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Cause-specific mortality attributed to fine particles in Mashhad, Iran (2013-2017)

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ABSTRACT:

Introduction: This study aimed to determine the number of all-cause, lung cancer, chronic obstructive pulmonary disease (COPD), ischemic heart disease (IHD), and stroke deaths due to exposure to $PM_{2.5}$ in Mashhad during March 2013-March 2017 using the AirQ+ model.
Materials and methods: Hourly concentrations of fine particulate matter were obtained from Department of Environment (DOE) of Iran, and validated according to APHEKOM study and WHO's criteria. Baseline incidence (BI) values for all-cause, COPD, lung cancer, IHD and stroke mortality was obtained from Ministry of Health and Medical Education.
Results: The annual average of (±SD) was determined for all four years and the average four- year were 36.07 (± 26.93), 27.29 (± 13.24), 30.53 (± 13.82), 30.14 (± 15.94), and 31.01 (± 10.22) µg / m^3, respectively. The averages of $PM_{2.5}$ concentrations during the cold months of years was higher than those in the warm months. Calculating the daily air quality index (AQI) indicated that only few days (48 days) during this period of time (4 years) had a "standard" air quality and a concentration lower that 12.5 µg / m^3. The total number of deaths in all the four years was 4457 cases. Furthermore, the total number of COPD, lung cancer, IHD, and stroke mortality was 146, 142, 5263, and 2608 cases, respectively. The trend of death numbers did not follow a specific direction, and some fluctuations can be observed.
Conclusion: Due to the considerable health effects of the poor air quality in Mashhad, controlling actions should be implemented to reduce the levels of air pollution.

Introduction

Air pollution is known as the most important environmental risk factor of health in the world [1]. Hundreds of cities suffer from high concentrations of global air pollution. The World Health Organization (WHO) announced that approximately 7 million deaths are attributed to exposure to air pollution, which 3.7 million could be the result of exposure to ambient air pollution [2]. Epidemiological studies have shown significant

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associations between exposure to air pollutants such as particulate matter of aerodynamic diameter less than 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3) and carbon monoxide (CO) and adverse health outcomes [3-7]. Particulate air pollution was introduced by International Agency for Research on Cancer (IARC) as a carcinogen to human [8].

The health effects attributed to the air pollution can be estimated. Modelling approaches are developed to estimate the number of deaths (or hospital admissions) that are caused by a specific air pollutant in a particular area [9]. Determining the number of health effects attributed to air pollution can be useful for management purposes. Since each death, hospitalization or medication forces a financial burden to health-care systems [10, 11], managers benefit from the results of health impact assessments to allocate financial resources in more effective way.

Several studies have been conducted to estimate the health impacts of air pollution in Iran [12-18]. In some research, it was used AirQ 2.2.3 to estimate the health effects of PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2 during 2013-2016 period [12]. In another study, gender-specific lung cancer deaths due to exposure to $PM_{2.5}$ were estimated by AirQ+ for 10 cities of Iran during 2013–2016 [13]. In another study, spatial and temporal trends of short-term health effects of $PM_{2.5}$ in Iranian cities were estimated by AirQ+ modelling approach [17]. In another study, the number of deaths due to chronic obstructive pulmonary disease (COPD), lung cancer, and all-natural causes were estimated for Tehran [19]. In addition, the number of ischemic heart disease (IHD) and stroke deaths attributed to $PM_{2.5}$ in 15 Iranian cities were estimated in another study [20].

Mashhad with more than 3 million residents is the second most populous city in Iran. This city is located in the northeast of the country. Every year about 25 million pilgrims and tourists visit this city. This has led to a major air pollution problem for Mashhad, as other cities of Iran [21-26]. There are limited studies that quantify the health effects of atmospheric $PM_{2.5}$ in Mashhad using AirQ+. This software was released by the WHO in 2016 and is based on new epidemiological findings. It quantifies the health effects attributed to exposure to outdoor and indoor air pollution [27].

This study aimed to estimate the number of all-cause, lung cancer, COPD, IHD and stroke deaths due to exposure to $PM_{2.5}$ in Mashhad during March 2013-March 2017. The procedure used in this study to validate monitoring stations was performed according to the European Commission guideline, which has some innovative criteria [28]. Despite previous studies, the baseline incidence of mortality used in this study is based on trustworthy information acquired from Ministry of Health and Medical Education [29].

Materials and Methods

Study design

Mashhad with more than 3 million residents is located in the northeast of the country. We studied the fine particulate air quality of Mashhad and its attributed health effects during March 2013-March 2017. The interest health effects was determined in this study included the number of all-cause mortality among people older than 30 years old, COPD deaths among people older than 30 years old, the number of lung cancer deaths among people older than 30 years old, the number of IHD deaths among people older than 25 years old, and the number of stroke deaths among people older than 25 years old. The estimation of health effects was performed by AirQ+ modelling software.

AirQ+ software

AirQ+ requires the following input data for a health impact evaluation: air quality data, total and at-risk population (over 25 years old for IHD and stroke and over 30 years old for COPD and lung cancer), baseline incidence of the interest health outcome i.e. all-cause deaths, lung cancer, COPD IHD and stroke, a cut-off value for pollutants' concentration, and Relative Risk (RRs) values if different from the default ones provided by WHO [30]. AirQ+ calculates different health-related estimates, including attributable proportion of cases, number of attributable cases, number of attributable cases per 100,000 at - risk population, proportion of cases in pollutant concentration range, and cumulative distribution by air pollutant concentration. These different estimates can be used in various ways depending on the assessment's objectives [30].

Air quality data

Hourly concentrations of fine particulate matter were obtained from Department of Environment (DOE) of Iran. At first, zero and negative values were removed; then, daily concentrations were calculated just in monitoring stations that met APHEKOM criteria for health impact assessment of air pollution [31]. According to these criteria, only stations are valid that have more than 75 % valid data in a year. In addition, the ratio of valid data in summer to winter or winter to summer should not exceed 2 [32]. Daily concentrations of $PM_{2.5}$ in the selected year was prepared to enter the AirQ+ model.

Demographic data

Age - specific population of Mashhad was received from Statistical Centre of Iran. At–risk population (the number of people >25 years old and >30 years old) was calculated. Table 1 presents total population, population over 25 and 30 years old in Mashhad during the study period.

Baseline incidence (BI)

Baseline incidence (BI) values for all-cause, COPD, lung cancer, IHD and stroke mortality was obtained from Ministry of Health and Medical Education [29].

Results and Discussion

Fig. 1 shows the descriptive statistics and probability density of the 24 h averages of $PM_{2.5}$ over each year. We also calculated the 4 years averages of daily $PM_{2.5}$ concentrations, and the results of its distribution are presented in Fig. 1. The median concentrations over each of the four years and the 4 years averages were 30.90, 24.80, 28.00, 27.04, and 29.28 µg / m^3, respectively. In addition, the average (±SD) of each years and the average four – year were 36.07 (± 26.93), 27.29 (± 13.24), 30.53 (± 13.82), 30.14 (± 15.94), and 31.01 (± 10.22) µg / m^3, respectively. Fig. 1 shows that the first year (2013 - 2014) had a wide range of concentrations, comparing to other years. The distribution of concentrations in the Fig. 1 indicates that there is a skewness for the high concentrations of each year.

According to our findings, the annual average

Table 1. Total population and population with age more than 25 and 30 years old

Population	Year			
	2013-2014	2014-2015	2015-2016	2016-2017
Total population	2831220	2982200	3046550	3012090
>25 years old population	1622880	1733550	1791400	1822725
>30 years old population	1295910	1396200	1457950	1506161

concentrations of $PM_{2.5}$ in Mashhad was about 2.7 - 3.6 times higher than the value recommended by the WHO [33]. This means that there is extremely high risk for the health of Mashhad residents. In comparison to other studies, our results showed a good agreement. In a study, the average concentrations of $PM_{2.5}$ in Mashhad during three years was between 30 and 40 µg / m^3 [13]. Similar results were reported in some other studies [17, 20]. In another study, the annual mean of PM_{10} concentrations was calculated to be 84 µg / m^3 [34]. In another study, the authors investigated the $PM_{2.5}$ concentrations in Mashhad during the 2013. They reported that the annual average of $PM_{2.5}$ was 37.85 µg / m^3 [35]. In another study, the annual average (±SD) concentration of $PM_{2.5}$ in Mashhad within 2014 - 2015 was reported to be 40.72 (± 16.87) µg / m^3 [36]. This value was considerably higher than the average concentration for the 2014-2015 period reported in this study (27.29 µg / m^3). This is possibly due to the different methods of data validation, as we only considered the monitoring stations that had at least 75 % data completeness.

Fig. 2 shows the monthly averages of $PM_{2.5}$ during the each year and 4 year averages. According to this Figure, the second half of each year had higher concentrations comparing to the first half of that year. This can be due to the higher meteorological stability and incidence of inversion in the mornings that traps traffic - related emissions in the first layer of atmosphere and increases the air pollution levels [37]. In another study conducted in Mashhad, it was reported that the cold season $PM_{2.5}$ average (42.79 µg / m^3) was higher than that observed in the warm season (31.07 µg / m^3). According to their results, the maximum concentration of $PM_{2.5}$ in the cold season was 302.96 µg / m^3, which was higher than 118.55 µg / m^3 that was recorded in the warm season [35]. In another study, the winter mean of PM_{10} concentrations was 85 µg / m^3 and was higher than that calculated for summer (82 µg / m^3) [34].

We calculated the air quality index (AQI) based

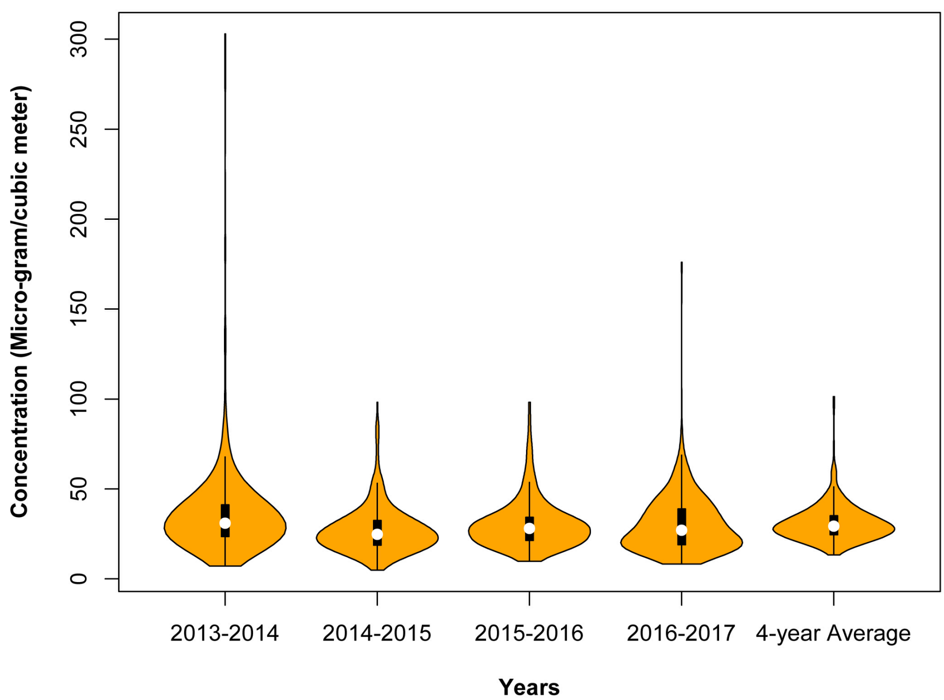

Fig. 1. Descriptive statistics and probability density of the 24 h averages of $PM_{2.5}$

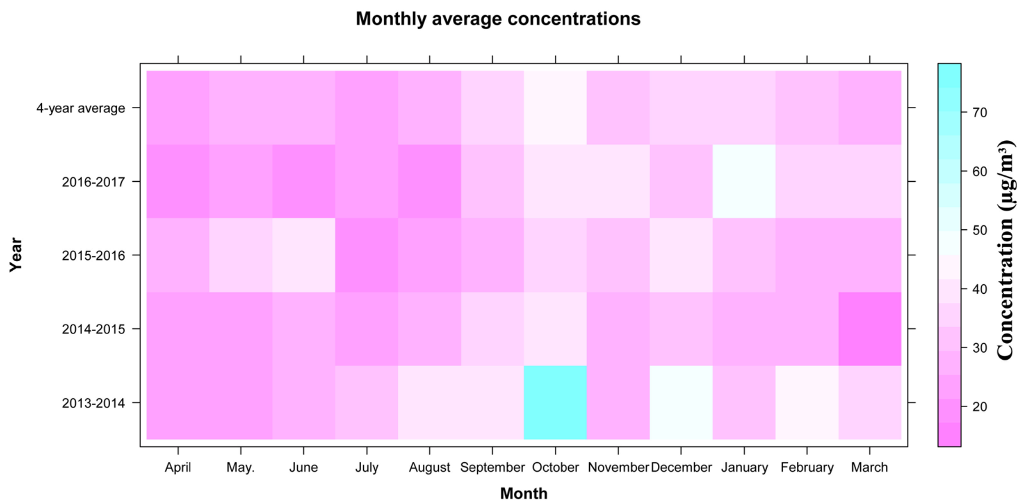

Fig. 2. Monthly averages of $PM_{2.5}$ concentrations in each year

on only $PM_{2.5}$ concentrations in Mashhad. Table 2 presents the results of AQI calculations and the number of days in each AQI category. The results showed that the first year had 135 unhealthy days, and eventually poorer air quality comparing to other years. Two days in the first year had "hazardous" air quality. The second and third years showed to have better air quality (295 and 276 days with good and moderate air quality), in comparison to other years. In overall, these results indicate that only few days (48 days) during this 4-year period had a good air quality and a concentration lower that 12.5 µg / m^3. In a study, the 24 h average concentrations of $PM_{2.5}$ in Mashhad were investigated. Their results showed that only about 1.62 % of days have $PM_{2.5}$ concentrations lower than 10 µg / m^3. About 17.41 %, 32.39 %, 29.96 %, and 18.62 % of days had concentrations in the range of 10-20, 20-30, 30-40, and 40-50 µg / m^3, respectively [35].

The number of deaths attributed to long-term exposure to $PM_{2.5}$ is presented in Table 3. It should be noted that the number of deaths for all - cause, COPD, and lung cancer was calculated for individuals older than 30 years. In addition, the IHD and stroke mortality were estimated for the individuals older than 25 years old. According to this Table, the number of all - cause deaths was 1297, 1106, 941, and 1113 cases in the first, second, third, and fourth year, respectively. The total number of deaths in all the four years was 4457 cases. Furthermore, the total number of COPD,

Table 2. Number of days in each AQI category during the four years

Categories	AQI	Breakpoints (µg / m^3)	Number of days			
			Y1*	Y2*	Y3*	Y4*
Good	0-50	0-12.5	6	20	4	18
Moderate	51-100	12.6-35	196	275	272	229
Unhealthy for sensitive groups	101-150	35.1-65.4	121	60	77	114
Unhealthy	151-200	65.5-150.4	14	8	12	4
Very unhealthy	201-300	150.5-250.4	1	0	0	1
Hazardous	301-500	250.5-500	2	0	0	0

* Y1-Y4 indicate the first year (2013-2014), second year (2014-2015), third year (2015-2016), and fourth year (2016-2017).

lung cancer, IHD, and stroke mortality was 146, 142, 5263, and 2608 cases, respectively. The trend of death numbers did not follow a specific direction, and some fluctuations can be observed. In a study, the number of lung cancer deaths attributed to $PM_{2.5}$ in Mashhad during three years was 18, 16, and 18 deaths, respectively [13]. In another study, short-term mortality and morbidity attributed to fine particulate matter in the ambient air of eight Iranian cities including Mashhad were estimated. Using AirQ 2.2.3, they reported that the total, cardiovascular, and respiratory mortality attributed to PM_{10} were 634, 396, and 118, respectively. In addition, the number of total deaths attributed to short - term exposure to $PM_{2.5}$ was 754 [34]. In a study, the health effects attributed to the short-term exposure to $PM_{2.5}$ in Mashhad were quantified. The authors reported that the number of total, cardiovascular, and respiratory deaths attributed to the short-term exposure to $PM_{2.5}$ during 2013 was 332, 263, and 32, respectively. They also reported that about 1.93 %, 1.02 %, and 2.12 % of total, cardiovascular, and respiratory deaths are attributed to the short-term exposure to $PM_{2.5}$ [35]. In another study, the authors estimated the number of total deaths attributed to the short-term exposure to $PM_{2.5}$ in Mashhad during the 2014-2015 period using the AirQ 2.2.3 software. Their results showed that 600 deaths were caused by $PM_{2.5}$ [36]. These results are not in agreement with our findings. This is possibly due to the different modelling softwares that use different exposure-response functions and relative risk (RR) values. In addition, the last two study estimated the short-term effects of $PM_{2.5}$, that are obviously smaller that long-term effects in our study.

Conclusion

This study investigated the concentrations of $PM_{2.5}$ in Mashhad as the second most populated city in Iran. In addition, the number of all-cause, COPD, lung cancer, IHD, and stroke deaths attributed to long-term exposure to fine particles were estimated using the AirQ+ modelling software. Annual concentrations of $PM_{2.5}$ were several times higher than the WHO guideline value. The averages of $PM_{2.5}$ concentrations during the cold months of years were higher than those in the warm months. High numbers of deaths were found to be caused by $PM_{2.5}$. No yearly specific trend was observed in case of $PM_{2.5}$ concentrations and number of deaths. In addition, daily air quality index (AQI) was calculated for all the four years. The results showed that only few days (48 days) during this 4-year period had a good air quality. In overall, due to the poor air quality in Mashhad that caused considerable health effects, controlling actions should be implemented to reduce the levels of air pollution.

Table 3. Cause-specific mortality attributed to long-term exposure to $PM_{2.5}$ in Mashhad during the study period (CI 95 %)

Cause of death	Number of deaths (CI 95 %)			
	Year 2013-2014	Year 2014-2015	Year 2015-2016	Year 2016-2017
All-cause	1297 (860-1,692)	1106 (733-1,442)	941 (623-1230)	1113 (740-1449)
COPD *	29 (11-44)	41 (17-65)	35 (14-57)	41 (18-63)
Lung cancer	38 (9-59)	36 (9-57)	32 (7-50)	36 (10-55)
IHD *	1116 (827-1372)	1442 (1066-1770)	1345 (988-1644)	1360 (1016-1682)
Stroke	639 (294-866)	685 (317-927)	617 (281-844)	667 (313-886)

* COPD: chronic obstructive pulmonary disease; IHD: ischemic heart disease.

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Competing Interests

The authors declare that there are no competing interests.

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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 ob-served by the authors."

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