Spatial and Temporal Trends of Short-Term Health Impacts of PM$_{2.5}$ in Iranian Cities; a Modelling Approach (2013–2016)

Philip K. Hopke$^{1,2}$, Seyed Saeed Hashemi Nazari$^3$, Mostafa Hadei$^4$, Maryam Yarahmadi$^5$, Majid Kermani$^6$, Elham Yarahmadi$^7$, Abbas Shahsavani$^8,9$

$^1$ Department of Public Health Sciences, University of Rochester School of Medicine and Dentistry, Rochester, NY 14642, USA
$^2$ Center for Air Resources Engineering and Science, Clarkson University, Potsdam, NY 13699-5708, USA
$^3$ Safety Promotion and Injury Prevention Research Center, Department of Epidemiology, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran
$^4$ Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
$^5$ Environmental and Occupational Health Center, Ministry of Health and Medical Education, Tehran, Iran
$^6$ Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran
$^7$ Department of Climatology, University of Lorestan, Khorramabad, Iran
$^8$ Environmental and Occupational Hazards Control Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran
$^9$ Department of Environmental Health Engineering, School of Public Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran

ABSTRACT

Estimation of the spatial and temporal trends of health impacts attributable to air pollution is an effective measure for evaluating implemented interventions. The aim of this study was to estimate the short-term mortality attributable to exposure to PM$_{2.5}$ among individuals older than 30 years old in ten Iranian cities from March 2013 to March 2016 using the World Health Organization’s (WHO) AirQ+ software. Hourly concentrations of PM$_{2.5}$ were acquired from the Department of Environment and Tehran Air Quality Control Company. Only stations with 75% and 50% of valid data were qualified for Tehran and other cities, respectively. The annual average PM$_{2.5}$ concentrations in all ten of the cities were higher than the WHO guideline value of 10 µg m$^{-3}$. The total number of attributable short-term deaths during the three-year period in these 10 cities was 3284 (95% CI: 1207–5244). The average daily premature deaths were calculated to be 3. The highest number of premature deaths within the three-year period was estimated to be 548 in Tehran, largely reflecting its population of nearly 9 million. The western and southern cities of Iran experience severe dust storms and showed a high estimated rate of death attributed to air pollution. The health impacts in all cities decreased in the third year compared to the first year except for Ahvaz, Khoram Abad, and Ilam. Governmental interventions need to be enforced more effectively to reduce the high level of adverse health impacts in Iran. Special considerations should be given to the air quality of cities affected by dust storms.

Keywords: Particulate matter; AirQ+; Middle Eastern dust storm; Health impact assessment; Air pollution.

INTRODUCTION

Over the past several decades, many studies have reported adverse human health effects from exposure to air pollution in areas around the world (Rahlenbeck and Kahl, 1996; Sunyer et al., 1996; Michelozzi et al., 1998; Saez et al., 2002; Shin et al., 2008; Burnett et al., 2014; Global Burden of Disease (GBD), 2015). One of the most important criteria air pollutants is particulate matter (PM), for which previous investigations have presented clear evidence of relationships to acute and chronic effects on health, including cardiovascular and respiratory mortality and hospitalizations (Chen et al., 2008; Wang et al., 2013; MohseniBandpi et al., 2017). PM with an aerodynamic diameter of 2.5 µm or
less (PM$_{2.5}$) is a more robust mortality-related exposure metric than PM with an aerodynamic diameter of 10 μm or less (PM$_{10}$) (USEPA, 2012).

Estimation of attributable health impacts of air pollution can clarify the economic and health burden of air pollutants for a given country (World Bank, 2016). The Iranian government’s air quality management (AQM) activities have expanded from understanding the scope of the problem to targeting interventions. Thus, identification of spatial and temporal trends of health impacts attributable to air pollution is becoming more critical as an approach to assess the effectiveness of the control strategies (Liu et al., 2017).

AirQ+ is a software tool for quantifying the health impacts of air pollution developed by the WHO Regional Office for Europe. The software can handle different air pollutants, such as PM$_{2.5}$, PM$_{10}$, NO$_2$, O$_3$, and black carbon (BC). This software has been developed to assess the effects of long-term and short-term exposure to ambient air pollution. In addition, AirQ+ can estimate the effects of household air pollution related to Solid Fuel Use (SFU). Acute and chronic mortality and morbidity of several health outcomes can be considered to enter the model. The underlying scientific evidence on health effects from ambient air pollution used in the software is derived mainly from epidemiological studies conducted in Western Europe and North America (Mudiv et al., 2016).

Many health impact assessments of air pollution have been conducted around the world, including Iran. A study in Greece estimated the adverse health effects of PM$_{10}$ concentrations recorded at six monitoring stations in the GAA (Greater Athens Area) in the 13-year period from 2001 till 2013 using the AirQ 2.2.3 software developed by WHO (Ntoufrou et al., 2017). In the European Apheis study, PM$_{10}$ concentrations of 19 cities were used in a health impact assessment. The results showed that the reduction in long-term exposure to PM$_{10}$ concentrations by 5 μg m$^{-3}$ would have prevented between 3300 and 7700 premature deaths annually, 500 to 1000 of which were associated with short-term exposure (Medina et al., 2004). Health impacts of air pollution in several cities of Iran have been estimated in several studies using AirQ software (Goudarzi, 2014; Asl et al., 2015; Nourmoradi et al., 2015; Ghozikali et al., 2016; Miri et al., 2016; Mohammadi et al., 2016; Nourmoradi et al., 2016; Khaniabadi et al., 2017). However, only a few of them have considered the health effects of PM$_{2.5}$ as a pollutant.

In a study on spatial and temporal trends in the mortality burden of air pollution in China during 2004–2012, the health burden showed strong spatial variations, with high attributable deaths concentrated in areas with high air pollution, high population, or both. Temporal trends were observed in most provinces but with varied growth rates (Liu et al., 2017). In Tehran, Kermani et al. (2016) estimated the short-term health impacts attributable to PM$_{2.5}$ over the period 2005–2015. The total number of short-term premature deaths during this decade was estimated to be 20,015 (Kermani et al., 2016).

Many cities of Iran are ranked as highly polluted areas of the world according to the WHO report (WHO, 2016). Iran is faced with rapid industrial growth, a large number of old vehicles, and environmental crises such as Middle Eastern dust storms (MED) (Shahsavani et al., 2012a; b; Sowlat et al., 2012, 2013; Shahbazi et al., 2015). The Department of Environment (DOE) has designed and initiated plans and actions to control air pollution, including fuel substitution in mobile sources and power plants (Department of Environment (DOE), 2017). Monitoring and identification of the trend of reduction in air pollution and its health impacts can be an effective measure to evaluate implemented interventions (Liu et al., 2017).

The aim of this study was to estimate the short-term mortality attributable to exposure to PM$_{2.5}$ among individuals older than 30 years old in 10 cities of Iran during March 2013–March 2016 using AirQ+ modelling software.

**METHODS**

**Location and Time**

Ten cities of Iran were selected for a health impact assessment of the exposure to PM$_{2.5}$. These cities were Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad, and Ilam. These cities were selected because of the availability of ambient air monitoring data during the 21 March 2013 to 19 March 2016 period, which are three sequential years of the Iranian calendar: 21 March 2013–20 March 2014, 21 March 2014–20 March 2015, and 21 March 2015–19 March 2016.

**Air Quality Data**

Hourly concentrations of PM$_{2.5}$ were acquired from the Department of Environment and Tehran Air Quality Control Company. Only monitoring stations in residential areas were selected, and industrial and suburban (where there is no population exposure) areas were excluded. Negative and zero values were removed from the dataset. In Tehran, only stations with more than 75% data in each of the three years were considered as valid stations (EC Directive, 2008). In other cities, due to less completeness of datasets, stations with more than 50% data were considered valid (WHO, 1999). The monitoring stations with seasonal ratios of valid data greater than 2 were omitted from the dataset (WHO, 1999). Then, 24-hour averages were calculated and entered in AirQ+. WHO’s air quality guideline for 24-h concentrations of PM$_{2.5}$ (25 μg m$^{-3}$) was used as the cut-off value. AirQ+ estimates only the health effects attributable to concentrations over this cut-off value.

**Demographical Data**

This study investigates the mortality among people who have attained the age of 30 years or more. Thus, the total population and at-risk population (> 30 years old) of all cities were acquired from the Statistical Centre of Iran. The total population and at-risk population of all cities were approximately 20 and 10 million, respectively. Detailed city-specific demographical information is presented in Table S1 of Supplementary Material.

**Baseline Incidence**

Baseline incidence (BI) values for all cause, non-accidental
AirQ+ Software

For quantifying the short-term effects of particulate matter, the following input data are required: detailed concentration distributions (frequency of days with specified pollutant concentration values), the at-risk population, health data such as baseline rates of given health outcomes, a cut-off value of concentration for consideration, and Relative Risk (RRs) values if different from the default ones provided by WHO (Mudu et al., 2016). However, it only provides morbidity and mortality risk estimates for ozone, sulfur dioxide, nitrogen dioxide, black carbon, PM10, and PM2.5. It does not provide estimates for PM chemical components except for black carbon or more specific particle sizes such as ultrafine particles.

AirQ+ calculates different health-related estimates, including the attributable proportion of cases, number of attributable cases, number of attributable cases per 100,000 at-risk population, proportion of cases in a 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 (Mudu et al., 2016).

RESULTS

PM2.5 Concentration

Table 1 presents the average concentrations of PM2.5 in ten cities of Iran during the periods of March 2013 to March 2014, March 2014 to March 2015, and March 2015 to March 2016. It should be noted that the annual mean PM2.5 concentrations in all ten cities were higher than 10 µg m⁻³, which has been proposed by WHO as a health protective guideline for annual mean PM2.5. The most polluted cities in all three years were Ahvaz and Isfahan.

In all the cities except Ahvaz and Khoram Abad, concentrations of PM2.5, in the third year were significantly lower than those in the first year. In the cases of Ahvaz and Khoram Abad, concentrations of PM2.5, in the third year had decreased significantly in comparison to the second year. PM2.5 concentrations were compared between these ten cities. The details of the statistical results are provided as supplementary material.

Short-Term Mortality

Table 2 presents the attributable proportion of mortality due to short-term exposure to PM2.5 in the selected 10 cities. Attributable proportion is the percentage of disease in the exposed group that can be attributed to the exposure.

In Table 3, the total attributable short-term deaths during the three-year period in the ten Iranian cities is estimated to be 3284 (95% CI: 1207–5244). The average daily number of deaths due to PM2.5 short-term exposure was calculated to be 3. The most premature deaths, with a three-year average of 548, were estimated to be in Tehran, reflecting its nearly 9 million population. After Tehran, Isfahan and Mashhad have the most estimated premature deaths over the three-year period. The fewest cases have been estimated for Ilam and Sanandaj.

Table 4 gives the estimated rates of attributable premature deaths per 100,000 in the 10 cities. The western and southern cities of Iran, with occurrences of severe dust storms, showed a high rate of premature death. Among these cities, Ahvaz showed a higher value, with a three-year average of 19.24 premature deaths per 100,000 population. However, the premature death rate in Isfahan, an industrialized megacity, was calculated to be 17.72 per 100,000 population—higher than other cities except for Ahvaz.

Figs. 1 and 2 illustrate the spatial distribution of three-year averages of PM2.5 concentrations and estimated mortality, respectively. The western and southern cities of Iran have higher concentrations of PM2.5 than other areas. However, the estimated mortality in these cities is lower than in central areas.

### Table 1. Annual average concentrations (± SD) of PM2.5 in 10 selected cities (2013–2016)

<table>
<thead>
<tr>
<th>City</th>
<th>Average (± standard deviation), µg m⁻³</th>
<th>Monitors: total (valid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tehran</td>
<td>41.89 (± 15.45) 39.17 (± 17.81) 36.42 (± 17.98)</td>
<td>37 (7)</td>
</tr>
<tr>
<td>Mashhad</td>
<td>36.05 (± 26.96) 27.29 (± 13.24) 30.59 (± 13.8)</td>
<td>12 (8)</td>
</tr>
<tr>
<td>Isfahan</td>
<td>56.15 (± 28.73) 54.99 (± 25.58) 37.29 (± 13.72)</td>
<td>7 (4)</td>
</tr>
<tr>
<td>Shiraz</td>
<td>32.22 (± 14.92) 25 (± 10.41) 26.8 (± 15.5)</td>
<td>3 (2)</td>
</tr>
<tr>
<td>Tabriz</td>
<td>30.68 (± 22.67) 17.22 (± 8.36) 22.72 (± 12.63)</td>
<td>6 (2)</td>
</tr>
<tr>
<td>Ahvaz</td>
<td>62.6 (± 71.68) 53.08 (± 52.58) 60.88 (± 61.67)</td>
<td>3 (2)</td>
</tr>
<tr>
<td>Arak</td>
<td>43.13 (± 34.25) 32.53 (± 17.71) 23.63 (± 14.5)</td>
<td>2 (1)</td>
</tr>
<tr>
<td>Sanandaj</td>
<td>29.77 (± 18.43) 29.73 (± 20.12) 25.02 (± 15.9)</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Khoram Abad</td>
<td>32.57 (± 28.07) 41.01 (± 33.41) 33.94 (± 38.42)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Ilam</td>
<td>28.77 (± 23.68) 26.04 (± 27.37) 28.15 (± 31.93)</td>
<td>1 (1)</td>
</tr>
</tbody>
</table>

*These concentrations are reported previously (Hadei et al., 2017a, b).
Table 2. Attributable proportion (AP) of mortality due to short-term exposure to PM$_{2.5}$ among individuals older than 30 years in March 2013–March 2016.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tehran</td>
<td>1.8 (0.66–2.92)</td>
<td>1.38 (0.51–2.25)</td>
<td>1.04 (0.38–1.7)</td>
</tr>
<tr>
<td>Mashhad</td>
<td>1.6 (0.58–2.65)</td>
<td>0.68 (0.25–1.11)</td>
<td>0.96 (0.35–1.57)</td>
</tr>
<tr>
<td>Isfahan</td>
<td>4.13 (1.52–6.71)</td>
<td>3.68 (1.36–5.97)</td>
<td>1.56 (0.57–2.54)</td>
</tr>
<tr>
<td>Shiraz</td>
<td>1.14 (0.42–1.86)</td>
<td>0.4 (0.15–0.66)</td>
<td>0.69 (0.25–1.14)</td>
</tr>
<tr>
<td>Tabriz</td>
<td>1.23 (0.45–2.02)</td>
<td>0.16 (0.06–0.27)</td>
<td>0.44 (0.16–0.73)</td>
</tr>
<tr>
<td>Ahvaz</td>
<td>5.02 (1.75–8.78)</td>
<td>3.6 (1.28–6.06)</td>
<td>4.59 (1.63–7.71)</td>
</tr>
<tr>
<td>Arak</td>
<td>2.58 (0.94–4.25)</td>
<td>1.17 (0.43–1.91)</td>
<td>0.51 (0.18–0.84)</td>
</tr>
<tr>
<td>Sanandaj</td>
<td>1.12 (0.41–1.84)</td>
<td>0.96 (0.35–1.59)</td>
<td>0.67 (0.24–1.09)</td>
</tr>
<tr>
<td>Khoram Abad</td>
<td>1.52 (0.55–2.52)</td>
<td>2.4 (0.87–3.96)</td>
<td>1.83 (0.65–3.1)</td>
</tr>
<tr>
<td>Ilam</td>
<td>0.96 (0.34–1.59)</td>
<td>0.85 (0.3–1.43)</td>
<td>1.18 (0.42–2)</td>
</tr>
<tr>
<td>Total/Average</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3. Number of attributable premature deaths due to short-term exposure to PM$_{2.5}$ among individuals older than 30 years in March 2013–March 2016.

<table>
<thead>
<tr>
<th>City</th>
<th>Total attributable mortality (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tehran</td>
<td>676 (249–1097)</td>
</tr>
<tr>
<td>Mashhad</td>
<td>118 (43–193)</td>
</tr>
<tr>
<td>Isfahan</td>
<td>228 (84–369)</td>
</tr>
<tr>
<td>Shiraz</td>
<td>120 (44–195)</td>
</tr>
<tr>
<td>Tabriz</td>
<td>56 (21–92)</td>
</tr>
<tr>
<td>Ahvaz</td>
<td>117 (43–190)</td>
</tr>
<tr>
<td>Arak</td>
<td>36 (13–59)</td>
</tr>
<tr>
<td>Sanandaj</td>
<td>13 (5–21)</td>
</tr>
<tr>
<td>Khoram Abad</td>
<td>14 (5–23)</td>
</tr>
<tr>
<td>Ilam</td>
<td>4 (1–7)</td>
</tr>
<tr>
<td>Total/Average</td>
<td>1382 (508–2146)</td>
</tr>
</tbody>
</table>

Table 4. Number of attributable premature deaths per 100,000 population due to short-term exposure to PM$_{2.5}$ among individuals older than 30 years in March 2013–March 2016.

<table>
<thead>
<tr>
<th>City</th>
<th>attributable mortality per 100,000 population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tehran</td>
<td>14.57 (5.36–23.64)</td>
</tr>
<tr>
<td>Mashhad</td>
<td>9.1 (3.31–14.89)</td>
</tr>
<tr>
<td>Isfahan</td>
<td>21.83 (8.04–35.34)</td>
</tr>
<tr>
<td>Shiraz</td>
<td>15.67 (5.74–25.47)</td>
</tr>
<tr>
<td>Tabriz</td>
<td>6.94 (2.6–11.41)</td>
</tr>
<tr>
<td>Ahvaz</td>
<td>21.3 (7.8–34.58)</td>
</tr>
<tr>
<td>Arak</td>
<td>13.1 (4.75–21.58)</td>
</tr>
<tr>
<td>Sanandaj</td>
<td>7.29 (2.8–11.78)</td>
</tr>
<tr>
<td>Khoram Abad</td>
<td>8.5 (3.05–14.03)</td>
</tr>
<tr>
<td>Ilam</td>
<td>4.99 (1.24–8.7)</td>
</tr>
<tr>
<td>Total/Average</td>
<td>14.2 (5.18–21.9)</td>
</tr>
</tbody>
</table>

DISCUSSION

The attributable proportion and number of short-term deaths caused by PM$_{2.5}$ exposure among people older than 30 years in ten cities of Iran during March 2013 to March 2016 were estimated using the AirQ+ modelling approach. Prior works (Hoek et al., 2013; WHO-Europe, 2013; Burnett et al., 2014) have suggested that the risk estimates for people older than 30 years are more robust than those including younger individuals. The results showed some spatial and temporal variations.

Source identification and apportionment studies have only been conducted in Ahvaz. To better understand the causes of spatial variations in PM concentrations, the sources of PM$_{2.5}$ in each city or region will need to be investigated. Traffic will be important in all cities, but there are likely to
Fig. 1. Spatial distribution of three-year average of PM$_{2.5}$ concentrations in ten Iranian cities (March 2013–March 2016).

Fig. 2. Spatial distribution of three-year average of mortality attributed to PM$_{2.5}$ concentrations in ten Iranian cities (March 2013–March 2016).
be different local fine-PM sources in each city, including industrial activities and dust storms. The western and southern cities of Iran, such as Ahvaz, Khorram Abad, Sanandaj, and Ilam, have been subjected to Middle Eastern dust storms (MED) in recent years. The MED events are probably responsible for the high rate of death attributable to air pollution in these cities. However, their relatively low population moderates the effect of high PM$_{2.5}$ concentrations. In a study during a Middle Eastern dust storm period (April–September 2010) in Ahvaz, overall mean values of 319.6 ± 407.1, 69.5 ± 83.2, and 37.0 ± 34.9 µg m$^{-3}$ were monitored for PM$_{10}$, PM$_{2.5}$, and PM$_{1}$, respectively, with corresponding maximum values of 5338, 911, and 495 µg m$^{-3}$, respectively (Shahsavani et al., 2012a, 2017). Two studies have been conducted to apportion the sources of PM$_{10}$ and TSP in Ahvaz (Sowlat et al., 2012, 2013). The possible sources of PM$_{10}$ were crustal dust (41.5%), road dust (5.5%), motor vehicles (11.5%), marine aerosol (8.0%), secondary aerosol (9.5%), metallurgical plants (6.0%), petrochemical industries and fossil fuel combustion (13.0%), and vegetative burning (5.0%). In addition, seven sources were identified for TSP, namely, crustal dust (56%), road dust (7%), motor vehicles (8%), marine aerosol (9%), secondary aerosol (7%), metallurgical plants (4.5%), and finally petrochemical plants and fossil fuel combustion (8.5%). For Tehran, Isfahan, Mashhad, Tabriz, and Shiraz, mobile sources are likely to make significant PM contributions, given the number of registered vehicles. However, there have not been comparable studies in any other city.

The average PM$_{10}$ concentrations during dust episodes in Sanandaj (187 µg m$^{-3}$) were significantly higher than on other days (48.7 µg m$^{-3}$) (Ebrahimi et al., 2014). According to WHO’s database, the annual average PM$_{2.5}$ concentrations in Ahvaz and Sanandaj during 2010 were 95 and 41 µg m$^{-3}$, respectively (WHO, 2016). The annual, winter, and summer averages of PM$_{10}$ in Khorram Abad were reported to be 80.59, 58.28, and 80.59 µg m$^{-3}$, respectively (Nourmoradi et al., 2015). Mirhosseini et al. (2013) have reported that the daily average concentrations of particulate matter in Khorram Abad during the warm seasons (spring and summer) were higher than the average concentrations in cold seasons (autumn and winter) (Mirhosseini et al., 2013). Middle Eastern dust storms are likely to be the main cause of this seasonal difference, even given the extensive anthropogenic activities as major PM sources.

The most premature deaths were estimated to be in Tehran. The high mortality in Tehran is driven by both its high population and high concentrations of PM$_{2.5}$. It is reported that about 70% of particulate air pollutants in Tehran were emitted from mobile sources during 2015 (Ahadi et al., 2016). There are more than three million personal vehicles in Tehran, 75% of which have emissions meeting the Euro-2 standards or lower. In addition, there are about 750,000 motorcycles, 40% of which are older than 10 years, and more than 95% of their emissions meet the Euro-2 standard or lower (Shahbazi et al., 2015). About 76% of the air pollution in Isfahan was reported to be produced by mobile sources in 2010 (Zarabi et al., 2010). The major source of particulate matter in Arak is probably different. Industries have been suggested as the main sources of air pollution in this city (Hosseini and Shahrabi, 2016).

Studies about the use of AirQ+ are very rare (Hadei et al., 2017a, 2017c); however, many studies can be found about the quantification of health effects attributable to air pollution using the AirQ 2.2.3 model. Hadei et al. (2013) estimated short-term mortality attributable to various air pollutants. The total number of mortality cases attributable to PM$_{2.5}$ over the three-year period 2013–2016 was 4336 (Hadei et al., 2017b). In a study in Mashhad, the number of premature deaths due to short-term exposure to PM$_{2.5}$ was estimated to be 600 during the 2014–2015 period (Miri et al., 2016). Another study in Ahvaz showed that the number of mortality cases attributed to short-term exposure to PM$_{10}$ was 278 in 2014 (Nourmoradi et al., 2015). These values seem to be higher than those obtained in this study. The difference is due to different relative risk values, functions, and interest populations. In addition, a different procedure was used in this study to obtain PM$_{2.5}$ concentrations that were used as the population exposure.

The temporal trends showed a decline in health impacts observed in Tehran, Isfahan, Arak, and Sanandaj. Some interventions performed by the government, such as fuel substitution in mobile sources and the industrial sector, and the replacement of older vehicles with new ones, may be the reason for this reduction, especially in Tehran (Department of Environment (DOE), 2017). Other cities have shown variations within the three-year period. However, one-year variations cannot be the basis for determining long- and medium-term trends. The third year’s results can be compared with the first year’s values to identify a short-term difference. This comparison showed that health impacts in all cities decreased in the third year compared to the first year, except for Ahvaz, Khorram Abad, and Ilam. This lack of change may be due to the occurrence of severe dust storms in these cities.

This approach has limitations that must be recognized. The model considers the air pollutant’s concentration as the measure of population exposure. In addition, due to the limitations in epidemiological studies, the model calculations do not account for multiple exposure cases or multipollutant scenarios. Finally, the exposure–outcome data that are the basis of the health outcome estimates were developed by epidemiological assessments conducted outside of this region. Thus, they represent the relationships in different populations, exposure to different particle mixtures, and other socio-economic conditions Therefore, the results that have been obtained have additional uncertainties and should be considered with caution and expert judgment (WHO Regional Office for Europe, 2016).

CONCLUSIONS

Based on these results, it can be concluded that interventions initiated by the government may have provided some improvement in air quality and lowered estimated mortality. However, given the high remaining concentrations, they need to be more aggressive to reduce the high health...
impacts of PM$_{2.5}$ in Iran. Special considerations should be
given to the air quality of cities that are affected by Middle
Eastern dust storms, such as Ahvaz, Khorram Abad, and
Ilam. For future studies, satellite-based PM$_{2.5}$ concentrations
may provide better estimates of spatially-specific population
exposure and more reliable health-impact assessments.

**ACKNOWLEDGEMENTS**

The authors wish to thank Shahid Beheshti University of
Medical Sciences (grant number #12381). We thank the
Environmental and Occupational Health Centre of the
Ministry of Health and Medical Education, as well as the
Environmental and Occupational Hazards Control Research
Centre, for providing data.

**SUPPLEMENTARY MATERIAL**

Supplementary data associated with this article can be
found in the online version at http://www.aaqr.org.

**REFERENCES**

Annual report on the ambient air quality of tehran, 2015-
2016 (1394), Tehran Air Quality Control Company
(TAQCC), Tehran, Iran.

Asl, F.B., Kermani, M., Aghaei, M., Karimzadeh, S., Arian,
of diseases and mortality attributed to NO$_2$ pollutant in
five metropolises of iran using airq model in 2011-2012.

Burnett, R.T., Arden Pope Iii, C., Ezzati, M., Olives, C.,
Lim, S.S., Mehta, S., Shin, H.H., Singh, G., Hubbell, B.,
Brauer, M., Ross Anderson, H., Smith, K.R., Balmes,
J.R., Bruce, N.G., Kan, H., Laden, F., Prüss-Ustün, A.,
Turner, M.C., Gapstur, S.M., Diver, W.R. and Cohen,
A. (2014). An integrated risk function for estimating the
global burden of disease attributable to ambient fine
122: 397–403.

Chen, G., Song, G., Jiang, L., Zhang, Y., Zhao, N., Chen,
gaseous pollutants and particulate matter on daily
47.

Department of Environment (DOE) (2017). Actions and
programs of the national center for air and climate change
[in Persian], Deapartment of Environment (DOE).

Ebrahimi, S.J.A., Ebrahimi Zadeh, L., Eslam, A. and
Bidarpoor, F. (2014). Effects of dust storm events on
emergency admissions for cardiovascular and respiratory
12: 110.

ambient air quality and cleaner air for Europe. Official
Journal of the European Communities, L 151, pp. 1–44.

Ghozikali, M.G., Heibati, B., Naddafi, K., Klooq, I., Conti,
chronic obstructive pulmonary disease (COPD) attributed
to atmospheric O$_3$, NO$_2$, and SO$_2$ using Air Q Model

Global Burden of Disease (GBD) (2015). Global, regional,
and national age–sex specific all-cause and cause-specific
mortality for 240 causes of death, 1990–2013: A
systematic analysis for the Global Burden of Disease

Goudarzi, G., Geravandi, S., Salamzadeh, S., Mohammadi,
M. and Zallaghi, E. (2014). The number of myocardial
infarction and cardiovascular death cases associated
with sulfur dioxide exposure in Ahvaz, Iran. *Arch. Hig. Sci.* 3: 112–119.

Hadei, M., Hashemi Nazari, S.S., Yarahmadi, M., Kermani,
of gender-specific lung cancer deaths due to exposure to
PM$_{2.5}$ in 10 cities of Iran during 2013-2016: A modeling

Hadei, M., Hopke, P.K., Hashemi Nazari, S.S., Yarahmadi,
of mortality and hospital admissions attributed to criteria

Hadei, M., Nazari, S.S.H., Yarahmadi, E., Kermani, M.,
Estimation of lung cancer mortality attributed to long-
term exposure to PM$_{2.5}$ in 15 Iranian cities during 2015-

Hoek, G., Krishan, R.M., Beelen, R., Peters, A., Ostro,
air pollution exposure and cardio-respiratory mortality:


Kermani, M., Dowlati, M., Jafari, A.J. and Kalantari, R.R.
(2016). Health risks attributed to particulate matter of

Khanibadi, Y.O., Goudarzi G., Daryanoosh, S.M., Borgini,
PM$_{10}$, NO$_2$, and O$_3$ and Impacts on human health.

Liu, M., Huang, Y., Ma, Z., Jin, Z., Liu, X., Wang, H., Liu,
temporal trends in the mortality burden of air pollution

Medina, S., Plasencia, A., Ballester, F., Mücke, H. and
Schwartz, J. (2004). Aphis: Public health impact of

Micheleozzi, P., Forastiere, F., Fusco, D., Perucci, C., Ostro,

Mirhosseini, S.H., Birjandi, M., Zare, M.R. and Fatehizadeh,
A. (2013). Analysis of particulate matter (PM$_{10}$ and
PM$_{2.5}$) concentration in Khorrabad city. *Int. J. Environ. Health Eng.* 2: 3.

Miri, M., Derakhshan, Z., Allahabadi, A., Ahmadi, E.,


WHO Regional Office for Europe (2016). Airq+: Key features, WHO Regional Office for Europe.

