



## Spatial modelling of PM<sub>2.5</sub> concentrations in Tehran using Kriging and inverse distance weighting (IDW) methods

Kazhal Masroor<sup>1</sup>, Farzad Fanaei<sup>2</sup>, Somayeh Yousefi<sup>1</sup>, Mohammad Raeesi<sup>1</sup>, Hossein Abbaslou<sup>1</sup>, Abbas Shahsavani<sup>3,4,\*</sup>, Mostafa Hadei<sup>1</sup>

<sup>1</sup> Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

<sup>2</sup> Department of Environmental Health Engineering, School of Public Health, Iran University of Medical Sciences, Tehran, Iran

<sup>3</sup> Environmental and Occupational Hazards Control Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran

<sup>4</sup> Department of Environmental Health Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran

### ARTICLE INFORMATION

#### Article Chronology:

Received 4 April 2020

Revised 16 May 2020

Accepted 03 June 2020

Published 29 June 2020

#### Keywords:

Exposure; Interpolation; Particulate matter; Ambient air pollution; Geographic information system (GIS)

### CORRESPONDING AUTHOR:

ashahsavani@gmail.com

Tel: (+98 21) 22432040

Fax: (+98 21) 22432037

### 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  $\mu$  (PM<sub>2.5</sub>) in the metropolis of Tehran.

**Materials and methods:** The hourly concentrations of PM<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub> concentrations. According to the final map, the highest annual concentrations of PM<sub>2.5</sub> were observed in the southern and southwestern areas of Tehran (districts 10, 15, 16, 17, and 18). The lowest exposure to PM<sub>2.5</sub> 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<sub>2.5</sub> more accurately than IDW method.

### Introduction

Nowadays, air pollution is a global environmental problem that affects many cities in the world [1-3]. The World Health Organization (WHO) and the International Agency for Research on Cancer (IARC) have identified air pollution as a carcinogens for humans. The Lancet Pollution

Commission, which has conducted a comprehensive assessment of the health and economic effects of major forms of air, water, and soil pollution, estimates that 9 million people annually die as a result of air pollution, which represents 16% of deaths worldwide [4]. According to the estimates, this factor is the highest cause of pre-

mature death by 2050 [5]. In recent decades, high concentrations air pollutants such as particulate matter below 10 and 2.5  $\mu$  have been reported in Tehran [6, 7].

Prediction of the concentration of particles in the field of air pollution control and health such as epidemiology is very important. One of the useful tools used in air quality assessment, and subsequently, determination of air pollution exposure is the Geographic Information System (GIS), the combination of pollution station information, and spatial analysis methods, respectively [8]. Spatial analysis methods may include inverse distance weighting (IDW) and Kriging method, which is divided into two categories of Universal Kriging and Ordinary Kriging [9]. In IDW, distance is the only effective factor for weighting the concentration. This method does not require determining the pattern of spatial changes, i.e. variogram [10]. Kriging model is based on the regression-based internalization methods. The weight distribution is based not only on the distance between the surrounding points, but also on the correlation between the measured points [11].

Interpolation methods in air pollution have been extensively used in recent years. In a study, a research conducted using IDW and Kriging methods and reported poor weather quality in the fall. Another study showed that the best method for pollution control strategies is to use the common Kriging method for air pollution distribution maps [12]. The Montero study is the first comprehensive study in 2018 that uses Kriging functional models to predict air pollution in Spain. The results showed that this method is very accurate for interpolation [13].

Given the health importance of ambient PM<sub>2.5</sub>, and also high concentrations of this pollutant in

Tehran (Iran) [6], there is a need to develop spatial models to predict and estimate its spatial pattern over this city. Limited relevant studies have been conducted in Iran and especially Tehran. This study aimed to evaluate various methods of spatial analysis (Kriging and IDW) to spatially estimate the concentrations of PM<sub>2.5</sub> in Tehran during the 2017-2018.

## **Materials and methods**

### ***Case study***

Tehran with a population of nearly 10 million has the highest population growth rate among Iranian cities. The city has a latitude and longitude between 51°02' to 51°36' and 35°34' to 35°50'. The total area of this city is 751 km<sup>2</sup>. Tehran has 22 districts for urban services. Tehran is facing many environmental problems caused by the uncontrolled growth of population, one of which, is air pollution. Although in the past, industries were considered the main responsible for air pollution, more than half of the current air pollution emissions in Tehran is caused by mobile sector. Provincial and national authorities have implemented some programs, including odd and even plan from the house doors hoping to reduce air pollution in Iran. Even though, particulate air pollution induce significant health burden to Tehran's population.

### ***Data collection***

The hourly concentrations of PM<sub>2.5</sub> for the period 2017-2018 were obtained from the Department of Environment (DOE) and Air Quality Control Company of Tehran (AQCC). Twenty five monitoring stations across the city measure PM<sub>2.5</sub> concentrations. We checked the validation of each monitoring station. First, the negative or zero val-

ues were removed from the dataset. Second, only the stations were marked as valid if more than 75% of its hourly concentrations were available. By the end, 19 stations were valid and included to the study. Then, the 24-h average concentrations were calculated. In the next stage, the data were imported to ArcMap software to estimate the exposure to  $PM_{2.5}$ . Two methods were applied to the dataset: 1) inverse distance weighting (IDW), 2) Kriging (Universal Kriging and Ordinary Kriging). Figure 1 shows the approximate location of valid stations in Tehran.

#### GIS software

The geographic information system (GIS) is a computer-based information system that examines the geographical effects and phenomena and events on the earth's surface [14]. This information is defined in a multi-layered form based on its coordinates and geographical features, and

each layer contains specific information about a specific case. The technology of geographic information system has been widely used in the fields of environmental studies, air pollution, water resources, etc. due to the advancement of science and computer systems. The use of geographic information system as an auxiliary tools plays a major role in the effective management of environmental health issues. ArcMap v. 10.3 was used for spatial modelling of  $PM_{2.5}$  concentrations across Tehran.

#### IDW

Interpolation is one of the methods of extracting values in non-sample sites based on the values in sample sites. In fact, the basis of interpolation is the calculation of the average weight:

$$V_0 = \sum_{i=1}^n w_i v_i \quad (1)$$

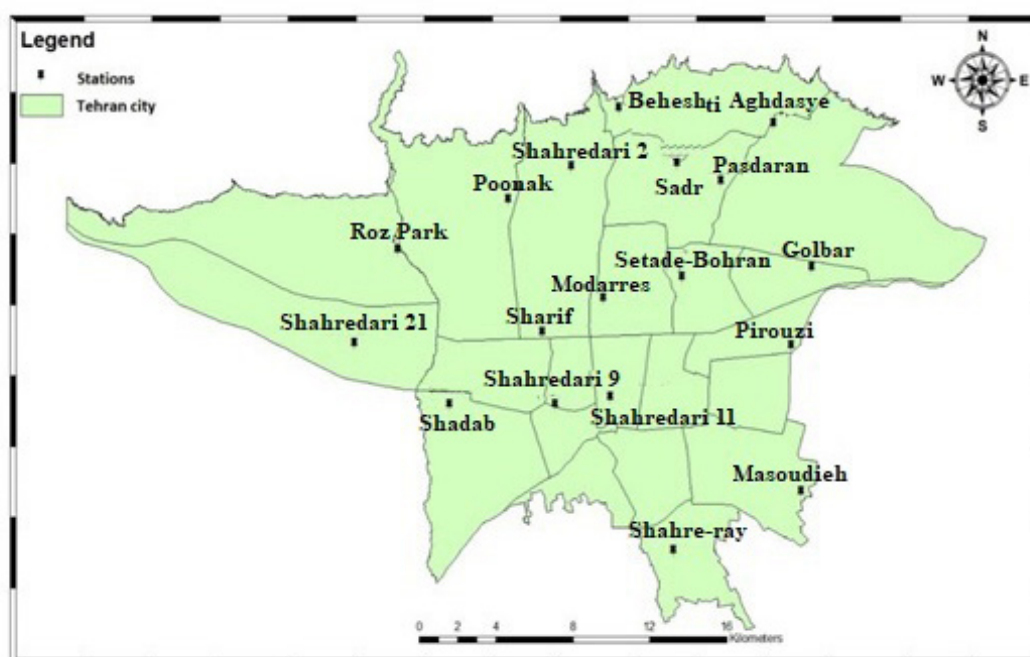


Fig. 1. Approximate location of valid monitoring stations

IDW is one of the simplest and most popular methods of interpolation. This type of interpolation estimates the required unknown values with the mean weight of the sample data points, with the weighted factors proportional to the inverse distance. This method considers a weight based on the distance between a specific point with available data and the position of an unknown point. These weights are then controlled by the weighting power. Larger exponentials reduce the effect of points farther from the estimated point, and smaller powers distribute weights more evenly between adjacent points. Of course, this method only considers the distance between points, regardless of location and arrangement. This means that points that have the same distance from the estimate point have the same weight [15]. The amount of weight factor is calculated using the following equation:

$$\lambda_i = (D_i - a) / \sum_{i=1}^n D_i - a \quad (2)$$

Where  $\lambda_i$  is the weight of the  $i^{\text{th}}$  station;  $D_i$  is the distance between the  $i^{\text{th}}$  station to the unknown point and  $a$  is the weighting exponent.

**Kriging interpolation method**

Kriging method is a geostatistical estimation and interpolation method, which is able to provide a linear estimate and variance in an unknown location. This theory is an optimal statistical mediator in the sense that it minimizes the variance of the estimation when the variogram (measuring the spatial continuity of the variable being studied) specified and when the constant assumption is used. The main advantages of Kriging method comparing to the IDW include (1) the reliability of the estimation according to the number of data used in the estimate, (2) the ability to consider the

spatial structure of the data points, and (3) the availability of the estimation variance, which measures the accuracy of each input value. This estimation method can play a dual role. The first case assesses the reliability of the estimates. Second, it can be used as a guide to identify the most uncertain areas for future measurements [16]. Kriging method has different models. Ordinary and Universal Kriging models have been used in this study.

**Ordinary model**

This geostatistical method is based on the moving weighted average, and can be expressed as follows:

$$Z^*(x) = \sum_{i=0}^n \lambda_i Z(X_i) \quad (3)$$

Where  $Z^*$  is the estimated value,  $\lambda_i$  is the weight of the  $i^{\text{th}}$  sample, and  $Z(X_i)$  is the measured variable value.

This type of Kriging is called linear Kriging, because there is n number of data that the condition of using this data meets the linear composition of the normal distribution. Otherwise, either nonlinear Kriging should be used or the variables should be distributed normally [17].

**Universal model**

The assumption of the model is that there is also a deviation in the values of z in addition to the correlation between points in terms of location. In this way, the Kriging is combined with a first- and second-order polynomial [18].

**Results and discussion**

Table 1 shows the descriptive statistics of seasonal concentrations of PM<sub>2.5</sub> particles during the

2017-2018 period. The seasonal average concentrations of PM<sub>2.5</sub> ranged from 25.31 to 38.32 µg/m<sup>3</sup>. The annual concentration of PM<sub>2.5</sub> was 30.53 µg/m<sup>3</sup>, about 3 times higher than the guideline recommended by the World Health Organization. In a study, researchers showed that in the cold season, the concentration of particles was 2.5 times higher than those in the other seasons in Ahwaz, which is in line with the present research [19]. In another study, the maximum concentration of PM was observed in the spring due to the dust episodes [20]. On the other hand, another study showed that the average concentration of particles in winter was 2.5 times more than spring, which is consistent with the present results [21]. The highest emissions of PM in Tehran are related to the mobile sources [6, 7]. In this study, (Root-Mean-Square Error) RMSE and Mean Error (ME) were calculated for PM<sub>2.5</sub> according to deterministic and geostatistical methods (Table 2). The value of RMSE in the Kriging method was lower than that in the IDW

method. This indicates the appropriateness of the Kriging method rather than the IDW. The lower RMSE value of each interpolation method indicates its optimization. Although the ME values of all methods were almost close to each other, this amount was lower in the Kriging method. In another study which conducted to spatially model the air pollutants concentrations in Spain [22] similar results to the present study were reported. In the present study, after identifying the best interpolation method, that method was used to map the spatial distribution of PM<sub>2.5</sub> in Tehran (Fig. 4). The results of some other similar studies [23-25] have shown that in most cases, the geostatistical methods for PM<sub>2.5</sub> modelling is better than the deterministic methods. According to the results, the highest annual concentration in Tehran can be observed in the southern and southwestern areas of the city. These areas covers municipal districts of 10, 15, 16, 17, and 18. Furthermore, districts 1, 2, 3, 6, and 8 have been illustrated to experience the lowest annual PM<sub>2.5</sub> concentrations.

Table 1. Statistical summary of PM<sub>2.5</sub> concentrations (µg/m<sup>3</sup>) in Tehran (2017-2018)

Time period	Average	Median	SD	Max	Min.	P25	P75
Spring	25.31	24.89	7.68	49.49	8.59	20.16	30.06
Summer	28.53	28.86	3.5	37.11	6.54	25.76	30.68
Autumn	37.08	34.5	16.21	97.54	9.87	26.55	44.28
Winter	38.32	33.9	17.92	117.39	13.06	27.38	44.54
Total	32.31	30.53	11.32	37.11	6.54	24.96	37.39

Table 2. Comparison of interpolation methods

Method	RMSE	ME	Standard RMSE	Standard ME
Ordinary Kriging	0.0633	1.006	0.52	7.87
Universal Kriging	0.633	1.006	0.52	7.87
IDW	8.18	0.74	-	-

In the southern part of the city, the high concentrations of PM can be due to the proximity to the highway and more importantly, the near to the intercity bus terminal and the mainline of the city buses. In the southern and central regions this can be due to the high density of population and the existence of large commercial and administrative complexes and finally heavy traffic in these areas. According to the results of interpolation using IDW, the most polluted areas are points 15

and 16. Moreover, the lowest pollution levels can be observed in the points 1, 2, and 6. According to the Ordinary Kriging interpolation, the most polluted areas are in the southern and southeastern districts of the city, and the cleanest areas are in the eastern districts of the city. In Universal Kriging interpolation, the most and least polluted areas are located in the southwest and northeast of Tehran.

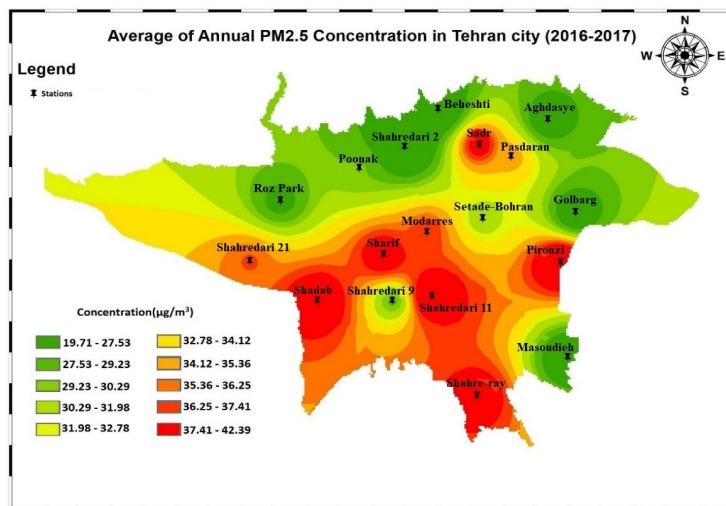


Fig. 2. Map of annual PM<sub>2.5</sub> concentrations obtained from the inverse distance weighting (IDW) method

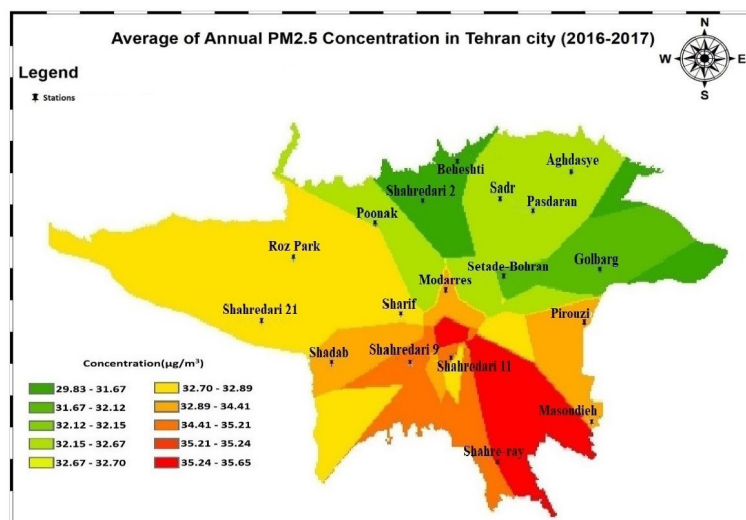


Fig. 3. Map of annual PM<sub>2.5</sub> concentrations obtained from ordinary Kriging interpolation method

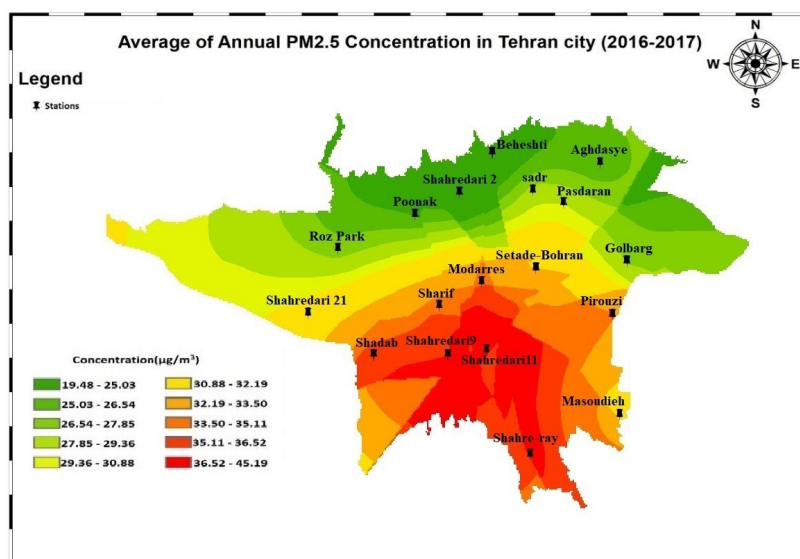


Fig. 4. Map of annual PM<sub>2.5</sub> concentrations obtained from universal Kriging interpolation method

## Conclusion

The present study was conducted to estimate PM<sub>2.5</sub> levels across Tehran using the measurements of air quality monitoring system and three interpolation methods: inverse distance weighting (IDW), Universal Kriging, and Ordinary Kriging. Although, the ME values of all methods were almost close to each other, this amount was lower in the Kriging method, indicating that the Kriging method was more suitable than the IDW. Generally, we can be concluded that the highest annual concentration of PM<sub>2.5</sub> can be observed in the southern and southwestern areas of Tehran. The results of this study could help health authorities to recognize the most polluted areas of Tehran, and policymakers to design and perform action plans to reduce atmospheric concentrations of PM<sub>2.5</sub>.

## Financial supports

The authors want to thank Shahid Beheshti University of Medical Sciences for their full support of this study (Project number: 20330).

## Competing interests

The authors declare that there are no competing interests.

## Acknowledgement

The authors would like to thank Department of Environment (DOE) and Air Quality Control Company of Tehran (AQCC), and the authors want to thank Shahid Beheshti University of Medical Sciences for their full support of this study (Project number: 20330).

## Ethical considerations

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

## References

1. Choi J, Oh JY, Lee YS, Min KH, Hur GY, Lee SY, et al. Harmful impact of air pollution on severe acute exacerbation of chronic obstructive pulmonary disease: particulate matter is hazardous. International journal of

- chronic obstructive pulmonary disease. 2018;13:1053.
2. Nabizadeh R, Yousefian F, Moghadam VK, Hadei M. Characteristics of cohort studies of long-term exposure to  $PM_{2.5}$ : a systematic review. *Environmental Science and Pollution Research*. 2019;1-7.
  3. Hadei M, Naddafi K. Cardiovascular effects of airborne particulate matter: A review of rodent model studies. *Chemosphere*. 2020;242:125204.
  4. Landrigan PJ, Fuller R, Acosta NJ, Adeyi O, Arnold R, Baldé AB, et al. The Lancet Commission on pollution and health. *The lancet*. 2018;391(10119):462-512.
  5. Landrigan PJ, Fuller R, Horton R. Environmental pollution, health, and development: a Lancet–Global Alliance on Health and Pollution–Icahn School of Medicine at Mount Sinai Commission. *The Lancet*. 2015;386(10002):1429-31.
  6. Shahsavani A, Tobías A, Querol X, Stafoggia M, Abdolshahnejad M, Mayvaneh F, et al. Short-term effects of particulate matter during desert and non-desert dust days on mortality in Iran. *Environ Int*. 2020;134:105299.
  7. Hadei M, Shahsavani A, Krzyzanowski M, Querol X, Stafoggia M, Nazari SSH, et al. Burden of mortality attributed to  $PM_{2.5}$  exposure in cities of Iran; contribution of short-term pollution peaks. *Atmospheric Environment*. 2020;224:117365.
  8. Borge R, Narros A, Artiñano B, Yagüe C, Gómez-Moreno FJ, de la Paz D, et al. Assessment of microscale spatio-temporal variation of air pollution at an urban hotspot in Madrid (Spain) through an extensive field campaign. *Atmospheric environment*. 2016;140:432-45.
  9. Gunarathna M, Kumari M, Nirmanee K. Evaluation of interpolation methods for mapping pH of groundwater. *International journal of latest technology in engineering, management & applied science*. 2016;3:1-5.
  10. Deligiorgi D, Philippopoulos K. Spatial interpolation methodologies in urban air pollution modeling: application for the greater area of metropolitan Athens, Greece. *Advanced Air Pollution*. 2011:341-62.
  11. Eslami A, Ghasemi SM. Determination of the best interpolation method in estimating the concentration of environmental air pollutants in Tehran city in 2015. *Journal of Air Pollution and Health*. 2018.
  12. Hoshdar Tehrani sh ER, and G.g. S. Study of Spatial Distribution Pattern of Carbon Monoxide in Mashhad City Using Interpolation Methods During 2017-2018. *Journal of Research in Environmental Health, journal of Research in Environmental Health*, 2019;5(1): p:53-64.
  13. Montero J-M, Fernández-Avilés G. Functional kriging prediction of atmospheric particulate matter concentrations in Madrid, Spain: Is the new monitoring system masking potential public health problems? *Journal of Cleaner Production*. 2018;175:283-93.
  14. Khan J, Kakosimos K, Raaschou-Nielsen O, Brandt J, Jensen SS, Ellermann T, et al. Development and performance evaluation of new AirGIS—a GIS based air pollution and human exposure modelling system. *Atmospheric environment*. 2019;198:102-21.
  15. Shi X, Li M, Hunter O, Guetti B, Andrew A, Stommel E, et al. Estimation of environmental exposure: interpolation, kernel density estimation or snapshotting. *Annals of GIS*. 2019;25(1):1-8.
  16. Tuna F, Buluc M. Analysis of  $PM_{10}$  pollutant in İstanbul by using Kriging and IDW methods: between 2003 and 2012. *Int J Comput Inf Technol*. 2015;4(1):170-5.
  17. Sun S, Stewart JD, Eliot MN, Yanosky JD, Liao D, Tinker LF, et al. Short-term exposure to air pollution and incidence of stroke in the Women’s Health Initiative. *Environment international*. 2019;132:105065.
  18. Xu H, Bechle MJ, Wang M, Szpiro AA, Vedal S, Bai Y, et al. National  $PM_{2.5}$  and  $NO_2$  exposure models for China based on land use regression, satellite measurements, and universal kriging. *Science of the Total Environment*. 2019;655:423-33.
  19. Daştoorpoor M, Idani E, Goudarzi G, Khanjani N. Acute effects of air pollution on spontaneous abortion, premature delivery, and stillbirth in Ahvaz, Iran: a time-series study. *Environmental Science and Pollution Research*. 2018;25(6):5447-58.
  20. 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.
  21. Miri A, Ahmadi H, Ghanbari A, Moghaddamnia A. Dust storms impacts on air pollution and public health under hot and dry climate. *Int J Energy Environ*. 2007;2(1):101-5.
  22. Pinto JA, Kumar P, Alonso MF, Andreão WL, Pedruzzi R, Espinosa SI, et al. Kriging method application and traffic behavior profiles from local radar network database: A proposal to support traffic solutions and air pollution control strategies. *Sustainable Cities and Society*. 2020:102062.
  23. Yu H, Russell A, Mulholland J, Odman T, Hu Y, Chang HH, et al. Cross-comparison and evaluation of air pollution field estimation methods. *Atmospheric environment*. 2018;179:49-60.
  24. Qiao P, Lei M, Yang S, Yang J, Guo G, Zhou X. Comparing ordinary kriging and inverse distance weighting for soil as pollution in Beijing. *Environmental Science and Pollution Research*. 2018;25(16):15597-608.
  25. Tsui H-C, Chen C-H, Wu Y-H, Chiang H-C, Chen B-Y, Guo YL. Lifetime exposure to particulate air pollutants is negatively associated with lung function in non-asthmatic children. *Environmental Pollution*. 2018;236:953-61.