Estimation of Gender-Specific Lung Cancer Deaths due to Exposure to PM2.5 in 10 Cities of Iran During 2013 - 2016: A Modeling Approach

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Abstract

Background: Various epidemiological studies have related fine particles (PM2.5) to incidence of lung cancer. In addition, particulate air pollution has been classified as Group 1 carcinogen by international agency for research on cancer (IARC) in 2013.

Objectives: The aim of this study was to quantify the number of gender-specific lung cancer deaths due to exposure to PM2.5 among individuals aged over 30 years using WHO AirQ+ model in 10 cities of Iran during March 2013-March 2016.

Methods: Hourly concentrations of PM2.5 were obtained from department of environment (DOE) of Iran and Tehran air quality control company (TAQCC). Demographic information and baseline incidence (BI) were acquired from statistical center of Iran, ministry of health and medical education, respectively. AirQ+ model was used to quantify the lung cancer deaths among males and females aged over 30 years.

Results: The highest lung cancer deaths were in Tehran with approximately 407 cases of death during the whole three-year period. The total deaths among men and women in the whole period were 433 and 431 cases, respectively. The sum of lung cancer deaths due to PM2.5 exposure in all the 10 cities during these 3 years were estimated 864 cases. In addition, the attributable proportion of lung cancer due to PM2.5 exposure in each city was estimated. Despite the high number of lung cancer deaths in Tehran, higher AP values were observed in cities such as Isfahan, Ahvaz, Khoram Abad and Arak, reflecting the higher risk of death per unit of population.

Conclusions: The results of this study could be used by authorities for making air pollution reduction strategies and plans. Furthermore, any reduction in attributed mortality and hospitalization reduces financial burden in health organizations.

Keywords: Health Impact Assessment, Particulate Matter, Mortality, AirQ Plus

1. Background

Air pollution is introduced as the fourth risk factor to human health according to the world bank (1). Annually, it causes approximately 7 million deaths all around the world (2, 3). Several air pollutants such as particulate matter, nitrogen dioxide, ozone, sulphur dioxide, etc. are determined to be associated with different health outcomes. Epidemiological studies have been conducted in various countries to investigate this relationship precisely (4-8). Particulate matter of 2.5 micrometers or smaller (PM2.5) is a part of particulate matter, but is able to enter the alveolar lung region, a place to exchange the blood. PM2.5 represents the high-risk breathable component of the particulate matter of 10 micrometers or smaller (PM10) (9).

PM2.5 concentrations have been associated with short- and long-term cause-specific mortality and morbidity incidence. Short-term exposure to high PM2.5 levels has been known as a significant risk factor for patients with chronic obstructive pulmonary diseases (COPDs) or ischemic diseases. In addition, long-term exposure is associated to deaths due to cardiovascular diseases, respiratory diseases, and lung cancer (9). A cohort study showed that the incidence of lung cancer increased by 8% per 10 µg/m3 increase in concentration of PM2.5 (10). A sub-analysis of about 190,000 never-smokers in a cohort study showed a significant effect of long-term exposure to PM2.5, with a 15% - 27% increase in cancer mortality per 10 µg/m3 increase in concentration (11). According to the international agency for research on cancer (IARC), there is sufficient evidence on the relationship between exposure to air pollution and the incidence of lung and bladder cancers. In this context, particulate matter has been classified as Group 1 carcinogen (carcinogenic to humans) (12).
In case of lung cancer, the mechanisms can be related to cellular stress induced by particles and DNA damage. PM$_{2.5}$ as a mass indicator contains many elements and compounds. The organic fraction of fine particles such as nitrogen compounds or metabolically activated polycyclic aromatic hydrocarbons (PAHs) are capable to form bulky DNA adducts. Furthermore, the PM$_{2.5}$ mixture contains various components which can increase reactive oxygen species (ROSs). These molecules are implicated in oxidative stress, which is an important toxicological mechanism of particle-induced lung cancer (9, 13). In addition, elemental carbon is recognized as a risk factor of lung cancer (14). However, more studies are needed to determine the exact genes and affecting mechanisms (15, 16).

According to WHO, ambient air pollution has caused about 402,250 deaths due to lung cancer globally in 2012 (17). The world bank has reported that air pollution is responsible for about 24% of lung cancer deaths in the world. While in 1990 the air pollution’s outcomes were largely attributable to pneumonia. In 2011 the cause shifted to cardiovascular disease and lung cancer (1). Ministry of health and medical education of Iran has reported that the cancer of lung and bronchus is the fourteenth cause of death (9, 13). In addition, AirQ+ was taken from Ministry of Health and Medical Education (18). In addition, AirQ+ default relative risk (RR) values were used to evaluate the health impacts of PM$_{2.5}$ (33). The study was approved by the medical ethics committee of the Shahid Beheshti University of Medical Sciences (reference number of research ethics committee: 273).

2. Methods

2.1. Location and Time

Iran with more than 80 million people is located in the Middle East. Ten cities of Iran were chosen to be assessed in case of lung cancer mortality attributed to the PM$_{2.5}$ ambient air concentrations, including Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad and Ilam. The related populations and locations are presented in Table 1 and Figure 1, respectively. The total population of these 10 cities were more than 20 million in 2015. According to statistical centre of Iran, the number of people with age more than 30 years was about 11 million in the same year, including approximately 50.5% men and 49.5% women.

The study period was between March 21th, 2013 and March 19th, 2016, which is three years on Persian calendar. The first yearly period was from March 21th, 2013 to March 20th, 2014. The second period was from March 21th, 2014 to March 20th, 2015, and the third period was between March 21th, 2015 and March 19th, 2016.

2.2. Data Collection

Hourly concentrations of PM$_{2.5}$ and PM$_{10}$ were obtained from department of environment (DOE) of Iran. In addition to DOE monitoring stations, PM$_{2.5}$ measurements in Tehran are provided by Tehran air quality control company (TAQCC). In cities, where PM$_{2.5}$ measurements were unavailable, PM$_{2.5}$ levels were calculated using PM$_{10}$ levels and the PM$_{2.5}$/PM$_{10}$ conversion factor of 0.33 provided by the WHO (31). Demographical information was acquired from statistical center of Iran (32). Baseline incidence (BI) for lung cancer mortality was taken from Ministry of Health and Medical Education (18). In addition, AirQ+ default relative risk (RR) values were used to evaluate the health impacts of PM$_{2.5}$ (33). The study was approved by the medical ethics committee of the Shahid Beheshti University of Medical Sciences (reference number of research ethics committee: 273).

2.3. Data Validation

Outlier and zero hourly values were omitted from the dataset, and 24-hour averages were calculated. Criteria for validity of stations provided by WHO were used in order to validate PM$_{2.5}$ measured concentrations (34). The ratio between the number of valid data for the two seasons of each year cannot be greater than 2. To obtain 24-hour average values from data with a smaller averaging time, over 50% of 1-hour valid data should be valid.

2.4. AirQ+

AirQ+ is a software developed by the WHO regional office for Europe in order to quantify the health effects and calculate the burden of disease related to ambient 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) (35).

Running AirQ+ requires some input data such as the mean concentration of the pollutant, total population, at-risk population, baseline incidence, relative risk and area size (km²). All these data were provided as was mentioned before. In addition, no human subjects were used in this modelling study, so there was no need to provide ethical permission.
Table 1. The Approximate Total Population and At-Risk Population of the 10 Cities (2013 - 2016)

| Cities   | Gender | 2013 – 2014<sup>a</sup> | 2014 – 2015<sup>b</sup> | 2015 – 2016<sup>c</sup> |
|----------|--------|--------------------------|--------------------------|--------------------------|
|          | Total  | At-Risk                  | Total                    | At-Risk                  | Total                    | At-Risk                  |
| Tehran   | Male   | 8672250                  | 2138323                  | 2403331                  | 8866500                  | 2488339                  |
|          | Female | 2317766                  | 663687                  | 692655                  | 722940                  |
| Mashhad  | Male   | 2831220                  | 659055                  | 688604                  | 3046550                  | 718152                  |
|          | Female | 54080                   | 139886                  | 428330                  | 449500                  |
| Isfahan  | Male   | 2002670                  | 52920                   | 550080                  | 2222580                  | 603840                  |
|          | Female | 395966                  | 103328                  | 157850                  | 450320                  |
| Shiraz   | Male   | 1578720                  | 398528                  | 403971                  | 1755000                  | 4472720                  |
|          | Female | 395966                  | 166550                  | 424444                  | 4472720                  |
| Tabriz   | Male   | 1557600                  | 40533                   | 410660                  | 167380                   | 451360                  |
|          | Female | 40693                   | 160200                  | 428330                  | 449500                  |
| Ahvaz    | Male   | 1256920                  | 274398                  | 308800                  | 1349715                  | 322800                  |
|          | Female | 270255                  | 1282058                 | 283675                  | 310440                  |
| Arak     | Male   | 555390                   | 139886                  | 157620                  | 632800                  | 164835                  |
|          | Female | 153127                  | 609400                  | 150700                  | 157850                  |
| Sanandaj | Male   | 387600                   | 93432                   | 98800                   | 420000                  | 102400                  |
|          | Female | 87971                   | 404430                  | 93749                   | 9847                    |
| Khoram Abad | Male | 352000                  | 84566                   | 89080                   | 393050                  | 95940                   |
|          | Female | 84952                   | 377400                  | 90440                   | 95940                   |
| Ilam     | Male   | 177600                   | 42425                   | 187000                  | 198640                  | 47840                   |
|          | Female | 41357                   | 43849                   | 46800                   | 46800                   |
| Total    |        | 1937970                  | 9795073                 | 19947098                | 20558215                | 10885305                |

<sup>a</sup>March 21th, 2013 to March 20th, 2014.<br><sup>b</sup>March 21th, 2014 to March 20th, 2015.<br><sup>c</sup>March 21th, 2015 to March 19th, 2016.

3. Results

3.1. PM<sub>2.5</sub> Concentrations

Table 2 presents the mean concentrations of PM<sub>2.5</sub> in the 10 cities in Iran during March 2013 - March 2016.

Comparison of the average concentration of these 10 cities showed that Ahvaz has been ranked as the most polluted city in the first and third years. The highest PM<sub>2.5</sub> concentrations in the second year were observed in Isfahan. As is presented in Table 2, average concentration of PM<sub>2.5</sub> in these 10 cities are 39.15, 34.34 and 32.09 for the first to the third periods, respectively. The results in Table 2 reveal that all these 10 cities in all the years have not met WHO guideline value of 10 µg/m<sup>3</sup> for PM<sub>2.5</sub> concentration in ambient air (36). The quality of ambient air in Tehran, Isfahan, Arak and Sanandaj has been improved constantly during the three-year period.

3.2. Lung Cancer Mortality

Lung cancer mortality in male and female individuals aged over 30 years was estimated, and the results are presented in Table 3.

The attributable deaths of lung cancer due to exposure to PM<sub>2.5</sub> in Tehran, Mashhad, Isfahan, Shiraz, Tabriz and Ahvaz during the whole period were estimated 407, 105, 118, 58, 52 and 69 cases, respectively. In addition, the attributable cases of lung cancer mortality due to PM<sub>2.5</sub> exposure in Arak, Sanandaj, Khoram Abad and Ilam within the 3 years were 22, 12, 16 and 6, respectively.

According to Table 3, the number of deaths in males were slightly greater than females, which is because of higher population of men in the study. The total deaths among men and women in the whole three years were 433 and 431 cases, respectively. On the other hand, the most number of deaths in all the three years have been at-
contributed to Tehran, which reflects its both high concentration and population. The least lung cancer deaths during all the periods have occurred in Ilam. Total cases of PM$_{2.5}$’s attributable lung cancer deaths in March 2013-March 2014, March 2014-March 2015 and March 2015-March 2016 periods were 300, 282 and 282, respectively. Furthermore, the sum of lung cancer deaths due to PM$_{2.5}$ in all the 10 cities during the 3-year period was estimated 864 cases.

4. Discussion

4.1. PM$_{2.5}$ Concentration

Recent studies have proved the association between PM$_{2.5}$ and lung cancer (37, 38). The urban concentrations of PM$_{2.5}$ in North America, Europe, Africa and Asia are reported 17, 15 - 20, 15 - 30 and 30 - 60 µg/m$^3$, respectively. About 90% of US monitoring stations records PM$_{2.5}$ concentrations below 16 µg/m$^3$ (9). However, Iranian cities are among the most polluted cities in the world in case of ambient air particulate pollution. Zabol is known to have the highest PM$_{2.5}$ concentrations in the world during 2012. Ahvaz, a city investigated in this study, is the 43rd polluted city in the world in terms of PM$_{2.5}$ (19). Western and Southern cities of Iran such as Ahvaz and Khoram Abad are being affected by the Middle Eastern dust storms, which increase the particulate matter concentrations (20, 21). It is reported that about 70% of particulate air pollutants in Tehran have been emitted from mobile sources during 2015 (39). In addition, about 76% of air pollution in Isfahan is reported to be produced by mobile sources in 2010 (25).

4.2. Lung Cancer Mortality

In order to remove the effect of demographical characteristics, the attributable proportions (APs) are calculated and presented in Table 3. The higher AP means higher number of deaths per unit of population. In March 2013-March 2014 period, the highest APs were those of Ahvaz, Isfahan and Arak. In March 2014-March 2015 period, Isfahan, Ahvaz and Khoram Abad showed higher AP values, compared to other cities. In addition, the same cities had the highest APs in March 2015-March 2016, but in a different order. On the other hand, the trend of AP values in a city over time can be interpreted as a representative of the environmental conditions and effectiveness of air pollution control plans. For instance, the trend of APs in Tehran, Isfahan and Arak shows a constant decline during these three years, which means PM$_{2.5}$ is becoming a less important risk factor to the public health in case of lung cancer. For other cities, the AP values have been fluctuated through the three-year period.

In a study to determine the spatial and temporal trends in the mortality burden of air pollutants in China, the lung cancer deaths increased from 93 thousand (95% CI: 33 -127) cases in 2004 to 169 thousand (95% CI: 61 -227) cases in 2012. In 2012, 27.9% of deaths caused by lung cancer could be attributed to exposure to ambient PM$_{2.5}$ (40).

It is estimated that particulate matter causes about half of the lung cancer incidence in China and other East Asian countries (41). In a study in China, the authors compared attributable fraction (AF) of lung cancer in cities in order to remove the effects of different populations. The results indicated that except for some cases, most of Chinese provinces showed an increasing trend in AF during 2004-2012. All of the provinces with the decreasing trend are located in the Southern China, which is known to have high amount of precipitation, vast forests, lack of winter heating, and the occurrence of sea-land breeze. The combination of these have led to high deposition and dispersion and low production of particulate matter (40). In a study in Poland, the highest attributable fractions were obtained in southern areas, where the emissions originate from municipal and household sources (so-called low-stack emission), road transport and heavy industry. On the other hand, due to lower density of emission sources and better climatic conditions for dispersion of air pollutants, the lowest values were observed in eastern and northern areas (42).

The estimation of lung cancer mortality attributed to PM$_{2.5}$ in 23 European cities with 36 million people showed that 1296 and 1901 lung cancer deaths could be prevented each year if PM$_{2.5}$ concentration were reduced to 20 and 15 µg/m$^3$, respectively. The number of deaths per 100,000 people were estimated to be 4 and 5 for the two above mentioned scenarios, respectively (43).

### Table 2. The Mean Concentrations (± SD) of PM$_{2.5}$ in the 10 Cities in Iran (2013 - 2016)

| City     | Mean Concentration (± SD) µg/m$^3$ |
|----------|----------------------------------|
|          | 2013 - 2014$^a$ | 2014 - 2015$^b$ | 2015 - 2016$^c$ |
| Tehran  | 39.46 (± 11.42) | 36.42 (± 9.41) | 31.87 (± 13.68) |
| Mashhad | 36.06 (± 26.97) | 27.29 (± 15.24) | 30.60 (± 13.8)  |
| Isfahan | 56.15 (± 28.73) | 54.99 (± 25.59) | 37.29 (± 13.72) |
| Shiraz  | 32.23 (± 14.93) | 25.00 (± 10.41) | 26.80 (± 15.5)  |
| Tabriz  | 30.68 (± 22.67) | 17.21 (± 8.36)  | 22.72 (± 12.64) |
| Ahvaz   | 62.61 (± 71.69) | 53.09 (± 52.58) | 60.88 (± 61.67) |
| Arak    | 43.14 (± 34.26) | 32.53 (± 17.72) | 23.61 (± 14.51) |
| Sanandaj| 29.78 (± 18.44) | 29.74 (± 20.12) | 25.02 (± 15.97) |
| Khoram Abad | 32.58 (± 28.08) | 40.02 (± 31.41) | 33.95 (± 38.43) |
| Ilam    | 28.78 (± 23.68) | 26.04 (± 27.37) | 28.35 (± 31.94) |
| Average | 39.15 (± 28.09) | 34.14 (± 21.82) | 32.09 (± 23.19) |

$^a$March 21th, 2013 to March 20th, 2014.
$^b$March 21th, 2014 to March 20th, 2015.
$^c$March 21th, 2015 to March 19th, 2016.
Table 3. Number of Lung Cancer Deaths in Male and Female Individuals Over 30 Years Old in the Ten Cities in Iran, (2013 - 2016)∗

| City     | Gender | 2013 – 2014a | 2014 – 2015b | 2015 – 2016c |
|----------|--------|--------------|--------------|--------------|
|          |        | AP (CI 95%)  | Deaths (CI 95%) | AP (CI 95%)  | Deaths (CI 95%) | AP (CI 95%)  | Deaths (CI 95%) |
| Tehran   | Male   | 19.66 (5.66 - 29.08) | 71 (20 - 105) | 18.24 (4.76 - 27.7) | 68 (18 - 103) | 16.66 (3.85 - 25.37) | 64 (15 - 98) |
|          | Female | 19.66 (5.66 - 29.08) | 71 (20 - 105) | 18.24 (4.76 - 27.7) | 68 (18 - 103) | 16.66 (3.85 - 25.37) | 65 (15 - 99) |
| Mashhad  | Male   | 18.03 (4.76 - 27.49) | 18 (5 - 28) | 14.6 (3 - 23.3) | 16 (3 - 25) | 15.97 (3.85 - 25.26) | 18 (4 - 28) |
|          | Female | 18.03 (4.76 - 27.49) | 19 (5 - 28) | 14.6 (3 - 23.3) | 16 (3 - 25) | 15.97 (3.85 - 25.26) | 18 (4 - 28) |
| Isfahan  | Male   | 25.37 (8.26 - 35.74) | 21 (7 - 29) | 24.35 (7.57 - 34.72) | 20 (6 - 29) | 18.7 (4.76 - 28.35) | 17 (4 - 26) |
|          | Female | 25.37 (8.26 - 35.74) | 21 (7 - 29) | 24.35 (7.57 - 34.72) | 20 (6 - 29) | 18.7 (4.76 - 28.35) | 17 (4 - 26) |
| Shiraz   | Male   | 16.83 (3.85 - 25.5) | 10 (2 - 16) | 13.79 (2.91 - 21.9) | 9 (2 - 14) | 14.31 (2.91 - 22.9) | 10 (2 - 14) |
|          | Female | 16.83 (3.85 - 25.5) | 10 (2 - 16) | 13.79 (2.91 - 21.9) | 9 (2 - 14) | 14.31 (2.91 - 22.9) | 10 (2 - 14) |
| Tabriz   | Male   | 15.97 (3.85 - 25.17) | 10 (2 - 16) | 10 (1.96 - 16) | 7 (1 - 11) | 12.28 (2.91 - 20.22) | 9 (2 - 14) |
|          | Female | 15.97 (3.85 - 25.17) | 10 (2 - 16) | 10 (1.96 - 16) | 7 (1 - 11) | 12.28 (2.91 - 20.22) | 9 (2 - 14) |
| Ahvaz    | Male   | 26.47 (9.09 - 36.7) | 11 (4 - 16) | 23.66 (7.41 - 33.77) | 10 (3 - 15) | 25.93 (8.26 - 36.12) | 13 (4 - 18) |
|          | Female | 26.47 (9.09 - 36.7) | 11 (4 - 16) | 23.66 (7.41 - 33.77) | 10 (3 - 15) | 25.93 (8.26 - 36.12) | 13 (4 - 18) |
| Arak     | Male   | 20.67 (5.66 - 30.58) | 4 (1 - 7) | 17.01 (3.85 - 25.65) | 4 (1 - 6) | 12.77 (2.91 - 20.21) | 3 (1 - 5) |
|          | Female | 20.67 (5.66 - 30.58) | 4 (1 - 6) | 17.01 (3.85 - 25.65) | 4 (1 - 6) | 12.77 (2.91 - 20.21) | 3 (1 - 5) |
| Sanandaj | Male   | 15.95 (3.8 - 24.8) | 2 (1 - 4) | 15.61 (3.85 - 14.52) | 2 (1 - 4) | 13.74 (2.91 - 21.83) | 2 (0.5 - 3) |
|          | Female | 15.95 (3.8 - 24.8) | 2 (1 - 4) | 15.61 (3.85 - 14.52) | 2 (1 - 4) | 13.74 (2.91 - 21.83) | 2 (0.5 - 3) |
| Khoram Abad | Male  | 17 (3.84 - 25.7) | 2 (1 - 3) | 20.41 (5.6 - 29.89) | 3 (1 - 4) | 17.55 (4.76 - 26.63) | 3 (1 - 4) |
|          | Female | 17 (3.84 - 25.7) | 2 (1 - 3) | 20.41 (5.6 - 29.89) | 3 (1 - 4) | 17.55 (4.76 - 26.63) | 3 (1 - 4) |
| Ilam     | Male   | 15.25 (3.8 - 24.35) | 1 (0.5 - 2) | 13.79 (2.91 - 22.47) | 1 (0.5 - 2) | 15.25 (3.8 - 23.72) | 1 (0.5 - 2) |
|          | Female | 15.25 (3.8 - 24.35) | 1 (0.5 - 2) | 13.79 (2.91 - 22.47) | 1 (0.5 - 2) | 15.25 (3.8 - 23.72) | 1 (0.5 - 2) |
| Total    |        | - | 300 (87 - 449) | - | 282 (73 - 428) | - | 282 (86 - 429) |

*Abbreviation: AP, attributable proportion.
aMarch 21th, 2013 to March 20th, 2014.
bMarch 21th, 2014 to March 20th, 2015.
cMarch 21th, 2015 to March 19th, 2016.

Years of life lost (YLLs) due to exposure to PM$_{2.5}$ for individuals older than 30 years were estimated using AirQ 2.2.3 in an industrial area in Italy. The results showed that for lung cancer, about 433 and 1204 years of life lost are attributed to the concentrations higher than 10 µg/m$^3$ during the first year and the next 10 years, respectively. The an-
nual average concentration of PM$_{2.5}$ were calculated to be 42 µg/m$^3$ (44).

WHO has estimated the lung cancer mortality and burden of disease attributed to ambient air pollution in 2012 within the world. However, the related database included the concentrations of particulate matter (PM$_{10}$ and PM$_{2.5}$). The report provides the country-specific number of deaths, YLLs and DALYs regarding the lung cancer caused by air pollution. The number of deaths, YLLs and DALYs of lung cancer attributed to air pollution in Iran during 2012 were calculated 1460, 37,894 and 38,258, respectively (17). In addition to WHO, the world bank group has estimated the total deaths from air pollution in Iran, considering the value of 31.89 µg/m$^3$ as the PM$_{2.5}$ national concentration. About 21680 deaths were attributed to ambient PM$_{2.5}$ in Iran during 2013 (1).

The mortality and morbidity caused by air pollution impose a financial burden on the countries. The world bank has estimated that the total welfare losses and the total forgone labor output caused by PM$_{2.5}$ 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 total welfare losses and the total forgone labor output caused by PM$_{2.5}$ are announced 14 and 2.5 billion USD, respectively (1). Therefore, any reduction in air pollutants concentration can decrease the financial burden on the health systems.

In conclusion, AirQ+ model was used to estimate the lung cancer deaths among males and females over 30 years old due to exposure to particulate matter of 2.5 micrometers or smaller (PM$_{2.5}$) in Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad and Ilam during March 2013-March 2016. Most of lung cancer deaths were observed to be in Tehran, due to both high population and PM$_{2.5}$ concentrations. However, the comparison between attributable proportion values showed that Ahvaz, Isfahan, Khoram Abad and Arak air pollution is a higher risk factor in case of lung cancer incidence per unit of population. Mobile sources have been introduced as the major source of Tehran and Isfahan air pollution. Ahvaz and Khoram Abad are being influenced by Middle Eastern dust storms. The results of this study could be used by authorities for making air pollution reduction strategies and plans. Furthermore, any reduction in attributed mortality and hospitalization reduces treatment costs in health organizations.

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Footnotes

Authors’ Contribution: None declared.

Conflicts of Interest: The authors declare that there are no conflicts of interest.

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References

1. Bank W. The cost of air pollution: strengthening the economic case for action. Washington: World Bank Group; 2016.
2. World Health Organization (WHO). 7 million premature deaths annually linked to air pollution. World Health Organization; 2014.
3. G. B. D. Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990-2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet. 2016;388(10053):1659-724. doi: 10.1016/S0140-6736(16)31679-8. [PubMed: 27732884].
4. Fischer PH, Marra M, Ameling CB, Hoek G, Beelen R, de Hoogh K, et al. Air Pollution and Mortality in Seven Million Adults: The Dutch Environmental Longitudinal Study (DUELS). Environ Health Perspect. 2015;123(7):969-704. doi: 10.1289/ehp.1406825. [PubMed: 25760672].
5. Crouse DL, Peters PA, Hystad P, Brook JR, van Donkelaar A, Martin RV, et al. Ambient PM$_{2.5}$, O$_{3}$, and NO$_{2}$ Exposures and Associations with Mortality over 16 Years of Follow-Up in the Canadian Census Health and Environment Cohort (CanCHEC). Environ Health Perspect. 2015;123(1):1180-6. doi: 10.1289/ehp.1409276. [PubMed: 2652872].
6. Dai L, Zanobetti A, Koutrakis P, Schwartz JD. Associations of fine particulate matter species with mortality in the United States: a multicity time-series analysis. Environ Health Perspect. 2014;122(6):837-42. doi: 10.1289/ehp.1305863. [PubMed: 24800826].
7. Cesaroni G, Badaloni C, Garazzo C, Stafiggita M, Sozzi R, Davoli M, et al. Long-term exposure to urban air pollution and mortality in a cohort of more than a million adults in Rome. Environ Health Perspect. 2013;121(3):324-31. doi: 10.1289/ehp.1205862. [PubMed: 23108401].
8. Yang Y, Cao Y, Li W, Li R, Wang M, Wu Z, et al. Multi-site time series analysis of acute effects of multiple air pollutants on respiratory mortality: a population-based study in Beijing, China. Sci Total Environ. 2015;508:878-87. doi: 10.1016/j.scitotenv.2014.10.070. [PubMed: 25478654].
9. Traversi D, Schiliro T, Degran R, Pignata C, Alessandria L, Gilli G. Involvement of nitro-compounds in the mutagenicity of urban PM$_{2.5}$ and PM$_{10}$ in Turin. Mutation Research/Genetic Toxicology and Environmental Mutagenesis. 2011;726(1):54-9. doi: 10.1016/j.mrgentox.2011.09.002.
10. Pope C3, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA. 2002;287(23):3132-41. [PubMed: 11979101].
11. Turner MC, Krewski D, Pope C3, Chen Y, Gapstur SM, Thun MJ. Long-term ambient fine particulate matter air pollution and lung cancer in a large cohort of never-smokers. Am J Respir Crit Care
26. Naddafi K, Hassanvand MS, Yunesian M, Momeniha F, Nabizadeh R, Asghar Zarabi JM, Abdollahi AA. Investigation and evaluation of stationary and mobile sources of Isfahan's air pollution. Clean-Sew. Water. 2011; 41(2):104–15. doi: 10.1007/s10098-011-1065-z. [PubMed: 21524761].
27. Miri M, Derakhshani Z, Allahabadi A, Ahmadi E, Oliveri Conti G, Ferrante M, et al. Mortality and morbidity due to exposure to outdoor air pollution in Mashhad metropolis, Iran. The AirQ model approach. Environ Res. 2016;151:451-7. doi: 10.1016/j.envres.2016.07.039. [PubMed: 27565880].
28. Goudarzi G, Geravandi S, Vosoughi M, Javad Mohammadi M, Sadat Taghaviard S. Cardiovascular deaths related to Carbon monoxide Exposure in Ahvaz, Iran. Int J Health Safety Environ. 2014;3(3):126–31.
29. Mohammadi A, Azhdarpoor A, Shahasvani A, Tabatabaea H. Investigating the Health Effects of Exposure to Criteria Pollutants Using AirQ2.2.1 in Shiraz, Iran. Aerosol Air Qual Res. 2015;16(4):1034-43. doi: 10.4209/aaqr.2015.07.0434.
30. Bahrami Asf F, Kermani M, Aghaai M, Karimzadeh S, Salahshour Arian S, Shahasvani A, et al. Estimation of Diseases and Mortality Attributed to NO2 pollutant in five metropolises of Iran using AirQ1model in 2011-2012. J Mazandaran Univ Med Sci. 2015;24(12):239-49.
31. WHO. Conversion factors from WHO Ambient air quality database. World Health Organization; 2016.
32. Iran SCo. Detailed results of the General Census of Population and Housing. ; 2011.
33. World Health Organization (WHO) . Monitoring ambient air quality for health impact assessment. ; 1999.
34. Pierpaolo MCG, Maria D. AirQ+ 1.0 example of calculations. World Health Organization; 2011.
35. Organization WH. Air quality guidelines: global update 2005: particulate matter, ozone, nitrogen dioxide, and sulfur dioxide. World Health Organization; 2006.
36. Raaschou-Nielsen O, Andersen ZJ, Beelen R, Stafoggia M, Weinmayr G, et al. Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). Lancet Oncol. 2013;14(9):813–22. doi: 10.1016/S1470-2045(13)70279-1. [PubMed: 23849338].
37. Hamra GB, Guha N, Cohen A, Laden F, Raaschou-Nielsen O, Samet JM, et al. Outdoor particulate matter exposure and lung cancer: a systematic review and meta-analysis. Environ Health Perspect. 2014;122(9):906-11. doi: 10.1289/ehp.1308092. [PubMed: 24196130].
38. Boldo E, Medina S, LeTertre A, Hurley F, Mucke HG, Hadei M et al. Human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy. Environ Res. 2013;118(8):1321-7. doi: 10.1016/j.envres.2013.06.012. [PubMed: 23764052].