Quantification of mortality and morbidity in general population of heavily-industrialized city of Abadan: Effect of long-term exposure

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ABSTRACT:
Introduction: In the 21st century, air pollution has become a global and environmental challenge. The increase in cases of illness and mortality due to air pollution is not hidden from anyone. Therefore, in this study, we estimated the mortality rate due to cause by air pollution agents (PM₂.₅) in the southernmost city of Khuzestan province (Abadan city) at 2018-2019.

Materials and methods: To estimate the mortality due to air pollution, data related to PM₂.₅ particles daily concentrations was received from the Abadan Environmental Protection Organization. The average 24-h concentrations of PM₂.₅ were calculated using Excel. Then, mortality data were obtained from the Vice Chancellor for Health, Abadan University of Medical Sciences. Finally, by AirQ+ software, each of the mortality in 2018-2019 in Abadan was estimated.

Results: The obtained data indicated that the concentration of PM₂.₅ particles within the one-year period was higher than the value set by WHO guideline and EPA standard. Which caused the citizens of Abadan to be exposed to PM₂.₅ more than 8.23 times than the guidelines of the WHO and 5.34 times more than the standard of the EPA. The output of the model used in this study was as follows: natural mortality (462 cases, AP: 38.25%), mortality due to LC (6 cases, AP: 32.18%), mortality due to COPD (8 cases, AP: 8.64%), mortality due to Stroke (86 cases, AP: 71.26%), mortality due to IHD (183 cases, AP: 68.34%) and mortality due to ALRI (2 cases, AP: 32.9%).

Conclusion: Planning appropriate strategies of air pollution control to reduce exposure and attributable mortalities is important and necessary.
nogenic to humans by the IARC, and now it is one of the 5 top causes of death in the world [3]. As a result, it can be said that air pollution have a one of the hazard agent for human life continuity [5,4]. On the other hand, exposure to causes of air pollution can be endanger human health [6]. Air pollutants contain carcinogenic and dangerous compounds [8,7]. Particulate matter with a diameter of less than 2.5 μm are the causes of air pollution and the impact on human health [9]. About 87% of the People of the world living in countries where the level of air pollution (level of PM$_{2.5}$) is higher than the allowable limit set by regulatory agencies (10 μg/m$^3$), including the WHO [10]. Mortality due to exposure of air pollution agents ambient (PM$_{2.5}$) has reached a very high levels [11]. So that, nearly 7 million deaths and 3.7 million premature deaths occur annually in urban and rural areas due to exposure to these fine particles [13,12]. In during the recent decade’s mortality due to LC, COPD, stroke, IHD and ALRI due to exposure to PM$_{2.5}$ particles has increased [14]. Air pollution in addition to health effects it was increases the negative effects on the economies of countries. In 2016 the costs of air pollution were estimated to be as much as the gross domestic product (GDP) in some countries such as India, Canada, and Mexico [15]. Numerous studies have examined exposure to suspended particles and adverse health effects. In the crouse study, mortality from cardiovascular diseases increased by 10–20% due to an increase in PM$_{2.5}$ particle concentration [16]. Some researchers showed an association among fine particles and fatality from IHD, cardiovascular disease and LC [17]. And also in a study by other researchers, association among fine particles and mortality from IHD, cardiovascular disease and LC it was found [18]. Dust in parts of Iran, especially in Khuzestan province and cities of that province, has disrupted people’s lives and severely overshadowed people’s quality of life [19]. Continuation and recurrence of this pollution, especially with the prevailing weather conditions in autumn and winter, is a warning sign of an increase in cardiovascular disease, lung disease, cancer and an increase in deaths [20]. Quantifying the health effects of air pollution is an important guide for community decision makers and determines the extent of the health effects of air pollution and prioritizes air pollution control over In comparison with to other hazard agent [21]. Abadan city as one of the industrial cities of Iran because of unsustainable development, incompatible ambient air quality standards along, existence of the largest oil refinery in Iran and in neighboring countries, dust hotspot in the city itself, and most importantly, the dust imported from Iraq and Saudi Arabia, has seriously faced sever ambient air pollution[22]. Since the carcinogenicity of air pollution has been proven, the necessary measures to prevent such diseases and mortality are of great importance. In addition, the chemical properties of fine particles in this city have been studied to some extent, however, the health effects of these pollutants on the residents of this city have not been evaluated so far [23]. Thus, the current research was carried out with the following aim: estimating all naturally mortality cases, lung cancer (LC) in adults (over 30 years), COPD in adults (over 30 years), stroke in adults (over 25 years), IHD in adults (over 25 years), ALRI in childhood (Less than 5 years), and attributed to exposure to PM$_{2.5}$ in the atmosphere of Abadan city from March 2018 to March 2019 using AirQ+. 

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Material and methods

Description of study area

Abadan city in Khuzestan province with geographical features of 48°17’E and 30°20’N and 3 m above sea level is known as one of the most famous cities in the south of Iran. Abadan city borders the cities of Khorramshahr, Shadegan and Mahshahr, so that the south of this city leads to the Persian Gulf. On the other hand, two rivers, Arvand and Bahmanshir, are flowing in this city. (Fig. 1). According to the 2016 enumeration, this city with a population of 300,000 people after Ahvaz and Dezful is the third most populous city in Khuzestan province. This city due to the largest oil refinery in the Middle East and access to open waters, petrochemical plants play a serious pattern in the Iranian economy, and along with the Tehran city (the capital of Iran) and Karaj (the capital of Alborz province) are known as the most industrial cities of Iran. The growth of this city has been based on the principles of urban planning due to the existence of a large oil refinery, something that the center of the province has been deprived of in recent decades. Abadan, like most cities in Khuzestan province, has a hot and humid climate and has hot summers and humid winters with mild weather. The average of annual rainfall, temperature in winter and summer was 350 mm, 5°C and 57°C, respectively. The hottest and coldest months of the year in this city are August and February, respectively [24].

On the other hand, Abadan, like other cities in Khuzestan province, is no exception to air pollution. In a way, in most seasons of the year, we see catastrophic pollution in this city. The source of most pollution in Abadan air can be attributed to fine dust. These dust particles are can be attributed to the destruction of vegetation and drying of wetlands in Khuzestan province, Iraq and also the Saudi desert and phenomenon of climate change. However, the pollution caused by the oil industry refinery should not be ignored. In this city, there is a fixed station for measuring air pollutants, which is owned by the city’s environmental protection department. The installation site of Abadan Hilal Barim station is the Environmental Protection Office.

Quantification

To express the effects of air pollutants on humans, several indicators can be used, one of the most important methods is the quantification of effects. In this method, the amount of effects attributed to each pollutant is estimated. Quantification in air pollution in order to measuring the effect of air pollution on public health is done with the aim of is possible by using mathematical and statistical models and relationships. One of the methods of quantifying the effects of air pollution is AirQ+ introduced by WHO. The AirQ+ that May 2016 by the European Office of the WHO to quantify of pollutants (which is actually an upgraded version of AirQ2.2.3), is a user-friendly model. Acute and chronic consequences on human health due to contact with various air pollutants, along with mortality and disease can be estimated using this software [26,25].

Data collection and processing

Abadan city, there is a one air pollution measuring station which is at the access of the environmental protection organization. Therefore, daily air quality of this city is measured by this station. In order to estimate the mortality due to exposure with PM$_{2.5}$ particles, the average 24-h concentrations of fine particles should be taken into account in the relevant calculations. Therefore, the
In this study, in order to estimate the health effects of PM$_{2.5}$ that include estimating all naturally mortality cases, acute lower respiratory infections (ALRI) (childhood<5 years old), chronic obstructive pulmonary disease (COPD) (adults 30<years), ischemic heart disease (IHD) (adults 25<years), lung cancer (LC) (adults 30<years) and stroke (adults 25<years)( long and short term), the following parameters were needed [a] annual mean concentration of PM2.5 [b] data for exposed population including the total adults (≥ 30 years of age) [c] epidemiological parameters, such as baseline rates (BR) [d] a cut-off value for studied pollutants (10 µg/m$^3$, according to WHO recommendation) and the values relative risk (RRs). The model is based on the attributable to proportion (AP) defined as the section of the health effect related to exposure air pollution, and is calculated based on the following equation:

$$AP = \left( \frac{\left(\frac{RR(c)-1}{RR(c)}\right) \times p(c)}{\left(\frac{RR\times p(c)}{RR(c)}\right)} \right)$$

**Baseline incidence (BI)**

The population of Abadan city from 2018-2019, in age groups (all ages, ≤5 years of age, ≥25, and ≥30) were obtained from the Statistical Center of Iran. Based on the number of deaths classified by ICD 10 codes in Abadan during 2018-2019 obtained from the Ministry of Health and Medical Education the baseline incidence rates (BI) of natural mortality and other mortality due to COPD, IHD, LC, and stroke were calculated using integrated exposure response (IER) function [27].

**Health risk assessment**

In this study, In order to estimate the health effects of PM$_{2.5}$ particles were taken from air pollution monitoring stations from March 2018 to March 2019. Data according to the EPA criteria were processed using Excel. The 24 h averages for PM$_{2.5}$ was calculated based on WHO guideline. Afterwards, only valid data measurements were analyzed in current study by AirQ+ to quantify health effects.

**Air pollution situation in Abadan**

As mentioned, there is one air pollution measuring station in Abadan. A total of 301 days of results of measuring station showed that 280 times in 1397, the 24-h concentration of PM$_{2.5}$ was more than the guideline of WHO. (Guideline for 24-h average concentration: 25µg/m$^3$). Also, as Fig. 1 shows the air pollution situation in Abadan are seriously exposed to various diseases caused by air pollution. Furthermore, the data showed that 40% of the days the quality was unhealthy and 8% of the days the quality was dangerous. This indicates that the citizens of Abadan are seriously exposed to various diseases caused by air pollution.
Where RR(c) is the relative risk for the health outcome in the Population exposed to air pollutants (c), and p(c) is the proportion of the population in the category of exposure (c). And also, the relative risk is calculated by the Eq. 2:

\[ RR = \exp(\beta \ln(x - x_0)) \]  

(2)

\( \beta \) is a confidence interval (95% CI), \( X \) is the concentration of air pollutant, \( X_0 \) the value of the counterfactual. On the other hand, the amount of health effects caused by exposure to fine particles (IE), and the number of cases related to exposure to fine particles (NE), are calculated using the following equations:

\[ BE = B \times AP \]  

(3)

\[ NE = BE \times N \]  

(4)

B: baseline incidence of the health outcome (per 100000 people). N: number of the at-risk population

Results and discussion

Air pollution situation in Abadan

As mentioned, there is one air pollution measuring station in Abadan. A total of 301 days of measuring \( \text{PM}_{2.5} \) were found that in this city 10% of the total days of 2018-2019 have healthy air, 38% of days have unhealthy for sensitive groups, 10% of days have unhealthy, 9% of days have very bad Unhealthy and 8% of the days the quality was dangerous. This indicates that the citizens of Abadan are seriously exposed to various diseases caused by air pollution. Furthermore, the results of measuring station showed that 280 times in 1397, the 24-h concentration of \( \text{PM}_{2.5} \) was more than the guideline of WHO. (Guideline for 24-h average concentration: 25\( \mu \text{g/m}^3 \)). Also, concentration of \( \text{PM}_{2.5} \) in Abadan was 230 times more than the EPA standard. (EPA standard for 24-h average concentration: 35 \( \mu \text{g/m}^3 \)). The results show that \( \text{PM}_{2.5} \) particles are the most important pollutants in Abadan urban air. Average concentration of this pollutant in 2018-2019 was 80.023 \( \mu \text{g/m}^3 \), which 8.23 times more than the WHO guideline for annual concentration (10 \( \mu \text{g/m}^3 \)) and 5.34 times higher than the EPA standard for annual concentration (15 \( \mu \text{g/m}^3 \)). In a study by Fanai et al. In 2020, the annual particle concentration \( \text{PM}_{2.5} \) particles was 4 times higher than his WHO guide [28]. On the other hand, other researchers estimated the mean annual concentration \( \text{PM}_{2.5} \) particles as 68.98 \( \mu \text{g/m}^3 \) [29]. Finally, a researcher in Hong Kong obtained the mean annual concentration \( \text{PM}_{2.5} \) particles as 57.40 \( \mu \text{g/m}^3 \) [30]. Table 1 compares the \( \text{PM}_{2.5} \) particle concentrations obtained in the studies with our study.

| Country          | Year | PM\(_{2.5}\) concentration |
|------------------|------|---------------------------|
| Italy            | 2001 | 45                        |
| Pakistan         | 2009 | 75                        |
| Turkey           | 2005 | 64                        |
| Iran (Urmia city)| 2013 | 30                        |
| Iran (Bushahr city)| 2017 | 65.77                     |
| Iran (Abadan city)| 2018-2019 (present study) | 80.32                    |

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Potential health effects
The Potential health risk attributed to long-term exposure of ambient PM$_{2.5}$ concentrations above 10 µg/m$^3$ in Abadan city at 2018-2019 obtained by the proposed model of the World Health Organization (AirQ +) are given in Table 2. Based on the results, the attributable to proportion estimated for the natural mortality related to PM$_{2.5}$ concentrations was 38.25% (95% CI: 26.12-44.39) and the excess cases of death 462 (312-584) cases with RR (1.53) were estimated. Comparison of the number of natural mortality in our study was different from other studies. In one of the industrial cities of Iran (Karaj), this amount of 948 deaths was achieved [17]. In a study, over a 10-year period, 5895 cases mortality occurred due to natural causes [31]. Other researchers 4061 numeral of death due to long-term exposure to PM$_{2.5}$ in Ahvaz city during of 2006-2015 was estimated [18]. On the other hand, Some researchers 4336 numeral of death due to exposure of PM$_{2.5}$ to natural causes for 10 cities in Iran country was estimated [32]. Also, the numbers of causes related to long-term exposure to PM$_{2.5}$ in capital of Iran during 2015-2016 and 2017-2018 were 5070 and 6710 cases, respectively [33 ,32]. A study of the United States found that 130,000 deaths from 2005 to 2018 were related to long term exposure to PM$_{2.5}$ [34]. The reason for the increase in the number of deaths due to long term exposure to PM$_{2.5}$ in Tehran and United States compared to the present study can be attributed to the high population at risk in these studies. In a study of Ahvaz, it was found that approximately 40% of deaths were due to natural causes [18]. Accordingly, in our study at Abadan city in 2018-2019, 35% of the total number of deaths attributed to long term exposure to PM$_{2.5}$. Which was similar to study of researchers in Ahvaz and Tehran [35 ,18].

**LC attributable cases**
Non-communicable diseases (NCD) by air pollution caused that becomes the main factors of death in the world. So that the AIRC has classified air pollution as a dangerous and carcinogenic substance. Undoubtedly, one of these non-communicable diseases caused by exposure to PM$_{2.5}$ particles is lung cancer. Studies have shown that air pollutants can greatly cause lung cancer. Researchers have predicted that mortality from lung cancer worldwide to increase by about 12 million due to air pollution by 2030 [36]. In this study, total mortality of lung cancer related to exposure of

| Exposure   | Pollutant | Health Outcome | BL  | RR  | AP (%) | Excess cases | Attributable cases per100000 |
|------------|-----------|----------------|-----|-----|--------|--------------|-----------------------------|
| Long-term  | PM$_{2.5}$| Natural Mortality | 827.12 | 1.44 | 38.25 | 462 (312-584) | 936.31 |
|            |           | LC             | 14.16 | 1.44 | 32.18 | 6 (9-21)     | 16.52 |
|            |           | COPD           | 11.25 | 1.44 | 25.64 | 8 (6-13)     | 10.27 |
|            |           | Stroke         | 64.82 | 3.27 | 71.26 | 86 (44-92)   | 67.81 |
|            |           | IHD            | 112.26 | 2.63 | 68.34 | 183 (146-225) | 150.32 |
|            |           | ALRI           | 6.89  | 1.19 | 32.19 | 2 (1-3)      | 6.53  |

Table 2. BL, RR, AP, Excess cases and attributable cases for residents of Abadan city

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PM$_{2.5}$ particles for Abadan city in 2018-2019 for a population over 30 years were estimated using AirQ+. (Table 2). As can be seen that the mortality of Lung cancer due to long term exposure of PM$_{2.5}$ with AP 32.18% (95% CI: 13.28-46.37%) in 2018-2019 was estimated 6 (9-21) cases. Numerous studies, have examined the significant relevance between air pollution and lung cancer [39,38,37,4]. In similar studies were obtained the number of deaths due to LC in Tabriz were 7 cases [40]. But in Karaj (2012-2016) and Tehran city that 139 and 427 cases was reported [17]. The incidence of baseline mortality may be one of the reasons for the difference in lung cancer mortality due to contact with PM$_{2.5}$ particles in these two studies with our study. A study by Parascandola in 2016 at Poland also found that lung cancer was the most important destructive effect of fine particles [41]. The European Union is working to control deaths from lung cancer due to contact with PM$_{2.5}$ particles by reducing particulate matter in the air. Also, a researcher showed in Taiwan that between 2008 and 2015, deaths due to LC decreased nearly by 16% [42]. The differences in baseline mortalities can be considered as the key reason for the differences in the values in the previous studies and the present study in the number of attributable deaths from LC.

**COPD attributable cases**

Among the deaths related to exposure of PM$_{2.5}$ particles, COPD is a great importance. Because they are also the most vulnerable group. So that in 2016, it accounted for almost 5% of all deaths [43]. In our study, the total mortality of COPD attributable to PM$_{2.5}$ during 2018-2019 with AP 25.64% (95% CI: 14.06-35.97%) was estimated 8 (6-13) cases (Table 2). Researchers in Tehran [32], Karaj (2012-2016) [17], Rom[44] and Ahvaz [18] reported the COPD mortality due to long term exposure of PM$_{2.5}$ respectively 158, 124, 279 and 75. The differences in baseline mortalities can be considered as the key reason for the differences in the values in the previous studies and the present study in the number of attributable deaths from COPD.

**Stroke attributable cases**

As mentioned, air pollution have several effects on humans. The correlation between air pollution and stroke due to exposure with airborne particles has attracted the attention of many researchers. With increasing every 5 µg/m$^3$ at a particle concentration of PM$_{2.5}$ can cause to increase of hazard ratio about 1.15 (95% CI: 1.05, 1.23) mortality of stroke. The number of mortality due to stroke in Abadan city at period of this study with AP 71.26% (95% CI: 42.56-72.31%) was estimated to be 86 (44-92) cases (Table 2). In a study, 34% of the population exposed to air pollution suffered a stroke [45]. Also, in Tehran city, 1500 cases of mortality due to strokes in 2015 and in 2017, during a similar study in the same city, 1145 deaths were estimated [46,33]. For the city of Karaj, due to the existence of many industries and factories that exist, the death rate due to stroke in period of 2012 -2016 was estimated at 1834 cases [17]. The differences in baseline mortalities can be considered as the key reason for the differences in the values in the previous studies and the present study in the number of attributable deaths from Stroke.

**IHD attributable cases**

In a report by World Health Organization Categorized IHD (the first), stroke (The second) and COPD (Third) as cause of mortality related to exposure of PM$_{2.5}$ particles in ambient air [47].
our study, the highest mortality rates were related to IHD, stroke, and COPD, respectively (Table 2). In a study of Karaj, it was found that with every 10 µg/m³ increase in the concentration of PM$_{2.5}$ particles, the cardiovascular admissions increases by 0.35 times [17]. Table 2 showed that the total mortality of IHD related to PM$_{2.5}$ in 2018-2019 at Abadan city with AP 68.34% (95% CI: 52.68-86.49%) was estimated 183 (146-225) cases, respectively. Mortality due to IHD attributable cases in this study were different from other studies. Including they can be referred to a study by some researchers, which reported number of 3797 cases deaths related to IHD [46]. The differences in baseline mortalities can be considered as the key reason for the differences in the values in the previous studies and the present study in the number of attributable deaths from IHD.

**ALRI attributable cases**

The effects of fine particles are not limited to adults and the aged, but in all ages it has its effects in various forms. One of these effects is ALR in children under 5 years of age. As there is no research about this issue in Abadan city, in this study we evaluate the effect of exposure to PM$_{2.5}$ on ALR-related mortality in children population (<5 years old) the city of Abadan and findings are shown in Table 2. Since the population at risk to PM$_{2.5}$ particles is lower, so we will see less mortality due to ALR. As you can see in Table 2, total mortality of ALR related to PM$_{2.5}$ in 2018-2019 at Abadan city with AP 32.19% (95% CI: 20.54-40.29%) was estimated 2 (3-1) cases, respectively. In similar studies conducted by other researchers at tehran, tehran and karaj city, 27, 21 and 13 cases mortality due to ALR in children population (<5 years old) respectively, was estimated [33, 17, 31]. The differences in baseline mortalities can be considered as the key reason for the differences in the values in the previous studies and the present study in the number of attributable deaths from ALR.

**Conclusion**

The current study describes and analyzes the air of Abadan during 2018-2019 in terms of particle index of PM$_{2.5}$ and also assess the health risk of long exposure to ambient air pollutants. In this study, total natural mortality, mortality due to lung cancer, chronic obstructive pulmonary disease, stroke, ischemic heart disease, and Acute Lower Respiratory Infections (ALRI) was estimate using AirQ+. Citizens of Abadan in 2018-2019 approximately 8.23 times more than the amount guideline of the WHO will be exposed to air pollution especially PM$_{2.5}$. In other words, that citizens of Abadan during 2018-2019 in almost 280 days of a year were exposed to PM$_{2.5}$ more than the guidelines of WHO. The number of deaths due to natural mortality, LC, COPD, stroke, IHD ALRI associated with ambient PM$_{2.5}$ were 462, 6, 8, 86, 188 and 2, respectively. Based on our study estimation, 38.25% of the natural mortality, 32.18% of LC, 25.64% of COPD, 71.26 % of Stroke, 68.34% of IHD, and 32.19% of ALRI mortalities in Abadan was due to long-term exposure of ambient PM$_{2.5}$. The current study indicates the mortality have a direct and indirect effects especially in terms of economic aspects for the city. The results from this research recommend that suitable controlling policies should be regulated to reduce ambient air PM$_{2.5}$ and its adverse health endpoints in Abadan.

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Competing interests
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Ethical issues (Including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors

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