Original Article

Investigation of relationship between particulate matter (PM$_{2.5}$) and meteorological parameters in Isfahan, Iran

Majid Kermani[1,2], Ahmad Jonidi Jafari[1,2], Mitra Gholami[1,2], Mahdi Farzadkia[1,2], Hossein Arfaeinia[3,4], Abbas Shahsavani[5,6] , Abbas Norouzian[2], Mohsen Dowlati[2], Farzad Fanaei[7,*]

[1] Research Center of Environmental Health Technology, Iran University of Medical Sciences, Tehran, Iran

[2] Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

[3] Systems Environmental Health and Energy Research Center, The Persian Gulf Biomedical Sciences Research Institute, Bushehr University of Medical Sciences, Bushehr, Iran

[4] Department of Environmental Health Engineering, Faculty of Health and Nutrition, Bushehr University of Medical Sciences, Bushehr, Iran

[5] Environmental and Occupational Hazards Control Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[6] Department of Environmental Health Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran

[7] Student Research Committee, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

ARTICLE INFORMATION

CORRESPONDING AUTHOR:

farzadfanaei37@gmail.com
Tel: (+98 21) 88622707
Fax: (+98 21) 88622707

ABSTRACT:

Introduction: Estimating air pollution levels in areas with no measurements is a major concern in health-related studies. Therefore, the aim of this study was to investigate the amount of exposure to particulate matter below 2.5 μ (PM$_{2.5}$) in the metropolis of Tehran.

Materials and methods: The hourly concentrations of PM$_{2.5}$ during 2017-2018 period were acquired from the Department of Environment (DOE) and Air Quality Control Company of Tehran (AQCC). The hourly concentrations were validated and 24-h concentrations were calculated. Inverse distance weighting (IDW), Universal Kriging, and Ordinary Kriging were used to spatially model the PM$_{2.5}$ over Tehran metropolis area. Root Mean Square Error (RMSE) and Mean Error (ME) were used to measure and control for the accuracy of the methods.

Results: The results of this study showed that RMSE and MENA values in Kriging method was less than the IDW, which indicates that the Kriging was the best method to estimate PM$_{2.5}$ concentrations. According to the final map, the highest annual concentrations of PM$_{2.5}$ were observed in the southern and southwestern areas of Tehran (districts 10, 15, 16, 17, and 18). The lowest exposure to PM$_{2.5}$ was found to be in districts 1, 2, 3, 6, and 8.

Conclusion: It can be concluded that Kriging method can predict spatial variations of PM$_{2.5}$ more accurately than IDW method.

Introduction

The modern life has affected by air pollution [1]. Exposure to outdoor air pollution and its adverse health impacts have become the most consider-able risk factor, especially in developing countries [2]. Air pollution is not limited to the village, city or country, but is an important environmental issue that affects the whole world [3]. Research

by the World Health Organization (WHO) has shown that half the people of the world live somewhere that the concentrations of air pollutants is higher than the standard level [4]. Depending on the pollutant type, level, exposure type, and time of exposure, adverse effects resulting from exposure to ambient air pollution are categorized as acute and chronic outcomes [5]. so air pollution is one of the global problems that wherever we live in earth, air pollution is existing high or low [6]. So it can be said that there is no clean air [7]D1F84610A0}. In addition to the heavy costs that air pollution on governments impose, those include a variety of diseases ranging from asthma to stroke and eventually death [8]. According to the report by the World Bank in 2005 on the mortality rate and the resulting costs published, total death from air pollution in Iran is approximately 0.57% of GDP There are also about 45,000 mortality annually from air pollution diseases in Iran will be recorded [4, 9]. Major air pollutants include CO, HCHO, NO_X, SO_2, O_3 and suspended particles [10]. However, particles with aerodynamic diameter smaller than 2.5 µm ($PM_{2.5}$) is execute the most role in air pollution [11]. $PM_{2.5}$ particles with their strength and influence go deep into the lungs and cause respiratory disorders [12, 13]. Particles cause an effects on meteorological parameter including impact on the amount of solarization and ultimately change the Earth's surface temperatures and reduce visibility [12]. Concentrations of these particles can be vary alternation that depending on geographical location, weather conditions and period of time [14]. Isfahan as one of the biggest cities of Iran has faced severe ambient air pollution because of unsustainable development, densely vehicular traffic, and lack of ambient air quality standards along with high daily consumptions of fossil fuels and associated emissions [15].

Numerous studies have been performed on influence of particle concentration on the meteorological parameters [16]. In study at Tehran (2017-2018), was reviewed influence of changing meteorological parameters on the ambient fine particulate matter. It was found that there is a weak correlation between $PM_{2.5}$ particles and mean monthly temperature (r=0.42, P<0.05) and mean relative humidity (r=0.37, P<0.05) [17]. In another study at Turkey, it was found a negative effect of meteorological parameters (temperature, precipitation and pressure) on $PM_{2.5}$ particle concentrations [18]. In Malaysia too, the concentration of particles with wind speed and relative humidity has shown a negative effect [19]. In another study at Austria showed that the highest concentration of particles was in winter [20]. In the other hand in his article showed that the relative humidity and precipitation are negative correlation, and temperature and wind speed are positive correlation to the concentration of particles in the air [21]. Thus, the current research was carried out with the following aims: i) investigating the seasonal variations $PM_{2.5}$ in ambient air of Isfahan, Iran; and ii) investigate the effect of meteorological parameters including temperature, relative humidity, pressure, ultraviolet rate, precipitation, UV and Wind speed on the concentration of $PM_{2.5}$ in the ambient air of Isfahan from March 2019 to March 2020.

Material and methods
Location and time
Isfahan city with a population of more than two million is the capital of Isfahan Province in Iran and it is one of the largest and the most beautiful

cities in the world. Isfahan with an area of 543 km^2, one of the most important industrial cities in central Iran. Isfahan is located between longitude 59°39'E and latitude 32°38'N with a height of 1570 m above sea level. Fig. 1 shows the map of the study area and air quality monitoring stations. Because of the connection between this cities with the provinces of the country, it faces a large volume of pollutants daily. This reason causes an intensification air pollution from the most important source of its formation, namely moving vehicles [22]. On the other hand, due to the proximity of industries such as petrochemicals and large and small factories to city can expectation that peoples of this city in daily exposure to concentrations of particles, and this affair,

Isfahan is convert in to one of the polluted cities of the country. Although there are sporadic studies on the concentration of particulate matter in this city, but there is not exist integrated data that can be based on organizational policies in order to advancement control of air pollution changed.

$PM_{2.5}$ sampling

For the intention of sampling particles $PM_{2.5}$ from a peripheral pump (SKC) and a Personal Modular Impactor (PMI) holder was used (Fig. 2a). PMI, single-stage impactor designed for highly efficient collection of $PM_{2.5}$ at 3 L/min, includes impactor and filter cassette with support screen; requires collection media and impaction substrate, which are purchased separately The PMI closely
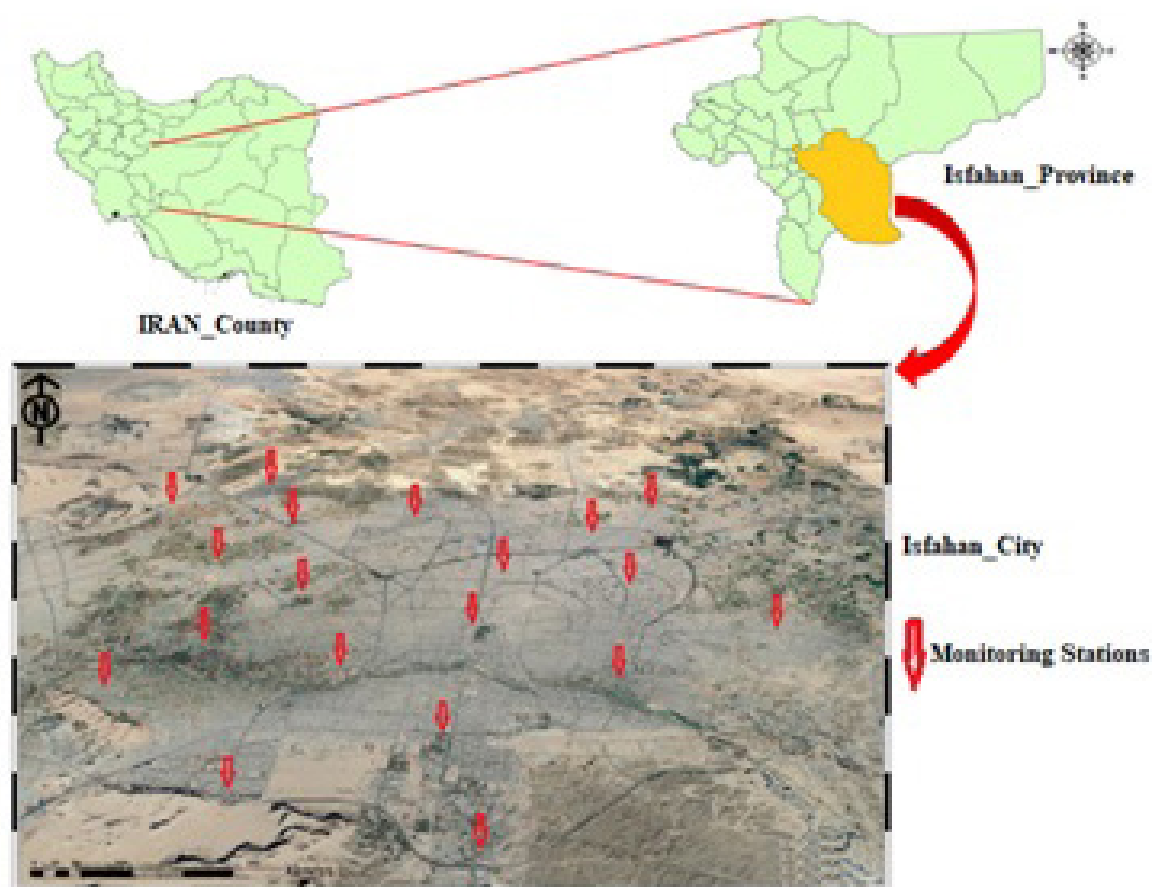

Fig.1. The map of study area and monitoring stations

follows $PM_{2.5}$ as defined by EPA.The PTFE filter (Zephon) with a diameter of 1 mm were selected according to the type of holder. For as much as purpose is to measurement $PM_{2.5}$ particles, therefore, the filter diameter used was selected one micron. Sampling time was selected based on guideline EPA-TO/13 A 24 h and flow rate samples according to the type of filter used and guideline of maker company on the 3 L/min adjustment (Fig. 2b). Because if the flow rate above this value enter the holder filter, due to Create turbulence in space internal impactor, $PM_{2.5}$ particles do not fit properly on the filter. Accordingly, before each time sampling the pump used was calibrated by a rotameter. And also, to achieve better results for city planning, sampling was performed for one year (spring-summer- autumn and winter seasons from March 2019 to March 2020).

Meteorological data

In during the period of sampling, meteorological parameter including temperature (° C), relative humidity (%), pressure (mmHg), UV, precipitation (mm) and wind speed (m/s) was also recorded using a portable PHB-318 device. Information as to cloud coverage, UV and dew points obtained it from Isfahan Department of Environmental (affiliated to Isfahan Municipality). At the end of the sampling (24 h), again these parameters were measured, and afterwards, the obtained data imported into Excel and they were processed.

Statistical analysis

After calculating the $PM_{2.5}$ concentrations by gravimetric method and calculate the average meteorological parameters in four seasons, SPSS software was used to obtain the correlation coefficient and correlation between meteorological data. At this step the normality of data was identified by KALMOGAROV-Smiranov, and to the reason of normality of data, spearman correlation coefficient method was used for correlation analysis. Boxplot diagram of $PM_{2.5}$ concentrations was drawn by R. On the other hand, for zoning $PM_{2.5}$ concentrations GIS was used.
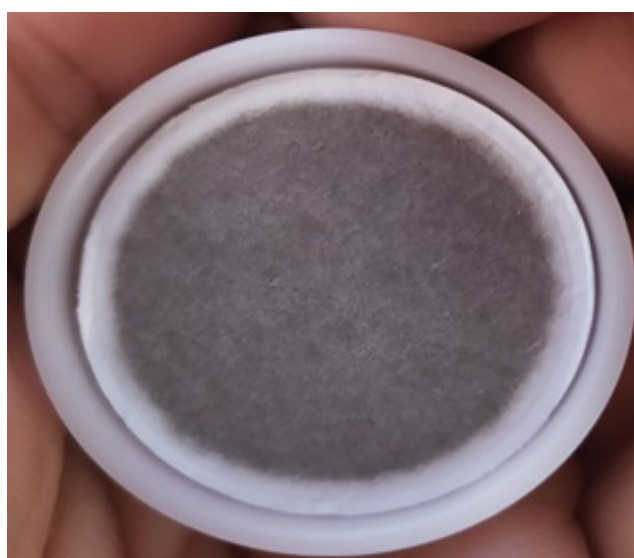
(a)   (b)

Fig. 2. a: Sampling pilot, b: Sampling filter after 24 h

Results and discussion

Concentrations of PM$_{2.5}$

The minimum, and maximum and the annual mean concentration of PM$_{2.5}$ was recorded 6.94 (in summer), 114.24 (in winter) and 47.32 µg/m³, respectively. The annual mean concentrations of PM$_{2.5}$ is approximately 4.7 times greater than the WHO guideline (10 µg/m³) and 3.9 times greater than the US-EPA Standards (12 µg/m³), respectively. These values in other researchers studies, were 6 and 7 times higher than the WHO guideline, respectively [23, 24]. Fig. 3 shows a boxplot diagram concentration of PM$_{2.5}$ seasonally sampled points. As shown in this figure, the highest mean concentration of PM$_{2.5}$ was found in winter (64.06 µg/m³) and the lowest is in summer (31.32 µg/m³). In the study conducted at Tehran (2017-2018), maximum PM$_{2.5}$ concentration occurred in October [25]. Also, another study, the maximum concentration for Tehran in winter was estimated [26]. In another study in Tehran by the maximum particle concentration in summer was reported [27]. In 2019 - 2020 the residents of Isfahan city about 279 days (75% days of the year) were exposed to the daily mean concentration of PM$_{2.5}$ greater than the WHO guideline (25

µg/m³). The distribution of PM$_{2.5}$ concentrations in the 19 monitoring stations drown by GIS software is shown in Fig. 4. As shown in Fig. 4, the highest concentration of PM$_{2.5}$ were related to the northern, northeast, Southwest and central areas of the city. The reason for the high concentration of PM$_{2.5}$ in these areas can be expressed as follows: i) In the northern part of the city, due to the highway and the near to the intercity bus terminal; ii) In the southeast and central regions due to the high density of population and the existence of large commercial and administrative complexes and finally high traffic in these areas; iv) In the eastern regions, due to the beltway and the high transit of diesel vehicles.

Meteorological parameters

In Fig. 5 Variation of average temperature, relative humidity, pressure, ultraviolet radiation, precipitation, and wind speed in four seasons during year 2019-2020 is brought. The average of annual temperature (°c), humidity (%), pressure (mmHg), UV radiation, precipitation (mm) and wind speed are 23.37, 21.38, 632.7, 4.69, 6, 125.2 and 12.8, respectively.
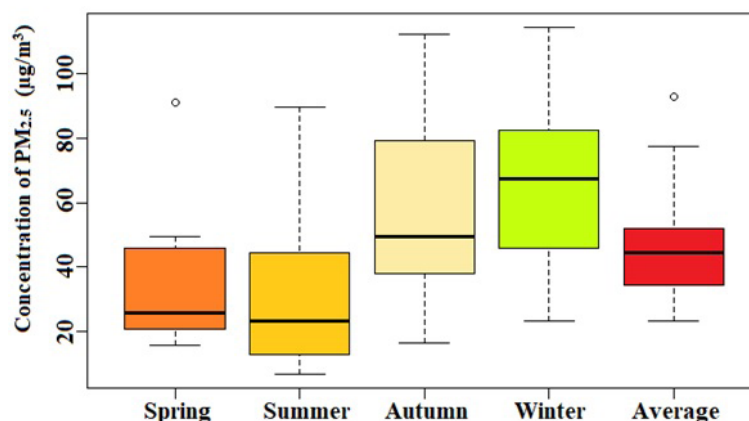

Fig. 3. Average seasonal concentrations of PM$_{2.5}$ in ambient air of the study area (2019-2020)

Table 1 shows the relationship between the mean annual of $PM_{2.5}$ concentrations with the meteorological parameters. As you can see in Table 1, a positive relationship between mean annual $PM_{2.5}$ concentrations with temperature (r = 0.37, P<0.017), relative humidity (r = 0.39, P <0.05), pressure (r = 0.219, P <0.05) in period of study at Isfahan was observed. In addition, a negative relationship between UV radiation (r = -0.34, P <0.41), wind speed rate (r = -0.412, P <0.018) and precipitation (r=-0.27, P<0.214) was observed in Isfahan at 2019-2020.

As you can see in Table 1, $PM_{2.5}$ particles had a negative relationship with precipitation, wind speed and UV radiation. On the other hand, the relative humidity, air temperature, dew point and pressure had a positive relationship on the $PM_{2.5}$ concentration. In a similar study at Tehran [17] China [21] urban Mediterranean area [28], Tehran (2006-2015), Beijing [29] also a positive relationship were reported between temperature and

concentration of $PM_{2.5}$. However, in a one-year study a negative relationship between these parameters [30]. Also, in a study in Italy showed that air temperature had a positive effect on air particle concentrations [31]. Also, a study showed that $PM_{2.5}$ concentration was positively correlation with air temperature in four seasons [32]. The case of air humidity and concentration of $PM_{2.5}$, the results of our study were also in consistent with those reported by other researchers [17]. The results of this study were corresponded with the other studies [33]. In addition, there was a negative relationship between the amount of precipitation and the presence of scattered clouds in the sky and their relationship with the concentration of $PM_{2.5}$ particles in our study. In some studies, it was also founded a negative relationship between this parameter and the concentration of particles in their study [17]. Scottn Williams states that precipitation decreases in winter when the $PM_{2.5}$ concentration reaches its maximum which
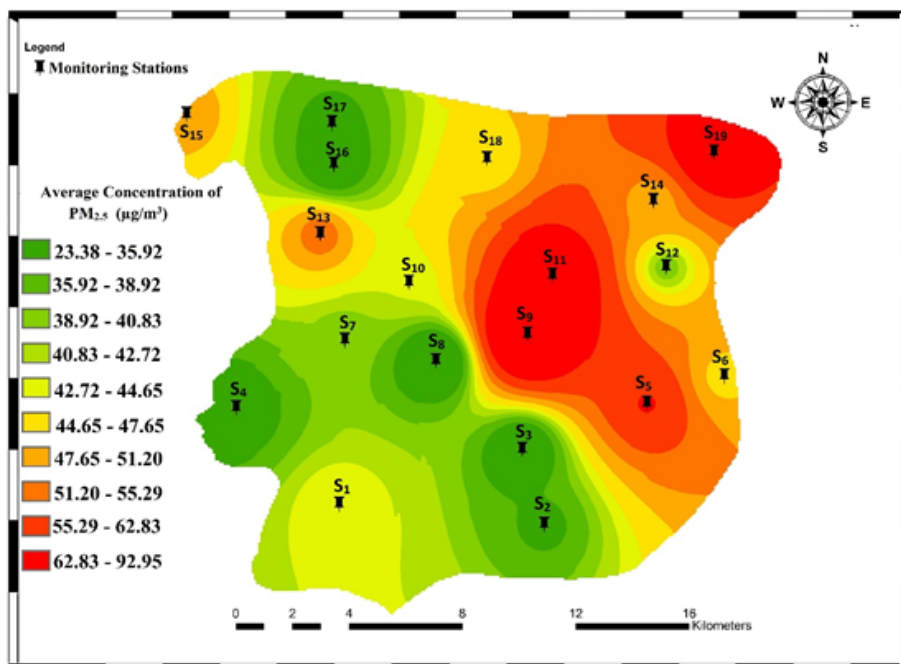

Fig. 4. Distribution of average annual concentration of $PM_{2.5}$ in monitoring of stations (2019-2020)

indicates a weak or negative correlation between these two parameters [34]. In other study, it was reached to this conclusion that $PM_{2.5}$ concentrations was negatively correlated with precipitation (r= -0.19 P<0.5) [35]. Based on contents said a negative relationship between $PM_{2.5}$ concentration and ultraviolet radiation was observed in Isfahan during 2019-2020. (r= -0.34, P<0.41). Barnard in his study showed that air pollution can diminish the increase of ultraviolet levels [36]. On the other hand, in a study that was done on ultraviolet there is a negative correlation between $PM_{2.5}$ and ultraviolet radiation [37]. Statistical analysis also showed a negative relationship between wind speed and concentration of $PM_{2.5}$ particles in this study which is similar to the other study which was done by many researchers. Correlation analysis in the present study showed that there was a positive relationship between air pressure (mmHg) and $PM_{2.5}$ concentrations during the period of study (r=0.219, P<0.05). On cold days of the year air pressure has increased as a result, it increases the concentration of the particles. Other studies also came to this conclusion [38].

Conclusion

The current research was designed to association between meteorological parameter and $PM_{2.5}$ concentration in Isfahan at March 2019 to March 2020. The results of the study showed that the residents of Isfahan are exposed to $PM_{2.5}$ on aver-

age 4-5 times higher than the guidelines of WHO. Subsequently it was found that temperature, relative humidity and pressure increased the concentration of $PM_{2.5}$ and the rate of precipitation, wind speed, and UV reduces the concentration of them. The results from this research recommends that suitable controlling policies should be regulated to reduce both ambient air $PM_{2.5}$ and its adverse health endpoints in in Isfahan.

Competing interests

The authors declare they have no actual or potential competing interests.

Ethical considerations

Ethical issues (Including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors

Table 1. Bivariate correlations between $PM_{2.5}$ with meteorological parameter in Isfahan from 2019-2020

	Temperature	Wind Speed	Precipitation	Reality humidity	Pressure	Ultra Violet
R	0.37	-0.412	-0.219	0.39	0.27	-0.34
P$_{value}$	0.017	0.018	0.214	0.05	0.214	0.41

Fig. 5. Average monthly pressure, temperature, relative humidity, wind speed, Ultra Violet , precipitation , in Isfahan city (2019-2020)

References

1. Deng Q, Lu C, Norbäck D, Bornehag C-G, Zhang Y, Liu W, et al. Early life exposure to ambient air pollution and childhood asthma in China. Environmental research. 2015;143:83-92.

2. Rovira J, Domingo JL, Schuhmacher M. Air quality, health impacts and burden of disease due to air pollution (PM10, PM2.5, NO2 and O3): Application of AirQ+ model to the Camp de Tarragona County (Catalonia, Spain). Science of The Total Environment. 2020;703:135538.

3. Schraufnagel DE, Balmes JR, Cowl CT, De Matteis S, Jung S-H, Mortimer K, et al. Air pollution and noncommunicable diseases: A review by the Forum of International Respiratory Societies' Environmental Committee, Part 2: Air pollution and organ systems. Chest. 2019;155(2):417-26.

4. Loomis D, Huang W, Chen G. The International Agency for Research on Cancer (IARC) evaluation of the carcinogenicity of outdoor air pollution: focus on China. Chinese journal of cancer. 2014;33(4):189.

5. Heydari G, Ranjbar Vakilabadi D, Kermani M, Rayani M, Poureshgh Y, Behroozi M, et al. Load characteristics and inhalation risk assessment of benzene series (BTEX) pollutant in indoor air of Ghalyan and/or cigarette cafes compared to smoking-free cafes. Environmental Pollutants and Bioavailability. 2020;32(1):26-35.

6. Kermani M, Jafari AJ, Gholami M, Fanaei F, Arfaeinia H. Association between meteorological parameter and PM2.5 concentration in Karaj, Iran. International Journal of Environmental Health Engineering. 2020;9(1):4.

7. Isen A, Rossin-Slater M, Walker WR. Every breath you take-every dollar you'll make: The long-term consequences of the clean air act of 1970. Journal of Political Economy. 2017;125(3):848-902.

8. Deryugina T, Heutel G, Miller NH, Molitor D, Reif J. The mortality and medical costs of air pollution: Evidence from changes in wind direction. American Economic Review. 2019;109(12):4178-219.

9. Tavakoly M. Estimation of acute air pollution conditions in Tehran due to the concentration of ozone and particulate matter using artificial neural network: Masters Thesis], Ministry of Science, Research, Technology Tarbiat Modares.

10. Vahidi MH, Fanaei F, Kermani M. Long-term health impact assessment of PM2.5 and PM10: Karaj, Iran. International Journal of Environmental Health Engineering. 2020;9(1):8.

11. Dehghani MH, Jarahzadeh S, Hadei M, Mansouri N, Rashidi Y, Yousefi M. The data on the dispersion modeling of traffic-related PM10 and CO emissions using CALINE3; A case study in Tehran, Iran. Data in brief. 2018;19:2284-90.

12. Nabizadeh R, Yousefi M, Azimi F. Study of particle number size distributions at Azadi terminal in Tehran, comparing high-traffic and no traffic area. MethodsX. 2018;5:1549-55.

13. Matus P, Oyarzún M. Impact of Particulate Matter (PM2.5) and children's hospitalizations for respiratory diseases. A case cross-over study. Revista chilena de pediatria. 2019;90(04):166-74.

14. Huang F, Li X, Wang C, Xu Q, Wang W, Luo Y, et al. PM2.5 spatiotemporal variations and the relationship with meteorological factors during 2013-2014 in Beijing, China. PloS one. 2015;10(11).

15. Soleimani M, Amini N, Sadeghian B, Wang D, Fang L. Heavy metals and their source identification in particulate matter (PM2.5) in Isfahan City, Iran. Journal of Environmental Sciences. 2018;72:166-75.

16. Ilten N, Selici AT. Investigating the impacts of some meteorological parameters on air pollution in Balikesir, Turkey. Environmental monitoring and assessment. 2008;140(1-3):267-77.

17. Ansari M, Ehrampoush MH. Meteorological correlates and AirQ+ health risk assessment of ambient fine particulate matter in Tehran, Iran. Environmental research. 2019;170:141-50.

18. Tecer LH, Süren P, Alagha O, Karaca F, Tuncel G. Effect of meteorological parameters on fine and coarse particulate matter mass concentration in a coal-mining area in Zonguldak, Turkey. Journal of the Air & Waste Management Association. 2008;58(4):543-52.

19. Dominick D, Latif MT, Juahir H, Aris AZ, Zain SM. An assessment of influence of meteorological factors on PM10 and NO2 at selected stations in Malaysia. Sustainable Environment Research. 2012;22(5):305-15.

20. Sammaritano MA, Bustos DG, Poblete AG, Wannaz ED. Elemental composition of PM2.5 in the urban environment of San Juan, Argentina. Environmental Science and Pollution Research. 2018;25(5):4197-203.

21. Zhang H, Wang Y, Hu J, Ying Q, Hu X-M. Relationships between meteorological parameters and criteria air pollutants in three megacities in China. Environmental research. 2015;140:242-54.

22. Abdolahnejad A, Jafari N, Mohammadi A, Miri M, Hajizadeh Y. Mortality and Morbidity Due to Exposure to Ambient NO2, SO2, and O3 in Isfahan in 2013–2014. International journal of preventive medicine. 2018;9.

23. Al-Hemoud A, Gasana J, Al-Dabbous A, Alajeel A, Al-Shatti A, Behbehani W, et al. Exposure levels of air pollution (PM2.5) and associated health risk in Kuwait. Environmental research. 2019;179:108730.

24. Conti GO, Heibati B, Kloog I, Fiore M, Ferrante M. A review of AirQ Models and their applications for forecasting the air pollution health outcomes. Environmental Science and Pollution Research. 2017;24(7):6426-45.

25. Asrari E. Investigation of the airborne particulate matter concentration trend changes in Mashhad by using meteorological data during 2010-2015. 2018.

26. Miri M, Derakhshan Z, Allahabadi A, Ahmadi E, Conti GO, Ferrante M, et al. Mortality and morbidity due to exposure to outdoor air pollution in Mashhad metropo-

lis, Iran. The AirQ model approach. Environmental research. 2016;151:451-7.

27. Asl FB, Leili M, Vaziri Y, Arian SS, Cristaldi A, Conti GO, et al. Health impacts quantification of ambient air pollutants using AirQ model approach in Hamadan, Iran. Environmental research. 2018;161:114-21.

28. Hou X, Fei D, Kang H, Zhang Y, Gao J. Seasonal statistical analysis of the impact of meteorological factors on fine particle pollution in China in 2013–2017. Natural Hazards. 2018;93(2):677-98.

29. Asimakopoulos D, Flocas H, Maggos T, Vasilakos C. The role of meteorology on different sized aerosol fractions (PM10, PM2.5, PM2.5–10). Science of the Total Environment. 2012;419:124-35.

30. Wang J, Ogawa S. Effects of meteorological conditions on PM2.5 concentrations in Nagasaki, Japan. International journal of environmental research and public health. 2015;12(8):9089-101.

31. Santi D, Magnani E, Michelangeli M, Grassi R, Vecchi B, Pedroni G, et al. Seasonal variation of semen parameters correlates with environmental temperature and air pollution: A big data analysis over 6 years. Environmental Pollution. 2018;235:806-13.

32. Liu M, Huang Y, Ma Z, Jin Z, Liu X, Wang H, et al. Spatial and temporal trends in the mortality burden of air pollution in China: 2004–2012. Environment international. 2017;98:75-81.

33. Gao X, Colicino E, Shen J, Kioumourtzoglou M-A, Just AC, Nwanaji-Enwerem JC, et al. Impacts of air pollution, temperature, and relative humidity on leukocyte distribution: an epigenetic perspective. Environment international. 2019;126:395-405.

34. Williamson SN, Hik DS, Gamon JA, Jarosch AH, Anslow FS, Clarke GK, et al. Spring and summer monthly MODIS LST is inherently biased compared to air temperature in snow covered sub-Arctic mountains. Remote Sensing of Environment. 2017;189:14-24.

35. Faridi S, Shamsipour M, Krzyzanowski M, Künzli N, Amini H, Azimi F, et al. Long-term trends and health impact of PM2.5 and O3 in Tehran, Iran, 2006–2015. Environment international. 2018;114:37-49.

36. Barnard WF, Saxena V, Wenny B, DeLuisi J. Daily surface UV exposure and its relationship to surface pollutant measurements. Journal of the Air & Waste Management Association. 2003;53(2):237-45.

37. Hoseinzadeh E, Taha P, Wei C, Godini H, Ashraf GM, Taghavi M, et al. The impact of air pollutants, UV exposure and geographic location on vitamin D deficiency. Food and Chemical Toxicology. 2018;113:241-54.

38. Wang H, Li J, Peng Y, Zhang M, Che H, Zhang X. The impacts of the meteorology features on PM2.5 levels during a severe haze episode in central-east China. Atmospheric Environment. 2019;197:177-89.