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Original Article

Health risks attributed to particulate matter of 2.5 microns or less in Tehran air 2005-2014

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Abstract

Introduction: Air pollution, especially particulate matter, is one of the main causes of mortality in humans. Therefore, the present study aimed to estimate health risks attributed to particulate matters of 2.5 microns or less (PM2.5) in Tehran air in the last ten years (2005-2014).

Methods: In this descriptive–analytical study, hourly data of pollutants were obtained from Tehran's Environmental Protection Agency and Air Quality Control Company and validated according to the WHO guidelines. Required statistical parameters were calculated for quantifying the health impacts and finally the processed data were converted to the format required by AirQ software in Excel® and the health impacts were quantified.

Results: The results showed that the ratio of annual mean concentration of PM2.5 in Tehran to standard values of Iran and WHO was 3.49, 3.02, 3.3, 4.14, 3.83, 4.7, 4.73, 4.07, 4.32 and 3.61 respectively from 2005 to 2014. In addition, total death toll caused by exposure to PM2.5 was 20015 people in the last decade.

Conclusion: The results showed that, like any other pollutants, particulate matter especially PM2.5 adversely impacts human health. During the last decade, the amount of particulate matter in Tehran's air and its related health risks extremely increased. An appropriate plan is therefore needed to control air pollution, especially particulate matter.

Introduction

Today, air pollution is one of the most important factors threatening human health in metropolitan areas such as Tehran in Iran, which causes mortality, morbidity, and numerous health outcomes. Air pollution seriously endangers human health in various ways including the formation of acid rain, photochemical and acid smog, inversions that trap pollutants near Earth's surface, and tropospheric ozone formation (4-1). The WHO reported an annual mortality rate of 3.7 million deaths induced by outdoor air pollution in 2012. (5). Over the past two decades, epidemiologic studies across the world have examined the effects of air pollution on human health and revealed the increased mortality associated with environmental pollutants. Studies indicate that particulate matter (PM) is one of the main pollutants regarding public health hazards. These studies provide strong evidence that both long-term and short-term exposures to particulate matter cause death and other health outcomes in human (6). Numerous studies in recent decades have revealed that PM, especially fine PM, is associated with a high mortality rate in the long- and short-term exposure (21-7). Most types of PM are created from fuel combustion in both mobile and stationary sources and are associated with a wide range of acute and chronic health effects, ranging from minor disorders to death from respiratory and cardiovascular diseases and lung cancer (22). Increases in mortality, respiratory infections, asthma and bronchitis are among the acute health effects of elevated concentrations of fine particulates such as $PM_{2.5}$. Furthermore, they directly irritate and obstruct airways, and damage mucus linings (23). It is believed that $PM_{2.5}$ is a greater health threat than PM_{10} because smaller particles are more probable to deposit in distal areas of the lungs. In addition, studies have shown that smaller particulates can also penetrate into buildings and affect health more seriously (24-26). Cohen et al. (2005) used the AirQ model to determine the global burden of disease due to outdoor air pollution, and reported that $PM_{2.5}$ caused about 0.8 million premature deaths and 6.4 million years of life lost (23). According to global statistics, approximately 8% of deaths from lung cancer, 3% of deaths from respiratory infections and 5% of deaths from the cardiovascular and respiratory diseases are attributed to PM. This disease burden is more noticeable in developing countries (22). A study by Joneidi et al. (2006) showed that 39.9% of the total number of deaths in Tehran were caused by exposure to $PM_{2.5}$ (27). A study by Kermani et al., titled 'Estimation of morbidity and mortality attributed to NO_2 in five metropolitan areas of Iran using AirQ model in 2011-2012, showed that Isfahan had the highest concentration of NO_2 with an annual mean concentration of 128 $\mu g/m^3$. The annual mean concentration of NO_2 in all metropolitan areas was higher than the standard level of Iran. The total number of deaths, deaths due to cardiovascular causes, and hospitalization for COPD in Mashhad was 286, 161 and 43 cases, respectively, which were higher than those in other metropolises (28). In a study by Naddafi et al. (2012), PM had the largest share of health effects of air pollutants in Tehran. Its annual mean concentration was 4.5 times the WHO guidelines (29). All these factors and other studies have drawn much attention to PM in air pollution discussions. All strategies for controlling air pollution and PM require a source of accurate information about the status of air quality and its effect on human health. Tehran suffers air pollution because it is the most populated metropolitan area in Iran and has specific geographical (topography and meteorology), social (population distribution and traffic), cultural (the cultural level and related education) and urban development conditions. Quantification of the effects attributed to air pollution particularly explains the impact of air pollutants on people, and indicates the critical conditions of air quality. The AirQ model is one of the most reliable methods to quantify the effects of air pollution on the basis of "risk assessment". It is mostly an epidemiological and statistical model introduced by the WHO European Center for Environment and Health in 2004. This model enables the user to assess the potential effects of exposure to an identified contaminant on humans in a specific urban area and during a specific period. It is a valid and reliable tool for predicting short-term effects of air pollutants (30).

Therefore, the present study was conducted to estimate the health hazards associated with $PM_{2.5}$ in Tehran air during the last ten years (2005-2014).

Materials and Methods

This was a cross-sectional study. The hourly raw data related to the specified pollutant was collected from Tehran Air Quality Control Company. The recorded raw data of stations underwent primary and secondary processes in order to determine their validity for statistical analysis based on the WHO criteria. The primary processing removed some pollutants, classified pollutants and matched them for time to measure their mean. The number of stations with valid data were identified on the basis of WHO criteria. Accordingly, the ratio of the number of valid data for two seasons (hot and cold seasons) should not be greater than double. Also, there must be at least 50% valid data to achieve mean 24-hour values. Secondary processing used programming in Excel®, where required statistical indicators including annual mean, hot season mean, cold season mean, the annual 98^{th} percentile, annual maximum, hot season maximum and cold season maximum of the pollutants were calculated. The population reported by the Statistical Center of Iran according to the population census was considered as the population exposed to pollution. The software determines adverse health effects according to the pollutant mass inhaled. So, the input data should be in weight-volume units ($\mu g/m^3$). Accordingly, data units were converted based on the conditions of temperature and pressure by programming in Excel®. The following general formula was used to convert mass units to volume units, where P is air pressure, T is temperature, and MW is molecular weight of the pollutant:

$$\frac{\mu g}{m^3} = \frac{P\ (mmHg) \times MW \times ppm}{62/4 \times T\ (°K) \times 1000}$$

Up to 2011, most of the stations did not measure $PM_{2.5}$. As a result, the concentration of $PM_{2.5}$ in these stations was estimated according to the measured concentration of PM_{10} and using the $PM_{10}/PM_{2.5}$ ratio. According to WHO, this ratio ranged between 0.5-0.8 in developing countries in 2008. Since a large percentage of particles in large industrial cities are emitted from vehicles, it is supposed that this ratio is greater than 0.5 in such cities. Therefore, $PM_{2.5}$ was estimated by applying the ratio of 0.6 in stations that did not measure $PM_{2.5}$ (30). Finally, by entering the processed data in the AirQ software, the results were obtained as attributable fraction and number of deaths due to exposure to PM and were presented in the form of tables and graphs. Air pollution is mainly measured in air pollution stations in Tehran (figure 1) by the products of "FAG Kugelfischer, Germany", "Environment SA, France", "Ecotech, Australia", "Horiba, Japan" Companies. PM is measured by direct readings using Horiba and Environment SA devices.

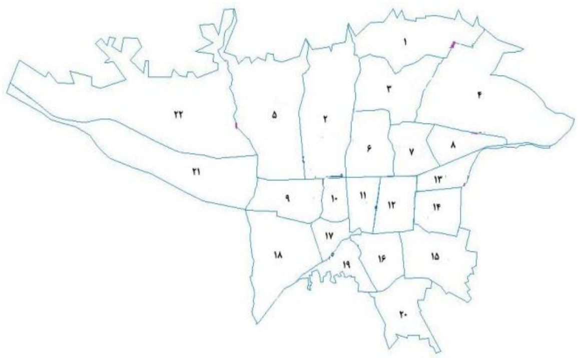

Figure 1. Map of Tehran

Findings

The results of this study are presented as tables and graphs in this section, including statistical parameters of $PM_{2.5}$ concentration in Tehran during 2005-2014 and the results obtained from the software. The following stations were considered valid during 2005-2010, 3 out of 11 stations in 2005, 4 out of 14 stations in 2006, 4 out of 14 stations in 2007, 7 out of 15 stations in 2008, 6 out of 18 stations in 2009, and 6 out of 37 stations in 2010. Values of PM_{10} were converted to $PM_{2.5}$ concentration by applying the 0.6 coefficient, and analyzed. From 2010 onwards, the $PM_{2.5}$ was measured directly. In addition to the converted data of PM_{10} concentration from previous stations, 9 out of 11 stations in 2011, 27 out of 14 stations in 2012, 10 out of 14 stations in 2013, 26 out of 15 stations in 2014, were considered valid. After primary and secondary processing of raw data, the necessary criteria for the model were determined (Table 1).

After determining annual mean values for PM, the amounts for each year were compared with the guideline amounts (31) and different standards. The results are presented in Tables 2 and 3. Changes in annual mean PM2.5 concentration showed that PM levels were higher than the standard limits in local guidelines (2009), WHO guidelines (2005), the Europe Union standard (2012) and the EPA national standard for air quality in the study period (Figure 2).

After the analysis and based on the results of the AirQ software, the extra cases, and the $PM_{2.5}$ attributable fraction for total number of deaths, the lower, upper and middle limits of relative risk used in this study for $PM_{2.5}$ per 10 micrograms per cubic meter were estimated 1.011, 1.015, 1.019. In this study, instead of using the default basic incidence of the software which was designed for European countries, the default basic incidence of the studies in Iran (543.5 per 105 people) was used in the software (29). Table 4 shows the results of quantification of PM2.5 health impacts.

Table 1. Statistical indicators required for the model to examine the effects of $PM_{2.5}$ concentration in Tehran during 2005-2014 (µg/m^3)

Year	Annual mean	Cold season mean	Hot season mean	Annual 98th percentile	Maximum Annual	Cold season maximum	Hot season maximum
2005	34.92	31.87	37.86	62.50	86.57	65.47	86.57
2006	30.29	26.94	33.52	54.10	66.27	64.45	66.27
2007	33.09	37.39	28.95	58.61	73.75	73.75	51.47
2008	41.40	35.79	46.83	87.83	132.30	108.22	132.30
2009	38.38	31.79	44.72	93.46	379.29	92.82	379.29
2010	47.02	47.61	46.46	94.64	161.45	114.01	161.45
2011	47.31	43.28	51.19	100.29	166.54	110.38	166.54
2012	40.75	42.04	39.46	71.38	129.71	75.76	129.71
2013	43.26	45.95	40.67	83.90	99.27	99.27	97.47
2014	36.15	38.40	33.98	67.33	100.57	100.57	83.12

Table 2. A comparison of the mean annual concentration of PM2.5 with various standards in Tehran during 2005-2014

Guidelines and Standards	Iran standards (2009)	WHO guidelines (2005)	the Europe Union standard (2012)
Annual mean (µg/m3)	10	10	25
Year	The ratio of mean annual concentration of PM2.5 in Tehran to other standards		
2005	3.49	3.49	1.39
2006	3.02	3.02	1.21
2007	3.3	3.3	1.32
2008	4.14	4.14	1.65
2009	3.83	3.83	1.53
2010	4.7	4.7	1.88
2011	4.73	4.73	1.89
2012	4.07	4.07	1.63
2013	4.32	4.32	1.73
2014	3.61	3.61	1.44

Table 3. A comparison of the 24-hour mean concentration of PM2.5 with the guidelines and standards during 2005-2014 in Tehran

Guidelines and Standards	Iran standards (2009)	the Europe Union standard (2012)	WHO guidelines (2005)	EPA national standard for air quality
24-hour mean (µg/m3)	25	25	25	35
Year	The number of times a 24-hour concentration of PM2.5 in Tehran was higher than any of the standards.			
2005	282	282	282	178
2006	246	246	246	111
2007	277	277	277	151
2008	306	306	306	217
2009	270	270	270	177
2010	307	307	307	247
2011	330	330	330	274
2012	342	342	342	238
2013	326	326	326	239
2014	285	285	285	175

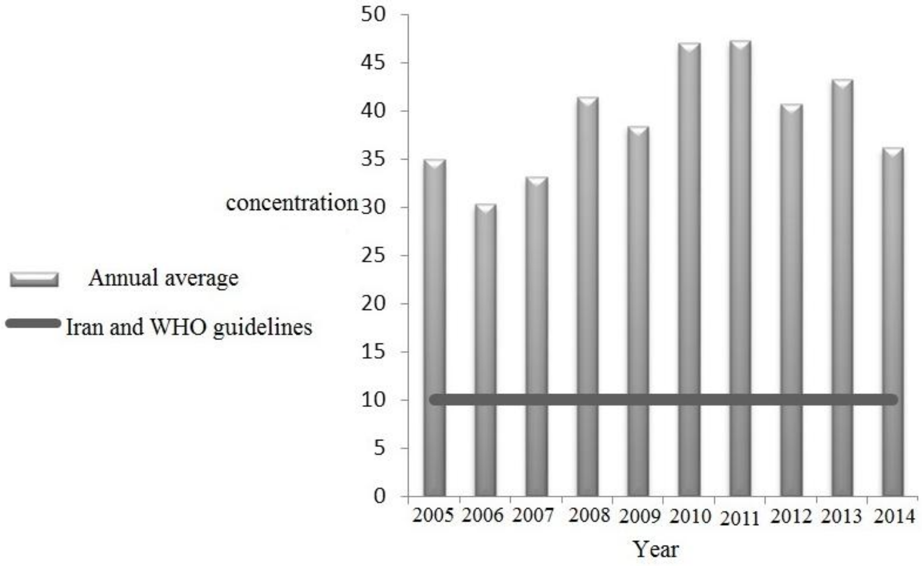

Figure 2. A comparison of the mean annual PM concentration in Tehran with Iran and WHO guidelines during 2005-2014

Table 4. Estimates of relative risk and attributable fraction of $PM_{2.5}$ for total number of deaths in Tehran (BI=543.5 per 100,000 people)

Index	The relative risk (RR) for each 10 μg/m³					
Estimation	Lower limit		Middle limit		Upper limit	
	1.011		1.015		1.019	
Year	Estimated attributable fraction (%)	Number of attributed cases (n)	Estimated attributable fraction (%)	Number of attributed cases (n)	Estimated attributable fraction (%)	Number of attributed cases (n)
2005	2.68	1180	3.62	1594	4.54	2000
2006	2.19	933	2.97	1343	3.73	1688
2007	2.46	1131	2.33	1529	4.18	1919
2008	3.32	1545	4.47	2081	5.6	2605
2009	3.01	1423	4.07	1919	5.10	2405
2010	3.91	1872	5.26	2516	6.57	3144
2011	3.96	1926	5.33	2589	6.66	3233
2012	3.26	1608	4.4	2167	5.51	2713
2013	3.53	1763	4.75	2373	5.94	2969
2014	2.78	1410	3.75	1904	4.71	2378
2005-2014	-	14791	-	20015	-	25054

Figure 3 presents the percentage of days people in Tehran were exposed to PM2.5 during ten years.

According to Statistical Center of Iran, Tehran's population in the study period (2005-2014) was respectively 8.098 million, 8.312 million, 8.432 million, 8.553 million, 8.676 million, 8.801 million, 8.928 million, 9.056 million, 9.187 million and 9.319 million people.

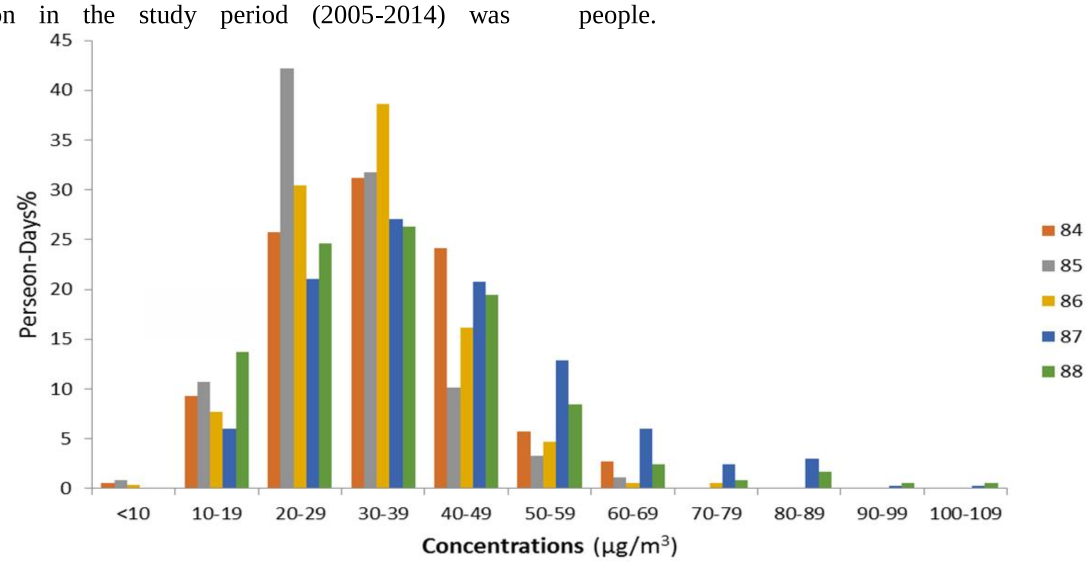

Figure 3. The percentage of days people in Tehran were exposed to various amounts of $PM_{2.5}$ during 2005-2009

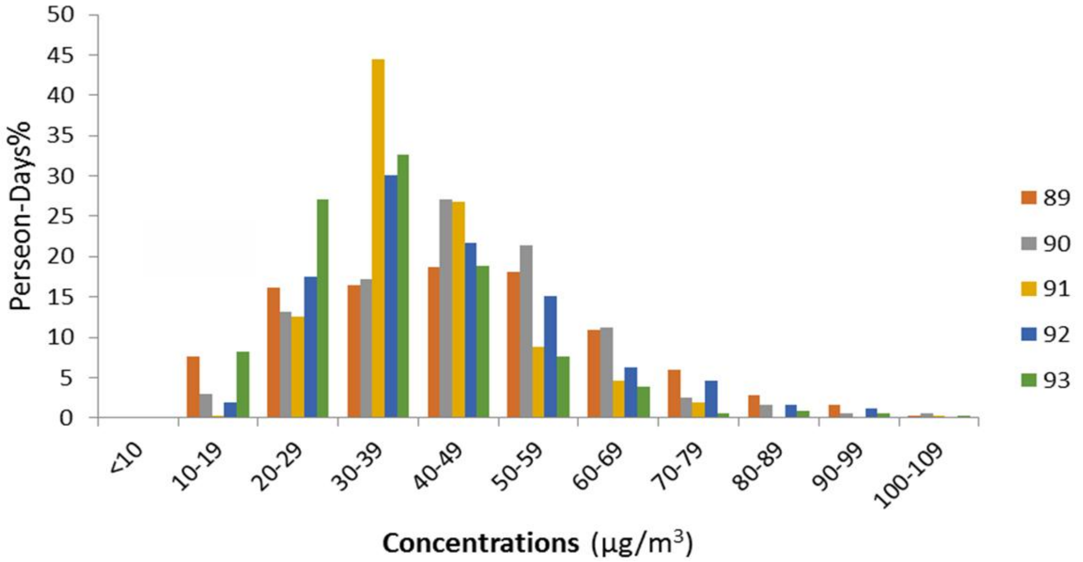

Figure 3. The percentage of days people in Tehran were exposed to various amounts of $PM_{2.5}$ during 2009-2014

Discussion

In this study, the concentration of $PM_{2.5}$ in Tehran was analyzed and compared with the standards during a ten-year period and the health effects attributed to this pollutant was quantified and calculated. Iran's clean air standard for $PM_{2.5}$ is µg/m^3 for mean annual concentration and 25 µg/m^3 for maximum 24-hour concentration. The results showed that the highest mean annual concentration of $PM_{2.5}$ was in 2010, 2011 and 2013 (47, 43 µg/m^3) which were 4.7 and 4.3 times the Iran clean air standards and WHO guidelines, respectively. The mean concentration in Tehran exceeded the limits during the whole period and was several times more than the standard level. As compared with guideline values (25 µg/m^3), the 24-hour mean concentration of $PM_{2.5}$ during the study period was beyond upper limit 300 days each year in the past decade. In the present study, every 10 µg/m^3 increase in $PM_{2.5}$ concentration increased the total mortality risk by 1.5%. The results of the cumulative number of deaths attributed to $PM_{2.5}$ suggested that this air pollutant accounted for 4% of all deaths on average, and caused a total of 20015 deaths over ten years. Naddafi et al. estimated the total number of deaths attributed to $PM_{2.5}$ as 2194 cases, which was about 4.6% of all deaths in Tehran (except for deaths due to accidents) (29). It is noteworthy that in all formulas used in the AirQ model, it is supposed that the estimates used in the analysis are controlled for all possible confounding factors (30). A study in two cities in an industrialized area of northern Italy also showed that short-term exposure to $PM_{2.5}$ with the 4.5% attributable fraction accounted for 8 out of 177 deaths per year for a population of 24,000 people in the two cities and had the greatest effect among other pollutants (29). A study on fine particulate air pollution and mortality in six cities in the United States indicated that for 10 µg/m^3 increase of fine particulate from mobile sources, 3.4% (CI=5.2%-1.7) increase was observed in daily mortality rate, while an increase of 10 µg/m^3 fine particulate matter from fossil caused 1.1 % (CI=2%-0.3) increase in the mortality rate (30). Surveys conducted in 29 European cities, 20 American cities and a number of Asian countries indicated the fact that the health impacts of short-term exposure to PM_{10} in different cities of developed and developing countries are similar and for every 10 µg/m^3 increase in the daily concentration of PM_{10}, the risk of death increases by 0.5%. Therefore, the concentration of 100 µg/m^3 leads to a 5% increase in daily mortality rate (34-36). The results indicate the fact that air pollution contributes to mortality and morbidity in metropolitan areas of Iran, and thus needs more attention on the part of authorities and experts to control air and particulate matter pollution. Measures should be taken to control air pollutants and to reduce their adverse effects on public health. The suggestions to reduce pollution can include appropriate control measures to prevent particulate matter, such as restoration of wetlands as strong ecosystems, creating greenbelts around cities, cloud seeding, appropriate vegetation and water transport, which are effective in reducing dust. In addition, appropriate management programs such as constant air quality monitoring, cost-effectiveness analysis, incorporating air quality management programs in the regional development programs, and measures such as vehicle inspection, public transport improvement and using clean technologies can protect public health and prevent damage.

Conclusion

Dust and particulate matter concentrations have sharply risen in recent years. The results of this study suggest that Tehran witnessed a high mortality rate due to high levels of air pollution, clearly indicating the adverse effects of air pollution especially PM on human health. Quantification of the attributable effects of air pollution clearly indicates the impact of air pollutants on population and shows the critical conditions of air quality. The attributable fraction estimates, morbidity and mortality due to $PM_{2.5}$ indicate Tehran's bad conditions, which could be due to the persistence of days with a higher concentration of PM or its higher mean. As a result, the reduction of PM and its health hazards and the improvement of the people's health need planning and scientific and practical measures to deal with dust and particulate matter.

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