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DISTRIBUTION AND NUMBER OF ISCHEMIC HEART DISEASE (IHD) AND STROKE DEATHS DUE TO CHRONIC EXPOSURE TO $PM_{2.5}$ IN 10 CITIES OF IRAN (2013 - 2015); AN AIRQ+ MODELLING

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ABSTRACT:

Introductions: Particulate air pollution is known as a major risk factors of ischemic heart disease (IHD) and stroke. The aim of this study was to estimate the premature IHD and stroke deaths attributed to long-term exposure to $PM_{2.5}$ in 10 cities of Iran during March 2013 to March 2015 using AirQ+ model.

Materials and methods: Ten cities of Iran including Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad, and Ilam were chosen, and their air quality data were acquired from Department of Environment (DoE) and Tehran Air Quality Control Company (AQCC). Validation of monitoring stations were accomplished according to WHO and APHEKOM criteria for health impact assessment of air pollution. The number of deaths due to IHD and stroke was estimated using AirQ+ , which is developed by WHO.

Results: The total number of IHD and stroke deaths in the March 2013- March 2014 and March 2014 - March 2015 periods were 15479 and 15321 deaths, respectively. In case of both IHD and stroke mortality, the highest number of IHD and stroke deaths was estimated to be in Tehran, Mashhad and Isfahan, respectively. The highest number of attributable deaths per 100,000 population were estimated to be in Ahvaz and Isfahan. The average of excess IHD and stroke deaths due to exposure to $PM_{2.5}$ in all cities were 84 and 41 per 100,000 population, respectively.

Conclusions: The results of this study indicated the necessity of urgent actions to improve the outdoor air quality in Iranian cities.

INTRODUCTION

Air pollution has been introduced as the most important environmental risk factor for health in the world [1]. Many cities suffer from high concentrations of air pollution globally. The World Health Organization (WHO) reported that approximately 7 million deaths are attributed to exposure to air pollution, of which 3.7 million could

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be the result of exposure to ambient air pollution [2]. Epidemiological studies have shown positive associations between air pollutants such as particulate matter of aerodynamic diameter less than 10 μm (PM_{10}) and 2.5 μm ($PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3) and carbon monoxide (CO) and adverse health outcomes [3-6]. Particulate air pollution was introduced by International Agency for Research on Cancer (IARC) as carcinogen to human [7].

Coronary heart disease (CHD) or ischemic heart disease (IHD) is the most common cardiovascular disease [8]. Many studies have been conducted the relationship between long-term exposure to particulate air pollution and cardiovascular mortality [9]. In a cohort study, cardiovascular mortality increased by 8-18% per 10 μg/m^3 increase of $PM_{2.5}$ concentrations; however, a weak association was found between similar amount of $PM_{2.5}$ and respiratory mortality [10]. In another cohort study, the most significant association was found between $PM_{2.5}$ in one side, and IHD, cardiovascular diseases, and lung cancer in the other side [11]. Despite the counties in Europe and Northern America, Middle Eastern countries are experiencing high concentrations of airborne particulates, and incidence of cardiovascular diseases. Many studies have been conducted to evaluate the relationship between air pollution and cardiovascular diseases, particularly IHD [12-14].

Airborne concentrations of particulate matter are associated with high blood pressure and plasma viscosity. These factors are indicators of hemodynamic disorders and elevated amount of inflammation in circulatory system [15, 16]. These are known as major risk factors for stroke [17]. In a study on the effect of acute exposure to low levels of different fractions of particulates on stroke incidence in Finland, a significant relationship was found between particulates and incidence of stroke in warm seasons [18]. In general, less studies have been carried out about the association between air pollution and stroke, rather than other health outcomes. Some of these studies have been performed in Asia, where high concentrations of particulate air pollution presents.

Health impact assessment of air pollution can be useful for health authorities and policy-makers. Different methods and tools have been developed for this purpose, such as AirQ, BenMap, AirQ+, etc. AirQ+ is a software tool for quantifying the health impacts of air pollution developed by the WHO Regional Office for Europe. The software can handle different air pollutants such as $PM_{2.5}$, PM_{10}, NO_2, O_3. and black carbon (BC). This software has been developed to assess the effects of long-term and short-term exposure to ambient air pollution. In addition, AirQ+ can estimate the effects of household air pollution related to Solid Fuel Use (SFU). Acute and chronic mortality and morbidity of several health outcomes can be considered to enter the model. The underlying scientific evidence on health effects from ambient air pollution used in the software is derived mainly from epidemiological studies conducted in Western Europe and North America [19].

Iran is facing serious problems in case of ambient air pollution [20]. Several health impact assessments have been carried out in Iran to estimate the health effects of air pollution [21- 24]. In a study which AirQ 2.2.3 was used to estimate the health effects of PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2 during 2013-2016 period [24]. In another study, gender-specific lung cancer deaths due to exposure to $PM_{2.5}$ were estimated by AirQ+ for 10 cities of Iran during 2013–2016 [22]. In another study, spatial and temporal trends of short-term health impacts of $PM_{2.5}$ in Iranian cities were estimated by AirQ+ modelling approach [21].

Despite these studies, estimation of IHD and stroke mortality attributed to air pollution have not been estimated yet. The aim of this study was to estimate the premature IHD and stroke deaths attributed to long-term exposure to $PM_{2.5}$ in 10 cities of Iran during March 2013 to March 2015 .using AirQ+ model

MATERIALS AND METHODS

Location and time

Ten cities of Iran were chosen for a health impact assessment study about $PM_{2.5}$ exposure. These cities included Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad, and Ilam. In addition, the study period included

March 2013 to March 2014, and March 2014 to March 2015.

AirQ+ software

AirQ+ requires the following input data for a health impact evaluation: air quality data, total and at- risk population (over 25 years old, in case of IHD and stroke), baseline incidence of the interest health outcome i.e. IHD and stroke, a cut- off value for pollutants' concentration, and Relative Risk (RRs) values if different from the default ones provided by WHO [19]. AirQ+ calculates different health-related estimates, including attributable proportion of cases, number of attributable cases, number of attributable cases per 100,000 at- risk population, proportion of cases in pollutant concentration range, and cumulative distribution by air pollutant concentration. These different estimates can be used in various ways depending on the assessment's objectives [19].

Air quality data

Hourly concentrations of fine particulate matter were obtained from Department of Environment (DOE) of Iran. At first, zero and negative values were removed; then, daily concentrations were calculated just in monitoring stations that met APHEKOM and WHO's criteria for health impact assessment of air pollution for Tehran and other cities, respectively [25, 26]. According to these criteria, only stations are valid that have more than 75 % (APHEKOM) and 50 % (WHO's criterion) valid data in a year. In addition, the ratio of valid data in summer to winter or winter to summer should not exceed 2 [25]. Daily concentrations of $PM_{2.5}$ in the selected year was prepared to enter the AirQ+ model. In case of cities without $PM_{2.5}$ measurements, PM_{10} concentrations were multiplied by a conversion factor of 0.5 to obtain $PM_{2.5}$ concentrations.

Demographic data

Age- specific population of each city was received from Statistical Centre of Iran. At- risk population (>25 years old) was calculated. Table 1 presents at- risk population for each city. Population of individuals older than 25 years in all the 10 cities were about 21 and 13 million, respectively.

Baseline incidence (BI)

Baseline incidence (BI) values for IHD and stroke mortality was obtained from Ministry of Health and Medical Education [27]. Due to lack of valid precise city- by- city information, the baseline incidence for all the 10 cities except for Tehran was assumed to be the similar. In addition, AirQ+ default relative risk (RR) values were used to evaluate the health impacts of $PM_{2.5}$ [28].

Table 1. Population with age more than 25 years old during 2013-2015 period

Cities	2013-2014	2014-2015
Tehran	5662500	5805750
Mashhad	1622880	1733550
Isfahan	1287360	1321440
Shiraz	960000	1030000
Tabriz	977040	1035170
Ahvaz	700873	727512
Arak	338640	378950
Sanandaj	224200	237900
Khoram Abad	205440	230650
Ilam	102720	111000
Total	**12081653**	**12611922**

RESULTS AND DISCUSSION

Fig. 1 shows the average (± standard deviation) of $PM_{2.5}$ concentrations of 10 selected cities for this study. These concentrations are reported before [22, 24]. Highest average concentrations in the first year were observed in Ahvaz (62.61 ± 71.69), Isfahan (56.15 ± 28.73), and Arak (43.14 ± 34.26), respectively. Lowest average concentrations in the first year were observed in Ilam (28.78 ± 23.68), Sanandaj (29.78 ± 18.44), and Tabriz (30.68 ± 22.67), respectively. In case of the second year, the highest average concentrations were in Isfahan (54.99 ± 25.59), Ahvaz (53.09 ± 52.58), and Khoram Abad (41.02 ± 33.41), respectively. In addition, the lowest average concentrations in the second year were observed in Tabriz (17.23 ± 8.36), Shiraz (25.00 ± 10.41), and Ilam (26.04 ± 27.37), respectively.

Average concentrations of fine particulate matter in all the 10 cities were several times higher than the WHO's guideline value (10 μg / m^3) for annual $PM_{2.5}$ levels. The highest average concentrations in the first year were observed in Ahvaz, Isfahan, Arak, and Khoram Abad, respectively. The reason could be due to the occurrence of Middle Eastern dust storms in Ahvaz and Khoram Abad, and presence of large industries in Arak and Isfahan. In general, southern and western cities of Iran such as Ahvaz, Khoram Abad, etc. are faced to severe Middle Eastern dust storms in recent years. Very high concentrations of particulate matter have been reported for Ahvaz. Mean concentrations of TSP and PM_{10} in Ahvaz were reported 1,481.5 and 1,072.9 μg / m^3 during dust storms, respectively [29]. This could be due to inappropriate water management and exacerbation of desertification in the surrounding areas [30].

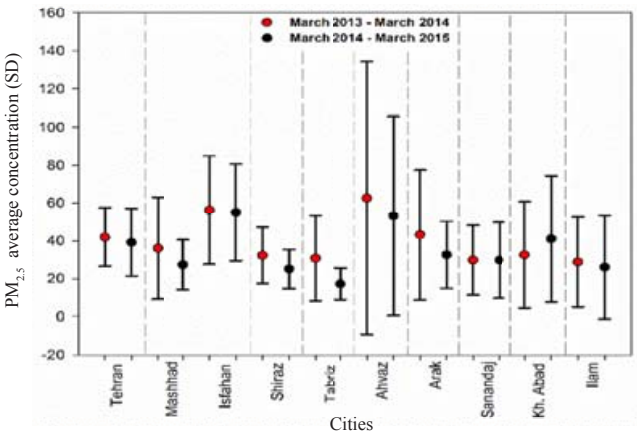

Fig. 1. Average (± standard deviation) of $PM_{2.5}$ concentrations during two consecutive years

The number of premature IHD and stroke deaths attributed to long-term exposure to $PM_{2.5}$ were estimated in 10 cities of Iran, including Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad, and Ilam. The at-risk population was individuals aging more than 25 years old. This is based on the recent epidemiological studies and their meta-analyses that provide relative risk values for AirQ+ model.

Table 2 presents the estimated number of premature IHD and stroke deaths due to long- term exposure to $PM_{2.5}$ among individuals older than 25 years in 10 cities of Iran. In case of both IHD and stroke mortality, the highest number of IHD and stroke deaths was estimated to be in Tehran, Mashhad and Isfahan, respectively. On the other hand, the lowest number of premature IHD and stroke deaths attributed to $PM_{2.5}$ exposure were estimated to be in Ilam, Sanandaj, and Khoram Abad, respectively. The total number of IHD and stroke deaths in the March 2013-March 2014 and March 2014-March 2015 periods were 15479 and 15321 deaths, respectively.

The highest number of IHD and stroke deaths was estimated to be in Tehran, Mashhad and Isfahan, respectively. On the other hand, the lowest number of premature IHD and stroke deaths attributed to $PM_{2.5}$ exposure were estimated to be in Ilam, Sanandaj, and Khoram Abad, respectively. These results mainly reflect the amount of population in each city. For instance, the most deaths were estimated to be in Tehran. The high mortality in Tehran is driven by both its high population and high concentrations of $PM_{2.5}$. It is reported that about 70 % of particulate air pollutants in Tehran were emitted from mobile sources during 2015 [31]. Therefore, a population-weighted index of mortality is required for better comparison between cities.

Table 3 shows the number of attributable IHD and stroke deaths per 100,000 population. In the first year, the most and least cases of IHD and stroke deaths per 100,000 population due to $PM_{2.5}$

exposure were in Ahvaz and Ilam, respectively. In the second year, the highest and lowest number of IHD and stroke deaths were estimated to be in Isfahan and Tabriz, respectively. The average of excess IHD death due to exposure to $PM_{2.5}$ in all cities were 86 and 82 for the first and second years, respectively. In addition, the average of excess stroke deaths attributed to exposure to $PM_{2.5}$ in the first year and second year was 42 and 39 cases, respectively.

The results of estimated IHD and stroke deaths per 100,000 due to $PM_{2.5}$ concentrations were different from those raw estimated numbers for whole population. In case of deaths per 100,000, the most cases of deaths were estimated to be in cities (Ahvaz and Isfahan) where population are exposed to high concentrations of $PM_{2.5}$, despite the size of population. In addition to Ahvaz, other Western and Southern cities such as Khoram Abad and Sanandaj showed high number of deaths per 100,000. This is due to the occurrence of Middle Eastern dust storms (MED) – as a consequence of improper management of water resources - in recent years [30]. Mean concentrations of TSP and PM_{10} in Ahvaz were reported 1,481.5 and 1,072.9 μg / m^3 during dust storms, respectively [29]. In another study during Middle Eastern dust storm period (April through September 2010) in Ahvaz, overall mean values of 319.6 ± 407.07, 69.5 ± 83.2, and 37.02 ± 34.9 μg / m^3 were monitored for PM_{10}, $PM_{2.5}$, and PM_1, respectively, with corresponding maximum values of 5338, 911, and 495 μg / m^3 [32, 33]. Various studies have indicated that the major source of particulate matter in Ahvaz is crustal dust [34 - 36].

The total number of IHD and stroke deaths in the March 2013-March 2014 and March 2014-March 2015 periods were 15479 and 15321 deaths, respectively. World Health Organization (WHO) have reported IHD and stroke mortality and burden of disease attributed to exposure to fine particulate matter ($PM_{2.5}$) for Iran in 2016. According to this report, years of life lost (YLL), disability-Adjusted Life Year (DALY), and number of IHD deaths attributed to $PM_{2.5}$ in Iran were 422105 years, 425114 years, and 16484 cases, respectively. In addition, YLL, DALY, and number of stroke deaths attributed to $PM_{2.5}$ in Iran were 180270 years, 183554 years, and 7290 cases, respectively [37]. These results are different from those obtained in the present study, mainly because this study considered only 10 cities of country with high population and more robust air quality dataset.

Table 2. Attributable number of IHD and stroke due to long- term exposure to $PM_{2.5}$ among individuals older than 25 years in March 2013 - March 2015

Cities	IHD ((95 % CI))		Stroke ((95 % CI))	
	2013-2014	2014-2015	2013-2014	2014-2015
Tehran	4851 (3642 - 6004)	4876 (3646 - 6033)	2411 (1163 - 3163)	2396 (1127- 3177)
Mashhad	1360 (1016 -1682)	1345 (988 -1644)	667 (313 - 886)	617 (281- 844)
Isfahan	1193 (919 -1464)	1213(929 -1492)	613 (324 - 760)	621 (325-777)
Shiraz	781 (579 - 965)	778 (569 - 946)	375 (175 - 506)	350 (158- 480)
Tabriz	785 (581- 964)	689 (496 - 828)	372 (172 - 504)	276 (121- 378)
Ahvaz	657 (507- 803)	662 (507-815)	338 (181- 415)	338 (174- 426)
Arak	296 (223 -366)	309 (229 -382)	148 (73-193)	149 (70 - 200)
Sanandaj	179 (133 -220)	189 (140 - 232)	85 (39 -115)	89 (41-121)
Khoram Abad	168 (124 -207)	200 (150 -248)	81 (38 -109)	100 (49-130)
Ilam	81 (60 -100)	85 (62-104)	38 (17-52)	39 (17-53)
Total	10351 (7784-12775)	10346 (7716-12724)	5128 (2495-6703)	4975 (2363- 6586)

Despite the WHO report, no studies have been conducted to estimate the number of IHD and stroke deaths in Iran. However, other health outcomes are well documented. According to a study, it was reported that the total number of deaths attributed to PM_{10}, $PM_{2.5}$, O_3, NO_2 and SO_2 over these three years were 4192, 4336, 1363, 2830, and 1216, respectively. The mortality in March 2015 – March 2016 showed a reduction of 9 %, 38 %, 14 % in comparison to March 2013 – March 2014 for $PM_{2.5}$, O_3, NO_2, and 25 %, respectively. Cardiovascular mortality due to PM_{10} was estimated to be 1075, 1100, and 1113 for each of the three years, respectively. Cardiovascular hospital admissions attributed to PM_{10} were 2185, 2236 and 2262 cases for each of the three years, respectively. The health impacts attributed to all pollutants except for PM_{10} were estimated to decrease in 2016, compared to the prior years, respectively [24]. In another study, 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 $PM_{2.5}$ exposure in all the 10 cities during these 3 years were estimated 864 cases. In addition, the attributable proportion of lung cancer due to $PM_{2.5}$ 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 [22].

In another study, total attributable short-term deaths due to $PM_{2.5}$ exposure during the three-year period in 10 cities of Iran were 3284 (95% CI: 1207-5244). The average daily premature deaths attributed to $PM_{2.5}$ were calculated to be 3 deaths per day. The highest number of premature deaths within the three-year period was estimated to be 548 in Tehran, largely reflecting mostly its population of nearly 9 million. The western and southern cities of Iran have occurrences of severe dust storms and showed high estimated rate of death attributed to air pollution. The health impacts in all cities have decreased in the third year compared to the first year except for Ahvaz, Khoram Abad, and Ilam [21]. In a study in Mashhad, the number of premature deaths due to short-term exposure to $PM_{2.5}$ was estimated to be 600 cases during 2014 - 2015 period [38]. Another study in Ahvaz showed that the number of mortality attributed to short-term exposure to PM_{10} was 278 cases in 2014 [39].

Table 3. Attributable number of IHD and stroke deaths per 100,000 population due to long-term exposure to $PM_{2.5}$ among individuals older than 25 years in March 2013 - March 2015

Cities	IHD (No. of attributable deaths)		Stroke (No. of attributable deaths)	
	2013 - 2014	2014 - 2015	2013 - 2014	2014 - 2015
Tehran	86	84	43	41
Mashhad	84	78	41	36
Isfahan	93	92	48	47
Shiraz	81	76	39	34
Tabriz	80	67	38	27
Ahvaz	94	91	48	46
Arak	87	82	44	39
Sanandaj	80	79	38	37
Khoram Abad	82	87	39	43
Ilam	79	77	37	35
Average	86	82	42	39

CONCLUSIONS

The number of premature deaths due to ischemic heart disease and stroke that are attributable to long-term exposure to $PM_{2.5}$ was estimated for 10 cities of Iran including included Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad, and Ilam. The results showed high IHD and stroke mortality due to $PM_{2.5}$ concentrations. Southern and Western cities showed high number of deaths per 100,000. Special considerations should be given to action plans for improving air quality in these cities. On the other hand, high-populated cities such as Tehran showed to have the most cases of estimated premature deaths. Any reduction in concentrations of $PM_{2.5}$ in Tehran can reduce the number of attributable deaths significantly. The results of this study indicated the necessity of urgent actions to improve the outdoor air quality in Iranian cities.

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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.

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