Int Cardiovasc Res J.2020;**14**(4):132-136.icrj.104746

International Cardiovascular Research Journal

www.ircrj.com

The Effect of Exposure to Ambient Air Pollutants on Cardiovascular Mortality in Arak, Iran

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ARTICLE INFO

Article Type:
Research Article

Article History:
Received: 8 May 2020
Revised: 19 Sep 2020
Accepted: 10 Oct 2020

Keywords:
Health
Air Pollution
Cardiovascular System

ABSTRACT

Background: Air pollution is one of the most critical environmental problems around the world.

Objectives: This study aimed to estimate cardiovascular mortality related to NO2, PM10, SO2, and O3 concentrations in Arak in 2014.

Methods: This ecological study was performed on 599634 participants. Data about air pollutant concentrations, including NO2, PM10, SO2, and O3, in the urban population of Arak in 2014 were obtained from Arak Environment Department. Cardiovascular mortality related to air pollutant exposure was estimated using Baseline Incidences (BI) and Relative Risks (RR) based on the World Health Organization (WHO) databases and time-series and case-crossover studies about the association between air pollutants and health outcomes and using the AirQ2.2.3 software.

Results: The results showed that the annual average concentrations of PM10, NO2, O3, and SO2 were 69, 38, 57, and 53 µg/m3, respectively during the study period. In addition, the number of excess cases for cardiovascular mortality in the central RR was 138, 100, 55, and 16 for PM10, SO2, O3, and NO2, respectively. The cumulative number of cardiovascular mortality due to exposure to NO2 (RR = 1.00, 1.002, and 1.004) was 16, while this measure was 55 for cardiovascular mortality due to O3 (RR = 1.00, 1.004, and 1.006).

Conclusions: This study showed that PM10 and SO2 had the highest adverse health effects in relation to cardiovascular mortality in Arak. This necessitates important and vital measures and planning by national and international officials.

1. Background

Nowadays, air pollution resulting from urbanization and industrial activities is one of the most important environmental health problems around the world, which has been found to be related to cardiovascular and respiratory morbidity and mortality, especially in developing countries including Iran (1-5). According to the World Health Organization (WHO) estimates in 2012, approximately 72% of ambient air pollution-related deaths were due to cardiovascular diseases and 28% were associated with respiratory diseases and lung cancer (6). Outdoor air pollution is a complex mixture of gases and particles, such as sulfur dioxide (SO2), nitrogen dioxide (NO2), ozone (O3), carbon monoxide (CO), and particulate matter (PM) (7). Significant sources of ambient air pollution in urban areas include exhaust emissions of road vehicles and industrial compounds (8-10).

Several time-series and case-crossover studies have shown the adverse effects of ambient air pollution on human health. These studies revealed that ambient air pollution could cause both long-term and short-term health effects, including mortality and morbidity from cardiovascular and respiratory diseases (11-15). Several studies carried out in Iran have also shown the adverse health effects of air

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pollutants on human health (3, 16, 17).

Arak, the capital of Markazi province, is one of the major industrial cities in Iran. It has been one of the most polluted cities of Iran in the last decades because of the presence of intense industrial activities, urbanization, and the large number of motor vehicles (14, 18, 19), However, there are few studies about the health effects of air pollutants in this city.

2. Objectives

This is in fact the first study using the Air Q software to estimate the impact of air pollutants on cardiovascular mortality in Arak, Iran.

3. Patients and Methods

3.1. Study Area

This ecological study was conducted in Arak, which is located in the central part of Iran with a population of about 599,634 according to the national census conducted in 2011 (20). The geographic coordinates of this city are 34° 5' N and 49° 41' E, and it stands 1748 meters above sea level.

Ambient air pollutant data were obtained from Arak Environment Department from January 2014 to January 2015. The hourly concentrations of four pollutants, including PM less than 10 μm (PM10), O3, NO2, and SO2, were measured daily in Arak by four fixed stations. The daily 24-h averages of PM10, NO2, and SO2 and 8-h averages of O3 were used for evaluating their health effects.

3.2. Air Q Software

The Air Quality Health Impact Assessment (AirQ2.2.3) software provided by WHO was used in this study. This model used air quality data and epidemiological information, including Relative Risks (RR), Attributed Proportions (AP), and Baseline Incidences (BI) based on the defaults reported by WHO and presented the results as the number of excess cases attributable to that pollutant (21).

AP has been defined as the fraction of the health outcome in a particular population due to exposure to a specific air pollutant, assuming the existence of a proven causal exposure-outcome association. AP could be estimated using the following equation (Eq. 1):

"$AP = \sum ([RR(c)-1] \times P(c)) / \sum [RR(c) \times P(c)]$"

Where AP was the attributable proportion of the health outcome, RR was the relative risk for a specific health outcome for people in a given exposure category obtained from the exposure-response functions derived from epidemiological studies, and P(c) represented the exposed population in each exposure category (9, 22).

If the baseline incidence of the health outcome in the study population was known, the attributable rate to the exposure could be estimated as follows (Eq. 2):

$IE = I \times AP$

Where IE was the rate of the health outcome attributable to the exposure and I represented the baseline incidence of health outcomes in the study population.

Considering the population size, the number of excess cases attributable to the exposure could be determined using the following equation (Eq. 3):

$NE = IE \times N$

Where NE was the number of excess cases attributable to a given pollutant and N was the number of people in the population under study (23, 24).

3.3. Input Adjustment

All air pollutant data inquired from Arak Environment Department were in volumetric units (ppm or ppb), while the Air Q software required data based on gravimetric units (μg/m3). Thus, the gaseous concentration data (SO2, NO2, and O3) were converted to gravimetric units. Then, the input data required by the Air Q software, including annual, summer, and winter mean values, annual, summer, and maximum winter values, and annual 98th percentiles, were calculated for all pollutants.

3.4. Exposure Assessment

RR shows the increase in the probability of the health outcome associated with a given change in the level of exposure. This index is taken from time-series and case-crossover studies about the association between air pollutants and health outcomes, including daily mortality and hospital admissions. In this study, the default values of RR (per each 10 μg/m3 increase in air pollutants) and the baseline cardiovascular mortality incidence (per 100,000 people) defined by the WHO were used. This software calculated the effects of exposure to PM10, SO2, NO2, and O3 on cardiovascular mortality as excess mortalities. The RR values for exposure to PM10, SO2, NO2, and O3 and the baseline incidence value for cardiovascular mortality (497/100,000 people each year) were used as default.

The study protocol was approved by the Institutional Review Board of the Faculty of Health, Kerman University of Medical Sciences and the Standing Committee on Ethics in Research of both Kerman University of Medical Sciences (code: IR.KMU.REC.1395.247) and Arak University of Medical Sciences (code: IR.ARAKMU.REC.1395.80).

4. Results

The annual indices of all pollutants in Arak have been presented in Table 1. Accordingly, the yearly average concentration of PM10 and NO2 in Arak was equal to 69 and 38 μg/m3, respectively. Besides, the maximum annual levels of PM10 and NO2 were detected in winter.

The estimated AP percentage and the number of excess cases of cardiovascular death caused by exposure to air pollutants (PM10, SO2, NO2, and O3) have been shown in Table 2. The results indicated that 4.63%, 3.36%, 0.56%, and 1.86% of the mortalities caused by cardiovascular diseases in Arak were attributable to PM10, SO2, NO2, and O3, respectively. The number of excess cases for cardiovascular death according to the central RR was at least 138, 100, 16, and 55 persons for PM10, SO2, NO2, and O3, respectively in Arak in 2014.

The percentage of days on which people were exposed to different levels of air pollutants in Arak has been depicted in Figure 1 (a–d). Accordingly, the residents of Arak were exposed to the SO2 and PM10 concentrations that were higher than the WHO standards on most days of the year. The number of non-standard days for PM10; i.e., > 50 μg/m3, was 243 (66.6%). Additionally, the concentration

Table 1. PM10, SO2, NO2, and O3 Concentrations (µg/m3) in Arak, Iran in 2014

Parameter (2014)	PM_{10} (µg/m³) 24-hour	SO_2 (µg/m³) 24-hour	NO_2 (µg/m³) 24-hour	O_3 8-hour
Annual average	69	53	38	57
Summer average	62	35	39	69
Winter average	105	100	41	41
Annual maximum	278	567	78	150
Summer maximum	146	62	50	109
Winter maximum	278	567	78	69
98th percentile	219	210	55	109

Table 2. Baseline Incidence Relative Risk with 95% Confidence Intervals (95% CI), Estimated Attributable Proportion Percentages, and Number of Excess Cases of Cardiovascular Mortality Due to Short-Term Exposure to SO2, PM10, NO2, and O3 Above 10 µg/m3 in Arak in 2014

Health Endpoint	BI *	Pollutants	RR (95% CI) per 10 µg/m³	AP% (Uncertainty Range)	No. of Excess Cases (Uncertainty Range)
Cardiovascular mortality	497	PM_{10}	1.008 (1.005 – 1.018)	4.6300 (2.9449 - 9.8476)	138.1 (87.8-293.7)
		SO_2	1.008(1.002 - 1.012)	3.3625 (0.8624 - 4.9603)	100.3 (25.7 - 147.9)
		NO_2	1.002 (1.00 – 1.004)	0.5555 (0.0000 - 1.1049)	16.6 (0.0-32.9)
		O_3	1.004 (1.00 – 1.006)	1.8580 (0.0000 - 2.7613)	55.4 (0.0 - 82.3)

Abbreviations: BI, baseline incidence; RR, relative risk; AP, attributable proportion

* Crude rate per 100,000 inhabitants per year

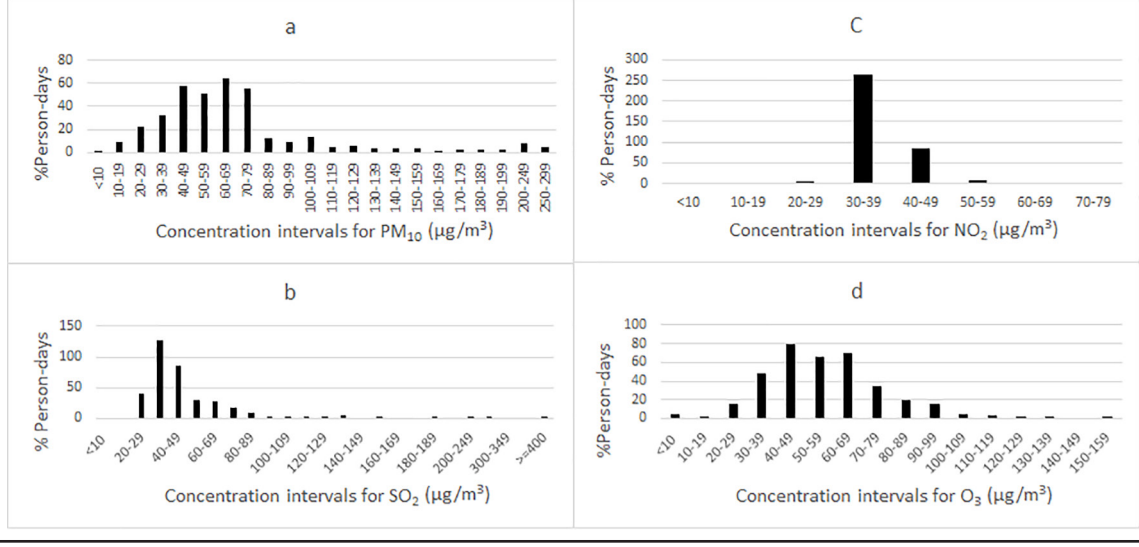

Figure 1. Percentage of the Days on Which People Were Exposed to Different Concentrations of (a) PM10, (b) SO2, (c) NO2, and (d) O3 in Arak (2014)

of SO2 was > 20 µg/m3 all through the year (365 days, 100%). Moreover, Arak inhabitants were exposed to various concentrations of NO2 (30 - 39 µg/m3) on 263 days (72%) during the study period (2014). Considering the central RR = 1.002 and AP = 0.56%, the cumulative number of excess cases for cardiovascular mortality was estimated to be 16.6 persons. Furthermore, the results demonstrated that 0.56% of cardiovascular mortality (95% CI: 0.0% - 1.11%) was attributed to exposure to NO2 concentrations higher than 10 µg/m3.

The results of quantification of the health outcomes obtained from the Air Q software for PM10, SO2, NO2, and O3 concentrations in Arak have been presented in Figure 2. The cumulative number of excess cases has been shown with 95% Confidence Intervals (CIs). The number of excess cases was calculated with upper, central, and lower RR in different ambient air pollution concentrations. Based on the results, the cumulative number of cardiovascular mortality due to exposure to PM10 was 138 (RR = 1.005, 1.0080, and 1.018). Additionally, the number of excess cases for cardiovascular mortality due to SO2 was 100 (RR=1.0020, 1.0080, and 1.012). Moreover, the cumulative number of cardiovascular mortality due to exposure to NO2 was 16 (RR = 1.00, 1.002, and 1.004), and the number of excess cases for cardiovascular mortality due to O3 was 55 (RR = 1.00, 1.004, and 1.006).

5. Discussion

In this study, the effects of air pollutants, including PM10, SO2, NO2, and O3 on cardiovascular death were estimated using the AirQ2.2.3 models in Arak, Iran. The results showed that during the study period, the annual average of PM10 was 1.4 times higher than the WHO air quality guidelines (50 µg/m3). The yearly average concentration of SO2 was also 2.65 times higher than the air quality guidelines (20 µg/m3) (25). However, the two other pollutants were not above the WHO guidelines.

In Arak, the maximum annual PM10 concentration

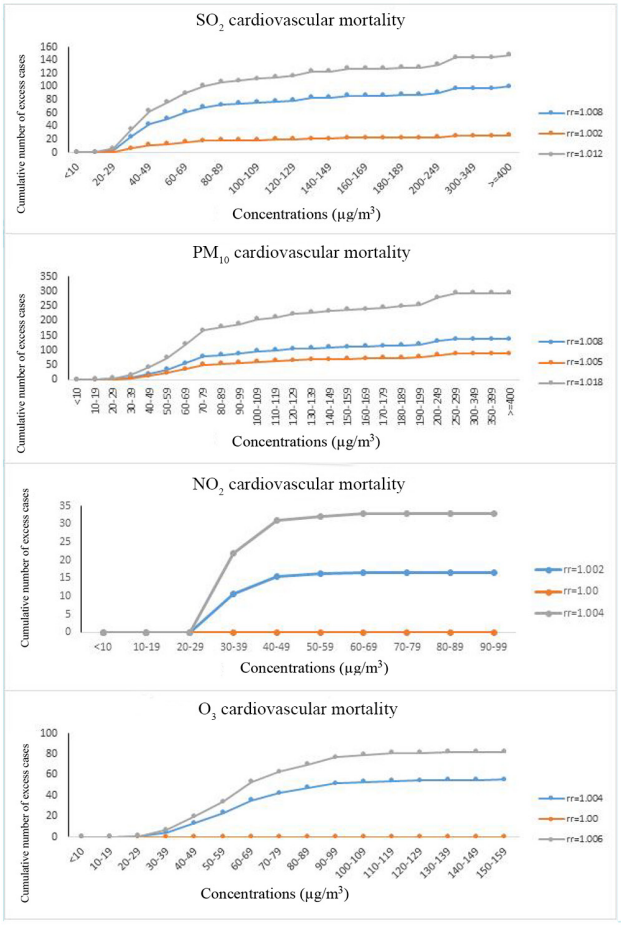

Figure 2. The Cumulative Number of Excess Cases Based on PM10, SO2, NO2, and O3 Concentrations in Arak

(278.0 µg/m3) was observed in January (winter). However, the maximum PM10 level was detected in summer in Shiraz, Iran (192.49 µg/m3) (8). The results also indicated that the maximum annual and 98th percentile of PM10 in Arak were relatively higher compared to Shiraz. However, the maximum yearly PM10 concentrations were higher in Kermanshah (533.12 µg/m3) (24) and Ilam (491 µg/m3) in comparison to the present study (26).

The result of a study conducted in Shiraz with about 1,500,000 population revealed that the number of excess cases for cardiovascular mortality due to exposure to PM10, SO2, and O3 was 344.7, 304, and 218.6, respectively according to the WHO baseline incidence in 2013. These measures were higher compared to the results of the current study. Even though the maximum annual pollution was higher in Arak, the average yearly amount of the suspended particles less than 10 micrograms was almost equal. Additionally, the concentration of SO2 was higher in Shiraz in comparison to Arak. Moreover, the highest 8-h average O3 concentrations to which people in Arak were exposed ranged from 40 to 49 µg/m3, while these values were 70 – 79 µg/m3 in Shiraz during 2013 (8).

The results of a previous study conducted in Suwon, South Korea indicated that the number of excess cases for cardiovascular mortality due to exposure to PM10, SO2, and O3 was 34.7, 4.8, and 15.7, respectively in 2013, which was lower compared to the results of the current study (27). In addition, the results of a cohort study conducted in cities of China disclosed that 1.8% increase (95% CI: 0.8 - 2.9%) in cardiovascular mortality risk was related to 10 µg/m3 increment in the PM10 level (28). Another study reported that each 10 µg/m3 increase in the PM10 level caused the rate of cardiovascular mortality to increase by about 0.68% in 20 states in the U.S. (29) and by 0.86% in 30 cities across Europe (30). A study conducted in Bushehr, Iran indicated that each 10 µg/m3 increase in the SO2 level was accompanied by an about 0.8% increase in cardiovascular mortality rate. In that study, the number of excess cases for cardiovascular death due to exposure to SO2 was 24 (31). Other studies conducted in Kermanshah and Urmia, Iran (32, 33) reported that the number of excess cases for cardiovascular death due to exposure to SO2 was 295 and 100, respectively. Notably, the number of cardiovascular deaths was higher in Kermanshah in comparison to Urmia, Bushehr, and the current study (Arak), which might result from the higher SO2 concentration in the city. SO2 concentrations were 103 µg/m3 (34), 89 µg/m3 (35), 44.10 µg/m3 (34), and 53 µg/m3 in Kermanshah, Urmia, Bushehr, and Arak, respectively.

The cumulative number of excess cases of cardiovascular mortality caused by exposure to NO2 was 20.5 in Shiraz, Iran (8), which was approximately consistent with the results of the present study. In fact, low NO2 concentrations were detected in both Shiraz (23.3 µg/m3) and Arak (38 µg/m3). However, this measure was found to be 34.2 persons in Tabriz with a population of about 1,500,000 persons (32), which was higher compared to the estimated excess cases in the current study. Nonetheless, NO2 levels were almost equal in both studies. Thus, the difference between the two studies might be attributed to the difference in the sample size.

5.1. Conclusion

The study findings showed that PM10 and SO2 had the highest adverse health effects regarding excess cardiovascular deaths in Arak. Furthermore, comparison of the results to those of other studies demonstrated that the top rate of excess cardiovascular mortality was related to the higher average level of air pollutants in each study area, and that this relationship did not always follow a linear trend. In fact, in addition to the level of air pollutants, other factors could also play a role, which are required to be explored in future investigations.

5.2. Ethical Approval

The Institutional Review Board of the Faculty of Health, Kerman University of Medical Sciences, and the Standing Committee on Ethics in Research of both Kerman University of Medical Sciences (Ethical Code: IR.KMU.REC.1395.247), and Arak University of Medical Sciences (Ethical Code: IR.ARAKMU.REC.1395.80) approved the study protocol.

Acknowledgements

The present study was extracted from a PhD dissertation and was financially supported by Kerman University of Medical Sciences (grant No. 95-247). The authors wish

to thank Kerman University of Medical Sciences, Arak University of Medical Sciences, and Arak Environment Department for their cooperation in this study.

Authors' Contribution

Data acquisition: M.M. Analysis and interpretation of data: N.K. and M.V. Drafting of the manuscript: O.G., M.V., N.K., and M.M. All authors have read the draft of the manuscript and have confirmed its final version.

Funding/Support

This study was funded by the Research Administration of Kerman University of Medical Sciences, Kerman, Iran.

Financial Disclosure

The authors have no financial interests related to the material in the manuscript.

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