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Original Article

PM_{10} and Risk of Mortality in Iran: Air Quality Modeling

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Abstract

Background & Aims: The aim of this study was to assess the health effect of exposure to particulate matter (PM_{10}) in the selected Iranian west and southwest cities.

Materials and Methods: The hourly in-situ PM_{10} data were transformed to daily, then used to assess mortality among under exposed people of Ahvaz, Khorramabad, and Ilan by the baseline incidence and relative risk (RR). The rate of total mortality (M-total), cardiovascular mortality (M-CV), and respiratory mortality (M-RD) were calculated finally.

Results: Our results revealed that the highest percentage of person-days (%PDE) was estimated at 130-139 μg m^{-3}. In addition, 6.8% (95% CI: 5.8-7.8%), 6.0% (95% CI: 5.1-6.9%), and 3.7% (95% CI: 3.1-4.2%) of M-total, 7.3% (95% CI: 4.8-15.1%), 6.4% (95% CI: 4.1-13.4%), and 3.9% (95% CI: 2.5-8.5%) of M-CV, and eventually 10.6% (95% CI: 7.3-15.1%), 9.3% (95% CI: 6.4-24.1%), and 5.8% (95% CI: 4.0-16.0%) of M-RD were for PM_{10} exposure more than 10 μg m^{-3} in the studied cities.

Conclusion: To control dust storms, some efforts should be organized on a governmental scale, including the desertification of the dust sources by green space. Further, health-care centers should recommend the public to use proven individual air masks.

Keywords: PM_{10}, Health risk behaviors, Middle East, Air pollution, Air quality, Dust storm

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1. Introduction

Due to industrialization, population, and urbanization, air pollution is one of the more important issues in the world [1-5], especially in developing countries [2, 6-9]. This problem was investigated in several studies worldwide so that different epidemiological studies have focused on the chronic and acute health effects [6, 10-14]. Among atmospheric pollutants, particles have high undesired harmful outcomes on human health [2, 7, 15]. Reported studies have shown that there is a strong statistical association between particles and respiratory diseases such as cancer and pulmonary mortality [7, 8, 16]. Particulate matter (PM_{10}) is a fraction of particles with an aerodynamic diameter ≤ 10 µm [17-19]. Exposure to PM_{10} may lead to cancer, respiratory diseases, and premature mortality among people [20-22]. Furthermore, desert dust events have influenced the geographical areas, especially in the Middle East where Iran is one of the important countries [23-25]. The south and west of Iran under exposure to the Middle Eastern Dust (MED) storms resulting from countries such as Arabian Peninsula, Kuwait, and Iraq [26-29]. According to different studies [2, 4, 5], there is a relationship between PM_{10} levels and health effects. The main aim of the current study was to estimate the health risk of PM_{10} as the representative of the MED storm on the rate of mortality in the exposed population in the western cities of Ahvaz, Khorramabad, and Ilam.

2. Materials and Methods

2.1. Study Area

Ahvaz (31°2′N, 48°4′E), Khorramabad (33°2′N, 48°2′E), and Ilam (33°3′N, 46°3′E) are the selected western and southwestern cities in the provinces of Khuzestan, Lorestan, and Ilam, respectively. The above-mentioned cities have a total population of 1.3 million, 540 000, and 172 000, respectively (Figure 1). The presence of several industrial factories (e.g., petroleum industry, petrochemical refinery, and power plant) in Ahvaz and a high number of automobiles, road traffic, and the vicinity to Iraq have changed Ahvaz, Khorramabad, and Ilam into polluted cities in the world [7, 30].

2.2. Particulate Matter Data

Hourly in-situ PM_{10} data were obtained from the local Environmental Protection Agency of Ahvaz (A-EPA), Khorramabad (K-EPA), and Ilam (I-EPA). Then, the hourly background monitoring stations were converted to 24-hour PM_{10} averages from more than 75% of validated hourly data.

2.3. Health Risk Assessment

A tool based on the exposure-response model, recommended by the World Health Organization (WHO), was applied in the current study. Air Quality Health Impact Assessment ($AirQ_{2.2.3}$) software has been

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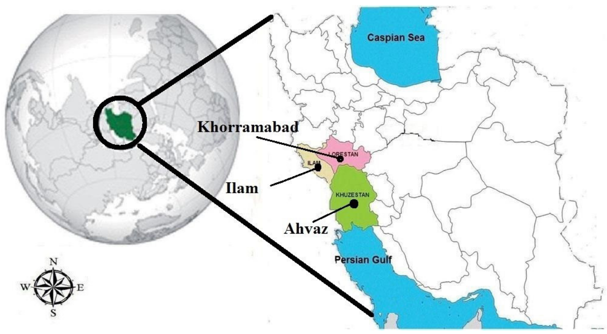

Figure 1. Map of Ahvaz, Khorramabad and Ilam in Iran.

used to assess the health risk of PM_{10} in different studies [11, 28, 31].

$AirQ_{2.2.3}$ software is used to determine short-term exposure to air pollution effects on people living in a specific time and region. The attributable proportion (AP), which explains the portion of health risk that occurs for certain people due to contact with air pollutants, is applied for measuring the health risk of air pollutants [2, 32]. The AP is determined by Eq. (1):

$$AP = \sum([RR(c)-1]*P(c)]) / \sum[RR(c)*P(c)] \quad (1)$$

where AP and RR (cc) are the AP of the health impact and relative risk for a certain health impact in the group c exposure, respectively. Moreover, P (c) denotes the fraction of the target population in group c exposure [31, 33, 34]. The amount attributable to the population exposure is calculated by Eq. (2) if the baseline frequency of the health effect in the studied population is clear.

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

where IE and I represent the rate of the health impact attributable to the contact and the baseline frequency of the health impact in the population, respectively. Finally, considering the population size, the total number of excess cases attributable to the exposure is specified by Eq. (3).

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

where *NE* and *N* indicate the number of persons attributed to the exposure and the total number of evaluated residents, respectively.

2.4. Relative Risk and Baseline Incidence

The main health-related parameters in the epidemiological studies by AirQ software include RR and baseline incidence (BI) [34, 35]. The RR represents the possibility of developing disease of exposure to an air pollutant per μg m^{-3} increase [2], and can be calculated by Eq. (4):

$$RR = \frac{\text{Probability of a health effect when exposed to air pollution}}{\text{Probability of a health effect when not exposed}} \quad (4)$$

Table 1 presents the amounts of RR (lower, central, and higher), BI, and AP (per 10^5 inhabitants). The RR and BI values were detected from the data files of AirQ software based on various conducted peer-reviewed papers [36-39]. Finally, the total mortality (M-total), cardiovascular mortality (M-CV), and respiratory mortality (M-RD) were computed by the recommended approach by the WHO using RR and BI.

3. Results

3.1. PM_{10} Concentration

The amounts of the maximum seasonal PM_{10} concentration in Ahvaz, Khorramabad, and Ilam were achieved at 6041 μg m^{-3}, 476.0 μg m^{-3}, and 688.0 μg m^{-3} within winter, respectively (Table 2). The maximum seasonal average of the PM_{10} concentration in Ahvaz (901.9 μg m^{-3}) was obtained in winter, while this condition for Khorramabad (102.9 μg m^{-3}) and Ilam (62.5 μg m^{-3}) happened in summer.

3.2. Person-Days

The percentage of days that people were exposed to different PM_{10} concentrations was in the interval of 130-139 μg m^{-3}, 60-69 μg m^{-3}, and 40-49 μg m^{-3} in Ahvaz, Khorramabad, and Ilam, respectively. The highest exposure per person in the day (%PDE) was observed in Ahvaz, demonstrating that people living in Ahvaz experienced a high level of PM_{10} concentration (μg m^{-3}) rather than the obtained levels in Khorramabad and Ilam.

3.3. Risk of Mortality

Table 3 provides data on the estimated AP under studied cities, along with the number of M-total, M-CV, and M-RD due to exposure to PM_{10} in Ahvaz, Khorramabad,

Table 1. RR, BI, and AP for Estimated Mortality due to PM_{10} Exposure in the Western Cities of Iran

Health Effect	BI	RR
Total mortality	1013	1.006 (1.007-1.009)
Cardiovascular mortality	497	1.008 (1.005-1.02)
Respiratory mortality	66	1.01 (1.008-1.04)

Note. BI: Baseline incidence; RR: Relative risk; AP: Attributable proportion; PM_{10}: Particulate matter.

Table 2. Seasonal Averages of PM_{10} (μg m^{-3}) in Different Cities

Time	Ahvaz	Khorramabad	Ilam
Annual			
Average (μg m^{-3})	534.8	80.6	60.5
Maximum (μg m^{-3})	6041.0	476.0	688.0
Summer			
Average (μg m^{-3})	257.6	102.9	69.5
Maximum (μg m^{-3})	1378.7	376.0	513.0
Winter			
Average (μg m^{-3})	901.9	58.3	51.5
Maximum (μg m^{-3})	6041.0	476.0	688.0

and Ilam. The number of non-accidental cases was obtained for M-total, M-CV, and M-RD for Ahvaz (760, 401, and 77 persons), Khorramabad (278, 146, and 28 persons), and Ilam (126, 67, and 13 persons), respectively. Higher mortality cases were obtained in Ahvaz than in other cities.

3.4. Short-term Health Assessment

Figure 2a shows the rate of M-total in Ahvaz, Khorramabad, and Ilam with 988, 278, and 126 persons, and the central RR of 1.006 and BI of 1013, respectively. The number of M-CV and M-RD was obtained in the RR of 1.008, 1.01, and BI of 497, and 66 in Ahvaz (526, 99 persons), Khorramabad (146, 28 persons), and Ilam (67, 13 persons). Our results also proved 6.8% (95% CI: 5.8-7.8%), 6.0% (95% CI: 5.1-6.9%), and 3.7% (95% CI: 3.1-4.2%) M-total, as well as 7.3% (95% CI: 4.8-15.1%), 6.4% (95% CI: 4.1-13.4%), and 3.9% (95% CI: 2.5-8.5%) M-CV. In addition, 10.6% (95% CI: 7.3-15.1%), 9.3% (95% CI: 6.4-24.1%), and 5.8% (95% CI: 4.0-16.0%) for M-RD in Ahvaz, Khorramabad, and Ilam were attributed to PM_{10} > 10 μg m^{-3}, respectively. With an increase of 10 μg m^{-3} in PM_{10}, the risk of M-total increased 0.6%, while M-CV and M-RD increased 0.8% and 1.0%, respectively.

4. Discussion

Annual winter and summer averages of PM_{10} in Ahvaz were higher than those of Khorramabad and Ilam. The annual averages of PM_{10} concentrations in these three cities were more than the National Ambient Air Quality Standard (NAAQS) with an amount of 50 μg m^{-3} for a year (24), whereas our findings for Khorramabad and Ilam were less than the NAAQS. Khaniabadi et al found that PM_{10} levels exceeded the NAAQS criteria during 180 days in Ilam in 2015 [24]. More exposure to the MED storms or winds with a high level of particles from Iraq, Kuwait, and/or Saudi Arabia [6, 11, 16, 24, 30, 33] led to an increase in the PM_{10} concentration in Ahvaz, Iran. MED storms are the main source of PM_{10} in the west and southern cities of Iran, but traffic load and industrial activities caused accumulated high levels of PM_{10} concentrations [24]. The higher level of the PM_{10} concentration in Ahvaz may be due to higher temperature and wind speed [7, 24]. The maximum PM_{10} concentration in summer in Ahvaz [11] was obtained in the study, whereas its maximum happened in winter in 2012 in the study by Zallaghi et al [40]. The result of a similar study demonstrated that the number of M-total, M-CV, and M-RD was 652, 344, and 67 cases [41] in Shiraz, Iran.

The annual averages of PM_{10} in three cities were higher than the result of Suwon, Korea with 52 μg m^{-3} [42]. Some studies reported that the highest MED storms in Iran mostly occur in western and southern cities [2, 16, 24, 43], which is in agreement with the results of our study. Khaniabadi et al also calculated the annual average PM_{10} in a city near the center of Iran (i.e., Hamadan); it was equal to 78 μg m^{-3} [6], which is more than the annual average of Ilam. The most percentage of person-days (%PDE) in three cities was related to Ahvaz (130-139 μg m^{-3}) and Khorramabad (60-69 μg m^{-3}); this is 2.6-2.78 and 1.2-1.38 times higher than the NAAQS criteria, respectively, while in Ilam, it was 40-49 μg m^{-3} lower than the recommended NAAQS standard.

In the study by Mohammadi et al in Shiraz, which is a western city, the highest PDE was similar to Khorramabad [41]. Habeebullah concluded that the maximum person-days of exposure to PM_{10} in Makkah, Saudi Arabia was 200-249 μg m^{-3} [44], which is more than 4-4.98 μg m^{-3} of the NAAQS. The findings of another similar study in Milan indicated the number of M-total due to PM_{10} exposure was 677 cases in 1.3 million people [45], while in Ahvaz with a similar population, it was higher due to more exposure to PM_{10} over a year. Although several studies conducted in the Middle East, including De Longueville et al [46], Sicard et al [2], Al-Hemoud et al [47], Al et al [48], and Khaniabadi et al [24] reported an M-CV due to MED storms, Al-Taiar and Thalib [49] found no significant effect of dust storms on the increase of mortality in the Arabian country of Kuwait. Al-Hemoud et al [47] created respiratory and non-respiratory groups and reported that there was a significant correlation between days with dust storms and bronchial asthma at the 0.05 level. Sicard et al [2] indicated that the higher PM_{10} concentrations in Iran toward European cities are due to MED storms with hourly concentrations of more than 200 μg m^{-3}. Only 3.89% of mortality occurred within days with PM_{10} concentrations less than 70 μg m^{-3}, and 99.17% of health impacts were in days with PM_{10} lower than 400 μg m^{-3}. More than 95% of mortality for PM_{10} exposure happened on days with a concentration lower than 350 μg m^{-3}. In Khorramabad, 8.01% of mortality corresponded to days with PM_{10} less than 20 μg m^{-3}, and

Table 3. Estimated AP (%) and the Rate of Mortality in Ahvaz, Khorramabad, and Ilam

Parameter	Estimated AP (%)			Estimated Cases (Person)		
	Ahvaz	Khorramabad	Ilam	Ahvaz	Khorramabad	Ilam
M-total	6.8 (5.8-7.8 (	6.0 (5.1-6.9)	3.7 (3.1-4.2)	988 (840-1132)	278 (235-320)	126 (106-146)
M-CV	7.3 (4.8-15.1)	6.4 (4.1-13.4)	3.9 (2.5-8.5)	521 (338-1047)	146 (94-305)	67 (42-143)
M-RD	10.6 (7.3-15.1)	9.3 (6.4-24.1)	5.8 (4.0-16.0)	99 (70-238)	28 (19-72)	13 (9-36)

Note. AP: Attributable proportion; M-CV: Cardiovascular mortality; M-RD: Respiratory mortality.

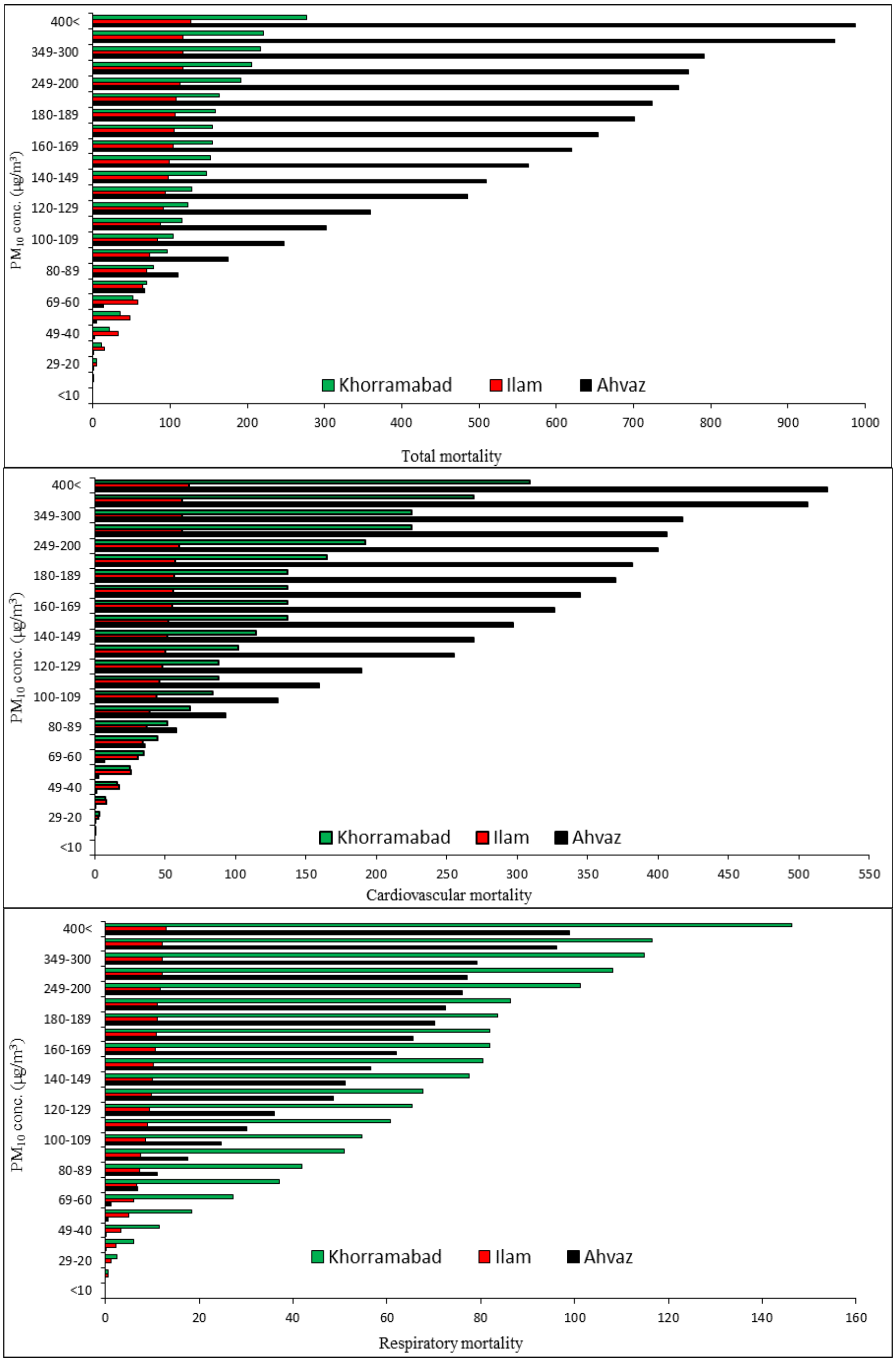

Figure 2. The rate of M-total (a), M-CV (b), and M-RD (C) versus PM_{10} concentration. *Note*. M-CV: Cardiovascular mortality; M-RD: Respiratory mortality; PM_{10}: Particulate matter.

97.63% of health impacts were related to levels lower than 200 μg m^{-3}. In Ilam, 1.8% of the mortality was attributed to PM_{10} concentrations lower than 20 μg m^{-3}. M-total in Khorramabad and Ilam was less than Ahvaz, which may be due to geographic conditions and more exposed population in this city [50). Tominz et al [51] found that the health impacts of PM_{10} using the $AirQ_{2.2.3}$ model were increased with rising concentrations in Trieste, Italy. A similar cohort study in 25 cities in China showed that 1.8% (0.8-2.9%) and 1.7% (0.3-3.2%) increases in mortality risk were related to a 10 μg m^{-3} increase in PM_{10} for M-CV and M-RD [52].

5. Conclusion

In the recent decade, a significant association was found between short- and long-term exposure to air particles and mortality due to cardiovascular and respiratory diseases. These health effects should be reduced by health training, reduction in activities during dusty days, especially elderly and children, and education of people about the effects of particles on the human health and respiratory system. Some governmental-scale measures should be conducted to control the entry of dust into our country using control methods such as spreading mulch and developing green spaces. To interpret RR, it should be noted that a value of 1 for this epidemiological parameter implies no adverse health impact on humans. However, severe harmful effects can be expected when the value of RR exceeds 1. The lower level of the RR value can be achieved if some air pollution control strategies are considered for reducing PM_{10} emissions.

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Authors' contributions
YOK conduced the experiments, analyzed the data, created the figures and tables, and drafted the manuscript. Reviewing and editing, and project administration was conducted by BD, SMM, and MA. Data gathering and reviewing the manuscript by HN, NG and PB. Reviewing, editing and validation by SS. All authors read and approved the final manuscript.

Conflict of Interests
No potential conflict of interests was reported by the authors.

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