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Original Article

Variations of $PM_{2.5}$ and Health Risk Assessment in the City of Mashhad During 2010-2018

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Abstract

Background: Air pollution stands as a significant environmental threat impacting human health across the globe, encompassing both developed and developing nations. This study aimed to survey the temporal variations of $PM_{2.5}$ and gauge its potential health effects in the city of Mashhad over the period of 2010-2018.
Methods: This cross-sectional study was carried out among the residents of Mashhad city. $PM_{2.5}$ concentration data spanning the years 2008-2019 were collected and subjected to analysis using Excel and AirQ software.
Results: The results indicate that the highest concentration of $PM_{2.5}$ was associated with the year 2010, while the lowest concentration was observed in 2015. The analytical findings demonstrated that for each 10 μg/m^3 increase in $PM_{2.5}$ concentrations, the relative risk for total mortality increased by 10.47%. Furthermore, based on the Air Quality Index (AQI) results, 2010 exhibited the most adverse condition in terms of $PM_{2.5}$ concentrations in Mashhad city.
Conclusion: In general, long-term exposure to ambient $PM_{2.5}$ significantly contributed to mortality in the megacity of Mashhad. As air pollution is a modifiable risk factor, it is advisable to implement sustainable control policies to protect public health.
Keywords: Air quality, $PM_{2.5}$, AirQ model, Mashhad

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Introduction

One of the main challenges that humans face in some urban areas is air pollution, which results from the excessive growth of industrial activities, fossil fuel consumption, and population density. Moreover, air pollution occurs when the air contains harmful substances that affect the health of humans, living beings and the environment.[1] Premature death, cardiovascular diseases, bronchitis, respiratory disorders and cancer are caused by air pollution, which is the fifth cause of death in the world. The World Health Organization (WHO) reported in 2012 that air pollution killed about seven million people. Furthermore, the United Nations report stated that particulate matter is the most significant air pollutant that directly increases the risk of death. Hence, it is essential to assess the various effects of $PM_{2.5}$ (particulate of aerodynamic diameter ≤ 2.5 μm) on human health. For this purpose, existing models can be applied, which are mainly of epidemiological statistical.[2] The model combines air quality data measured in specific concentration ranges with epidemiological factors like relative risk, base incidence, and attributable component. The result is then presented as mortality.[3] Air Q is one of the common models that has been confirmed by the WHO European Centre for Environment and Health (ECEH) for facilitation of health effect assessments. In this model, information on the relationship between contact and response is integrated with population exposure data to ultimately estimate the anticipated human health risk. Numerous recent studies across Iran have been conducted in this context.[4-6]

The quality of air in Iran is a serious issue, as some major cities such as Tehran, Mashhad, Tabriz, Isfahan, Ahvaz and Arak have very high levels of air pollutants. Mashhad, which is the second biggest religious city in the world, is also one of the most polluted cities in Iran.[7,8] The rapid increase in urban population, industrial operations, and the annual influx of over 14 million pilgrims and tourists contribute to substantial traffic congestion and pollution within the city. Additionally, the presence of numerous industrial sources, including compost factories and industries in the outskirts and nearby regions of Mashhad, adds to pollution concerns. The positioning of these industrial facilities is inconsistent with the prevailing wind direction, exacerbating the environmental challenges.[9] A study in Taiwan and Korea found that the death rate increased by 1% when the concentration of PM_{10} particles rose during the dust phenomenon. Using AirQ software to track the trend of timing pollutants in Tehran, the results revealed that the annual concentration of $PM_{2.5}$ that the citizens of Tehran faced was higher than the air quality guidelines of the WHO (10 μ/m^3), the American Environmental Protection Agency (EPA) and Iran's standard level (12 μ/m^3).[10] The estimate shows that brain disease mortality (stroke) increased by 24.5-36.2%, cardiovascular diseases mortality (ischemic heart disease, IHD) by 19.8- 24.1%, lung cancer (LC) by 13.6-19.2%, chronic obstructive pulmonary disease by 10.7-15.3% and acute lower respiratory tract infection (ALRI) by 15-25.2% due to long-term exposure to $PM_{2.5}$. The study also discovered that IHD caused the most deaths from long-term $PM_{2.5}$ exposure.[10] Moreover, Shen et al investigated total suspended particulates (TSP) and $PM_{2.5}$ in dust storms and air pollution events in Xi'an, China; their results indicated that the mass concentration of aerosols in dust events was up to eight times higher than that on normal days, and all types of particles led to reduced visibility.[11] Additionally, it is reported that concentration of PM_{10} and its chemical components were higher in winter compared to other seasons, demonstrating that the particles persist longer in the atmosphere due to low wind and low mixing height.[12] It appears that there has not been a thorough study conducted in Mashhad city regarding the analysis of temporal variations in suspended particle concentrations and the assessment of associated health impacts. Hence, there is an intention to carry out an ecological study in Mashhad, the second-largest metropolis in Iran. The outcomes of this study aim to assess air quality, cardiovascular diseases, and mortality linked to air pollution in Mashhad city, ultimately leading to viable solutions for pollutant control.

Materials and Methods

This cross-sectional study was undertaken among residents of Mashhad city from 2008 to 2019. The total daily $PM_{2.5}$ concentration data were collected from air pollution monitoring stations in the city over the same period. Population data were sourced from the Iranian Statistics Center of Mashhad. Data analysis was conducted using Excel (version 16) and AirQ 2.2.3 software. The analysis involved primary processing steps such as removal, pollutant classification, and time equalization for average estimation, as well as secondary processing steps, including code writing, average calculation, and conditional correction. Various statistical indicators, including annual averages, hot season averages, cold season averages, and maximum values for annual, warm season, and cold season periods, were computed.[13] Relative risk, a crucial component of health outcomes related to exposure in a specific population during a defined period, was calculated using Equation 1:

If the frequency of health effects in the population is known, the attributable exposure rate can be obtained as follows:

$$IE = I \times AP \tag{1}$$

where, IE is the occurrence rate of the exposure health effect and I is the frequency of the basic occurrence of the health effect in the population studied.

By considering the size of the population studied, the amount of additional health effects caused by exposure to air pollutants can be estimated using Equation 2:

$$NE = IE \times N \tag{2}$$

where, NE is the number of cases attributed to pollutant exposure and N is the population studied. The base incidence rate (BI) for total mortality, cardiovascular mortality and respiratory diseases mortality data were obtained from the Health Vice-Chancellor of Mashhad University of Medical Sciences.

Results and Discussion

Comparison of $PM_{2.5}$ Concentrations During Years

The average concentration of $PM_{2.5}$ (Figure 1a) reveals that the peak concentration occurred in October 2010 (125.21 μg/m^3), while the lowest was recorded in August 2014 (23.14 μg/m^3). The annual average $PM_{2.5}$ concentrations were 63.81 and 23.91 μg/m^3 in 2010 and 2015, respectively. According to Figure 1b, the $PM_{2.5}$ concentration across different months indicated the highest concentration (46.86 μg/m^3) in September and the lowest concentration (26.93 μg/m^3) in April.

The results of this study indicate a rise in $PM_{2.5}$ concentrations since the start of 2018, reaching its maximum level in November before subsequently decreasing. Additionally, the highest levels were observed in December and August, while the lowest concentrations were recorded in May and April in 2012. Furthermore, the peak occurred in August, and the lowest levels were noted in June in 2013. Generally, when comparing $PM_{2.5}$ concentrations across different seasons, it is evident that 2010 experienced higher $PM_{2.5}$ concentrations than other years. Moreover, the findings highlight the lowest $PM_{2.5}$ concentration compared to other years in 2014.

$PM_{2.5}$ Concentration Based on the Air Quality Index in Different Years and Months

The comparison of the air quality index (AQI) based on $PM_{2.5}$ concentrations across different years reveals that it was deemed unhealthy for the sensitive group in 2010. The results indicate that the AQI was elevated, particularly in October (117.35 μg/m^3), reaching unhealthy levels. Conversely, the lowest concentration was recorded in April (65.5 μg/m^3), still categorized as unhealthy for the sensitive group (Figure 2).

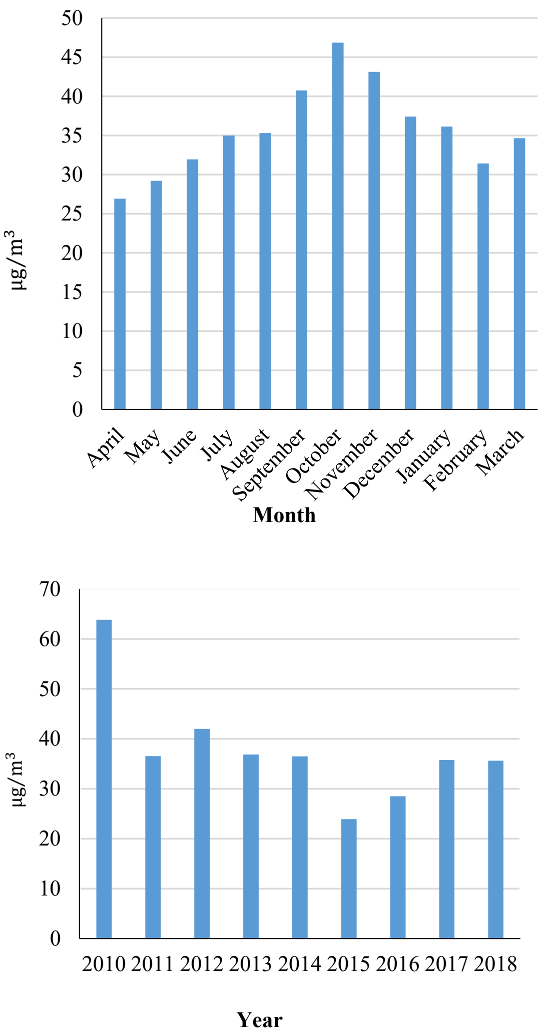

Figure 1. Average $PM_{2.5}$ Concentration in Mashhad City in Various Months (A) During 2010-2015 (B)

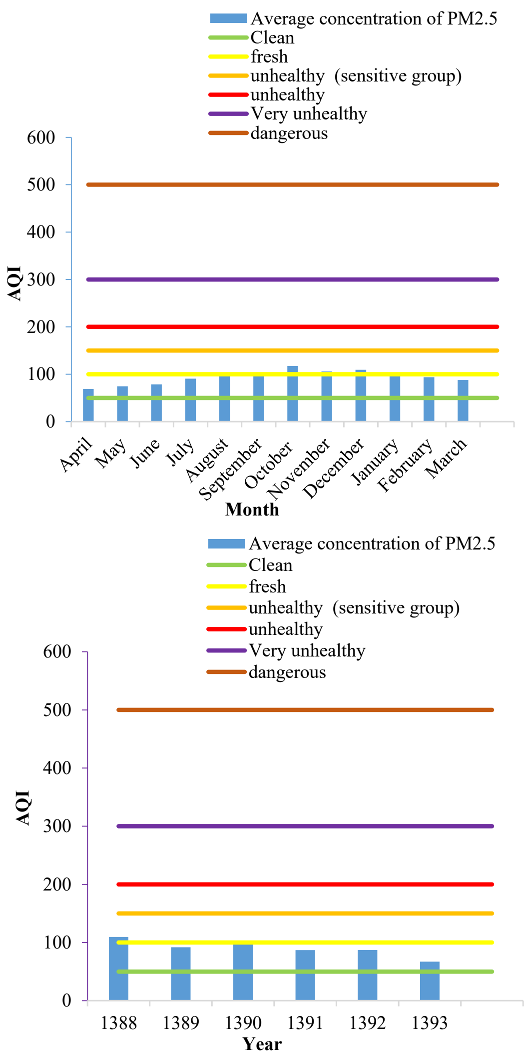

Figure 2. $PM_{2.5}$ Concentrations Based on the AQI Index in Different Years (A) and Months (B)

It was observed that for each additional 310 µg/m³ increase in pollutant concentration, there was a corresponding 10.47% rise in the relative risk of total mortality. Hence, it can be inferred that $PM_{2.5}$ has exerted the most significant impact on public health.

Total number of mortality (BI = 845)

Number of total deaths (BI = 845) due to exposure to $PM_{2.5}$ have been presented in Table 1. The results showed that the highest number of deaths (233.67) per 100000 population occurred in 2010 and the lowest number of deaths (83.67) occurred in 2015.

The total death outcomes (BI = 845) resulting from $PM_{2.5}$ exposure over the years indicated the highest number of deaths in 2010 and the lowest in 2013, reflecting variations in the mortality rate.

Number of Respiratory Infection Cases (BI = 19)

Table 2 shows that the highest respiratory infection cases (6.9) per 100 000 population occurred in 2018 and the lowest (3.9) was observed in 2013.

Number of acute respiratory infection cases (BI = 19) caused by exposure to $PM_{2.5}$ in different years shows that the highest number occurred in 2010 and the lowest in 2013.

Number of Cardiovascular Mortality Cases (BI = 177)

Based on the data presented in Table 3, the findings indicate that the highest incidence rate (74.54) per 100 000 populations was recorded in 2018, while the lowest (56.89) occurred in 2013.

According to the studies, the yearly mean level of $PM_{2.5}$ from 2010 to 2018 was 63.81, 36.52, 41.96, 36.84, 36.48, 23.91, 28.51, 78.35 and 35.62 µg/m³, respectively, with an overall average of 37.71 µg/m³. Except for 2013, when only data from spring were available, the $PM_{2.5}$ levels in all years exceeded the WHO standard (25 µg/m³). Moreover, the EPA recommended 35 µg/m³ as the outdoor $PM_{2.5}$ limit.[14] Faridi et al used AirQ software to analyze the $PM_{2.5}$ concentrations and its temporal trend and impacts in 21 stations across Tehran. They found that the annual exposure of Tehran's population to $PM_{2.5}$ exceeded the air quality standards of the WHO, US EPA, and Iran, which are 12 µg/m³.[15] Table 1-4 compares the $PM_{2.5}$ levels in

Table 1. Number of Total Deaths Due to Exposure to $PM_{2.5}$ During 2010-2018

Health outcome Mortality (BI = 845)							
NE/10^5	NE			IE			Year
Mean	Mean	Min	Max	Mean	Min	Max	
233.67	6167	4244	7781	27.65	19.03	34.89	2010
124.64	3372	2259	4358	14.75	9.88	19.07	2011
147.92	4101	2762	5274	17.5	11.79	22.51	2012
125.98	3551	2380	4589	14.91	9.99	19.27	2013
124.43	3566	2389	4609	14.72	9.86	19.03	2014
67.8	1976	1307	2585	8.03	5.31	10.05	2015
89.04	2636	1753	3435	10.54	7	13.72	2016
121.38	3656	2448	4729	14.37	9.62	18.58	2017
120.69	3696	2474	4781	14.28	9.56	18.48	2018

NE, Number of exposure; IE, Index exposure.

Table 2. Number of respiratory infection cases due to exposure to $PM_{2.5}$ during 2010-2018

Health outcome Respiratory infection cases ALRI (BI = 19)							
NE/10^5	NE			IE			Year
Mean	Mean	Min	Max	Mean	Min	Max	
6.9	182	143	219	36.33	28.6	43.67	2010
5.13	139	100	178	27.01	19.41	34.58	2011
5.56	154	115	193	29.29	21.86	36.7	2012
5.26	145	105	186	27.15	19.54	34.69	2013
5.13	147	106	188	26.99	19.38	34.56	2014
3.9	113	66	162	20.5	11.97	29.23	2015
4.39	130	84	176	23.12	14.9	31.29	2016
5.07	153	109	196	26.68	19.06	34.31	2017
5.05	155	110	199	26.6	18.96	34.23	2018

NE, Number of exposure; IE, Index exposure; ALRI, acute lower respiratory tract infection.

Table 3. Number of cardiovascular disease (IHD) cases due to exposure to $PM_{2.5}$ during 2010-2018

Health outcome Cardiovascular disease IHD) BI = 177)							
NE/10^5	NE			IE			Year
Mean	Mean	Min	Max	Mean	Min	Max	
74.54	1968	1176	2742	42.11	25.17	58.68	2010
64.57	1747	957	2425	36.48	19.98	64.5	2011
67.08	1860	1046	2577	37.9	21.32	52.52	2012
64.72	1824	1001	2532	36.57	20.06	50.75	2013
64.54	1850	1013	2568	36.47	19.97	50.62	2014
56.89	1657	851	2334	32.14	16.5	45.25	2015
60.09	1780	940	2502	33.95	17.93	47.71	2016
64.19	1934	1056	2686	36.17	19.8	50.38	2017
64.11	1963	1070	2728	36.22	19.76	50.33	2018

NE, Number of exposure; IE, Index exposure.

various countries such as Saudi Arabia, Italy, Turkey, Egypt, Lebanon, China, Korea, India, and the current study. Iran's average $PM_{2.5}$ is similar to those of Saudi Arabia, Lebanon, and Korea, which could be attributed to the fine dust from neighboring countries.

The study conducted in Tabriz city revealed that the mean yearly level of $PM_{2.5}$ in the urban region was 38 μg/m^3. Other studies indicated that densely populated areas have higher levels of suspended particles, although they still fall below the standard values.[24] In the current study, it was concluded that the problem of air pollution was due to the distribution of pollution sources, multi-variable nature and a lot of temporal-spatial variability. Moreover, the chemical processes of the atmosphere and solar radiation

Table 4. Comparison of $PM_{2.5}$ Annual Average Concentrations in Different Countries

Country	Sampling Zone	Year	$PM_{2.5}$	Ref
Saudi Arabia	Jade	2011	28.4	16
Italy	Milan	201	45	17
Turkey	Izmir	2004-2005	64	18
Egypt	Gahereh	2002	59	19
Lebanon	Beirut	2004-2005	38.9	20
China	Hong Kong	2000-2001	57.4	21
Korea	Seoul	2001	49	22
India	Hyderabad	2004-2005	50	23
Iran	Mashhad	2009-2016	37.71	Current study

play important role in pollution occurrence.[25] The relative importance of such factors depends on geographical areas, emission sources around the areas, relevant weather features and the season of the year. Mashhad is among the seven most polluted cities in the country and it is the second most polluted city after Tehran.[26] Mashhad with an approximate area of 2200 km^2 is considered as the second metropolis of the country, after Tehran, and one of the largest religious cities in the world. It is especially in the central areas of the city and around the holy court of Razavi. According to the report of the Mashhad Environmental Pollutants Monitoring Center for the years 2013 and 2014, the main pollutant in these years was suspended particles smaller than 2.5 µm.[27]

Conclusion

The findings of this study indicate that $PM_{2.5}$ in suspension have adverse effects on human health. This outcome can potentially serve as a valuable and practical resource for policymakers and decision-makers in formulating appropriate environmental and health regulations aimed at mitigating the health impacts of air pollutants. The study results also contribute to raising awareness among the population and authorities of Mashhad city regarding the levels of $PM_{2.5}$, while offering potential solutions to address and minimize the health consequences for the sake of protection. Furthermore, it is crucial to conduct more comprehensive epidemiological studies at a national level to obtain more precise measurements of these indicators and calculate mortality rates with greater accuracy.

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Authors' Contribution

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Supervision: Omid Rafiee, Mohammad Miri, Mahmud Taghavi.
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Writing–original draft: Omid Rafiee, Mahmud Taghavi.
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Competing Interests

The authors declared no conflict of interest.

Ethical Approval

There were no ethical considerations to be considered in this research.

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