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Health effects from particulate air pollution in one of the industrial cities of Iran

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ABSTRACT

Introduction: Particulate Matter (PM), also known as aerosol, is the sum of all particles suspended in droplets floating in the air, which can have harmful impacts on humans all over the world. This cross-sectional study set out to evaluate the potential health effects of over-exposure to PM_{10} and $PM_{2.5}$ on aggravating mortality and hospitalization due to cardiovascular and respiratory diseases among Arak citizens.

Materials and methods: In this cross-sectional survey, $AirQ^+$ model was used to estimate the health impacts of two particulate air pollutants (PM_{10} and $PM_{2.5}$) based on Relative Risk (RR), and Baseline Incidence (BI) obtained from reference documents.

Results: According to the calculations, the attributable proportion percentage (AP%) and attributable excess cases (persons) for total mortality from PM_{10} were 3.3% (95% CI, 2.8%-3.8%) in 2014 vs. 4.9% (95% CI, 4.1%-5.6%) in 2015 and 99 persons in 2014 vs. 148 persons in 2015, respectively. Likewise, the AP (%) and the number of excess cases (persons) calculated for total mortality from $PM_{2.5}$ were 3.3% (95% CI, 2.6%-4.1%) in 2014 vs. 1.1% (95% CI, 0.8%-1.3%) in 2015 and 99 persons in 2014 vs. 33 persons in 2015, respectively.

Conclusion: In this study, it was found that dominant west winds could increase the particle matters produced from power plants, petrochemical plants, and western dust storm, leading to a surge in the mortality and morbidity related to particulate air pollutants in Arak.

Introduction

The most important pollutants released from point or non-point sources are respirable particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), Nitrogen dioxide (NO2), Sulfur dioxide (SO_2), Ozone (O_3) and Carbon monoxide (CO), which are listed in the US National Ambient Air Quality Standards (NAAQS) and should be

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monitored via air pollution control measures because these are the main air pollutants in the cities [1-4]. Nowadays, mortality and morbidity due to exposure to indoor and outdoor pollutants are increasing. The World Health Organization (WHO) reported that outdoor and indoor air pollution caused approximately 7 million deaths in 2016 worldwide [5]. Air pollution in developing countries (including Iran) is one of the most important and recent health problems [6]. There is a plethora of such reports in related resources. For example, a study in China estimated that $PM_{2.5}$ (with an aerodynamic diameter less than 2.5 μm) alone caused 1.2 million early deaths [7] or, to be more precise, 35% of all such mortality in the world level [8, 9].

Particulate Matter (PM) emissions in the air result from natural and anthropogenic sources [10]. Ambient air pollution by PM especially $PM_{2.5}$ and PM_{10} can cause health impacts on human respiratory organs [11]. Fine particles can be infiltrated into sensitive lung tissue and result in the development of diseases such as emphysema, bronchitis, heart attack and premature death in extreme cases [12, 13]. In recent years, $PM_{2.5}$ has gained considerations among researchers with respect to its effects on the increased incidence of respiratory diseases [14-17]. The major problems with over-exposure to $PM_{2.5}$ include mortality, respiratory tract infections, asthma [18], blocking the air passages and damage to pulmonary mucosal pathways [19]. As such, PM_{10} has the potential adverse health impacts such as disorders of the central nervous system [20], atherosclerosis, increase in ischemic cardiovascular events [21, 22], damaged cells, coughing asthma, cancer, and death [23].

Air pollution modeling provides an accurate and definitive output according to the input data taken from valid and trusted resources about different aspects of air pollution. One of the models is AirQ (Air Quality) model set to achieve these goals. The AirQ models is a software tool for quantifying the health impacts of air pollution (mortality and morbidity) developed by the WHO. AirQ applications are estimates of total mortality, cardiovascular mortality, respiratory mortality, hospital admissions, respiratory disease, cardiovascular disease and Chronic Obstructive Pulmonary Disease (COPD) attributed to environmental pollutants [24, 25]. This tool has been recently used worldwide such as Italy [26] and Iran (Hamadan, Kermanshah, Ahaz) [3, 18] . For example, AirQ2.2.3 model demonstrated that $PM_{2.5}$ was responsible for 5,670 out of 87,907 deaths during a one-year -period in eight Iranian cities [27].

Arak is the capital city of the Markazi province and one of the eight largest cities in Iran. This city is located in proximity of industrial factories such as power plants, petrochemical plants, machine manufacturing, combine manufacturing, aluminum manufacturing, and other companies. Furthermore, emissions due to transport traffic as mobile sources have the potential health effects along with pollution from industrial plants. Arak enjoys the same climatic properties of the central Iranian plateau with cool, wet winters and warm, dry summers [28, 29]. These conditions provide a stable climate which can lead to inversion situation. As such, this study aimed to evaluate the potential health impacts of over-exposure to PM_{10} and $PM_{2.5}$ on aggravating mortality and hospitalization due to cardiovascular and respiratory diseases among Arak citizens.

Materials and methods

Study area

This cross-sectional study was performed between 2014 and 2019 in Arak, Iran. Arak is located at the latitude of 34°5′30″ N and the longitude of 49°41′21″ E, and is about 288 km far from Tehran (capital of Iran). The total population of Arak is around 600 000. The average elevation of the city is 1748 m above the sea level. The annual average temperature is 13.9°C. The maximum temperature has been recorded to rise up to 35°C degree in summer and fall to under -15°C in winter. The mean annual rainfall is about 262 mm, with the relative humidity 46% [28, 30, 31]. The map of Arak is shown in Fig. 1.

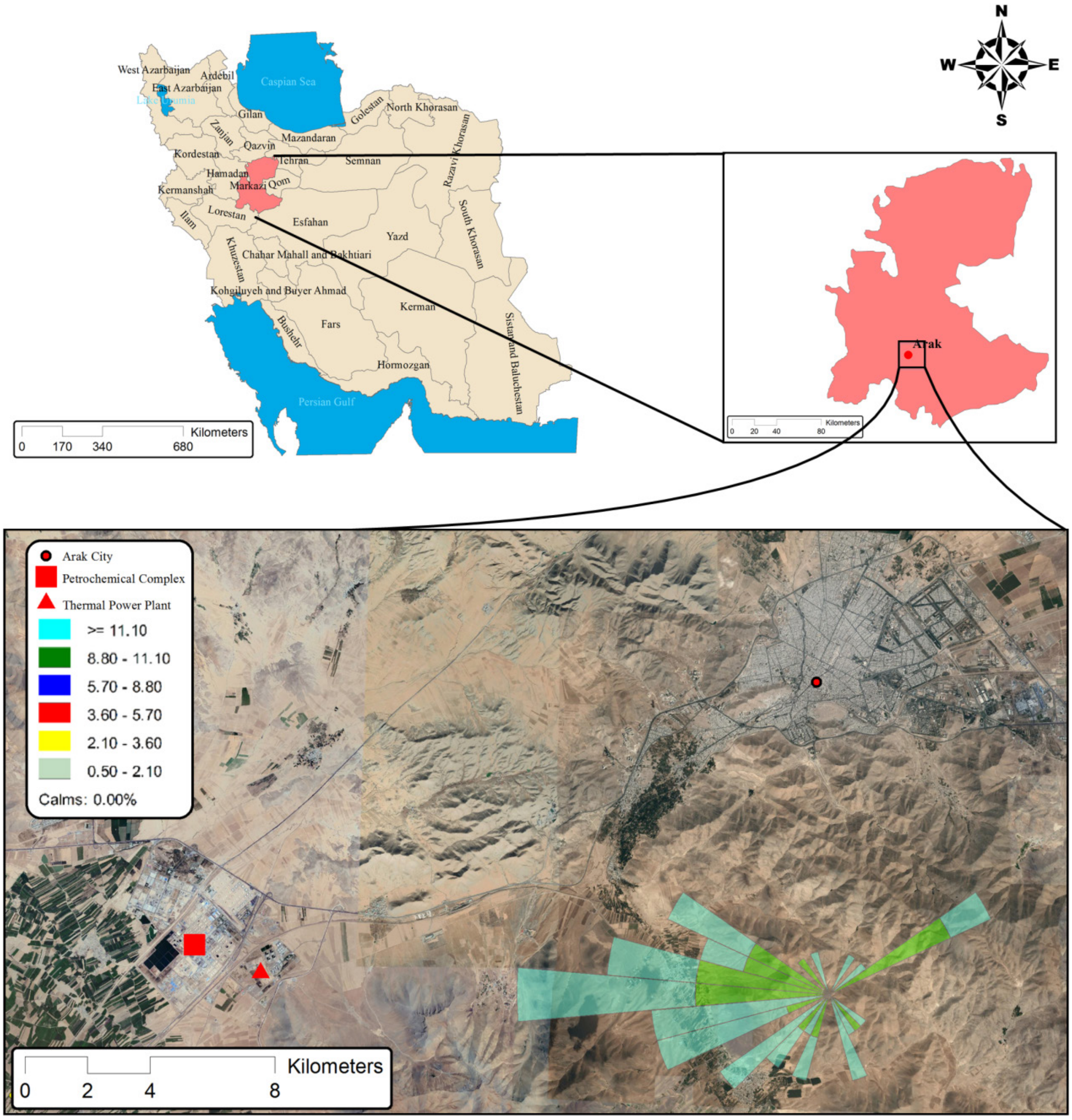

Fig. 1. Location and wind rose of the study area

AirQ⁺

In this cross-sectional study, AirQ$^+$ was applied to assess the health impacts of two air pollutants (PM_{10} and $PM_{2.5}$). To accomplish this aim, epidemiological indicators such as relative risk (RR), the attributed proportion (AP), and baseline incidence (BI) based on mathematical equations were utilized [26]. The AP value is usually called the fraction of the health consequence in target populations that are exposed to certain atmospheric contaminants, and can also be calculated using the Eq. 1 [32]:

$$AP = (\Sigma\{[RR(c) - 1 \times P(c)]/ (\Sigma\ [RR(c) \times P(c)]) \quad (1)$$

Where AP is the proportion attributable to the health effects; RR or relative risk is for a specific health outcome on people living in a given region, which is extracted from the exposure-response functions (ERF) from the result of cohort studies, and it is calculated via the ratio (the probability of an accident in exposed time to the probability of an accident in non-exposed time). P(c) is defined as the certain exposed population in category “c” of exposure [26, 33].

If the baseline frequency of the health impacts in the target population of a community is identified, the Eq. 2 can estimate the rate attributable to the exposed population:

$$IE = I \times AP \quad (2)$$

Where IE the health outcome rate (per 100 000 per year) attributable to the exposure and I or incidence is the baseline frequency of the health effects in the target population of a community (study population). Finally, considering the size of the population at risk, the attributable cases to the exposure can easily be calculated by the Eq. 3:

$$NE = IE \times N \quad (3)$$

Where NE is the number of cases attributed to the exposure and N is the size of the population at risk [26, 34]. RR indicator is accessible in the results of the meta-analysis of time-series studies. These time-series studies are conducted in such a way that day-to-day changes in air pollutants are linked to daily mortality hospital admissions (HA) and other public health indexes [26]. We received RR and BI indicators through similar studies in the field. RR mostly comes from the Air Pollution and Health: a European Approach study (APHEA), as the largest multicity study linked to the European population [26]. In our study, the RR values used for $PM_{2.5}$ and PM_{10} were taken from the WHO Air Quality Guidelines for Europe and a quantitative meta-analysis of peer-reviewed studies in Europe, respectively [35, 36]. Due to the significant difference in the age pyramid in Iran and Europe, we could not apply BI as the default value in AirQ. For example, in this software, BI for total mortality is about 1013 deaths per 100,000 people, which is specific to the European community. However, since the total population of Iran is younger than the European population, the BI value has been proposed to be in the range of 540-560 death per 100 000 people based on the United Nations (UN) guidelines for our country. In a study, the BI value for the total mortality, mortality attributable to cardiovascular and respiratory diseases rates were reported to be 543.5, 231.0 and 48.4 respectively [37]. The RR and baseline incidence (BI) for mortality and morbidity are summarized in Table 1.

Table 1. Baseline Incidence (BI) and relative risk (RR) with 95% confidence intervals (95% CI) used in this study

Health endpoint	Baseline incidence [a]	RR (95% CI) per 10 μg/m^3	
		PM_{10}	$PM_{2.5}$
Mortality			
Total mortality Total ICD-9-cm [b] <800	534.5	1.006 (1.004-1.008) [c] [35]	1.015 (1.011–1.019) [c] [36]
Cardiovascular mortality ICD-9-cm 390-459	231.0	1.009 (1.005-1.013) [c] [35]	-
Respiratory mortality ICD-9-cm 460-519	48.4	1.013 (1.005-1.020) [c] [35]	-
Morbidity			
Hospital admissions Respiratory disease	1260.0	1.008 (1.005-1.011) [c] [36]	-
Hospital admissions Cardiovascular disease	436.0	1.009 (1.006-1.013) [c] [36]	-

a. Crude rate per 100‹000 inhabitants.

b. International Classification of Diseases‹ 9th Revision‹ Clinical Modification (ICD-9-cm).

c. Daily average.

Input preparation and quantification exposure assessment

Arak has five air monitoring stations. Due to the fact that most of the stations had problems pertaining to recording data and hence did not have valid data, the PM_{10} and $PM_{2.5}$ data were collected from one of the most valid stations called Shariati. Since all data were in volumetric units (ppm or ppb), they were converted into the gravimetric units (μg/m^3). Because AirQ model doesn't allow the pollutants data to enter into volumetric units. In next step, the important indicators in statistics including the annual mean, the warm season mean, the cold season mean, the annual 98th percentile of pollutants, the annual maximum, the warm season maximum and the cold season maximum were calculated and simultaneously recorded into the software. As the final step, information such as the total populations under investigation, the population at risk, BI and daily average of PM_{10} and $PM_{2.5}$ were entered as a routine process of exposure evaluate in AirQ model.

Results and discussion

Pollutant concentration

PM_{10} and $PM_{2.5}$ data were collected from the Shariati station which is located in an urban area with medium traffic. This station is recognized as a valid station, because Shariati station is the first station to measure air pollutants and continually monitoring environmental pollutants. Tables S_1 and S_2 (supplementary material) show PM_{10} and $PM_{2.5}$ annual average, cold season averages, warm season averages and annual 98th percentile in 2014-2019. The results indicate that the lowest and highest annual average of PM_{10} were 56 μg/m^3 and 78 μg/m^3, respectively. Moreover, the lowest and highest value for $PM_{2.5}$ ranged between 16 – 32 μg/m^3. In addition, the results of one-way analysis of variance (ANOVA) showed that there was a significant difference between different groups of annual average, warm season averages, cold season averages, annual 98th percentile and PM_{10} and $PM_{2.5}$ concentration (μg/m^3) in 2014-2019 ($p<0.05$). Table S_3 provides the ratio of annual average (μg/m^3) of PM_{10} and $PM_{2.5}$ to WHO (2005) and Iran Clean Air guidelines (2011), respectively. The maximum of the above ratio for $PM_{2.5}$ was -according to WHO (3.2) and Iran Clean Air Act (3.2) guidelines in 2014.

Fig. 2 illustrates the percentage of people exposed to different concentrations (μg/m^3) of $PM_{2.5}$ (a), and PM_{10} (b) in 2014-15, and $PM_{2.5}$ (2016-2017) (c), $PM_{2.5}$ (2018-2019) (e), PM_{10} (2016-2017) (d), and PM_{10} (2018-2019) (f). The maximum $PM_{2.5}$ was reported to be in 10-19 (with person-days percentage of 32.68 and 59.62 in 2014 and 2015, respectively) and 20-29 interval (μg/m^3) (with person-days percentage of 60, 53 and 48 in 2017, 2018 and 2019, respectively). As such, a higher frequency of person-days percentage related to PM_{10} was observed in 40-49 interval (μg/m^3) in 2014, 50-59 interval (μg/m^3) in 2015 and 70-79 interval (μg/m^3) in 2016. In Hamadan, the annual maximum and the annual 98th percentile of PM_{10} were 200 and 133 μg/m^3, respectively. These two indexes (the annual maximum and the annual 98th percentile) for $PM_{2.5}$ were reported to be 120 and 80 μg/m^3, respectively [18].

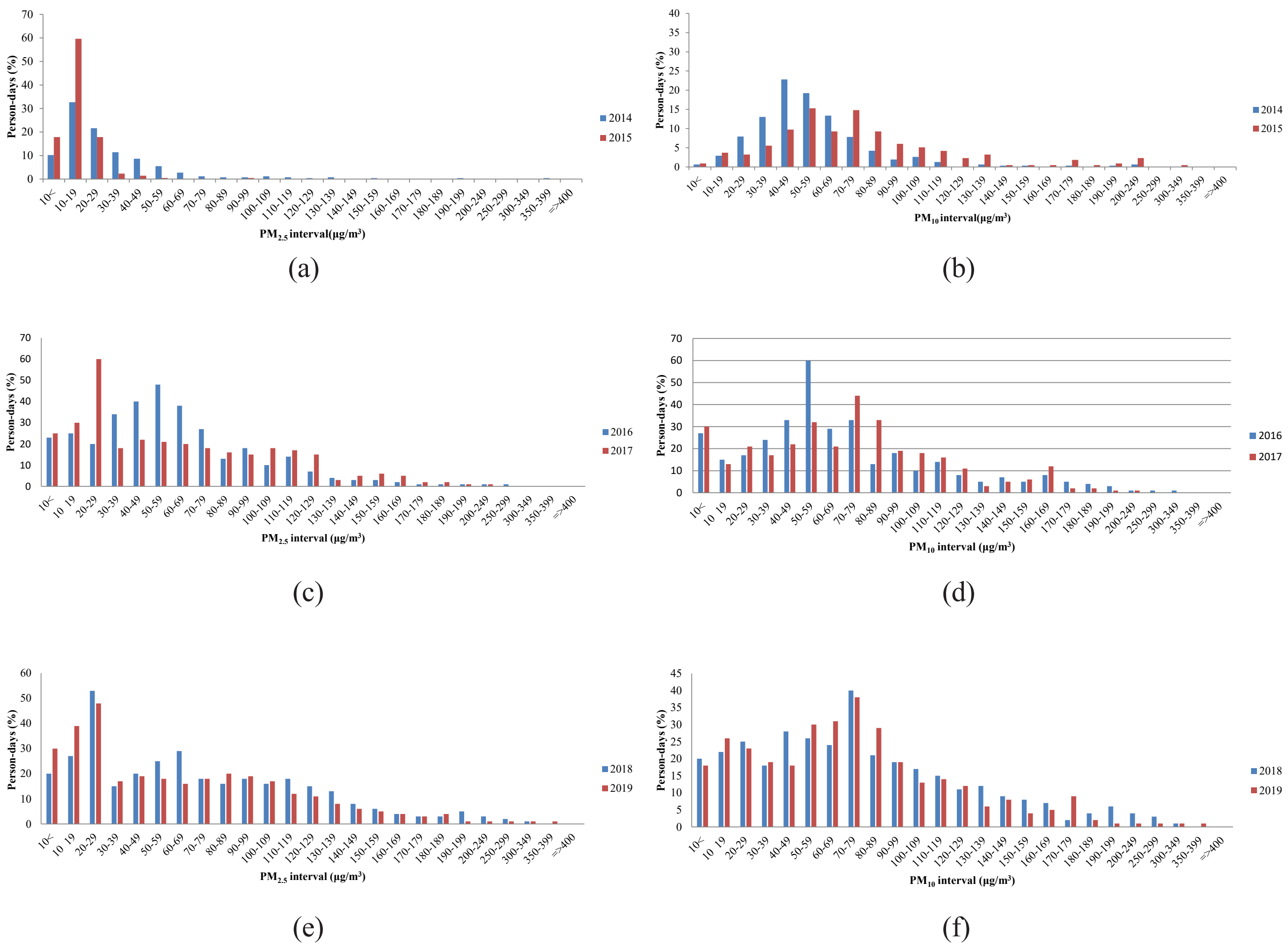

Fig. 2. Person-days percentage exposed to different concentration (μg/m³) of a) $PM_{2.5}$ (2014-2015); b) PM_{10} (2014-2015); c) $PM_{2.5}$ (2016-2017); d) PM_{10} (2016-2017); e) $PM_{2.5}$ (2018-2019); and f) PM_{10} , (2018-2019)

General wind rose plot of Arak (during 2014-2019) detected that approximately 23% of scanned points had gentle directions and 77% of it were in change orientation. The mean velocity of wind was calculated to be 5.3 knots and dominant wind (23%) was in West direction [38]. This wind rose plot is shown in Fig. 3. It was detected that dominant wind (23%) was in the west direction in Arak. Since industrial factories such as power plants and petrochemical plants are located on the same western side of Arak, it is possible that $PM_{2.5}$ and PM_{10} can be entered along with the air flow by the dominant wind towards the city. The consequence of this influence can be seen in Fig. 3, so that exposure to over the limited concentration of $PM_{2.5}$ and PM_{10} cause the adverse health impacts. On the other hand, the results of some studies showed that the influence of the air flow of dust carrier from western city of Iran and Middle Eastern Dust (MED) phenomenon can increase the concentration of particle matter in the cities located in the center of Iran such as Arak [3, 39].

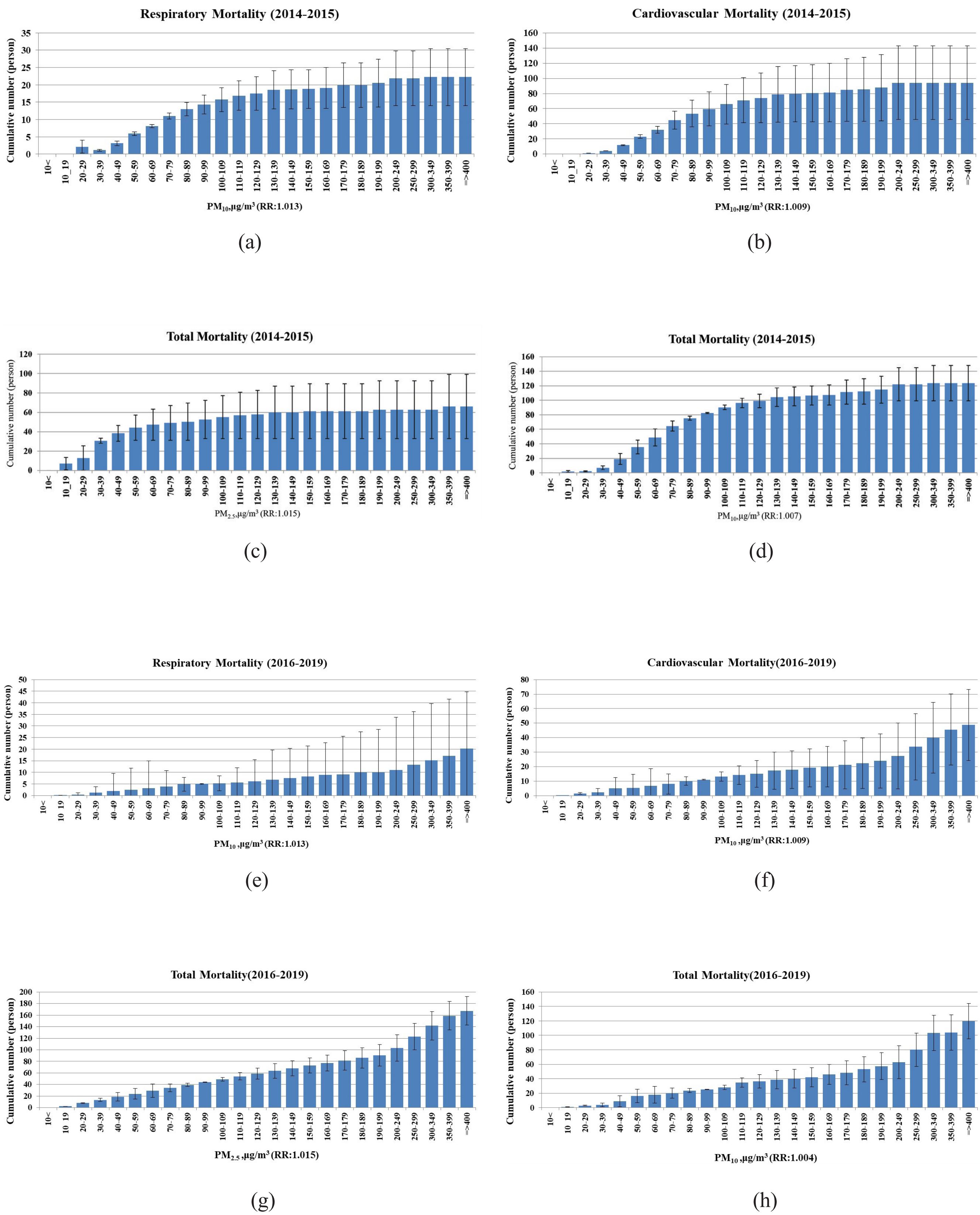

Fig. 3. Error bar of relationship between cumulative number (person) of respiratory mortality, cardiovascular mortality, total mortality due to $PM_{2.5}$, total mortality due to PM_{10} (a-h) in 2014-2019

Reports of AirQ⁺

Based on RR values (Table 1), AP and attributable excess cases (persons) of mortality and morbidity calculated by AirQ⁺ are shown in Table 2-4. According to the results, AP percentage estimated for total mortality to PM_{10} were 3.3% (95% CI, 2.8%-3.8%) in 2014 (Table 2), 4.9% (95% CI, 4.1%-5.6%) in 2015, 2.25% (95% CI, 1.51%-2.98%) in 2016 (Table 3), 3.06% (95% CI, 2.05%-4.06%) in 2017, 2.95% (95% CI, 1.98%-3.91%) in 2018 and 3% (95% CI, 2.02%-3.98%) in 2019 (Table 4), In addition, the number of excess cases (persons) for total mortality from PM_{10} were 99 persons in 2014, 148 persons in 2015, 64 persons in 2016, 88 persons in 2017, 85 persons in 2018, 88 persons in 2019. On the other hand, the AP percentage and the number of excess cases (persons) calculated for total mortality from $PM_{2.5}$ were 3.3% (95% CI, 2.6%-4.1%) in 2014 , 1.0% (95% CI, 0.8%-1.3%) in 2015, 1.19% (95% CI, 0.8%-1.58%) in 2016, 0.9% (95% CI, 0.61%-1.19%) in 2017, 0.95% (95% CI, 0.64%-1.27%) in 2018 and 0.52% (95% CI, 0.77%-1.03%) in 2019, and 99 persons in 2014, 33 persons in 2015, 34 persons in 2016, 26 persons in 2017, 28 persons in 2018 and 23 persons in 2019,respectively. As such, Fig. 3 shows the results of differences between cumulative number (person) of respiratory mortality (A), cardiovascular mortality (B), total mortality due to $PM_{2.5}$ (C) and total mortality due to PM_{10} (D) in the years 2014 and 2015 and respiratory mortality (E), cardiovascular mortality (F), total mortality due to $PM_{2.5}$ (G) and total mortality due to PM_{10} (H) during 2016 - 2019. In Kermanshah, located in the western part of Iran, AP percentage and the number of excess cases of cardiovascular mortality were estimated to be 6.621% (95% CI, 4.243%–13.759%) and 188 % (95% CI, 121%–390%), respectively with RR per 10 μg/m^3 of 1.0080 % (95% CI, 1.0050 %–1.0180%) and BI of 497/100 000 people [3]. While in our study, RR (95% CI) per 10 μg/m3 and BI was 1.009 (1.005-1.013) and 231/100 000 inhabitants, respectively. A study in Italy showed that AP percentage and the number of excess cases of total mortality in an industrialized area of Northern Italy were 2.5 % (95 CI%, 1.7%–3.3%) and 4.4% (95 CI%, 3.0%–5.8%), respectively [26]. All of these effects are not only specific to mortality, but also the role of suspended particles plays an important role in the impacts of morbidity. For example, AP percentage of hospital admissions due to cardiovascular disease for PM_{10} over 10 μg/m^3 was 4% (CI 95%, 2.7%-5.7%) in 2014 and, with ascending growth, 5.8% (CI 95%, 4.0%-8.3%) in 2015. The results of this report are consistent (with a lower percentage) with a research in Arak, as it proved a 0.7% (95% CI, 1.002%-1.010%) increase in cardiovascular hospital admissions, for each increase over 10 μg/m^3 of PM_{10} [40]. In addition, a similar study in Korea reported that cardiovascular hospital admissions increased 1.3% by over-exposure (10 μg/m^3) to PM_{10} levels [41].

Unlike PM_{10}, both the AP percentage and the number of excess persons in 2014 were higher than those in 2015. Some of researchers believe that total mortality attributable to $PM_{2.5}$ may be different based on the risk estimate used. Since $PM_{2.5}$ is more harmful than PM_{10}, due to high penetration power into the respiratory tract, it was already assumed the AP percentage and the number of excess number of excess persons for it will be greater than PM_{10}. While, based on Table 2, these two indexes for PM_{10} were more than $PM_{2.5}$, showing that our results are not in tandem with the same study [18].

Table 2. Modeled attributable proportion (AP) and attributable excess cases (persons) in 2014-2015

Health Endpoint	Pollutant	Modeled AP (%), 2014	Modeled AP (%), 2015	Attributable excess cases , 2014 (persons)	Attributable excess cases , 2015 (persons)
Total Mortality	PM_{10}				
Relative Risk (Lower)		2.8	4.1	84	125
Relative Risk (Central)		3.3	4.9	99	148
Relative Risk (Upper)		3.8	5.6	115	171
Cardiovascular Mortality	PM_{10}				
Relative Risk (Lower)		2.2	3.3	29	93
Relative Risk (Central)		3.5	5.8	46	163
Relative Risk (Upper)		7.7	8.3	98	229
Respiratory Mortality	PM_{10}				
Relative Risk (Lower)		3.5	3.3	14	12
Relative Risk (Central)		5.3	8.3	10	31
Relative Risk (Upper)		15.0	12.0	39	45
Hospital admissions	PM_{10}				
Respiratory Disease		2.1	3.2	151	227
Relative Risk (Lower)		3.5	5.2	248	370
Relative Risk (Central)		4.9	7.2	342	507
Relative Risk (Upper)					
Hospital admissions	PM_{10}				
Cardiovascular Disease		2.7	4.0	65	97
Relative Risk (Lower)		4.0	5.8	96	143
Relative Risk (Central)		5.7	8.3	136	201
Relative Risk (Upper)					
Total Mortality	$PM_{2.5}$				
Relative Risk (Lower)		2.6	0.8	73	24
Relative Risk (Central)		3.3	1.1	99	33
Relative Risk (Upper)		4.1	1.3	124	42

Table 3. Modeled Attributable Proportion (AP) and attributable excess cases (persons) in 2016-2017

Health Endpoint	Pollutant	Modeled AP (%), 2016	Modeled AP (%), 2017	Attributable excess cases , 2016 (persons)	Attributable excess cases , 2017 (persons)
Total Mortality	PM_{10}				
Relative Risk (Lower)		1.51	2.05	43	59
Relative Risk (Central)		2.25	3.06	64	88
Relative Risk (Upper)		2.98	4.06	85	117
Cardiovascular Mortality	PM_{10}				
Relative Risk (Lower)		1.51	2.05	18	26
Relative Risk (Central)		2.25	3.06	28	38
Relative Risk (Upper)		4.79	6.5	59	81
Respiratory Mortality	PM_{10}				
Relative Risk (Lower)		1.88	2.56	5	7
Relative Risk (Central)		4.79	6.5	12	17
Relative Risk (Upper)		7.25	9.87	19	25
Hospital admissions	PM_{10}				
Respiratory Disease		1.88	2.56	126	173
Relative Risk (Lower)		4.79	6.5	321	440
Relative Risk (Central)		7.25	9.78	485	663
Relative Risk (Upper)					
Hospital admissions	PM_{10}				
Cardiovascular Disease		2.25	3.06	52	72
Relative Risk (Lower)		3.35	4.55	78	107
Relative Risk (Central)		4.79	6.5	111	152
Relative Risk (Upper)					
Total Mortality	$PM_{2.5}$				
Relative Risk (Lower)		0.8	0.6	23	17
Relative Risk (Central)		1.19	0.9	34	26
Relative Risk (Upper)		1.58	1.19	45	34

Table 4. Modeled Attributable Proportion (AP) and attributable excess cases (persons) in 2018-2019.

Health Endpoint	Pollutant	Modeled AP (%), 2018	Modeled AP (%), 2019	Attributable excess cases , 2018 (persons)	Attributable excess cases , 2019 (persons)
Total Mortality	PM_{10}				
Relative Risk (Lower)		1.98	2.02	57	59
Relative Risk (Central)		2.95	3	85	88
Relative Risk (Upper)		3.91	3.98	113	116
Cardiovascular Mortality	PM_{10}				
Relative Risk (Lower)		2.46	2.51	31	32
Relative Risk (Central)		4.38	4.47	55	56
Relative Risk (Upper)		6.25	6.38	78	80
Respiratory Mortality	PM_{10}				
Relative Risk (Lower)		2.46	2.51	6	7
Relative Risk (Central)		6.25	6.38	16	17
Relative Risk (Upper)		9.43	9.61	25	25
Hospital admissions	PM_{10}				
Respiratory Disease		2.46	2.51	168	173
Relative Risk (Lower)		6.25	6.38	428	439
Relative Risk (Central)		9.43	9.61	644	661
Relative Risk (Upper)					
Hospital admissions	PM_{10}				
Cardiovascular Disease		2.95	3	70	72
Relative Risk (Lower)		4.38	4.47	104	106
Relative Risk (Central)		6.25	6.38	148	152
Relative Risk (Upper)					
Total Mortality	$PM_{2.5}$				
Relative Risk (Lower)		0.64	0.77	18	30
Relative Risk (Central)		0.95	0.52	28	23
Relative Risk (Upper)		1.27	1.03	37	15

Conclusion

This study estimated the health effects of PMs air pollution ($PM_{2.5}$ and PM_{10}) of Arak inhabitants with AirQ. The results showed that the pollutant concentrations were respectively 1.6 and 3.9 times greater than the WHO s and Iran Clean Air standards. The results of this study also revealed that the mortality and morbidity related to PMs in 2015 were found to be higher than those in the other years (2014-2019). Even at current ambient air concentrations, PMs air pollution continues to cause a health risk problem because their concentrations continue to increase. The prevailing wind direction, industries located at the west of the city, like other study as sample based on 26-year (1987-2013) wind rose in Arak [42] ,and MED phenomenon [43] are the possible reasons of PMs increase. Development of urban forest and green zones around the city (as sink for pollutants [44]) is proposed as a management solution at the governmental scale to reduce the health effect of PM. It should, however, be mentioned that the low number of air pollution measurement stations -due to the lack of enough and valid data- is considered one of the limitations of the current study. The increase of more stations on the part of governmental offices could help the researchers better in estimating and modelling of health effects related to air pollution. It is proposed that long term data and more advanced softwares such as BenMap (by USEPA) be utilized in the future studies.

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Competing interests

The authors state that there is 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.”

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