Spatial and temporal trends of short-term health impacts of $PM_{2.5}$ in Iranian cities; a modelling approach (2013-2016)

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ABSTRACT

Estimation of the spatial and temporal trends of health impacts attributable to air pollution is an effective measure to evaluate implemented interventions. The aim of this study was to estimate the short-term mortality attributed to exposure to $PM_{2.5}$ among individuals older than 30 years old in Iranian cities from March 2013 to March 2016 using the World Health Organization's (WHO) AirQ+ software. Hourly concentrations of $PM_{2.5}$ were acquired from Department of Environment, and Tehran Air Quality Control Company. Only stations with 75% and 50% of valid data were qualified for Tehran and other cities, respectively. The annual average of $PM_{2.5}$ concentrations in all the ten cities were higher than the WHO guideline value of 10 $\mu g\ m^{-3}$. Total attributable short-term deaths during the three-year period in these 10 cities were 3284 (95% CI: 1207-5244). The average daily premature deaths were calculated to be 3. 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. Government interventions need to be enforced more effectively to reduce the high level of adverse health impacts in Iran. Special considerations should be given to the air quality of cities affected by dust storms.

Keywords: Particulate matter, airQ+, Middle Eastern dust storm, Health impact assessment, Air pollution

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INTRODUCTION

Over the past several decades, many studies have reported adverse human health effects from exposure to air pollution in areas around the world (Rahlenbeck and Kahl, 1996; Sunyer et al., 1996; Michelozzi et al., 1998; Saez et al., 2002; Shin et al., 2008; Burnett et al., 2014; Global Burden of Disease (GBD), 2015). One of the most important criteria air pollutants is particulate matter (PM) for which previous investigations have presented clear evidence for relationships between acute and chronic effects on health by PM including cardiovascular and respiratory mortality and hospitalizations (Chen et al., 2008; Wang et al., 2013; Ye et al., 2016). PM with an aerodynamic diameter of 2.5 µm or less ($PM_{2.5}$) is a more robust mortality–related exposure metric than PM with an aerodynamic diameter of 10 µm or less (PM_{10}) (USEPA, 2012).

Estimation of attributable health impacts of air pollution can clarify the economic and health burden of air pollutants for a given country (World Bank, 2016). The Iranian government's air quality management (AQM) activities have expanded from understanding the scope of the problem to targeting interventions. Thus, identification of spatial and temporal trends of health impacts attributable to air pollution is becoming more critical as an approach to assess the effectiveness of the control strategies (Liu et al., 2017).

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 (Pierpaolo Mudu, 2016).

Many health impact assessments of air pollution have been conducted around the world, including Iran. A study in Greece estimated the adverse health effects of PM_{10} concentrations recorded at six monitoring stations in the GAA (greater Athens area) in the 13-year period of 2001 to 2013 using the AirQ 2.2.3 software developed by the WHO (Ntourou et al., 2017). In the European Apheis study PM_{10} concentrations of 19 cities were used in a health impact assessment. The results showed that the reduction in long-term exposure to PM_{10} concentrations by 5 μg m^{-3} would have prevented between 3300 and 7700 premature deaths annually, 500 to 1000 of which are associated with short-term exposure (Medina et al., 2004). Health impacts of air pollution in several cities of Iran have been estimated in several studies using AirQ software (Goudarzi, 2014; Geravandi et al., 2015; Nourmoradi et al., 2015; Ghozikali et al., 2016; Miri et al., 2016; Mohammadi et al., 2016; Nourmoradi et al., 2016; Khaniabadi et al., 2017). However, only a few of them have considered the health effects of $PM_{2.5}$ as a pollutant.

In a study on spatial and temporal trends in the mortality burden of air pollution in China during 2004-2012, the health burden showed strong spatial variations, with high attributable deaths concentrated in areas with high air pollution, high population, or both. Temporal trends were observed in most provinces, but with varied growth rates (Liu et al., 2017). In Tehran, Kermani et al. (2016) estimated the short-term health impacts attributed to $PM_{2.5}$ over the period of 2005-2015. The total number of short-term premature deaths during this decade was estimated to be 20,015 (Kermani et al., 2016).

Many cities of Iran are ranked as high-polluted areas of the world according to WHO report (WHO, 2016). Iran is faced with rapid industrial growth, large number of old vehicles, and environmental crises such as Middle Eastern dust storms (MED) (Shahsavani et al., 2012a; Shahsavani et al., 2012b; Sowlat et al., 2012; Sowlat et al., 2013; Shahbazi, 2015). The Department of Environment (DOE) has designed and initiated plans and actions to control air pollution, including fuel substitution in mobile sources and power plants (Department of Environment (DOE), 2017). Monitoring and identification of the trend of reduction in air pollution and its health impacts can be an effective measure to evaluate implemented interventions (Liu et al., 2017).

The aim of this study was to estimate the short-term mortality attributed to exposure to $PM_{2.5}$ among individuals older than 30 years old in 10 cities of Iran during March 2013-March 2016 using AirQ+ modelling software.

METHODS

Location and time

Ten cities of Iran were selected for a health impact assessment of the exposure to $PM_{2.5}$. These cities included Tehran, Mashhad, Isfahan, Shiraz, Tabriz, Ahvaz, Arak, Sanandaj, Khoram Abad, and Ilam. These cities were selected because of the availability of ambient air monitoring data during the 21 March 2013 to 19 March 2016 period, which are three sequential years of the Iranian calendar; 21 March 2013 to 20 March 2014, 21 March 2014 to 20 March 2015, and 21 March 2015 to 19 March 2016.

Air quality data

Hourly concentrations of $PM_{2.5}$ were acquired from Department of Environment, and Tehran Air Quality Control Company. Only monitoring stations in residential areas were selected, and industrial and sub-urban (where there is no population exposure) were excluded. Negative and zero values were removed from the dataset. In Tehran, only stations with more than 75% data in each of the three years were considered as valid stations (EC Directive, 2008). In other cities due to lower completeness of datasets, stations with more than 50% data were considered valid (World Health Organization, 1999). The monitoring stations with seasonal ratios of valid data greater than 2 were omitted from dataset (World Health Organization, 1999). Then, 24-hour averages were calculated and entered in AirQ+. WHO's air quality guideline for 24-h concentrations of $PM_{2.5}$ (25 μg m^{-3}) was used as the cut-off value. AirQ+ estimates only the health effects attributed to concentrations over than this cut-off value.

Demographical data

This study investigates the mortality among the people who have attained the age of 30 years or more. Thus, the total population and at-risk population (>30 years old) of all cities were acquired from the Statistical Centre of Iran. The total population and at-risk population of all cities were approximately 20 and 10 million, respectively. Detailed city-specific demographical information is presented in Table S1 of supplementary material.

Baseline incidence

Baseline incidence (BI) values for all cause, non-accidental death per 100,000 population was calculated by using the information obtained from Ministry of Health and Medical Education, and Statistical Centre of Iran. The applied baseline incidence rates for Tehran and other cities were 943 and 807 per 100,000 population, respectively. The BI for all cities other than Tehran was estimated from total non-accidental deaths in Iran outside of Tehran in 2011 for persons older than 30. Due to lack of valid precise city-by-city information, the baseline incidence for the 9 cities other than Tehran was assumed to be the same.

AirQ+ software

For quantifying the short-term effects of particulate matter, the following input data are required: detailed concentration distributions (frequency of days with specified pollutant concentration values), at-risk population, health data such as baseline rates of given health outcomes, a cut-off value of concentration for consideration, and Relative Risk (RRs) values if different from the default ones provided by WHO (Pierpaolo Mudu, 2016). However, it only provides morbidity and mortality risk estimates for ozone, sulfur dioxide, nitrogen dioxide, black carbon, PM_{10} and $PM_{2.5}$. However, it does not provide estimates for the PM chemical components except for black carbon or more specific particle sizes such as ultrafine particles.

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 (Pierpaolo Mudu, 2016).

RESULTS

$PM_{2.5}$ ***concentration***

Table 1 presents the average concentrations of $PM_{2.5}$ in ten cities of Iran during the periods of March 2013 to March 2014, March 2014 to March 2015, and March 2015 to March 2016. It should be noted that the annual concentrations of $PM_{2.5}$ are reported previously (Hadei et al., 2017a; Hadei et al., 2017b). The annual average of $PM_{2.5}$ concentrations in all ten cities were higher than 10 $\mu g\ m^{-3}$, which has been proposed by WHO as a health protective guideline for annual mean $PM_{2.5}$. The most polluted cities in all three years were Ahvaz and Isfahan.

In all the cities except Ahvaz and Khoram Abad, concentrations of $PM_{2.5}$ in the third year were significantly lower than those in the first year. In case of Ahvaz and Khoram Abad, concentrations of $PM_{2.5}$ in the third year had been decreased significantly in comparison to the second year. $PM_{2.5}$ concentrations were compared between these ten cities. The details of statistical results are provided as supplementary material.

Short-term mortality

Table 2 presents attributable proportion of mortality due to short-term exposure to $PM_{2.5}$ in the selected 10 cities. Attributable proportion is the percentage of disease in the exposed group that can be attributed to the exposure.

In Table 3, the total attributable short-term deaths during the three-year period in the country is estimated to be 3284 (95% CI: 1207-5244). The average daily number of deaths due to $PM_{2.5}$ short-term exposures was calculated to be 3. The most premature deaths with a three-year average of 548 were estimated to be in Tehran, reflecting its nearly 9 million population. After Tehran, Isfahan and Mashhad have the most estimated premature deaths over the three-year period. The fewest cases have been estimated for Ilam and Sanandaj.

Table 4 gives the estimated rates of attributable premature deaths per 100,000 in the 10 cities. The Western and Southern cities of Iran with occurrence of severe dust storms showed high rate of premature death. Among these cities, Ahvaz showed a higher value with the three-year average of 19.24 premature deaths per 100,000 population. However, the premature death rate in Isfahan, an industrialized megacity, was calculated to be 17.72 per 100,000 population, higher than other cities except for Ahvaz.

Figs. 1 and 2 demonstrate the spatial distribution of three-year average of $PM_{2.5}$ concentrations and estimated mortality, respectively. Western and southern cities of Iran have higher concentrations of $PM_{2.5}$ rather than other areas. However, the estimated mortality in these cities are lower than central areas.

DISCUSSION

The attributable proportion and number of short-term deaths caused by $PM_{2.5}$ exposure among people older the 30 years old in ten cities of Iran during March 2013-March 2016 were estimated using the AirQ+ modelling approach. Prior works (Hoek et al., 2013; WHO-Europe, 2013; Burnett et al., 2014) has suggested that the risk estimates for people older than 30 years are more robust than those including younger individuals. The results showed some spatial and temporal variations.

Source identification and apportionment studies have only been conducted to in Ahvaz. To better understand the causes of spatial variations in PM concentrations, the sources of $PM_{2.5}$ in each city or region will need to be investigated. Traffic will be important in all cities, but there are likely to different local fine PM sources in each city including industrial activities and dust storms. Western and Southern cities of Iran such as Ahvaz, Khoram Abad, Sanandaj and Ilam have been subjected to Middle Eastern dust storms (MED) in recent years. The MED events are probably responsible for high rate of death attributable to air pollution in these cities. However, their relatively low population moderates the effect of high $PM_{2.5}$ concentrations. In a study during Middle Eastern dust storm period (April through September 2010) in Ahvaz, overall mean values of 319.6 ± 407.1, 69.5 ± 83.2, and 37.0 ± 34.9 $\mu g\ m^{-3}$ were monitored for PM_{10}, $PM_{2.5}$, and PM_1, respectively, with corresponding maximum values of 5338, 911, and 495 $\mu g\ m^{-3}$ respectively (Shahsavani et al., 2012a; Shahsavani et al., 2017). Two studies have conducted to apportion the sources of PM_{10} and TSP in Ahvaz (Sowlat et al., 2012; Sowlat et al., 2013). The possible sources of PM_{10} were crustal dust (41.5%), road dust (5.5%), motor vehicles (11.5%), marine aerosol

(8.0%), secondary aerosol (9.5%), metallurgical plants (6.0%), petrochemical industries and fossil fuel combustion (13.0%), and vegetative burning (5.0%). In addition, the seven sources were identified for TSP, including crustal dust (56%), road dust (7%), motor vehicles (8%), marine aerosol (9%), secondary aerosol (7%), metallurgical plants (4.5%), and finally petrochemical plants & fossil fuel combustion (8.5%). For Tehran, Isfahan, Mashhad, Tabriz, and Shiraz, mobile sources are likely to make significant PM contributions given the number of registered vehicles. However, there have not been comparable studies in any other city.

The average PM_{10} concentrations during dust episodes in Sanandaj (187 µg m^{-3}) were significantly higher than the other days (48.7 µg m^{-3}) (Ebrahimi et al., 2014). According to WHO's database, the annual average $PM_{2.5}$ concentrations in Ahvaz and Sanandaj during 2010 were 95 and 41 µg m^{-3}, respectively (WHO, 2016). The annual, winter and summer averages of PM_{10} in Khoram Abad were reported to be 80.59, 58.28, and 80.59 µg m^{-3}, respectively (Nourmoradi et al., 2015). Mirhosseini et al. (2013) have reported that the daily average concentration of particulate matter in Khoram Abad during the warm seasons (spring and summer) were higher than average concentration in cold seasons (autumn and winter) (Mirhosseini et al., 2013). Middle Eastern dust storms is likely to the main cause for this seasonal difference even given the extensive anthropogenic activities as major PM sources.

The most premature 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 (Solmaz Ahadi, 2016). There are more than three million personal vehicles in Tehran, 75% of which have emissions meeting the Euro-2 standards or less. In addition, there are about 750,000 motorcycles, 40% of which are older than 10 years and more than 95% of their emissions meet Euro-2 standard or less (Shahbazi, 2015). About 76% of air pollution in Isfahan is reported to be produced by mobile sources in 2010 (Asghar Zarabi, 2010). The major source of particulate matter of Arak is probably different. Industries have been suggested as the main sources of air pollution in this city (Hosseini and Shahbazi, 2016).

The studies about the use of AirQ+ are very rare (Hadei et al., 2017a; Hadei et al., 2017c), however many studies can be found about the quantification of health effects attributed to air pollution using AirQ 2.2.3 model. Hadei et al. (2013), estimated short-term mortality attributed to various air pollutants. The total number of mortality attributed to $PM_{2.5}$ over the three-year period of 2013-2016 was 4336 cases (Hadei et al., 2017b). 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 (Miri et al., 2016). Another study in Ahvaz showed that the number of mortality attributed to short-term exposure to PM_{10} was 278 cases in 2014 (Nourmoradi et al., 2015). These values seem to be higher than those obtained in this study. The difference was due to different relative risk values, functions, and interest population. In addition, a different procedure was used in this study to obtain $PM_{2.5}$ concentrations that were used as the population exposure.

The temporal trends showed a decline in health impacts observed in Tehran, Isfahan, Arak, and Sanandaj. Some interventions performed by the government such as fuel substitution in mobile sources and the industrial sector, replacing older vehicles with new ones, etc. may be the reason for this reduction, especially in Tehran (Department of Environment (DOE), 2017). Other cities have shown variations within the three-year period. However, one-year variations cannot be the basis to determine long- and medium-term trends. The third year's results can be compared with the first year's values to identify a short-term difference. This comparison showed that health impacts in all cities decreased in the third year compared to the first year, except for Ahvaz, Khoram Abad, and Ilam. This lack of change may be due to the occurrence of severe dust storms in these cities.

This approach has limitations that must be recognized. The model considers the air pollutant's concentration as the measure of population exposure. In addition, due to limitations in epidemiological studies, the model calculations do not account for multiple exposure cases or multipollutant scenarios. Finally, the exposure-outcome data that are the basis of the health outcome estimates were developed by epidemiological assessments conducted outside of this region. Thus, they represent the relationships in different populations, exposure to different particle mixtures, and other socio-economic conditions Thus, the results that have been obtained have additional uncertainties, and should be considered with caution and expert judgment (WHO Regional Office for Europe, 2016).

CONCLUSIONS

Based on these results, it can be concluded that interventions initiated by the government may have provided some improvement in air quality and lowered estimated mortality. However, given the high remaining concentrations, they need to be more aggressive to reduce high health impacts of $PM_{2.5}$ in Iran. Special considerations should be given to the air quality of cities such as Ahvaz, Khoram Abad and Ilam that are affected by Middle Eastern dust storms. For future studies, satellite-based $PM_{2.5}$ concentrations may provide a better spatially specific population exposure estimates and provide more reliable health impact assessments.

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Table Titles

Table 1. Annual average concentrations (±SD) of $PM_{2.5}$ in 10 selected cities (2013-2016)

Table 2. Attributable proportion of mortality due to short-term exposure to $PM_{2.5}$ among individuals older than 30 years in March 2013-March 2016

Table 3. Number of premature deaths due to short-term exposure to $PM_{2.5}$ among individuals older than 30 years in March 2013-March 2016

Table 4. Number of premature deaths per 100,000 population due to short-term exposure to $PM_{2.5}$ among individuals older than 30 years in March 2013-March 2016

Table 1. Annual average concentrations (±SD) of $PM_{2.5}$ in 10 selected cities (2013-2016) [a]

City	Average (±standard deviation), μg m^{-3}			Monitors: total (valid)
	2013-2014	2014-2015	2015-2016	
Tehran	41.89 (±15.45)	39.17 (±17.81)	36.42 (±17.98)	37(7)

Mashhad	36.05 (±26.96)	27.29 (±13.24)	30.59 (±13.8)	12(8)
Isfahan	56.15 (±28.73)	54.99 (±25.58)	37.29 (±13.72)	7(4)
Shiraz	32.22 (±14.92)	25 (±10.41)	26.8 (±15.5)	3(2)
Tabriz	30.68 (±22.67)	17.22 (±8.36)	22.72 (±12.63)	6(2)
Ahvaz	62.6 (±71.68)	53.08 (±52.58)	60.88 (±61.67)	3(2)
Arak	43.13 (±34.25)	32.53 (±17.71)	23.63 (±14.5)	2(1)
Sanandaj	29.77 (±18.43)	29.73 (±20.12)	25.02 (±15.97)	2(2)
Khoram Abad	32.57 (±28.07)	41.01 (±33.41)	33.94 (±38.42)	1(1)
Ilam	28.77 (±23.68)	26.04 (±27.37)	28.15 (±31.93)	1(1)

[a] These concentrations are reported previously (Hadei et al., 2017a; Hadei et al., 2017b).

Table 2. Attributable proportion of mortality due to short-term exposure to $PM_{2.5}$ among individuals older than 30 years in March 2013-March 2016

City	Attributable proportion		
	2013-2014	2014-2015	2015-2016
Tehran	1.8 (0.66-2.92)	1.38 (0.51-2.25)	1.04 (0.38-1.7)
Mashhad	1.6 (0.58-2.65)	0.68 (0.25-1.11)	0.96 (0.35-1.57)
Isfahan	4.13 (1.52-6.71)	3.68 (1.36-5.97)	1.56 (0.57-2.54)
Shiraz	1.14 (0.42-1.86)	0.4 (0.15-0.66)	0.69 (0.25-1.14)
Tabriz	1.23 (0.45-2.02)	0.16 (0.06-0.27)	0.44 (0.16-0.73)
Ahvaz	5.02 (1.75-8.78)	3.6 (1.28-6.06)	4.59 (1.63-7.71)
Arak	2.58 (0.94-4.25)	1.17 (0.43-1.91)	0.51 (0.18-0.84)
Sanandaj	1.12 (0.41-1.84)	0.96 (0.35-1.59)	0.67 (0.24-1.09)
Khoram Abad	1.52 (0.55-2.52)	2.4 (0.87-3.96)	1.83 (0.65-3.1)
Ilam	0.96 (0.34-1.59)	0.85 (0.3-1.43)	1.18 (0.42-2)
Total/Average	-	-	-

Table 3. Number of premature deaths due to short-term exposure to $PM_{2.5}$ among individuals older than 30 years in March 2013-March 2016

City	Total mortality		
	2013-2014	2014-2015	2015-2016
Tehran	676 (249-1097)	561 (206-912)	408 (150-666)
Mashhad	118 (43-193)	64 (23-105)	94 (35-154)
Isfahan	228 (84-369)	226 (84-366)	125 (46-203)
Shiraz	120 (44-195)	24 (9-39)	40 (15-65)
Tabriz	56 (21-92)	11 (4-17)	27 (10-44)
Ahvaz	117 (43-190)	96 (35-156)	125 (46-204)
Arak	36 (13-59)	23 (8-37)	11 (4-18)
Sanandaj	13 (5-21)	11 (4-19)	8 (3-14)
Khoram Abad	14 (5-23)	23 (8-38)	16 (6-27)
Ilam	4 (1-7)	4 (1-6)	5 (2-8)
Total/Average	**1382 (508-2146)**	**1043 (382-1695)**	**859 (317-1403)**

Table 4. Number of premature deaths per 100,000 population due to short-term exposure to $PM_{2.5}$ among individuals older than 30 years in March 2013-March 2016

City	mortality per 100,000 population		
	2013-2014	2014-2015	2015-2016
Tehran	14.57 (5.36-23.64)	11.65 (4.27-18.94)	8.17 (3-13.35)
Mashhad	9.1 (3.31-14.89)	4.58 (1.64-7.52)	6.44 (2.4-10.56)
Isfahan	21.83 (8.04-35.34)	20.87 (7.76-33.81)	10.47 (3.85-17.01)
Shiraz	15.67 (5.74-25.47)	2.89 (1.08-4.7)	4.45 (1.67-7.24)
Tabriz	6.94 (2.6-11.41)	1.27 (0.46-1.97)	2.99 (1.11-4.88)
Ahvaz	21.3 (7.8-34.58)	16.69 (6.08-27.12)	19.74 (7.2-32.21)
Arak	13.1 (4.75-21.58)	7.46 (2.59-12.01)	3.36 (1.22-5.55)
Sanandaj	7.29 (2.8-11.78)	5.77 (2.1-9.98)	3.96 (1.48-6.93)
Khoram Abad	8.5 (3.05-14.03)	12.81 (4.45-21.16)	8.32 (3.1-14.05)
Ilam	4.99 (1.24-8.7)	4.59 (1.14-6.89)	5.28 (2.11-8.45)
Total/Average	**14.2 (5.18-21.9)**	**10.1 (3.7-16.42)**	**7.89 (2.91-12.88)**

Figure captions

Fig. 1. Spatial distribution of three-year average of $PM_{2.5}$ concentrations in Iran (March 2013-March 2016)

Fig. 2. Spatial distribution of three-year average of mortality attributed to $PM_{2.5}$ concentrations in Iran (March 2013-March 2016)

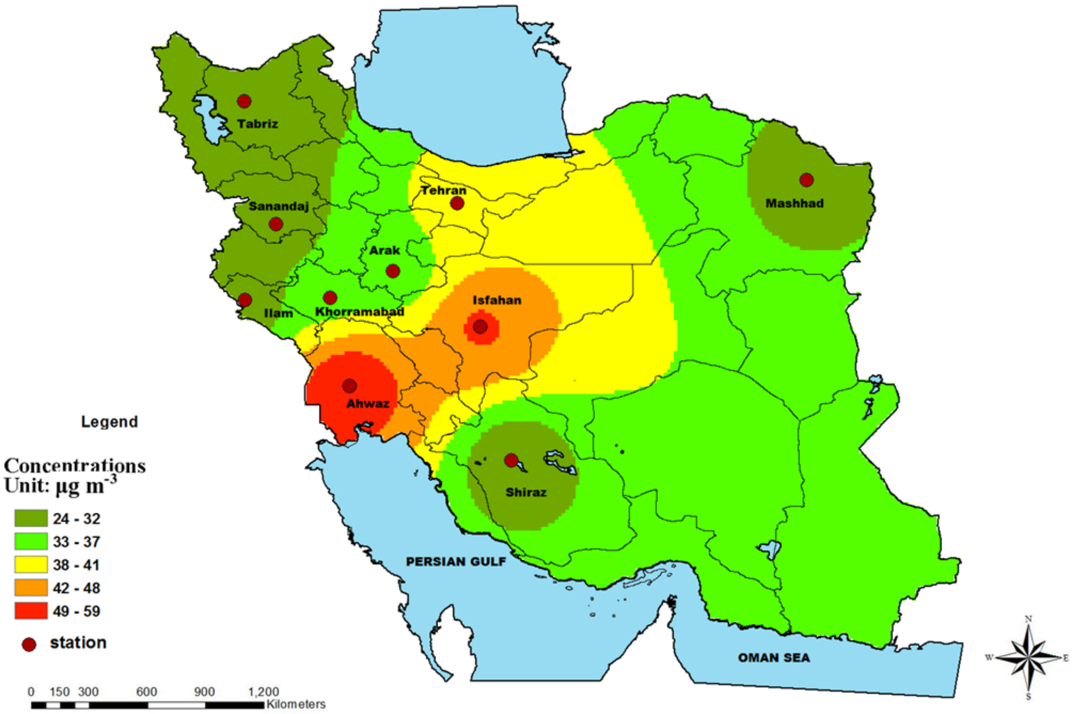

Fig. 1. Spatial distribution of three-year average of $PM_{2.5}$ concentrations in Iran (March 2013-March 2016)

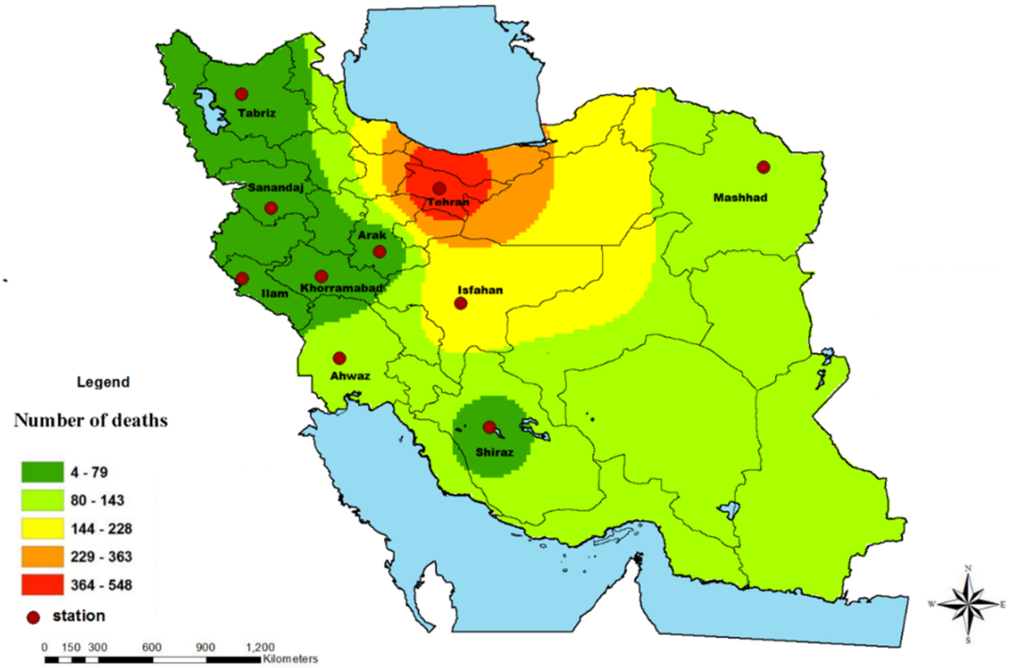

Fig. 2. Spatial distribution of three-year average of mortality attributed to $PM_{2.5}$ concentrations in Iran (March 2013-March 2016)