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Mortality and morbidity due to exposure to outdoor air pollution in Mashhad metropolis, Iran. The AirQ model approach



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ABSTRACT

In the past two decades, epidemiological studies have shown that air pollution is one of the causes of morbidity and mortality. In this study the effect of PM₁₀, PM_{2.5}, NO₂, SO₂ and O₃ pollutants on human health among the inhabitants of Mashhad has been evaluated. To evaluate the health effects due to air pollution, the AirQ model software 3.3.2, developed by WHO European Centre for Environment and Health, was used. The daily data related to the pollutants listed above has been used for the short term health effects (total mortality, cardiovascular and respiratory mortality, hospitalization due to cardiovascular and respiratory diseases, chronic obstructive pulmonary disease and acute myocardial infarction). PM_{2.5} had the most health effects on Mashhad inhabitants. With increasing in each 10 µg/m³, relative risk rate of pollutant concentration for total mortality due to PM₁₀, PM_{2.5}, SO₂, NO₂ and O₃ was increased of 0.6%, 1.5%, 0.4%, 0.3% and 0.46% respectively and, the attributable proportion of total mortality attributed to these pollutants was respectively equal to 4.24%, 4.57%, 0.99%, 2.21%, 2.08%, and 1.61% (CI 95%) of the total mortality (correct for the non-accident) occurred in the year of study. The results of this study have a good compatibility with other studies conducted on the effects of air pollution on humans. The AirQ software model can be used in decision-makings as a useful and easy tool.

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1. Introduction

Industrialization, urbanization and population growth leads to environmental pollution (Nicolás et al., 2008; Deshmukh et al., 2012; Sciacca & Oliveri Conti, 2009). Degradation of cities' air quality is one of the widespread and growing concerns, both in developed and developing countries (Sun et al., 2004; Lin et al., 2008).

Although much lower concentrations of air pollutants were registered respect to past years, these continue to have adverse effects on human health and air quality standards may be unable to protect sensitive groups adequately (Pope et al., 2002; Miller et al., 2007; Künzli et al., 2005; Bell et al., 2006; Fattore et al., 2011). Even air pollution caused by fuel combustion in recent years has declined significantly, the emergence of pollutants such as

ozone (O₃) and nitrogen oxides (NO₂) and, the change in the composition and size of suspended particles distribution have a significant impact on human health (Brunekreef and Holgate, 2002; Signorelli et al., 2006). In the past two decades, several epidemiological studies have shown that outdoor air pollution is one of the causes of mortality (by cardiovascular illness, reduced lung function, chronic bronchitis, etc.) and disability for exposed peoples (Oliveri Conti et al., 2011). The biological mechanisms through which these pollutants influence the human health, have not been determined unfortunately, but probably, they involves in a strong oxidation action and increase of thrombophilic plasma activity (Brunekreef and Holgate, 2002; Signorelli et al., 2006), either through the direct impact of cellular components in the airways that via activating intracellular oxidative pathways (Fattore et al., 2011).

According to World Health Organization 2006 (WHO) (Europe WHOROF, 2006), more than two million premature deaths each year can be attributed to outdoor and indoor air pollution. Several epidemiological studies have also reported the relationship

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between daily increase of O_3 , suspended particles and increased mortality but also between mortality and the hospitalization number due to respiratory and cardiovascular diseases (Pascal et al., 2013).

An assessment tool of air quality impact on health (Air Q) was developed by the WHO European Centre for Environmental Health, Bilthoven Division. AirQ software 3.2.2 is one special software which enables users to estimate potential effects on human health caused by exposure to pollution in a particular city and in a specific time (WHO, 2001). This software has been used in several studies in recent years (Fattore et al., 2011; Naddafi et al., 2012; Ghanbari Ghosikali et al., 2016; Kim et al., 2004; Lee et al., 2011).

Nitrogen dioxide (NO_2) is mainly obtained through oxidation of emitted nitrogen oxide with atmospheric oxidizers such as ozone (O_3). The main source of NO_2 is the combustion of organic fuels (heating, industrial centers and vehicles).

Sulfur dioxide (SO_2) is a highly reactive gas. The sources of SO_2 emissions are the fossil fuel combustion, mining plants and other industrial facilities. SO_2 is linked with a number of adverse effects on the respiratory system (U.S.EPA, 2016).

The tropospheric O_3 is one of reactive molecules able to producing secondary air pollutants.

O_3 concentration is generally related to others different atmospheric pollutants; in fact, it reaches a climax during the summer in suburban areas but not in urban areas. Finally, suspended particles differ with previous compounds; because it is not a single material, but it is a combination of different elements which is concentrated in liquid or solid phases. In our study we reviewed fractions smaller than $10\ \mu m$ (PM_{10}) and $2.5\ \mu m$ ($PM_{2.5}$) in diameter. Often the small fractions of suspended particles coming from combustion, instead, the larger fractions resulting from mechanical processes and re-suspension.

The Mashhad city is one of the most polluted cities of Iran for presence of numerous industrial plants but also for the excessive heavy urban traffic in most parts of city. Air quality of Mashhad is far from the ideal and this environmental conditions is a severe risk for the resident people.

In our study, the effects of pollutants NO_2 , SO_2 , O_3 , PM_{10} and $PM_{2.5}$, on health of citizens of Mashhad city have been evaluated using the AirQ software 3.2.2 approach.

2. Materials and methods

2.1. Study area

Mashhad is the second-largest metropolis of Iran and it is the capital of Razavi Khorasan province, Mashhad has been located in northeastern Iran. Mashhad has been situated in longitude from $59^{\circ}35'E$ to $59^{\circ}74'E$ and latitude from $36^{\circ}14'N$ to $36^{\circ}48'N$. Mashhad is about $315\ km^2$ and its population according to the last census is 2,766,258 people (Statistical Centre of Iran, 2015). Men and women represent 49.9% and 50.1% of citizen respectively. The Mashhad population is constituted by 24.2% of 15 years old, 58.2% of 15–64 years old age group and 27.6% of people that are more than 64 years old. In the age pyramid related to the city of Mashhad, the most numerous age group is between 25 and 29 years old that represents the young population of the city. Fig. 1 shows the location of Mashhad and of its air pollution monitoring stations.

2.2. Air Q software 2.2.3

In this model, evaluation is carried out by AirQ software 2.2.3 (WHO) based on the attributable proportion (AP). It is defined as

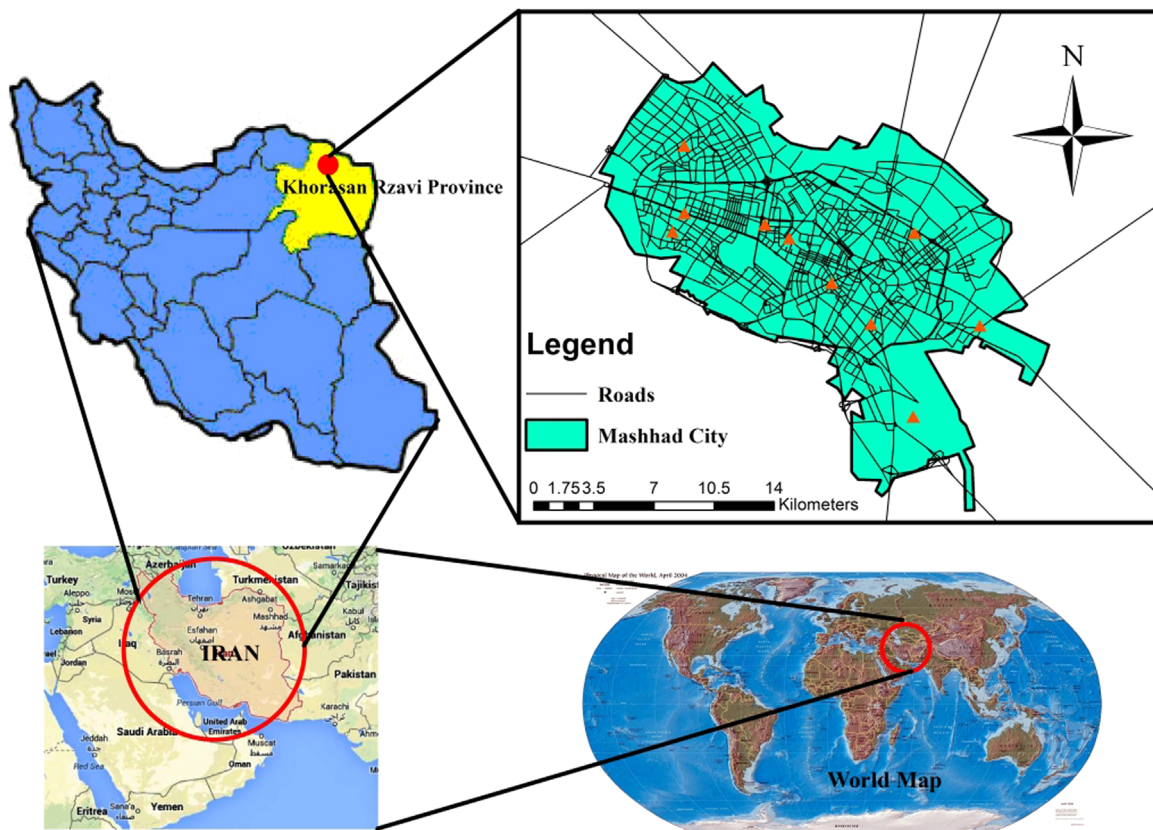


Fig. 1. Study area and monitoring stations.

the fraction of the health effect in a defined population attributable to exposure to atmospheric pollutant, assuming a demonstrated causal relation between exposure and health effect, and no major confounding effects in this association. AP can be obtained by the following equation:

$$AP = \left(\sum \{ [RR(c) - 1] \times P(c) \} \right) / \left(\sum [RR(c) \times P(c)] \right) \quad (1)$$

Where relative risk (RR) is the RR for a given health endpoint, in category “c” of exposure, obtained from the exposure-response functions derived from epidemiological study and P (c) implies the proportion of the population in category “c” of exposure.

If the baseline frequency of the health effect in the population under investigation is ascertained, the rate attributable to the exposure can be calculated as

$$IE = I \times AP \quad (2)$$

Where, IE is the amount of health effect attributable to the exposure, and I is the baseline frequency of the health effect in the population under investigation. Finally, knowing the size of the population, the number of cases attributable to the exposure can be estimated as follows:

$$NE = IE \times N \quad (3)$$

Where NE implies the number of cases attributed to the exposure and N implies the size of the investigated population (Naddafi et al., 2012; Gharehchahi et al., 2013; Hassanvand et al., 2013).

RR reflects the rate of a pollutant’s impact on the health by a change in exposure to air pollutants. RR is obtained through time series studies that evaluate the concentration changes of air pollutants and their effects on health during a long time period (Fattore et al., 2011).

Table 1 shows RR value used in this study. With regard to the fact that so far no time-series study has been done in Iran, the WHO default data available by AirQ software were used in this study. The RR value for PM₁₀ and PM_{2.5} based on the meta-analysis of peer-reviewed performed in Europe was used by Anderson et al. (2004). The amount of RR for NO₂, SO₂ and O₃ based on conducted studies were used by the APHEA project (Samoli et al., 2006; Gryparis et al., 2004).

Although the use of RR obtained from the studies carried out in other regions may increase prediction error of the model, it still can provide valuable information on the effects of air pollutants in the study area for policy-makers and officials in order to minimize the health effects and applying necessary management.

The baseline incidence (BI) rates were obtained for 2014–2015 from health deputy of Mashhad, total mortality, mortality caused by cardiovascular diseases and mortality resulting from respiratory diseases by University of Medical Sciences and, default AirQ software was used for other health effects investigated in this study.

2.3. Air pollution data monitoring and exposure assessment

There are 12 air pollution monitoring stations in the Mashhad city, which are available to Environmental Protection Agency. In this study necessary data from March 20, 2014 to March 20, 2015 was obtained from the Environmental Protection Agency. Based on WHO guideline, some cases out of the data taken from the stations were excluded from the study because invalid for evaluating the health effects caused by air pollutants.

Finally, for the pollutants NO₂, SO₂, O₃, PM₁₀ and PM_{2.5}, respectively, 9, 7, 4, 5 and 11 stations were used, covering so all areas of the city, and all stations were active throughout the study period. In order to enter air pollution data into AirQ software, with regard to the temperature and pressure in the study area, conversion of gaseous pollutants standard from ppb to µg/m³ was

Table 1
Relative risk (RR) with 95% CI and corresponding reference implemented in Air Q 2.2.3 software and used for the health effect estimates.

Outcome	Health endpoint ^b	Incidence	Relative risk ^a (95% CI) per 10 µ/m ³				
			PM ₁₀ (Daily average)	PM _{2.5} (Daily average)	O ₃ (1hr average)	NO ₂ (Daily average)	SO ₂ (Daily average)
Mortality	Total ICM-9-CMb < 800	443,44	1.006(1.004–1.008) (20)	1.015(1.011–1.019) (20)	1.0046(1.0028–1.0066) (22)	1.003(1.002–1.004) (21)	1.004(1.003–1.0048) (23)
	Cardiovascular ICM-9-CM 390–459	115,05	1.009(1.005–1.013) (20)		1.004(1.002–1.006) (22)	1.004(1.003–1.005)(21)	1.008(1.002–1.012) (24)
	Respiratory ICM-9-CM 460–519	72	1.013(1.005–1.02) (20)		1.008(1.004–1.012) (22)		1.01(1.006–1.014) (24)
Morbidity	HA ^c Respiratory Disease	1260	1.008(1.0048–1.0112) (25)				
	HA Cardiovascular Disease	436	1.009(1.006–1.013) (26)				
	HA CODP ^d	101,04		1.0058(1.0022–1.0094) (27)		1.0026(1.0006–1.0044) (21)	1.044(1.0–1.011) (27)
	Acute myocardial infraction	132				1.0036(1.0015–1.0084) (28)	1.0064(1.0026–1.0101) (28)

a Crude rate per 100,000 inhabitants.

b International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-cm).

c Hospital admissions.

d Chronic Obstructive Pulmonary Disease.

Table 2
Summary of the concentrations of air pollutants and meteorological variables in Mashhad city (2014–2015).

Pollutant (μm^3)	Min	Max	Mean	St. Deviation	98 percentiles	No. of station
PM10 annual average 24 h	14.5	341	82.9	38.51	164.05	5
PM2.5 annual average 24 h	7.72	126.35	40.72	16.87	89.3	11
NO2 annual average 24 h	25.71	911.79	87.09	108.59	473.09	9
SO2 annual average 24 h	25.22	120.54	73.86	7.74	89.44	7
O3 annual average 1 h	14.32	153.65	56.4	18.44	91.89	4
Relative humidity (%)	12	100	46.38	23.75	93.16	
Temperature ($^{\circ}\text{C}$)	−8	33.2	15.34	11.22	31.87	
Pressure (mbar)	886	919.73	902.23	5.13	913.56	

made and then they were classified at intervals of $10 \mu\text{g}/\text{m}^3$. The numbers of exposure days for each of the pollutants at specified intervals as well as the annual and seasonal mean, maximum annual and seasonal and 98th percentile of pollutants were calculated to enter into the software. The daily average was used for the NO_2 , SO_2 , PM_{10} and $\text{PM}_{2.5}$ pollutants and 1-hour average “moving average” was utilized for O_3 .

3. Results and discussion

The statistical summary of the various pollutants investigated in this study have been reported in Table 2.

During the study period, annual average of PM_{10} was $82.9 \mu\text{g}/\text{m}^3$, its concentration was 1.64 times greater than WHO guideline ($50 \mu\text{g}/\text{m}^3$) and for annual maximum it was 6.82 times greater than WHO guideline (Europe WHOROF, 2006). The annual average concentration of $\text{PM}_{2.5}$ was $40.72 \mu\text{g}/\text{m}^3$, its value is 1.62 times greater than the provided guideline ($25 \mu\text{g}/\text{m}^3$) (Europe WHOROF, 2006). Regarding NO_2 and SO_2 , the annual average was respectively $87.09 \mu\text{g}/\text{m}^3$ and $73.86 \mu\text{g}/\text{m}^3$ and both averages were higher than provided guideline of 40 and $20 \mu\text{g}/\text{m}^3$ respectively (Europe WHOROF, 2006).

The annual average concentration of one hour maximum O_3 was equal to $56.4 \mu\text{g}/\text{m}^3$ and lower than WHO standard of $100 \mu\text{g}/\text{m}^3$.

For pollutants PM_{10} , $\text{PM}_{2.5}$ and SO_2 , average concentration in winter was higher than summer and the highest concentration was observed in the winter. Summer was characterized by both higher average and maximum concentration for NO_2 and O_3 (Europe WHOROF, 2006).

In 2014–2015, humidity percentage for Mashhad city was in the range of 12–100% with an average of 47%. The annual averages of temperature and pressure were 16°C and 902 mbar respectively.

Fig. 2 (by A–E) show the percentage of days of exposure to different range of pollutants in the Mashhad city (respectively for SO_2 ; $\text{PM}_{2.5}$; PM_{10} ; O_3 and NO_2).

These data have been used to investigate short-term health effects of air pollutants on people's health. The highest percentage of exposure to SO_2 , NO_2 , $\text{PM}_{2.5}$, PM_{10} , O_3 was equal to 54.97%, 22.71%, 22.87%, 29.28% and 15.38% respectively, in the range concentrations of 30–39 $\mu\text{g}/\text{m}^3$ for SO_2 , $\text{PM}_{2.5}$, NO_2 pollutants, and PM_{10} and O_3 pollutants concentration range was 60–69. According to Fig. 2(A–E), residents of Mashhad were exposed at higher concentrations of SO_2 , $\text{PM}_{2.5}$ and PM_{10} pollutants respect to the WHO standards for most of days of year.

The short-term health effects (total mortality, cardiovascular mortality, respiratory mortality, hospitalization due to cardiovascular diseases, and hospitalization caused by respiratory diseases, HA COPD and acute myocardial infarction) caused by exposure to air pollutants have been listed in Table 2. The estimation of health effects caused by O_3 and NO_2 was carried out based on RR obtained respectively from the project APHEA-2 and for PM_{10} based

on meta-analysis carried out in 23 European cities (Samoli et al., 2006; Gryparis et al., 2004; Spix et al., 1998; Touloumi et al., 1996).

With regard to 13,117 cases of total non-accidental mortality in the Mashhad city in the study year 3403 mortality cases have resulted from cardiovascular diseases and 2130 deaths were caused by respiratory diseases. The total mortality of ≤ 15 years old was 614 cases and for ≥ 64 was 7037 cases.

We can be conclude that for pollutants SO_2 , NO_2 , O_3 , PM_{10} and $\text{PM}_{2.5}$ respectively 0.99%, 2.21%, 4.24%, 4.57%, 2.08%, and 1.61% of total mortality is related to these pollutants (with lag of several days as described by Gharehchahiet al., (2013) and 1.96%, 2.93%, 1.82%, 6.22% and 0% of deaths due to cardiovascular diseases are also attributable to these pollutants.

Similar studies, conducted in recent years, have shown that suspended particles have the greatest adverse effect on human health (Fattore et al., 2011; Naddafi et al., 2012).

In a study conducted in northern Italy by Fattore et al. (2011) the amount of AP to $\text{PM}_{2.5}$ was obtained equal to 4.5% and have the most adverse health effect among air pollutants. Moreover the AP for PM_{10} , was to 2.5% so less than $\text{PM}_{2.5}$.

Results of Fattore study were consistent with our study. Additionally, in the study carried out by Naddafi et al. (2012) in Tehran, another Iranian city with a population of 8.7 million people, the amount of AP to PM_{10} was higher among the studied pollutants but $\text{PM}_{2.5}$ was not investigated. The amount of calculated AP in this study was 4.6%.

RR reflects the increased risk caused by exposure to a pollutant which is obtained through time-series studies. It investigates the daily relationship between air pollution and emerged health effects, such as mortality due to cardiovascular and respiratory diseases or hospital admissions due to cardiovascular and respiratory diseases. With every $10 \mu\text{g}/\text{m}^3$ increase in pollutant concentration, the amount of RR for the increase of total mortality caused by NO_2 , SO_2 , O_3 , PM_{10} and $\text{PM}_{2.5}$, was 0.4%, 0.46%, 0.6%, 1.5% and 0.3% respectively. Given the increase in RR, it can be concluded that $\text{PM}_{2.5}$, by enhancing concentration, has had the most effect on human health.

In our study, 0.99% of the total mortality in Mashhad was attributed to SO_2 (130 cases), 2.21% was attributed to NO_2 (290 cases) and 2.09% of non-accidental deaths in Mashhad city was attributed to O_3 (274 cases). In a study conducted in South Korea, in Suwon city with a population of 1180000 residents, the attributable mortality rate and the (AP) for SO_2 , NO_2 and O_3 were 0.3% (11 cases), 1.9% (81 cases) and 1% (43 cases) respectively (Jeong, 2013).

In another study conducted in Italy, the amount of AP for total mortality attributable to NO_2 and O_3 were reported equal to 1.8% and 1.5% respectively (Fattore et al., 2011). Also, in a study carried out in Tehran, the amount of total mortality and AP attributable to SO_2 , NO_2 and O_3 pollutants were 1458 cases (3%), 1050 cases (2.2%) and 819 cases (1.83%) respectively (Naddafi et al., 2012). The AP amount attributable to NO_2 in this study was similar for both Tehran and Italy reports.

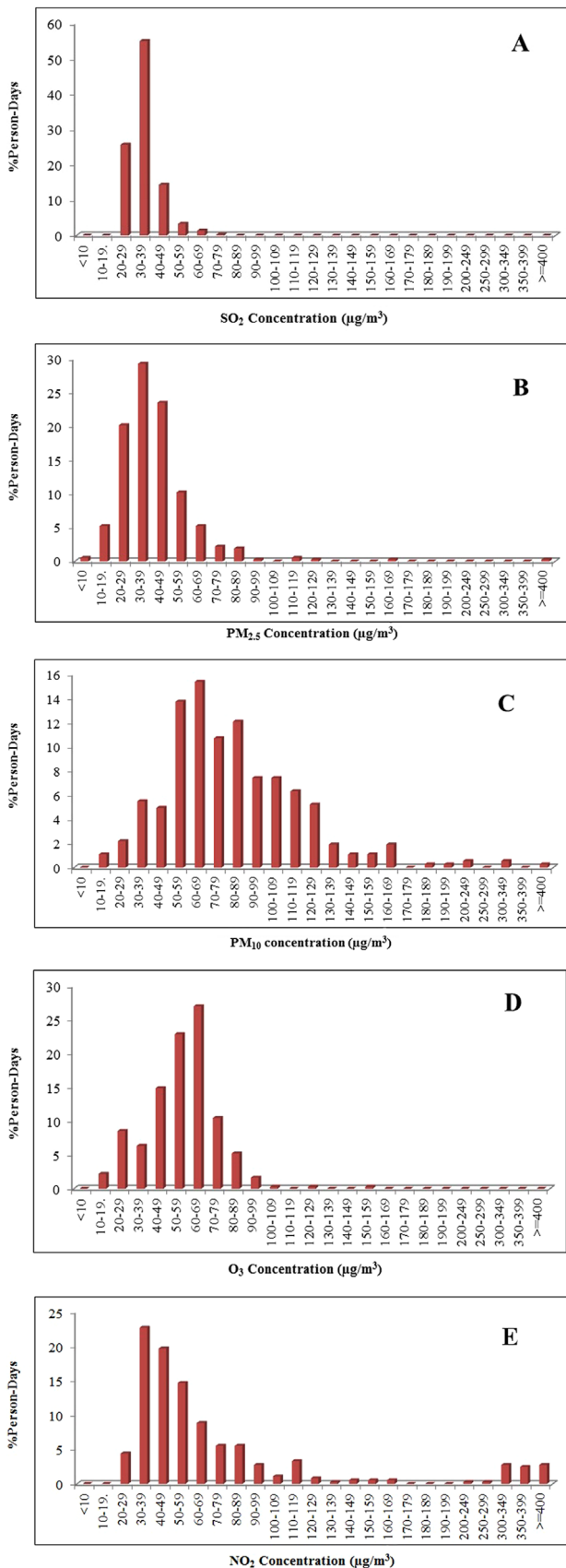


Fig. 2. A. Percentage of days on which Mashhad people are exposed to different concentrations of SO₂. B. Percentage of days on which Mashhad people are exposed to different concentrations of PM_{2.5}. C. Percentage of days on which Mashhad people are exposed to different concentrations of PM₁₀. D. Percentage of days on which Mashhad people are exposed to different concentrations of O₃. E. Percentage of days on which Mashhad people are exposed to different concentrations of NO₂.

One study conducted in Milan (Italy) (1,308,000 inhabitants), the total mortality caused by exposure to PM₁₀ was 677 people (Martuzzi et al., 2002). In a study carried out in 13 cities of Italy with a total population of about 9 million inhabitants during the years 2002–2004 (Martuzzi, 2006), it was reported, 8220 mean deaths in a year caused by exposure to PM₁₀ with concentration more than 20 µg/m³. In this study it was also estimated that 516 additional deaths occurs annually for exposure to O₃, and that for short term exposure to PM₁₀ 1372 extra mortality was occurred.

As shown in Table 3, the AMIs (Acute myocardial infarction) attributable to the NO₂ and SO₂ exposure in a year are been respectively 62 and 103 cases. The low amount of AP in chronic obstructive pulmonary disease (COPD) in Table 3 for SO₂ compared to NO₂ indicates low rate of relative risk at low level, so that 33 cases have been estimated in central RR level for the above cases. Based on the results obtained in Toronto, hospital admissions for COPD have been 7.72%, 4.40% of which were due to contact with NO₂ (Burnett et al., 1999). Goudarzi et al. used Air Q software model to estimate the health effects of NO₂ in Tehran. Based on their results 3.4% of total cardiovascular deaths, myocardial infarction and hospital admissions for chronic obstructive pulmonary disease were attributed to concentrations greater than 60 µg/m³ (Goudarzi et al., 2009).

A limitation of AirQ software model is that are not taken into consideration the health effects caused by exposure to mixtures of several pollutants or their synergistic effects, but only the effect of a single pollutant is investigated. However in quantitative assessments of health impacts by air pollution, the interaction between different pollutants cannot be investigated, because such investigations requires knowledge about the mechanism of the toxicity of different compounds toxicity, which are today rarely available.

Generally, to consider a health effect caused by the simultaneous presence of several pollutants in the environment, it is often assumed that simultaneous effect is additive compared to the effect of each pollutant. However, taking into account a single effect for an air pollutant is not true because most of the time it has a significant and positive correlation with each other. So, the health effects caused by a pollutant can be increased.

Other limitations of our study were:

- the use of few fix point data to investigate exposure of all people of Mashhad could be solved by using the mobile air pollution monitoring stations.

the use of RR related to studies conducted in European countries and U.S.A. therefore, given that RR could be different regarding the type and texture of population, it could increase the our prediction error, but this possibility was accepted by several editors (WHO, 2001).

4. Conclusion

The AirQ software developed by WHO to investigate health effects of air pollutants was used in this study. The quantitative effects resulting from exposure to pollutants NO₂, SO₂, O₃, PM₁₀ and PM_{2.5} in Mashhad were investigated. This study showed that suspended particles of PM_{2.5} and PM₁₀ have the greatest adverse effect on people's health. The results of this study were consistent with other studies in this topic.

Urgent actions are needed to reduce both air pollution and its negative health outcomes in Mashhad.

On the basis of our results, we recommend the adoption of several reliable actions useful to better manage the Mashhad's air pollution.

Table 3Estimated AP expressed as percentage and excess of number cases in a year due to short-term exposure above 10 µg/m³ for PM₁₀, PM_{2.5}, SO₂, O₃ and NO₂.

Health endpoints	Pollutants	AP (uncertainty range)	No. of excess cases (uncertainty range)
Total mortality	PM10	4.2473(2.8722–5.584)	557(377–733)
	PM2.5	4.5749(3.3963–5.725)	600(445–751)
	SO2	0.9923(0.746–1.1884)	130(98–156)
	NO2	2.2132(1.4864–2.9293)	290(195–384)
	O3	2.0912(1.2834–2.9734)	274(168–390)
Cardiovascular mortality	PM10	6.2385(3.5647–8.768)	212(121–298)
	SO2	1.965(0.4986–2.9189)	67 (17–99)
	NO2	2.9293(2.2132–3.635)	100 (75–124)
	O3	1.8234(0.9201–2.7104)	62 (31–92)
Respiratory mortality	PM10	8.768(3.5647–12.8811)	187(76–274)
	SO2	2.4443(1.4811–3.3889)	52 (32–72)
	O3	3.5816(1.8234–5.2778)	76 (39–112)
Hospital Admissions Cardiovascular Disease	PM10	5.584(3.427–7.646)	2081(1277–2850)
Hospital Admissions Respiratory Disease	PM10	6.2385(4.2473–8.768)	805 (548–1131)
Hospital Admissions COPD	SO2	1.0904(0.00–2.6822)	33 (0.0–80)
	NO2	1.9238(0.4506–3.2129)	58 (14–96)
	O3	2.6225(1.0112–4.1821)	79 (30–125)
	SO2	1.5782(0.6472–2.4681)	62 (25–96)
Acute Myocardial Infarction	NO2	2.6441(1.119–5.9596)	103(44–233)

Some indications are:

- The restriction of mineral oil's use preferring an eco-friendly mechanic energy and/or urban public transport systems;
- The improvement of urban traffic management through an urban and road planning coupled to greater and more efficient new auto industry productions but also encouraging the car sharing;
- The sponsorship of studies for the evaluation of the disease burden attributable to air pollution and of the health effects of air pollutants ;
- Finally, it recommends to increase the use of air Q models to better identify and manage the urban and industrial areas showing higher risks for air pollutant's emissions.

Despite limitations of this approach in our study and in similar studies, this AirQ model represents an useful and suitable tool for policy makers and decision makers to enact environmental and health rules in order to reduce the health effects of air pollutants.

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