ESTIMATION OF LUNG CANCER MORTALITY ATTRIBUTED TO LONG-TERM EXPOSURE TO PM$_{2.5}$ IN 15 IRANIAN CITIES DURING 2015 - 2016; AN AIRQ+ MODELING

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ABSTRACT:

Introduction: Long-term exposure to particulate matter with an aerodynamic diameter less than 2.5 μm is associated with lung cancer incidence. This study aimed to estimate the number of lung cancer deaths attributed to lung-term exposure to PM$_{2.5}$ among people older than 30 years in 15 cities of Iran during 2015- 2016 using AirQ+ modelling approach.

Materials and methods: Validation of monitoring stations was done according to WHO’s criteria for health impact assessment of air pollution. As AirQ+ needs, 24-h concentrations of PM$_{2.5}$ during a year, total population and at-risk population, baseline incidence of lung cancer, and cut-off value of 10 µg/m$^3$ for PM$_{2.5}$ concentration were prepared and entered into the model.

Results: Annual concentrations of particulate matter in all cities were 1.8 to 6.7 times higher than WHO’s guideline. The most and least cases of lung cancer deaths due to PM$_{2.5}$ were estimated to be in Karaj and Birjand, respectively. Total mortality of lung cancer attributed to PM$_{2.5}$ in these 15 cities were 120 cases.

Conclusions: Since air pollution’s health impacts impose financial losses to countries, results of this study can be useful for decision-makers to highlight areas requiring urgent action.

INTRODUCTION

World Bank has introduced air pollution as the fourth risk factor for human health [1]. In a report by World Health Organization (WHO), about 7 million annual deaths were attributed to indoor and outdoor air pollution [2]. There are several criteria air pollutants that can affect human health such as different fractions of particulate matter, nitrogen dioxide (NO$_2$), sulfur dioxide (SO$_2$), etc. [3]. Particulate matter with a diameter of 2.5 μm or smaller (PM$_{2.5}$) is a fraction of particles that is able to enter the alveolar region in lung, as a place for blood exchange. PM$_{2.5}$ represents the high-risk fraction of particulate matter in air [4].
Many epidemiological studies have shown a positive relationship between short- or/and long-term exposure to PM$_{2.5}$ and different adverse health effects [5]. PM$_{2.5}$’s short-term exposure is associated with ischemic heart disease (IHD) and chronic obstructive pulmonary disease (COPD). Its long-term exposure is related to lung cancer, and respiratory and cardiovascular diseases [4]. It is shown that lung cancer incidence increases per each 10 µg/m$^3$ PM$_{2.5}$ [6]. International Agency for Research on Cancer (IARC) has introduced particulate matter as Group 1 carcinogen (carcinogenic to humans) [7].

Several cities of Iran are experiencing high concentrations of air pollutants, especially PM$_{2.5}$ [8]. Southern and western cities are affected by Middle Eastern dust storm, which even reach Tehran in central Iran [9, 10]. Tehran as the capital of Iran is mainly affected by mobile sources of air pollution [11]. Annual concentrations PM$_{2.5}$ are reported to be 3 - 4 times higher than those in WHO’s guideline. These extremely high concentrations cause large numbers of deaths and hospital admissions [12].

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 [13]. Determining the number of health effects attributed to air pollution can be useful for management purposes. Authorities and policymakers benefit from these results to allocate financial resources in a more important way. It is because each death, hospitalization or medication forces a financial burden to health-care systems [14, 15].

Many studies have been carried out in Iran to estimate the health effects of air pollution [16-19]. However, no study has conducted to estimate the number of lung cancer deaths in Iran. On the other hand, all of these studies have used AirQ software, which is developed by WHO several years ago. Although, WHO released a newer tool for health impact assessment that is known as AirQ+ (AirQ plus). This software is based on recent epidemiological findings regarding the relationship between air pollution and health. AirQ+ was developed in 2016 to quantify the health effects and calculate the burden of disease attributed to outdoor air pollutants, including PM$_{2.5}$, PM$_{10}$, NO$_2$, O$_3$ and black carbon (BC). The software takes account of both short- and long-term cause-specific morbidity and mortality of mentioned air pollutants. In addition, it assesses the health impacts of household air pollution related to solid fuel use (SFU) [20, 21].

This study aimed to estimate the number of lung cancer deaths attributed to long-term exposure to PM$_{2.5}$ among people older than 30 years in 15 cities of Iran during March 2015-March 2016 using AirQ+ modelling approach.

**MATERIALS AND METHODS**

**Location and time**

Fifteen cities of Iran were chosen to assess the health impacts of exposure to PM$_{2.5}$. These cities were Karaj, Kermanshah, Boushehr, Yazd, Urmia, Yasuj, Hamadan, Kerman, Ghazvin, Shahr-e Kord, Birjand, Varamin, Shahriar, Shahr-e Ghods, and Pakdasht. The period of interest was 21 March 2015 to 19 March 2016, which is one year in Persian calendar.

**AirQ+**

Estimation of health impacts in AirQ+ needs some input data such as PM$_{2.5}$ daily concentrations during a year, total population and at-risk population, baseline incidence of selected disease in the interest population, a cut-off value of concentration, and relative risks (RRs). This model estimates the number of lung cancer deaths due to long-term exposure to air pollution for individuals older than 30 years old. This is based on the recent findings of epidemiological studies and systematic reviews [21, 22].

**Preparation of input data**

Hourly concentrations of particulate matter were obtained from Department of Environment (DOE) of Iran. After removing zero and negative values, daily concentrations were calculated just in monitoring stations that met WHO’s criteria for health impact assessment of air pollution [23].
According to these criteria, only stations are valid that have more than 50% valid data in a year. In addition, the ratio of valid data in summer to winter or winter to summer should not exceed 2 [24]. Daily concentrations of PM$_{2.5}$ in the selected year was prepared to enter the AirQ+ model. In case of days with PM$_{10}$ measurements and without PM$_{2.5}$ concentrations, PM$_{2.5}$ levels were calculated based on a city-specific ratio of PM$_{2.5}$/PM$_{10}$ obtained from other days with complete PM$_{2.5}$ and PM$_{10}$ data. Otherwise, a WHO’s approved conversion factor of 0.33 was used [8]. There are some more recent criteria for validation of monitoring stations [23], but they require 75% or 90% of valid data in each year, that is not available in many studied cities of Iran.

Age-specific population of each city was received from Statistical Centre of Iran. At-risk population (>30 years old) was calculated. Table 1 presents total population and at-risk population of each city. Total population and population of individuals older than 30 years in all the 15 cities were more than 9 and 4.6 million, respectively.

Baseline incidence (BI) for lung cancer mortality was obtained from Ministry of Health and Medical Education [25]. Due to lack of valid precise city-by-city information, the baseline incidence for all the 15 cities was assumed to be the similar. Integrated exposure-response (IER) function was used for relative risk (RR) values. This function generates RR values depending on a non-standard curve and the level of pollution. So, there is no fixed value of RR [26].

### RESULTS AND DISCUSSION

Table 2 presents the average concentrations of PM$_{2.5}$ during 21 March 2015 to 19 March 2016 period. The highest and lowest concentrations of particulate matter were observed in Shahr-e Kord and Birjand, respectively. In addition, the ratio of this annual concentration to WHO’s guideline value for annual average of PM$_{2.5}$ (10 µg/m$^3$) was calculated, and is presented in Table 2. All the yearly concentrations were higher than WHO’s guideline value. Fig.1 also shows the geographical distribution of PM$_{2.5}$ concentrations in Iran. According to this Figure, Western and Southern areas have higher concentrations of PM$_{2.5}$ rather than other areas.

The number of lung cancer deaths due to long-term exposure to PM$_{2.5}$ among individuals older than 30 years in 15 cities of Iran was estimated using AirQ+ modelling software. The number of lung cancer deaths due to long-term exposure to PM$_{2.5}$ are presented in Table 2. According to this Table, the most cases of lung cancer deaths due to PM$_{2.5}$ were estimated to be in Karaj. In addition, the least cases of deaths caused by PM$_{2.5}$ were observed in Birjand and Yasuj. The total mortality of lung cancer attributed to PM$_{2.5}$ concentrations in these 15 cities were 120 cases. Fig. 2 illustrates the geographical distribution of lung cancer mortality attributed to air pollution. The red areas are associated with higher mortality. The red areas in this Figure are different from those in Fig. 1.

<table>
<thead>
<tr>
<th>City</th>
<th>Total population</th>
<th>Population &gt; 30 year</th>
<th>City</th>
<th>Total population</th>
<th>Population &gt; 30 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karaj</td>
<td>2181150</td>
<td>1170125</td>
<td>Ghazvin</td>
<td>533120</td>
<td>269360</td>
</tr>
<tr>
<td>Kermanshah</td>
<td>913250</td>
<td>467350</td>
<td>Shahr-e Kord</td>
<td>315280</td>
<td>152320</td>
</tr>
<tr>
<td>Boushehr</td>
<td>264860</td>
<td>126480</td>
<td>Birjand</td>
<td>245700</td>
<td>104220</td>
</tr>
<tr>
<td>Yazd</td>
<td>595200</td>
<td>281600</td>
<td>Varamin</td>
<td>472800</td>
<td>266040</td>
</tr>
<tr>
<td>Urmia</td>
<td>786220</td>
<td>381900</td>
<td>Shahriar</td>
<td>602820</td>
<td>339201</td>
</tr>
<tr>
<td>Yasuj</td>
<td>135800</td>
<td>58450</td>
<td>Shahr-e Ghods</td>
<td>342780</td>
<td>192879</td>
</tr>
<tr>
<td>Hamadan</td>
<td>588500</td>
<td>306350</td>
<td>Pakdasht</td>
<td>295500</td>
<td>166275</td>
</tr>
<tr>
<td>Kerman</td>
<td>738400</td>
<td>334800</td>
<td></td>
<td>9011380</td>
<td>4617350</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>City</th>
<th>Average concentrations (±SD), µg/m$^3$</th>
<th>Conc./WHO guideline</th>
<th>Deaths (CI 95%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Karaj</td>
<td>32.85 (±18.76)</td>
<td>3.3</td>
<td>31 (7-47)</td>
</tr>
<tr>
<td>Kermanshah</td>
<td>36.31 (±30.11)</td>
<td>3.6</td>
<td>13 (3-20)</td>
</tr>
<tr>
<td>Boushehr</td>
<td>53.96 (±178.01)</td>
<td>5.4</td>
<td>5 (1-7)</td>
</tr>
<tr>
<td>Yazd</td>
<td>41.63 (±78.96)</td>
<td>4.2</td>
<td>9 (2-13)</td>
</tr>
<tr>
<td>Urmia</td>
<td>28.4 (±14.14)</td>
<td>2.8</td>
<td>9 (2-14)</td>
</tr>
<tr>
<td>Yasuj</td>
<td>49.69 (±57.17)</td>
<td>5.0</td>
<td>2 (1-3)</td>
</tr>
<tr>
<td>Hamadan</td>
<td>18.85 (±9.91)</td>
<td>1.9</td>
<td>5 (1-8)</td>
</tr>
<tr>
<td>Kerman</td>
<td>24.5 (±14.38)</td>
<td>2.5</td>
<td>7 (2-11)</td>
</tr>
<tr>
<td>Ghazvin</td>
<td>18.44 (±12.47)</td>
<td>1.8</td>
<td>4 (1-7)</td>
</tr>
<tr>
<td>Shahr-e Kord</td>
<td>66.65 (±44.81)</td>
<td>6.7</td>
<td>7 (2-9)</td>
</tr>
<tr>
<td>Birjand</td>
<td>17.69 (±13.97)</td>
<td>1.8</td>
<td>2 (0.5-3)</td>
</tr>
<tr>
<td>Varamin</td>
<td>34.45 (±15.95)</td>
<td>3.4</td>
<td>7 (2-11)</td>
</tr>
<tr>
<td>Shahriar</td>
<td>36.1 (±17.58)</td>
<td>3.6</td>
<td>10 (3-15)</td>
</tr>
<tr>
<td>Shahr-e Ghods</td>
<td>26.5 (±18.32)</td>
<td>2.7</td>
<td>4 (1-7)</td>
</tr>
<tr>
<td>Pakdasht</td>
<td>34.63 (±15)</td>
<td>3.5</td>
<td>5 (1-7)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>-</td>
<td>-</td>
<td>120 (29.5-182)</td>
</tr>
</tbody>
</table>

Fig. 1. Geographical distribution of PM$_{2.5}$ concentrations in Iran

Fig. 2. Geographical distribution of lung cancer mortality attributed to air pollution in Iran

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According to the results, yearly concentrations of particulate matter were 1.8 to 6.7 times higher than 10 μg/m³, which is set by WHO as the annual guideline value for PM₂.₅ concentrations. This value is the lowest level at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to PM₂.₅ [27]. Averages of PM₂.₅ concentrations in urban areas of North America, Europe, Africa and Asia are 17, 15-20, 15-30 and 30-60 μg/m³, respectively. About 90% of United States’ monitoring stations records PM₂.₅ concentrations lower than 16 μg/m³ [4].

High concentrations of particulate matter are very conventional in Asian cities, and Iran, in particular [10, 28, 29]. According to a database provided by WHO, Iranian cities are among the most polluted cities in the world [30]. A major source of air pollution in Iran is mobile sector, which have mainly poor quality in engine combustion and air pollution control mechanisms [31]. Another notable source of air pollution is Middle Eastern dust storms that are affecting Southern and Western cities of the country [32, 33]. These episodes raise average TSP and PM₁₀ concentrations to 1548.7 (± 1965.1) and 1152.4 (± 1510.3) μg/m³, respectively [10]. This can be due to unsustainable development of water resources in Middle Eastern countries, which has led to extensive desertification [34]. Karaj had the highest mortality of lung cancer due to fine particulate matter. This is not the same city that had the highest PM₂.₅ concentrations. This difference is quietly clear in Figs. 1 and 2. The reason relies on the high population of Karaj that has increased attributed mortality. This is the case for other some cities such as Kermanshah, Urmia and Shahriar. On the other hand, some cities with high concentrations of PM₂.₅ showed lower lung cancer mortality, since their population is less than others. This is important from the point of view of burden of disease or the economic losses that will be imposed to the societies and health-care systems [35].

No study has carried out in Iran to estimate lung cancer mortality that is caused by air pollution. However, WHO has studied about global lung cancer mortality and burden of disease attributed to PM₂.₅ concentrations in 2012. WHO’s report contains country-specific number of deaths, years of life lost (YLLs), and disability-adjusted life years (DALYs). According to this report, number of deaths, YLLs and DALYs of lung cancer attributed to PM₂.₅ in Iran during 2012 were 1460, 37894 and 38258, respectively [36]. Even so, WHO’s report faces a number of limitations. For instance, PM₂.₅ concentrations have been calculated from PM₁₀ measurements, not direct measurements of PM₂.₅.

Lung cancer mortality caused by PM₂.₅ in 23 European cities with 36 million people estimated, and the results showed that 1296 and 1901 lung cancer deaths could be prevented each year if PM₂.₅ concentrations were reduced to 20 and 15 μg/m³, respectively [37]. Years of life lost (YLLs) due to exposure to PM₂.₅ for people older than 30 years were calculated using AirQ 2.2.3 in an Italian industrial area. The authors reported that for lung cancer, about 433 and 1204 years of life lost can be attributed to PM₂.₅ concentrations higher than 10 μg/m³ during the first year and the next 10 years, respectively. The yearly average concentration of PM₂.₅ was 42 μg/m³ [38].

Health impacts of air pollution force economic losses to each country. These losses are either direct and indirect (15). According to the World Bank group evaluation, total welfare losses (TWL) and total forgone labor (TFL) output caused by PM₂.₅ in Iran were about 31 and 1.5 billion USD in 2013, respectively. These values contribute to 2.48% and 0.12% of gross domestic product (GDP) of the country, respectively. In 1990, the TWL and the TFL output caused by PM₂.₅ are announced 14 and 2.5 billion USD, respectively [1]. Thus, reducing concentrations of air pollutants to below guideline values not only decreases mortality or hospitalization rate, but also has positive influences on national economies.
CONCLUSIONS
AirQ+ model was used for estimation of lung cancer deaths due to long-term exposure to fine particulate matter (PM$_{2.5}$). Target population was people with more than 30 years old. High concentrations of PM$_{2.5}$ were observed in Western and Southern cities. Annual concentrations of PM$_{2.5}$ in all cities were much more than the WHO’s guideline. However, Karaj – as a city in Central areas- showed highest lung cancer mortality due to PM$_{2.5}$. That was mainly due to its higher population, in comparison to other cities. Beside the number of lung cancer deaths, the burden of disease (i.e. DALY) and also economic losses can be significant. Results of this study are interesting for authorities and decision-makers who are responsible for public health and also allocation of financial resources. They can raise the budget for air pollution reduction strategies and plans. Any reduction in air pollution’s level, and attributed mortality and hospitalization reduces the number of years lost due to illness, disability or early death, and cost of illness (COI).

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COMPETING INTERESTS
The authors declare that they have no conflict of interest.

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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 observed by the authors.

REFERENCES


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