years (DALY) due to exposure to airborne particles in Iran in 2012 were 1460, 37, 894, 38, 258 years Respectively. In the case of COPD, YLL, DALY and the number of deaths due to COPD due to long-term exposure to $PM_{2.5}$ were 8513 years, 23441 years and 434 cases, respectively. Also, the mortality rates of YLL, DALY and ischemic heart disease (IHD) due to exposure to $PM_{2.5}$ in Iran were estimated to be 422105 years, 425114 years and 16484, respectively [30]. Excessive costs have been imposed on countries due to air pollution. The health effects of environmental air pollution in Iran have led to a decrease in total welfare and GDP of 30.6 million dollars and 2.48% in 2013, respectively. Also, the total lost labor production and its share in Iran's GDP was 1471 million dollars and 0.12%, respectively [31]. Therefore, air pollution in Ahwaz is considered as a serious problem and requires the attention of policy makers to take preventive and control measures in this regard. By designing and implementing strategies and measures to control air pollution, including continuous monitoring of air pollution indicators and identifying influential factors, we can prevent both health effects and economic losses caused by air pollution. Since motor vehicles and dust storms in the middle east are the main source of air pollution in Ahwaz, to reduce the effects of these pollutions in Ahwaz, program development and cooperation between organizations and even neighboring countries as well as improvements in motor vehicles will definitely lead to significant effects. The results of this study will be useful for political and economic regulations. The strengths of this study were: 1), all data related to air pollutants and the baseline incidence have been collected from government and trusted organizations from the center in Khuzestan province (Ahvaz) and the ministry of health, which has led to a relatively large volume of data. 2) Compared to previous studies, given the length of the 7-year period and the large amount of data, it allowed us to examine communications at a high level of reliability and reliability. 3) The inclusion of 4 air pollution monitoring sites has provided a basis for better demonstration of the effects of air pollution compared to other studies. 4) This study was one of the few studies conducted in one of the most polluted cities in the world (Ahvaz) and in all gender and age groups (total population). However, this study has its limitations. Our research has some limitations. Similar to other studies, the effects and interplay between air pollutants and health (mortality and hospital admission) require interpretation-the effect might vary for each region. Fixed monitoring stations in specific urban locations represent the total exposure of people to pollutants for all residents of the area. This generalization may not always be true and represent the total contact of the population with the pollutant. On the other hand, exposure to pollutants depends on many conditions, such as indoor and outdoor activities, residence, occupational exposure, and so on. Other potential contributing factors, such as BMI, education and income, smoking, physical activity, and medical history, are not included in this study, which may have a potential impact on the relationship between air pollutants and hospitalization, mortality etc. The Relative Risks (RR) used to estimate the effects of pollutants on health are based on program defaults and studies 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, such as respiratory habits, age, diet, existing or genetic diseases, socioeconomic status etc.

Conclusion

We investigated the short-term and long-term health effects associated with exposure to $PM_{2.5}$, NO_2 and O_3 in Ahwaz, Iran over a seven-year period using the $AirQ^+$ model. Contaminant concentrations were often higher than WHO guidelines. Both long-term and short-term effects of $PM_{2.5}$ on health were greater than those of NO_2 and ozone. The total number of natural deaths due to $PM_{2.5}$ and NO_2 weight in all studied years were 13291, 3515 and 144, respectively. The death rates of IHD, COPD, lung cancer and ALRI and stroke related to $PM_{2.5}$ were 2023, 128, 110, 23, 802, respectively. The number of respiratory deaths attributed to ozone was 68. Other studies have shown that the health effects of air pollution impose direct and indirect costs on countries. Therefore, by designing and implementing strategies and measures to control air pollution, we might be able to curb both health effects and economic losses. Policymakers and experts in the field should focus on reducing air pollution.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely observed by the authors.

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