Journal of Advances in Environmental Health Research

Exploratory analysis of $PM_{2.5}$ variation trend of Tehran, Iran, in various time series and its relation with cardiovascular mortality rate using R software

Payman Kaseb[1], Ramin Nabizadeh[2], Kazem Nadafi[2], Kamyar Yaghmaeian[3]

1 Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
2 Center for Air Pollution Research (CAPR), Institute for Environmental Research (IER) AND Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
3 Center for Water Quality Research, Institute of Environmental Research (IER) AND Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

Original Article

Abstract

Among the numerous air pollutants, the strongest proof for adverse health effects has been reported for particulate matter (PM). The aim of this study was the exploration of short-term associations of air pollution with mortalities due to cardiovascular diseases (CVD) in Tehran, Iran, based on hospital and census data from 2007 to 2013. This descriptive and analytical research was conducted in 2015. Daily and hourly pollutant concentration was obtained from Tehran Metropolitan Municipality. Mortality rate records were obtained from the Ministry of Health, Central Municipal Cemetery, and Forensic Organization. In this study, data were analyzed using R software. Zoo, Time series, Stats, ts model, and Splines software packages were installed on R platform in order to outline the trend of different variables. The results showed that accidental mortality did not follow a particular trend and non-accidental mortality followed a descending or ascending trend. However, mortality pattern showed a decreasing trend from 2011 until the end of 2012. From the beginning of 2013, mortality pattern showed increasing trend. Moreover, the direct correlation of mortality rate and $PM_{2.5}$ concentration can be observed in a yearly and weekly time scale. Proof of a determined effect of airborne particles on mortality was found with $PM_{2.5}$. In addition, it was found that mortality rate shows a strong seasonal pattern, with a peak in winter and a minimum in fall. The peak the mortality rate in winter is most probably due to the spread of infectious diseases such as influenza as well as temperature-related phenomena in cold weather areas.
KEYWORDS: Air Pollution, Mortality, $PM_{2.5}$, R software

Date of submission: 15 May 2015, ***Date of acceptance:*** 24 Jul 2015

Citation: Kaseb P, Nabizadeh R, Nadafi K, Yaghmaeian K. **Exploratory analysis of PM2.5 variation trend of Tehran, Iran, in various time series and its relation with cardiovascular mortality rate using R software.** J Adv Environ Health Res 2015; 3(4): 276-83.

Introduction

During the previous 50 years, air pollution and its impact on individuals' health and the environment have been a global concern. The negative health effects of air pollution consist of a broad range of acute and chronic health effects causing increased hospital admissions,[1] increased emergency room visits,[2] and, most importantly, increased mortality.[3] The World Health Organization (WHO) estimated that ambient (outdoor) air pollution in both cities and rural areas caused 3.7 million premature deaths worldwide in 2012.[4] Epidemiological studies have revealed short-term and long-term associations between the levels of ambient air pollutants, and respiratory and cardiovascular mortalities in different parts of the world.[3]

Corresponding Author:
Ramin Nabizadeh
Email: rnabizadeh@tums.ac.ir

Previous studies regarding air pollution have focused mostly on nitrogen dioxide (NO_2), particulate matter (PM) with an aerodynamic diameter of less than 10 mm (PM10), sulfur dioxide (SO_2), or ozone (O_3).[4] Among the numerous air pollutants, the strongest proof for adverse health effects has been reported for PM.[5] Several studies have shown that short-term exposure to PM was associated with increased risk of mortality and morbidity.[6,7] The sources and constituents of the PM mixture are well-known to vary throughout the year. Therefore, besides the different exposure patterns of the population in different seasons, it is believed that the short-term relations between particulate air pollution and daily mortality can also change from season to season.[8] PM with an aerodynamic diameter of less than 2.5 mm ($PM_{2.5}$) has become the focus in recent research's due to its small size and capability to penetrate deep into the respiratory tract.[9] Inflammation, endothelial dysfunction, and autonomic nervous system injuries in rats due to $PM_{2.5}$ exposure have been reported in a recent study.[10] A committee of the American Heart Association in a review in 2004 expressed concern of a causal association between PM and harmful cardiovascular effects.[9] However, other adverse effects of $PM_{2.5}$ exposure have been reported in recent studies. For example, Santos et al. stated that exposure to PM could increase the risk of ventricular tachycardia for aging people with coronary artery disease (CAD).[11] Nevertheless, Xu et al. reported that cardiac autonomic function of elderly patients with heart disease can result from ambient $PM_{2.5}$ exposure, and subjects with hypertension seemed to be more susceptible to the autonomic dysfunction caused by $PM_{2.5}$.[12] Tehran, as the most overcrowded city in Iran, has experienced serious air quality problems in the recent years. Today, traffic, industrial processes, domestic heating, long-range transportation of pollutants and motor vehicle are the most significant emission sources in Tehran. With regard to the aforementioned pollution source, high levels of air pollution-related diseases are expected in Tehran. In Iran a number of studies have been conducted on air pollution related diseases.[13,14] Conversely, the association between $PM_{2.5}$ and cardiovascular morbidities has not been surveyed locally and in Iran. This study was conducted with the aim to explore short-term associations of air pollution with morbidities and mortalities caused by cardiovascular diseases (CVDs) in Tehran based on hospital and census data from 2007 to 2013.

Materials and Methods

Tehran (capital of Iran) is the largest city and urban area of Iran, the 2nd-largest city in Western Asia with an area of 686.3 km². Tehran County borders Shemiranat County to the north, Damavand County to the east, Eslamshahr, Pakdasht, and Rey counties to the south, and Karaj and Shahriar counties to the west. The city of Tehran has 22 municipal districts, each with its own administrative center. Tehran features a semi-arid climate with continental climate characteristics and a mediterranean climate precipitation pattern. Average temperatures in Tehran are between 35 and 40 °C. Most of the light annual precipitation occurs from late autumn until mid-spring.[15] Meteorological factors have significant effect on air pollution. Wind carries air pollutants away from their source, causing them to disperse. Generally, in higher wind speed, more pollutants are distributed and their concentrations are lowered. However, high wind speed can also transport dust from long range distances.[16]

This descriptive and analytical research was conducted in 2015. Daily and hourly pollutant concentration was obtained from the 34 air quality stations of Tehran Metropolitan Municipality. The air quality indicator in our study was PM with aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$). Mortality rate records of 2007-2013 were obtained from the Ministry of Health, Central Municipal Cemetery, and Forensic

Organization. Meteorological and demographic information of 22 districts of Tehran were obtained from the Meteorological office in Tehran. Deaths from all CVDs were considered.

The locations of air quality monitoring stations are shown in figure 1. A lack of uniformity was observed in the distribution of contaminants in different areas of Tehran, and thus, there was a possibility of data misinterpretation. Therefore, trimmed mean of pollutant concentration in the range of 10% was used instead of daily means of the concentrations calculated from the hourly data of pollutant. Trimmed mean is a reliable averaging method in which the highest and lowest reported data is discarded, and then, the average is taken from the remaining uniform data.[17]

After editing of incorrect and irrelevant data, all cases of mortality were classified based on age, sex, place of residence, and cause of death. In order to remove confounding factors and achieve correct results, all cases of death of 65 years of age or younger were selected. Given that the main objective of this research was the assessment of the relation of air pollution with mortality rate, it was necessary to discard deaths caused by accidents, cancers, and chronic CVD.

To evaluate the impact of air pollution on human health, epidemiological studies practice statistical approaches which are suitable tools for interpreting data. Time series studies are often used to determine statistical relations of ambient concentrations of pollutants and other environmental factors with mortality. The most favored statistical method over the past two decades has been Poisson regression with air pollution variables included as linear predictors and monitoring for time-varying confounders which are feasibly related both to mortality and air pollution.[18]

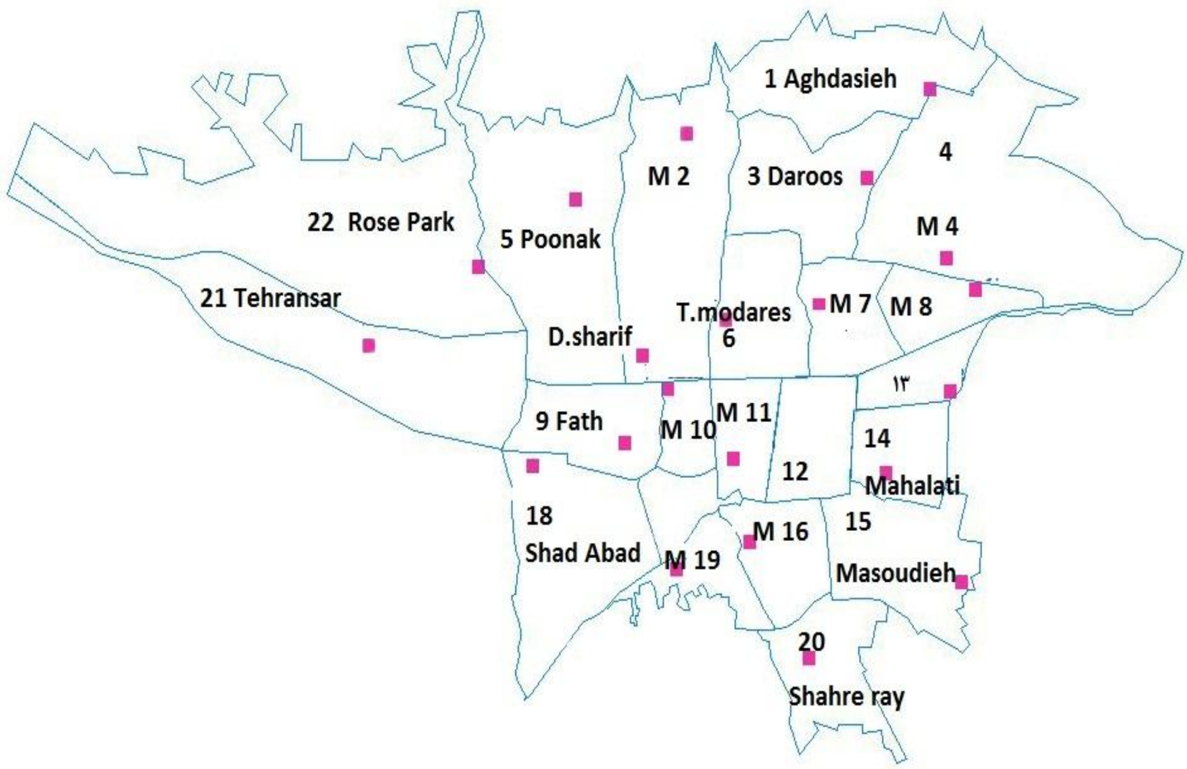

Figure1. Map of the study area including air quality monitoring stations

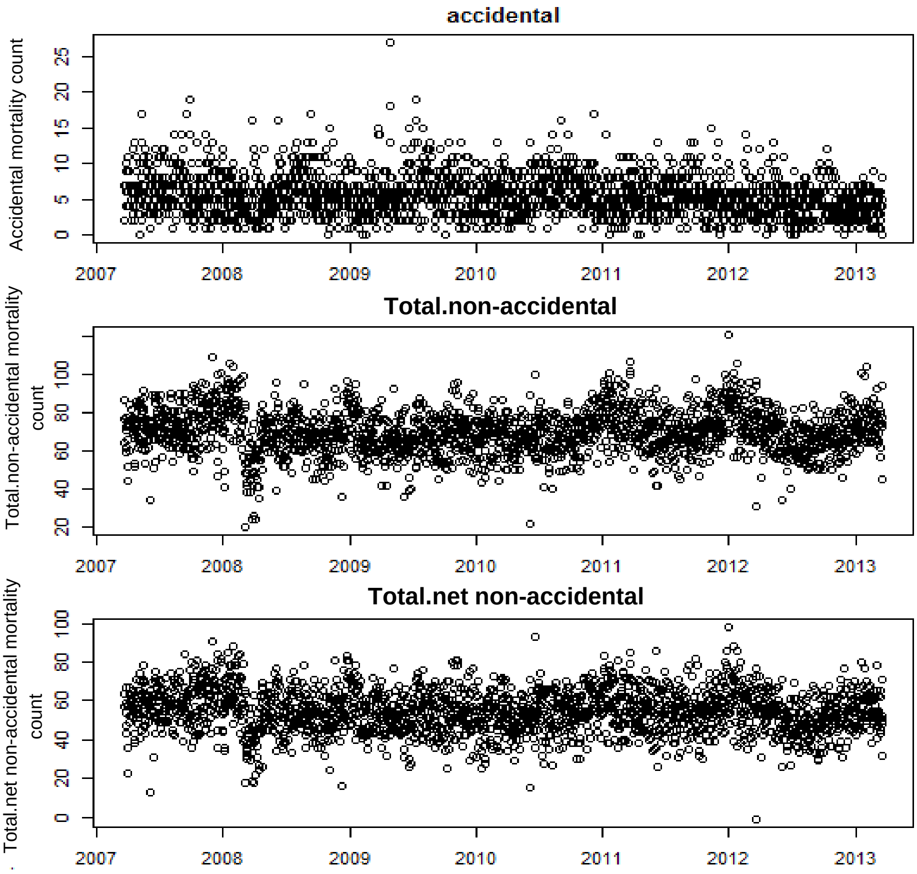

Figure 2. Daily mortality data on cases aged 65 years or younger in Tehran during 2007-2013

In this study, data were analyzed using R software (version 3.2, R Core Team). Zoo, time series, stats, ts model, and Splines software packages were installed on R platform in order to outline the trends of different variables. Moreover, the plot of the autocorrelation function (ACF) of the residuals was examined. To estimate linear trends of short-term effects of $PM_{2.5}$ on mortality, statistical tools developed by Peng et al.[19] were adapted to estimate time-varying relative rates.[20]

Results and Discussion

The mortality data for cases aged 65 or younger is presented in figure 2. As shown in figure 2, accidental mortality did not follow a particular trend. By excluding accidental mortality, non-accidental mortality followed a descending or ascending trend. In addition, figure 2 shows that net non-accidental mortality has the same pattern as non-accidental mortality.

Figure 3 shows $PM_{2.5}$ time series decomposition from 2007 to 2013. It appears that daily concentration of $PM_{2.5}$ has had a descending trend from 2011 to 2012. At the end of 2012, daily concentration of $PM_{2.5}$ showed an increasing trend. It can also be observed in figure 3 that the evident seasonal pattern in $PM_{2.5}$ concentration showed a peak in winter.

Environmental regulations proposed to protect human health are based on a foundation of scientific proof that arises from toxicological, clinical, and epidemiologic research. Their purpose is to reduce exposure to agents that have been found to harmfully affect health, and their application is thought to lead to a reduction in the burden of health effects caused by the exposure.[21]

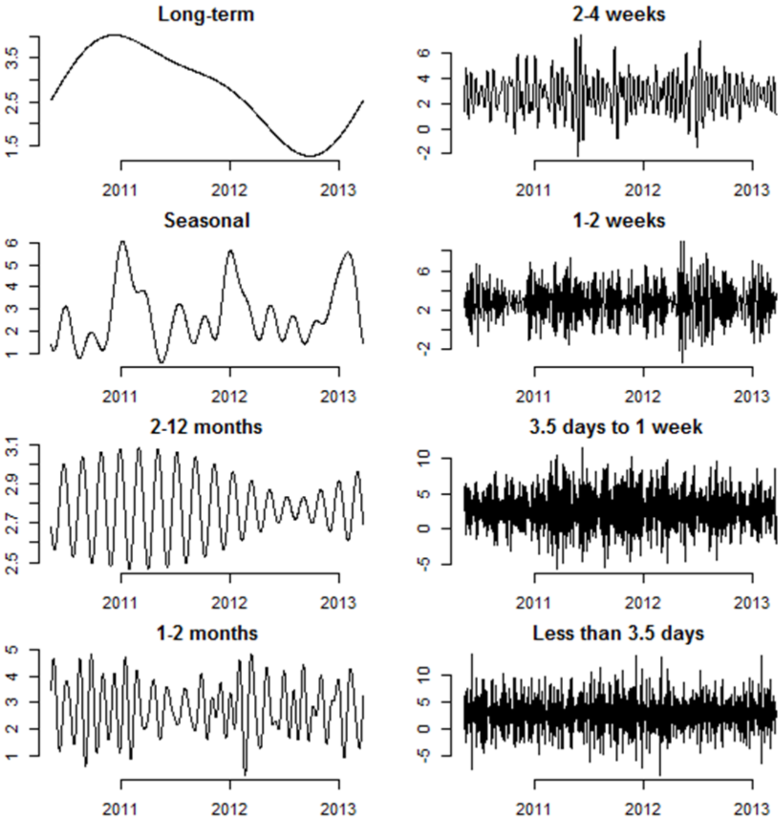

Figure 3. Tehran $PM_{2.5}$ timescale decomposition in 2007-2013

This paper presents evidence on the short-term effects of $PM_{2.5}$ on mortality during 2007-2013, when several air quality regulations were implemented. Specifically, changes in the risk of exposure to airborne particles were assessed over a period of substantial alterations in the sources and decline in ambient concentrations of airborne particles. For this purpose, almost all available data on $PM_{2.5}$ and mortality were used. As a result, proof of a determined effect of airborne particles on mortality was found with $PM_{2.5}$. In a study conducted by Shahi et al., effects of air pollution on cardiovascular and respiratory causes of emergency admission were evaluated.[22] The results of their study showed that carbon monoxide (CO) level was an independent risk factor of CVD while the increased level of $PM_{2.5}$ and O_3 led to increased rate of admissions to the emergency department due to respiratory causes.[22]

Figure 4 shows time series mortality rates among individuals of less than 65 years of age. As seen in figure 4, the mortality pattern shows a decreasing trend from 2011 until the end of 2012. From the beginning of 2013, mortality pattern shows an increasing trend.

Mortality rate showed a strong seasonal pattern with a peak in winter and a minimum in fall. However, a lower amount of $PM_{2.5}$ was observed in winter. Thus, the peak in winter mortality is most probably due to the spread of infectious diseases, such as influenza, as well as temperature-related phenomena in cold weather areas. Higher amount of $PM_{2.5}$ during fall can be related to car traffic since the schools open in the fall. According to our study, the risk of mortality due to air pollution can occur up to 50 days (50 days lag) after exposures especially lag 0. Goudarzi et al. studied the relationship between air pollution exposure and chronic obstructive pulmonary disease (COPD) in Ahvaz, Iran, in 2012.[23] The results of their study showed that the annual average PM_{10} concentration in 2012 was 727 $\mu g/m^3$. According to their results, a strong correlation was observed between hospital visits due to COPD and PM_{10} emission in Ahvaz. In addition, they found that approximately 6.2% of hospital admissions due to COPD occurred when PM_{10} concentration was higher than 30 µg/m³.

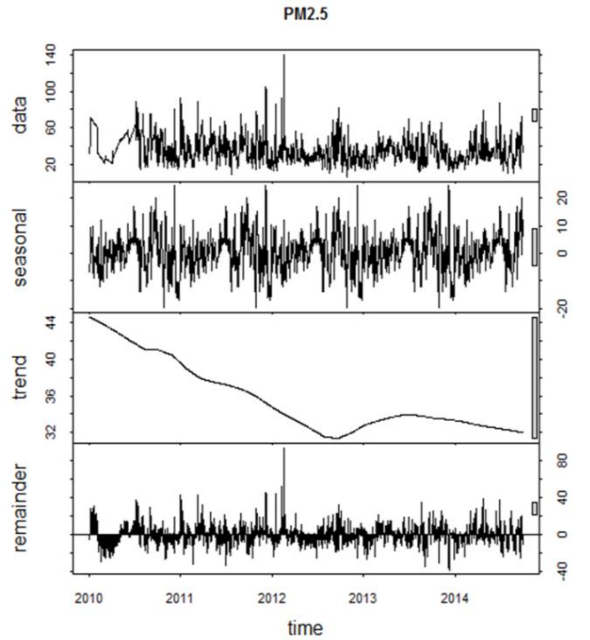

Figure 4. Tehran mortality timescale decomposition among individuals of less than 65 years of age in 2007-2013

Figure 5(a) shows a correlogram for the mortality data on Tehran. The correlogram can be computed in R using the ACF function in the stats package. The result shows a peak in lag 0. In other words, the plot shows the quick effect of $PM_{2.5}$ on mortality rate in the first day.

Nevertheless, a mild effect was observed in lag 5, 8, 15, and 21. Figure 4(b) shows the correlogram of the residuals after removing some of the seasonality of mortality data. The results showed that the effect of $PM_{2.5}$ on mortality was observed specifically in lag 0.

Cardiovascular mortality was associated especially with daily mean $PM_{2.5}$. Furthermore, $PM_{2.5}$ was not significantly associated with total non-accidental mortality. Based on ACF analysis, the results of the present study showed that $PM_{2.5}$ impacted mortality rate. In other cases, we have not seen any evident effect. This suggests that other seasonal diseases have a significant effect on mortality. Capraz et al. studied the association between air pollution and mortality in Istanbul, Turkey.[3] Their findings showed that the risk of mortality due to air pollution can occur up to 10 days (10 days lag) after exposure. Moreover, their results showed that cardiovascular mortality was related to daily mean SO_2, followed by NO_2 and PM_{10}.[3]

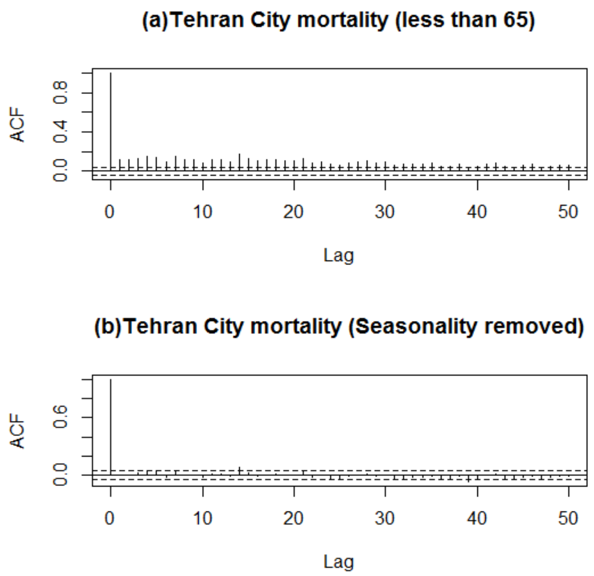

Figure 5. Autocorrelation functions for mortality data on Tehran for (a) raw data and (b) residuals after removing seasonality

Simultaneous changes in mortality rate and $PM_{2.5}$ concentration in annual, seasonal, and weekly time scale are shown in figure 6. As figure 6 shows, direct correlation between mortality rate and $PM_{2.5}$ concentration can be observed in the annual and weekly time scale. Valid correlation was not found in the seasonal time scale. In a study conducted by Lu et al., it was found that associations between air pollution and mortality were more distinct in the warm season than in the cool season.[24] They concluded that the increase in risk of mortality corresponded to an increase in current ambient concentrations of air pollutants. Qiu et al. studied the association between air pollution and mortality in china.[25] They found that for a 10 μg/m^3 increase in pollution concentration, a 1.6%-2.3% additional increase in mortality related to PM, NO_2, and SO_2 was observed among individuals aged 65 years or older compared with younger individuals.

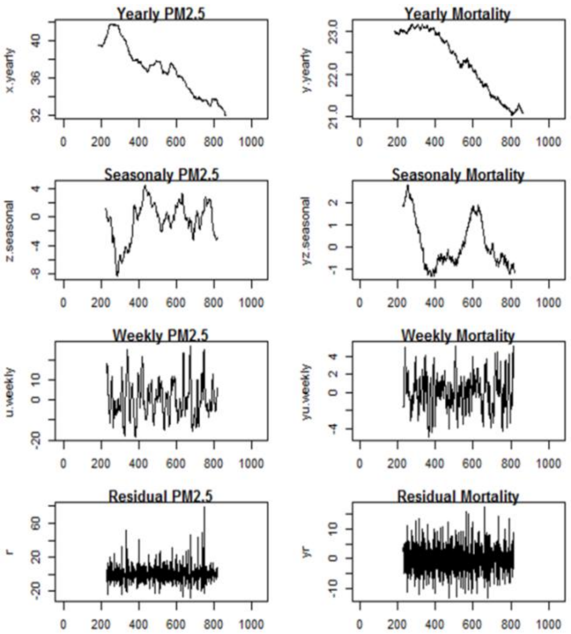

Figure 6. Timescale decomposition for $PM_{2.5}$ and mortality data in Tehran during 2007-2013

Conclusion

Our results showed that short-term exposure to outdoor air pollution ($PM_{2.5}$) was associated with CVD in Tehran between 2007 and 2013. High percentages of observed health effect (CVDs) were linked with high concentrations of $PM_{2.5}$. Therefore, application of methods to reduce $PM_{2.5}$ concentration plus suitable health and environmental monitoring are recommended. In the present study, it was also found that day-to-day variations in cardiovascular mortality are associated with ambient concentrations of $PM_{2.5}$. According to the results of this study, the risk of mortality due to air pollution can be observed up to 50 days (50 days lag) after the exposure.

Conflict of Interests

Authors have no conflict of interests.

Acknowledgements

This study was funded by the Vice Chancellery for Research of Tehran University of Medical Sciences, Iran.

References

1. European Centre for Environment and Health. Quantification of the health effects of exposure to air pollution. Proceedings of the WHO Working Group; 2000 Nov 20-22; Bilthoven, Netherlands.
2. Buka I, Koranteng S, Osornio-Vargas AR. The effects of air pollution on the health of children. Paediatr Child Health 2006; 11(8): 513-6.
3. Capraz O, Efe B, Deniz A. Study on the association between air pollution and mortality in stanbul, 2007-2012. Atmos Pollut Res 2016; 7(1): 147-54.
4. Tam WWS, Wong TW, Wong AHS. Association between air pollution and daily mortality and hospital admission due to ischaemic heart diseases in Hong Kong. Atmos Environ 2015; 120: 360-8.
5. Pope CA 3rd, Dockery DW. Health effects of fine particulate air pollution: lines that connect. J Air Waste Manag Assoc 2006; 56(6): 709-42.
6. Brook RD, Rajagopalan S, Pope CA 3rd, Brook JR, Bhatnagar A, Diez-Roux AV, et al. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation 2010; 121(21): 2331-78.
7. Kloog I, Ridgway B, Koutrakis P, Coull BA, Schwartz JD. Long-and short-term exposure to PM2.5 and mortality: using novel exposure models. Epidemiology 2013; 24(4): 555-61.
8. Chen R, Peng RD, Meng X, Zhou Z, Chen B, Kan H. Seasonal variation in the acute effect of particulate air pollution on mortality in the China Air Pollution and Health Effects Study (CAPES). Sci Total Environ 2013; 450-451: 259-65.
9. Cao J, Xu H, Xu Q, Chen B, Kan H. Fine particulate matter constituents and cardiopulmonary mortality in a heavily polluted Chinese city. Environ Health Perspect 2012; 120(3): 373-8.
10. Wang G, Zhen L, Lu P, Jiang R, Song W. Effects of ozone and fine particulate matter (PM2.5) on rat cardiac autonomic nervous system and systemic inflammation. Wei Sheng Yan Jiu 2013; 42(4): 554-60.
11. Santos UP, Terra-Filho M, Lin CA, Pereira LA, Vieira TC, Saldiva PH, et al. Cardiac arrhythmia emergency room visits and environmental air pollution in Sao Paulo, Brazil. J Epidemiol Community Health 2008; 62(3): 267-72.
12. Xu MM, Jia YP, Li GX, Liu LQ, Mo YZ, Jin XB, et al. Relationship between ambient fine particles and ventricular repolarization changes and heart

rate variability of elderly people with heart disease in Beijing, China. Biomed Environ Sci 2013; 26(8): 629-37.
13. Gholizadeh MH, Farajzadeh M, Darand M. the correlation between air pollution and human mortality in Tehran. Hakim Res J 2009; 12(2): 65-71. [In Persian].
14. Mousavi F, Jahed A, Rajab A, Nikuo Sokhantabar AK, Kashi G, Tabatabaee R. Survey of air pollution effect on variation of glycosylated hemoglobin a1c (hba1c) level in diabetic patients in Tehran. Iran J Health Environ 2013; 6(1): 123-32. [In Persian].
15. Tehran Municipality. Atlas of Tehran [Online]. [cited 2016]; Available from: URL: http://atlas.tehran.ir/Default.aspx?tabid=40
16. Ramos DP, Quijano S, Orrego D, Becerra MA. Dependence analysis using multiple linear regresion and principal component regression in air pollutants and meteorological parameters: case study. QUID: Investigacion, Ciencia y Tecnologia 2014; (23): 13-20.
17. Hellerstein JM. Quantitative data cleaning for large databases [Online]. [cited 2008 Feb 28]; Available from: URL: http://db.cs.berkeley.edu/jmh/papers/cleaning-unece.pdf
18. Anderson HR. Air pollution and mortality: A history. Atmos Environ 2009; 43(1): 142-52.
19. Peng RD, Dominici F, Pastor-Barriuso R, Zeger SL, Samet JM. Seasonal analyses of air pollution and mortality in 100 US cities. Am J Epidemiol 2005; 161(6): 585-94.
20. Chiogna M, Gaetan C. Dynamic generalized linear models with application to environmental epidemiology. J R Stat Soc Ser C Appl Stat 2002; 51(4): 453-68.
21. Dominici F, Peng RD, Zeger SL, White RH, Samet JM. Particulate air pollution and mortality in the United States: did the risks change from 1987 to 2000? Am J Epidemiol 2007; 166(8): 880-8.
22. Shahi AM, Omraninava A, Goli M, Soheilarezoomand HR, Mirzaei N. The Effects of Air Pollution on Cardiovascular and Respiratory Causes of Emergency Admission. Emerg (Tehran) 2014; 2(3): 107-14.
23. Goudarzi G, Geravandi S, Mohammadi MJ, Salmanzadeh S, Vosoughi M, Sahebalzamani M. The relationship between air pollution exposure and chronic obstructive pulmonary disease in Ahvaz, Iran. Chron Dis J 2015; 3(1): 14-20.
24. Lu F, Zhou L, Xu Y, Zheng T, Guo Y, Wellenius GA, et al. Short-term effects of air pollution on daily mortality and years of life lost in Nanjing, China. Sci Total Environ 2015; 536: 123-9.
25. Qiu H, Tian L, Ho KF, Pun VC, Wang X, Yu IT. Air pollution and mortality: effect modification by personal characteristics and specific cause of death in a case-only study. Environ Pollut 2015; 199: 192-7.