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Spatial modelling of $PM_{2.5}$ concentrations in Tehran using Kriging and inverse distance weighting (IDW) methods

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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

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-

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mature death by 2050 [5]. In recent decades, high concentrations air pollutants such as particulate matter below 10 and 2.5 μ 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 $PM_{2.5}$, 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 $PM_{2.5}$ 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^2. 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 $PM_{2.5}$ 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 $PM_{2.5}$ concentrations. We checked the validation of each monitoring station. First, the negative or zero values 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:

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

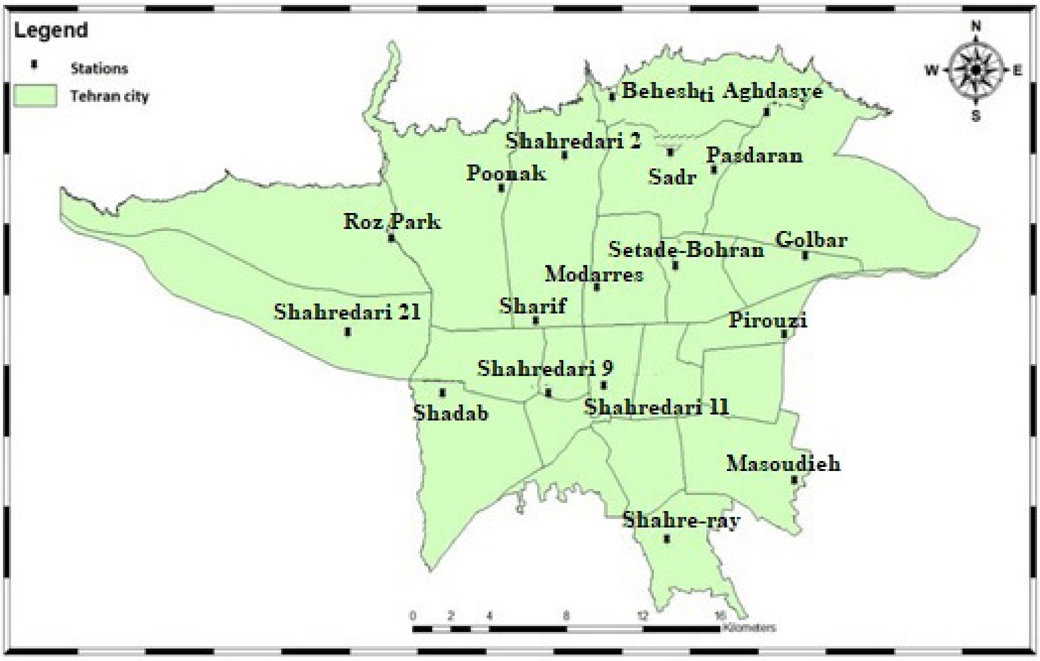

Fig. 1. Approximate location of valid monitoring stations

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 ,λ_i is the weight of the i^{th} station; D_i is the distance between the ith station to the unknown point and α 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:

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

Where Z* is the estimated value, λ_i is the weight of the i^{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 $PM_{2.5}$ particles during the

2017-2018 period. The seasonal average concentrations of $PM_{2.5}$ ranged from 25.31 to 38.32 µg/m^3. The annual concentration of $PM_{2.5}$ was 30.53 µg/m^3, 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 $PM_{2.5}$ 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 $PM_{2.5}$ in Tehran (Fig. 4). The results of some other similar studies [23-25] have shown that in most cases, the geostatistical methods for $PM_{2.5}$ 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 $PM_{2.5}$ concentrations.

Table 1. Statistical summary of $PM_{2.5}$ concentrations (µg/m^3) 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.

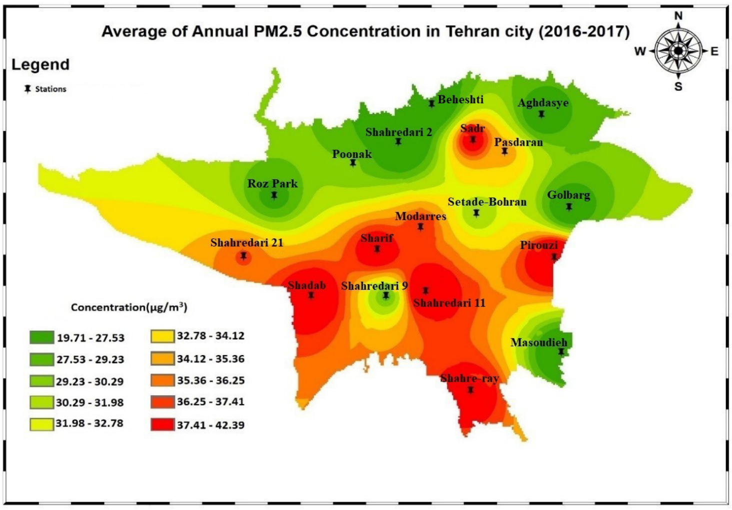

Fig. 2. Map of annual $PM_{2.5}$ concentrations obtained from the inverse distance weighting (IDW) method

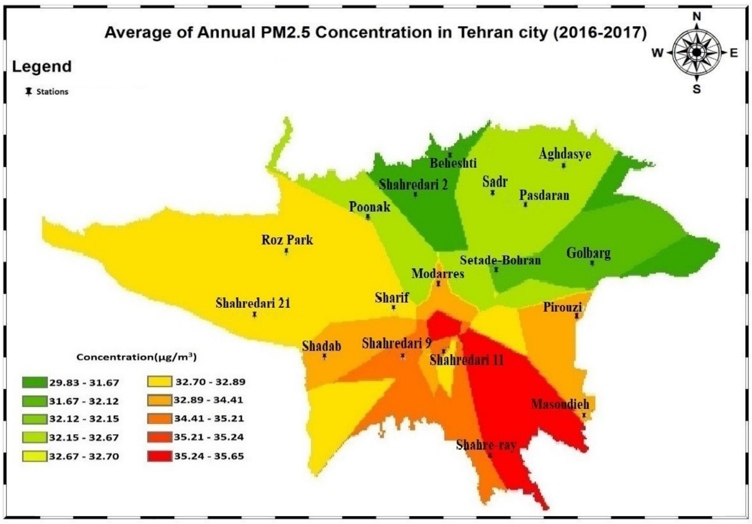

Fig. 3. Map of annual $PM_{2.5}$ concentrations obtained from ordinary Kriging interpolation method

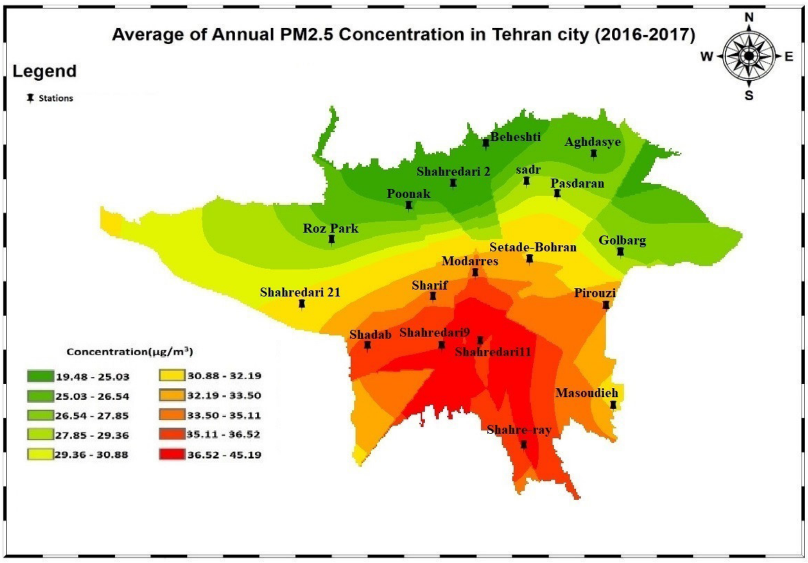

Fig. 4. Map of annual $PM_{2.5}$ concentrations obtained from universal Kriging interpolation method

Conclusion

The present study study was conducted to estimate $PM_{2.5}$ 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 $PM_{2.5}$ 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 $PM_{2.5}$.

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Competing interests

The authors declare that there are no competing interests.

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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."

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