Journal of Air Pollution and Health (Autumn 2018); 3(4): 187-198

Original Article

Available online at http://japh.tums.ac.ir

Determination of the best interpolation method in estimating the concentration of environmental air pollutants in Tehran city in 2015

Akbar Eslami[1], Seyed Mehdi Ghasemi[2,*]

[1] Environmental and Occupational Hazards Control Research Center, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2] Student Research Committee, Department of Environmental Health Engineering, School of Public Health and Safety, Shahid Beheshti University of Medical Sciences, Tehran, Iran

ARTICLE INFORMATION

Article Chronology:
Received 25 October 2018
Revised 5 November 2018
Accepted 10 December 2018
Published 30 December 2018

Keywords:
Air pollution; Tehran; Interpolation; Zoning; Cross-evaluation

CORRESPONDING AUTHOR:
ghasemimehdi61@gmail.com
Tel: (+98 21) 22432040
Fax: (+98 21) 22432037

ABSTRACT:

Introduction: Air pollution is one of the important issues in developing countries, due to increased population and industrialization. In this research, the spatial distribution of ambient air concentration such as CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3 and Air quality Index (AQI) in Tehran city in 2015 were evaluated using different deterministic (inverse distance weighted, local polynomial, global polynomial, radial basis functions) and geostatistical (Kriging, Cokriging) methods.
Materials and methods: Root Mean Square Error (RMSE) and Mean Error (ME) using cross-evaluation methods were used to control the accuracy of the interpolation. To find the secondary variables in the cokriging method, the Pearson coefficient of each pollutant was calculated with another pollutant.
Results: The Kolmogorov-Smirnov test showed that all data followed normal distribution. Also the results indicated that in most cases, geostatistical methods were the best methods to estimate ambient air concentration. Finally, after selecting the best interpolation method, the zoning map of the pollutant was drawn with ArcGIS.
Conclusion: The results of 71 methods showed that in most cases, the geostatistical method is better than the deterministic method.

Introduction

Environmental pollution is one of the serious problems in industrialized and developing countries around the world [1]. Among various sources of environmental pollution, air pollution causes the greatest damage to health and loss of well-being from environmental factors in Asian countries [2]. The average person will receive typically around 15 kg / day of air through breathing compared with 2-2.5 kg of water and 1-1.5 kg of food which indicates the importance of healthy air in human life [3]. Air pollution is the presence of one or more air pollutants above the desirable level which reduces the quality of human health or welfare [4]. The World Health Organization (WHO) predicted that around 7 million people in 2012 died from air pollution exposure, which is about one-eighth of the total deaths [5]. It is also estimated that air pollution in cities will become the leading cause of premature mortality worldwide by 2050 [6] . According to WHO guidelines, air pollution is one of the ten

Please cite this article as: Eslami A, Ghasemi S.M. 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; 3(4): 187-198.

cases that cause major damage to humans [7]. The main contaminants that cause health hazards include particulate matter, ozone, nitrogen dioxide, and sulfur dioxide [8]. The main sources of air pollution in urban areas are vehicular emissions, which account for 90% of air pollution in cities [9]. The health effects of air pollution include: pulmonary disease, acute lower respiratory illness, cerebrovascular disease, coronary artery disease [10], decline in sperm count and ejaculate volume [11, 12], endothelial dysfunction, thrombosis, arrhythmia, blood pressure, metabolism disorders [13], heart disease, lung cancer, acute respiratory infections in children, chronic bronchitis in adults, aggravating preexisting heart and lung disease, or asthmatic attacks [14]. Tehran is one of the most polluted cities in Iran, whose main reasons are the rapid population growth, industrialization, increase personal vehicle density, and limited public transportation options [15]75 . percent of Tehran›s air pollution is due to vehicles [16] .Each year more than 40 % of the days are unhealthy and unhealthy for sensitive groups [17]. It is estimated that 27 people die every day due to air pollution in Tehran [16]. The economic burden of diseases due to air pollution in Iranian urban areas is more than 8 billion dollars a year [15]. The main sources of air pollution in Tehran are CO, SO_2, HC, O_3, NO_X and PM [18].

One of the useful tools used and effective methods in air quality assessment is Geographic Information System (GIS) and interpolation techniques respectively [19]. Interpolation is a method or mathematical function that predicts an unknown quantity between two known quantities [20]. There are two main types of interpolation techniques: deterministic and geostatistical methods. Deterministic interpolation methods (inverse distance weighted, local polynomial, global polynomial, radial basis functions), based on the degree of similarity and degree of smoothing create the levels of measurement points and use mathematical functions for interpolation, but geostatistical interpolation (Kriging, cokriging) methods are based on both statistical and mathematical methods and are used for advanced modeling of prediction levels [21].

Many studies have been carried out on air quality assessment using interpolation methods. For example, a group of researchers compared three interpolation methods including Inverse Distance Weighting (IDW) method, Ordinary kriging (OK) method and Universal Kriging (UK) method for predicting air pollution conditions (PM_{10}) in the center of Thailand. According to the results of this study, the IDW method was the best interpolation method to predict the air pollution conditions [22]. Another group of researchers studied spatial variability of Suspended Particulate Matter (SPM), Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2), using kriging and IDW methods in Indian air. They found that IDW in all pollutants had a smaller error than Kriging and was the best interpolation method in Indian air quality [23].

Mexican researchers compares IDW, OK and nearest monitor interpolation methods for NO_2, SO_2, CO, O_3, PM_{10} and $PM_{2.5}$ in Mexico City air. They found that OK was the best method of interpolation compared to the other methods [24]. Iranian researchers studied spatial interpolation methods including IDW, Global Polynomial Interpolation (GPI), Local Polynomial Interpolation (LPI), Radial Basis Functions (RBF), Simple Kriging (SK), OK and Universal Kriging (UK) to evaluate the spatial distribution of AQI in the air of Tehran, Iran. According to their results, OK was the most accurate method for modeling AQI distribution because of its minimum RMSE [25]. The aim of this research is to compare various deterministic and geostatistical interpolation methods, including inverse distance weighted, local polynomial, global polynomial, radial basis functions and types of Kriging and Cokriging for estimating ambient air concentration such as CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3 and AQI in Tehran city in 2015.

Materials and methods

Study area

Tehran, as the capital of Iran, the world's 19^{th} largest city with a population of more than 8.5 million in 2011 and total surface area of 730 km^2 is located 35° 34' to 35° 50''N and 51° 8› to 51° 37'E. Tehran has more than 17,000 industrial units (26 % of the total units in Iran) with more than 4 million people working in it. The annual mean daily temperature is 17 C although highest and lowest recorded temperature was 39 °C and −6 °C respectively. The annual mean precipitation is about 230 mm with the maximum in March (39 mm) and the minimum in September (1 mm). The average elevation is 1200 m above sea level [15, 25-29].

Data collection

This study was conducted in 2015. 18 out of 21 monitoring stations with sufficient and valid data were evaluated. The stations belonged to the Air Quality Control Company (AQCC). The evaluated parameters were included CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3 and AQI. All parameters were divided into 6 categories from 0 to 500 according to their breaking point (as AQI). The geographic location of this stations is shown in Fig. 1. In the next step, the SPSS and the Kolmogorov-Smirnov test were used for statistical analysis of the data. Then for each air pollutant concentration, using deterministic (inverse distance weighted, local polynomial, global polynomial, radial basis functions) and geostatistical (Kriging and Cokriging) methods (according to the variability of powers and methods), overall with 71 methods, the RMSE value was obtained using cross-validation. Then, with the lowest RMSE value, the best interpolation method was selected and zoned by GIS9.3.

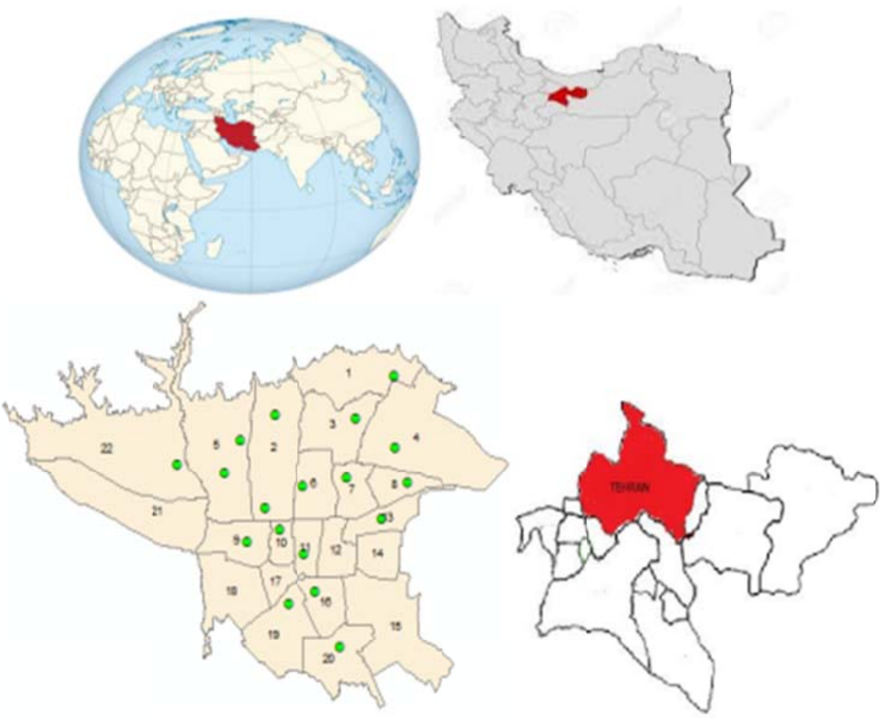

Fig. 1. Geographic location of studying area

Deterministic methods

Inverse Distance Weighting method (IDW)

The IDW model is one of the most common interpolating methods based on the hypothesis that the effect of a parameter on the surrounding points is not the same. As the distance from the origin increases, the effect and weight assigned to it will be reduced. In this method, unknown values are computed by a linear combination of values at known points .The usual expression of IDW is using Eq. (1) [30]:

$$z_j = \frac{\sum_i \frac{z_i}{d_{ij}^n}}{\sum_i \frac{1}{d_{ij}^n}} \quad (1)$$

Where

Z_j is estimated value for the unknown point at location j

d_{ij} is distance between known point i and unknown point j

Z_i is value at known point i

n is user-defined exponent for weighting

Radial Basis Function method (RBF)

The radial base function method (known as splines) is one of the interpolation methods in which the level of observation passes through observational values. This method is an artificial neural network. Another feature of this method is that the values are greater than the maximum observed values or less than the minimum observed values at the estimation level. In the IDW method, the level of estimation will pass through the observation values, but never estimates more than the maximum and minimum of the minimum observational data. There are 5 types of RBF which include: Completely Regularized Spline (RBF-CRS), Spline With Tension (RBF-SWT), Thin Plate Spline (RBF-TPS), Multiquadric (RBF-M), Inverse Multiquadric (RBF-IM) [31].

Global Polynomial Interpolation (GPI)

GPI uses a polynomial formula to fit a smooth surface to the input sample points. GPI interpolation is used to estimate the unknown points from the data of all measured points. The level changes in GPI are gradual and the effects of sudden changes in data are reduced. In fact, the GPI goal is to minimize errors [32].

Local Polynomial Interpolation method (LPI)

This method, like the GPI, uses a polynomial function for interpolation, and the only difference is that a large number of polynomials are fitted on limited data in a given neighborhoods. In fact, in the LPI model, data from all points is not used to estimate the amount of unknown points [33].

Geostatistical methods

Kriging

Kriging is one of the most important tools in the geostatistical techniques. This method produces less bias in predictions, so that they are known as best linear unbiased estimator (BLUE). Similar to IDW, Kriging uses a linear combination of measured weight values to generate estimates for unknown points. However, the weights in kriging, not only depends on the distance between the predicted points and the measured points, but also on the spatial correlation (i.e., semi-variogram) of the measured points [34].

Cokriging

Cokriging is developed form of kriging but there are secondary variables or covariates that can be used to improve the interpolation. In fact Cokriging can be effective for data with significant inter-variable correlation [35].

Validation of interpolation method

The Cross-Validation technique has been used to compare the interpolation methods and select the most appropriate method. This method initially temporarily removes one observation from the data set, and then the value of the deleted data is estimated using any interpolation method. In the next step, the original value returns to its location, and this is done for all data in the same way. In this study, the Root Mean Squared Error (RMSE) was used to evaluate interpolation. If RMSE is equal, the Mean Error (ME) used for evaluation. Any method that has the smallest RMSE is known as the most appropriate interpolation method. The RMSE can be calculated using Eq. (2) [36].

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Z(x_i) - Z^*(x_i))^2} \quad (2)$$

Where $Z^*(x_i)$ is observed value at point x_i , $Z^*(x_i)$ is predicted value at point x_i, N is number of samples.

Results and discussion

In order to investigate the spatial changes that were the main objectives of this research, a Normality Test was initially performed by SPSS using the Kolmogorov–Smirnov test. Because one of the important conditions in the statistical method is the normalization of the data. By analyzing the data, it was found that the air pollutant data was normal, so a change to normalize the data was not performed.

The annual air quality concentration (as AQI) obtained from average daily concentrations of pollutants is tabulated in Table 1. In total, it can be said that each pollutant passed at least once a year from about 100 number.

After the analysis of normality, we obtained RMSE for each pollutant in each season according to deterministic and geostatistical methods (Tables 2 and 3).

As shown in Tables 2 and 3, the value of RMSE is the same for some pollutants .In this case, other error estimation methods were used such as the Mean Error (ME). Finally, by checking RMSE and ME (the lower the better), the best interpolation method is obtained, which is shown in Table 4.

In the Kriging method, a secondary variable is used to improve interpolation. Pearson coefficient was used to select the secondary variable. Each pollutant that had the highest Pearson coefficient with another pollutant was selected as a secondary variable, as shown in Table 5.

Table 1. Annuall Descriptive Statistics as AQI

Pollutant	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
CO	3877	8.00	188.00	39	0.28033	17.45485	304.672
O_3	2790	5.00	154.00	39	0.38671	20.42603	417.223
SO_2	3127	3.00	101.00	26	0.20192	11.29102	127.487
NO_2	3689	7.00	178.00	66	0.52714	32.01684	1025.078
PM_{10}	3315	6.00	500.00	57	0.50942	29.33031	860.267
$PM_{2.5}$	3338	10.00	244.00	79	0.54496	31.48508	991.310
AQI	5361	7.00	500.00	73	0.44786	32.79163	1075.291

Table 2. Annual RMSE results of deterministic methods interpolation assessment

Types and power			CO	O_3	NO_2	SO_2	PM_{10}	$PM_{2.5}$	AQI
			RMSE						
IDW	Standard	1	7.33	11.7	25.5	7.38	15.46	11.17	11.41
		2	7	11.84	24.32	8.12	16.52	11.92	12.3
		3	7.29	12.69	23.47	8.95	17.76	12.79	13.3
		4	7.77	13.49	23.05	9.68	18.93	13.55	14.2
	Smoth	1	6.89	12.14	25.66	8.21	17.11	12.11	12.57
		2	7.15	12.7	24.05	8.84	17.93	12.46	13.18
		3	7.55	13.31	23.08	9.46	18.82	13.28	13.88
		4	7.96	13.89	22.71	10	19.64	13.87	14.56
GPI		1	7.98	11.45	27.64	7.5	15.28	11.49	11.89
		2	8.44	14.96	40.28	10.24	18.64	19.48	18.36
		3	11.44	19.21	87.61	16.01	40.08	15.92	14.23
LPI	Standard	1	7.47	11.59	25.25	7.58	15.44	11.59	12.04
		2	7.76	14.86	39.81	10.39	19.45	19.24	18.11
		3	11.92	19.87	107.4	16.16	42.14	16.06	14.66
	Smoth	1	7.48	11.59	28.69	7.58	15.44	11.59	12.04
		2	8.27	14.86	50.4	10.39	19.45	19.24	18.11
		3	13.33	19.87	71.17	16.16	42.14	16.06	14.66
RBF	Standard	CRS	6.58	12.09	12.43	8.27	16.8	12.17	12.56
		SWT	6.59	11.87	16.89	8.02	16.44	11.88	12.56
		M	6.84	13.65	15.25	9.85	19.25	13.79	14.47
		IM	6.68	10.87	12.89	6.92	14.79	10.63	10.77
		TPS	8.43	16.56	19.68	13.66	27.28	18.04	18.84
	Smoth	IM	7.16	11.81	16.16	7.99	17.12	12.04	12.31

Table 3. Annual RMSE results of geostatistical methods interpolation assessment

Types and power				CO	O_3	NO_2	SO_2	PM_{10}	$PM_{2.5}$	AQI
				RMSE						
Kriging	Standard	OK	CIR	6.69	11.69	21.61	6.9	15.03	11.24	10.68
			SPH	6.62	11.73	21.98	6.92	14.98	11.24	10.68
			EXP	6.75	11.73	24.63	6.92	14.98	10.68	10.68
			GAUS	6.56	11.69	24.88	6.92	14.98	10.68	10.68
		SK	CIR	6.58	11.58	17.69	6.54	14.1	10.09	10.13
			SPH	6.56	11.59	17.82	6.54	14.1	10.09	10.13
			EXP	6.96	11.59	21.25	6.54	14.1	10.09	10.13
			GAUS	6.59	11.57	19.91	6.54	14.1	10.09	10.13
		UK	CIR	6.64	11.7	21.44	6.92	14.98	10.68	10.68
			SPH	6.62	11.73	21.98	6.92	14.98	10.68	10.68
			EXP	6.75	11.73	24.63	6.92	14.98	10.68	10.68
			GAUS	6.56	11.69	24.88	6.92	14.98	10.68	10.68
	Smoth	OK	CIR	6.66	11.74	20.48	6.93	14.81	10.65	10.68
			SPH	6.63	11.76	20.8	6.93	14.81	10.65	10.68
			EXP	6.73	11.76	22.56	6.93	14.81	10.65	10.68
			GAUS	6.57	11.72	22.74	6.93	14.81	10.65	10.68
		SK	CIR	6.56	11.58	18.58	6.54	14.1	10.09	10.13
			SPH	6.55	11.59	18.78	6.54	14.1	10.09	10.13
			EXP	6.95	11.6	20.94	6.54	14.1	10.09	10.13
			GAUS	6.56	11.57	20.06	6.54	14.1	10.09	10.13
		UK	CIR	6.66	11.74	20.48	6.93	14.81	10.65	10.68
			SPH	6.63	11.76	20.8	6.93	14.81	10.65	10.68
			EXP	6.73	11.76	22.56	6.93	14.81	10.65	10.68
			GAUS	6.57	11.72	22.74	6.93	14.81	10.65	10.68
Cokriging	Standard	OK	CIR	6.67	11.58	30.09	7.38	14.89	11.2	11.44
			SPH	6.61	11.57	30.09	7.38	14.43	10.65	10.7
			EXP	6.73	11.45	30.09	7.38	14.45	10.53	10.61
			GAUS	6.53	11.63	30.09	7.38	14.44	10.68	10.7
		SK	CIR	6.56	10.93	17.81	6.53	14.1	10.46	10.54
			SPH	6.54	9.44	18.16	6.53	14.1	10.6	10.65
			EXP	6.73	9.67	21.41	6.53	14.2	7.19	7.65
			GAUS	6.57	10.98	20.29	6.53	14.2	10.51	10.66
		UK	CIR	6.62	11.58	28.1	8.52	14.43	10.66	10.7
			SPH	6.61	11.57	28.1	8.52	14.43	10.65	10.7
			EXP	6.73	11.45	28.1	8.52	14.45	10.53	10.61
			GAUS	6.53	11.63	28.1	8.52	14.44	10.68	10.7
		OK	CIR	6.64	11.62	28.32	7.33	14.96	10.63	10.69
			SPH	6.63	11.6	28.32	7.33	14.96	10.62	10.68
			EXP	6.72	11.48	28.32	7.33	14.97	10.49	10.6
			GAUS	6.54	11.66	28.32	7.33	14.96	10.65	10.68

Table 3. Annual RMSE results of geostatistical methods interpolation assessment

Types and power				CO	O_3	NO_2	SO_2	PM_{10}	$PM_{2.5}$	AQI
				RMSE						
Cokriging	Smoth	SK	CIR	6.55	10.93	18.1	6.53	14.1	10.44	10.54
			SPH	6.52	9.43	18.4	6.53	14.1	10.5	10.65
			EXP	6.72	9.67	21.09	6.53	14.2	7.17	7.64
			GAUS	6.53	10.98	20.12	6.53	14.12	10.49	10.66
		UK	CIR	6.64	11.62	27.21	8.96	14.96	10.63	10.69
			SPH	6.63	11.6	27.21	8.96	14.96	10.62	10.68
			EXP	6.72	11.48	27.21	8.96	14.97	10.49	10.6
			GAUS	6.54	11.66	27.21	8.96	14.96	10.65	10.68

Table 4. Best interpolation method for each pollutant by checking RMSE and ME

Season	CO	O_3	NO_2	SO_2	PM_{10}	$PM_{2.5}$	AQI
Spring	Kriging (SK-CIR-standard)	Cokriging (SK-EXP-smoth)	RBF (IM-standard)	Cokriging (SK-EXP- standard) cokriging(SK-EXP-smoth)	Kriging (SK-EXP-smoth)	Cokriging (SK-EXP-smoth)	Cokriging (SK-EXP-smoth)
Summer	Cokriging (SK-CIR-standard)	Cokriging (SK-GAUS-smoth)	Kriging (SK-CIR-smoth)	Cokriging (SK-CIR-standard) Cokriging (SK-CIR-smoth)	cokriging(SK-GAUS-smoth) Cokriging (SK-GAUS-standard)	Cokriging (SK-EXP-smoth)	Cokriging (SK-EXP-standard)
Autumn	LPI (type 1-smoth)	Cokriging (SK-EXP-standard)	RBF (CRS-standard)	Kriging (SK-SPH-smoth) Kriging (SK-SPH-standard)	Kriging (SK-SPH-standard)	Cokriging (SK-GAUS-smoth)	Cokriging (SK-EXP-smoth)
Winter	Cokriging (SK-EXP-standard)	Kriging (SK-GAUS-standard)	Kriging (SK-GAUS-standard)	Cokriging (OK-EXP-standard) Cokriging (UK-EXP-standard)	Cokriging (SK-SPH-standard)	Cokriging (SK-EXP-smoth)	Cokriging (OK-GAUS-standard)
Annual	Cokriging (SK-SPH-smoth)	Cokriging (SK-SPH-smoth)	RBF (CRS-standard)	Cokriging (SK-EXP-smoth) Cokriging (SK-EXP-standard)	Kriging (SK-all of 4 models-standard) Kriging (SK-all of 4 models-smoth)	Cokriging (SK-EXP-smoth)	Cokriging (SK-EXP-smoth)

Table 5. Summary of the results of the Pearson coefficient

Main pollutant		CO	O_3	SO_2	NO_2	PM_{10}	$PM_{2.5}$	AQI
Secondary variables	Spring	SO_2	PM_{10}	AQI	CO	AQI	AQI	$PM_{2.5}$
	Summer	$PM_{2.5}$	AQI	NO_2	SO_2	AQI	AQI	$PM_{2.5}$
	Autumn	AQI	SO_2	NO_2	SO_2	AQI	AQI	$PM_{2.5}$
	Winter	$PM_{2.5}$	SO_2	CO	CO	$PM_{2.5}$	AQI	$PM_{2.5}$
	Annual	$PM_{2.5}$	PM_{10}	NO_2	SO_2	AQI	AQI	$PM_{2.5}$

After identifying the best interpolation method for each pollutant, the zoning map of each pollutant was made using Arc Gis9.3 (Fig. 2). The best interpolation method for CO except for the autumn season has been the geostatistical method. The zoning map showed that in areas 10, 11 and 19, CO concentrations are higher than other points, which is probably due to high traffic loads. In the autumn and winter seasons, concentration of CO was slightly higher than the other seasons due to the opening of the schools and increased air inversion. Since 2011, changes in CO concentration have been decreased due to reducing carburetor vehicles, and improving fuel and vehicle quality. The best interpolation method for SO_2 was the geostatistical method. It is known that areas 10, 16 and 19 have a higher concentration, which is probably due to heavy vehicles. It should be noted that the concentration of SO_2 is lower than that of other pollutants due to lower sulfur content in gasoil [37]. The best interpolation method for NO_2 in the spring, autumn and annual was a deterministic method and for the summer and winter was a geostatistical method. The zoning map shows that in regions 2 and 11, concentrations of NO_2 are high and in the central regions is less. The best interpolation method for O_3 was the geostatistical method. The interpolation map showed that ozone concentrations were higher in the eastern border of the city due to the distance from the city and the intensity of more sunlight [37]. In central locations, ozone is used because of increased traffic load and presence to atmospheric reactions. In warm months, ozone concentrations are also higher compared to cold months due to higher radiation exposure. The best interpolation method for PM_{10} and $PM_{2.5}$ was the geostatistical method. In area 13 and especially in area 9, PM_{10} concentrations are higher than other areas. In the north and east areas, $PM_{2.5}$ concentrations are less than other parts. Also, in the summer, $PM_{2.5}$ concentration has increased compared to other seasons because of the dust phenomenon. In the spring, the concentration of $PM_{2.5}$ was low due to the new year holiday, reduced traffic and atmospheric conditions.

In general, it can be said that the concentration of $PM_{2.5}$ is in a worse situation compared to other pollutants and is currently the most important pollutant in Tehran. The best interpolation method for AQI was the geostatistical method. It is observed that the AQI index is higher in winter than the other seasons due to inversion and atmospheric stability. In general, One-way ANOVA showed that the average of CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3 and AQI (each separately) varies in different stations and seasons.

Conclusion

One of the important methods in the environmental assessment is the use of the GIS and geostatistical and deterministic interpolation methods.So the aim of this study was to determine the best interpolation for providing CO, NO_2, SO_2, $PM_{2.5}$, PM_{10}, O_3 and AQI maps in air of Tehran city. In order to compare the interpolation evaluation, RMSE and ME were used. The evaluation showed that the most important pollutant in Tehran is $PM_{2.5}$. The results of71 methods showed that in most cases, the geostatistical method is better than the deterministic method. Also in most seasons, Cokriging and RBF were the best geostatistical and deterministic interpolation methods respectively. After selecting the best interpolation method, the air quality maps of the area were drawn with ArcGIS.

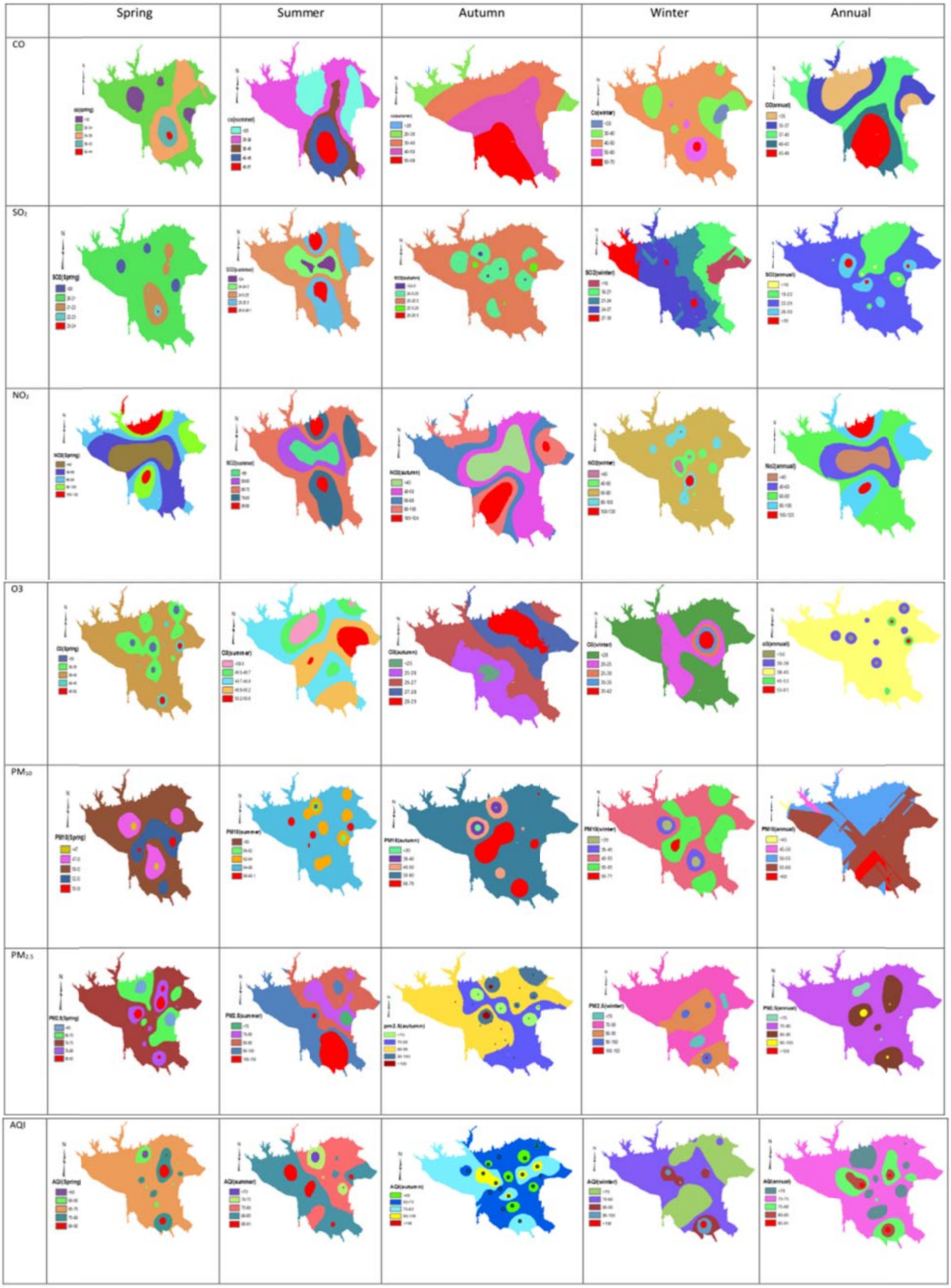

Fig. 2. Zoning of each pollutant with respect to the best interpolation method

List of abbreviations

IDW Inverse Distance Weighting
GPI Global Polynomial Interpolation
LPI Local Polynomial Interpolation
RBF Radial Basis Function
OK Ordinary kriging
SK Simple Kriging
UK Universal Kriging
RMSE Root Mean Square Error
ME Mean error
CIR Circular
SPH Spherical
EXP Exponential
GAUS Gaussian
CRS Completely Regularized Spline
SWT *Spline With Tension*
M Multiquadric
IM *Inverse* Multiquadric
TPS *Thin Plate Spline*

Financial supports

This study was financially supported by the Student Research Committee of Shahid Beheshti University of Medical Sciences.

Competing interests

The authors declare that there are no competing interests.

Acknowledgements

The authors would like to express their thanks to the Department of Environmental Health Engineering and Student Research Committee of School of Health and Safety for the financial support of this study.

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. Niaz Y, Jiti Z, Zhang Y. Influence of automotive emission on air pollution using GIS in Faisalabad, Pakistan. International journal of agricultural and biological engineering. 2015;8(1):111-6.
2. Dominick D, Juahir H, Latif MT, Zain SM, Aris AZ. Spatial assessment of air quality patterns in Malaysia using multivariate analysis. Atmospheric environment. 2012;60:172-81.
3. Aljeesh Y, Al Madhoun W, Shamh IA, Arcaya M. Assessment of indoor air quality in neonatal intensive care units in government hospitals in Gaza Strip, Palestine. Public health research. 2016;6(1):24-30.
4. Ni J-Q. Research and demonstration to improve air quality for the US animal feeding operations in the 21st century–A critical review. Environmental pollution. 2015;200:105-19.
5. Siddika N, Balogun HA, Amegah AK, Jaakkola JJ. Prenatal ambient air pollution exposure and the risk of stillbirth: systematic review and meta-analysis of the empirical evidence. Occupational and environmental medicine. 2016;73(9):573-81.
6. Cesur R, Tekin E, Ulker A. Air pollution and infant mortality: evidence from the expansion of natural gas infrastructure. The economic journal. 2016;127(600):330-62.
7. Dashtpagerdi MM, Sadatinejad SJ, Bidaki RZ, Khorsandi E. Evaluation of air pollution trend using GIS and RS applications in South West of Iran. Journal of the Indiansociety of remote sensing. 2014;42(1):179-86.
8. Nehr S, Hösen E, Tanabe SI. Emerging developments in the standardized chemical characterization of indoor air quality. Environment international. 2017;98:233-7.
9. Shakeel M, Arshad Q, Saeed R, Ahmed T, Khan HMT, Noreen M, et al. Application of GIS in vsualization and assessment of ambient air quality for SO2 and NOx in Sheikhupura City, Pakistan. Journal of Geography & Natural Disasters. 2015;5(3):1-7.
10. Lelieveld J, Evans J, Fnais M, Giannadaki D, Pozzer A. The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature. 2015;525(7569):367-71.
11. Lafuente R, García-Blàquez N, Jacquemin B, Checa MA. Outdoor air pollution and sperm quality. Fertility and sterility. 2016;106(4):880-96.
12. Deng Z, Chen F, Zhang M, Lan L, Qiao Z, Cui Y, et al. Association between air pollution and sperm quality: A systematic review and meta-analysis. Environmental pollution. 2016;208:663-9.
13. Khafaie MA, Yajnik CS, Salvi SS, Ojha A. Critical review of air pollution health effects with special concern on respiratory health. Journal of air pollution and health. 2016;1(2):123-36.

14. Kampa M, Castanas E. Human health effects of air pollution. Environmental pollution. 2008;151(2):362-7.
15. Shahbazi H, Reyhanian M, Hosseini V, Afshin H. The relative contributions of mobile sources to air pollutant emissions in Tehran, Iran: an emission inventory approach. Emission control science and technology. 2016;2(1):44-56.
16. Halimi M, Farajzadeh M, Zarei Z. Modeling spatial distribution of Tehran air pollutants using geostatistical methods incorporate uncertainty maps. Pollution. 2016;2(4):375-86.
17. Hassani A, Hosseini V. An assessment of gasoline motorcycle emissions performance and understanding their contribution to Tehran air pollution. Transportation research part D: Transport and environment. 2016;47:1-12.
18. Esfandani MA, Nematzadeh H. Prediction of air pollution in Tehran based on evolutionary models. Indian journal of science and technology. 2015;8(35):1-5.
19. TUNA F, BULUÇ M. Analysis of PM10 pollutant in Istanbul by using Kriging and IDW methods: Between 2003 and 2012. Analysis. International journal of computer and information technology. 2015;4(01):170-5.
20. Akkala A, Devabhaktuni V, Kumar A. Interpolation techniques and associated software for environmental data. Environmental progress & sustainable energy. 2010;29(2):134-41.
21. Erdogan S. A comparision of interpolation methods for producing digital elevation models at the field scale. Earth surface processes and landforms. 2009;34(3):366-76.
22. Vorapracha P, Phonprasert P, Khanaruksombat S, Pijarn N. A comparison of spatial interpolation methods for predicting concentrations of particle pollution (PM10). International journal of chemical, environmental & biological sciences 2015;3(4):302-6.
23. Jha DK, Sabesan M, Das A, Vinithkumar NV, Kirubagaran R. Evaluation of interpolation technique for air quality parameters in port blair, India. Universal journal of environmental research & technology. 2011;1(3):301-10
24. Rivera-González LO, Zhang Z, Sánchez BN, Zhang K, Brown DG, Rojas-Bracho L, et al. An assessment of air pollutant exposure methods in Mexico City, Mexico. Journal of the air & waste management association. 2015;65(5):581-91.
25. Saniei R, Zangiabadi A, Sharifikia M, Ghavidel Y. Air quality classification and its temporal trend in Tehran, Iran, 2002-2012. Geospatial health. 2016;11(2):213-20.
26. Amini H, Taghavi-Shahri SM, Henderson SB, Naddafi K, Nabizadeh R, Yunesian M. Land use regression models to estimate the annual and seasonal spatial variability of sulfur dioxide and particulate matter in Tehran, Iran. Science of the total environment. 2014;488:343-53.
27. Naddafi K, Sowlat MH, Safari MH. Integrated assessment of air pollution in Tehran, over the period from September 2008 to September 2009. Iranian journal of public health. 2012;41(2):77.
28. Amini H, Taghavi-Shahri SM, Henderson SB, Hosseini V, Hassankhany H, Naderi M, et al. Annual and seasonal spatial models for nitrogen oxides in Tehran, Iran. Scientific reports. 2016;6:1-11.
29. Sayadi M, Sayyed M, Kumar S. Short-term accumulative signatures of heavy metals in river bed sediments in the industrial area, Tehran, Iran. Environmental monitoring and assessment. 2010;162(1-4):465-73.
30. Gunarathna MH, Kumari MK, Nirmanee KG. Evaluation of interpolation methods for mapping pH of groundwater. International journal of latest technology in engineering, management & applied science. 2016;5(3):1-5.
31. Ahmadian M, Chavoshian M. Spatial variability zonation of groundwater-table by use geo-statistical methods in central region of Hamadan province. Annals of biological research. 2012;3(11):5304-12.
32. Seyedmohammadi J, Esmaeelnejad L, Shabanpour M. Spatial variation modeling of groundwater electrical conductivity using geostatistics and GIS. Modeling earth systems and environment. 2016;2(4):169.
33. Wang S, Huang GH, Lin QG, Li Z, Zhang H, Fan YR. Comparison of interpolation methods for estimating spatial distribution of precipitation in Ontario, Canada. International Journal of Climatology. 2014;34(14):3745-51.
34. Sagar R. Quality of ground water in aurangabad district (Maharashtra, India) using geostatistical method. International journal of innovative science, engineering & technology. 2015;2(2):7.
35. Zhang X, Lu X, Wang X. Comparison of spatial interpolation methods based on rain gauges for annual precipitation on the Tibetan Plateau. Polish journal of environmental studies. 2016;25(3).
36. Mair A, Fares A. Comparison of rainfall interpolation methods in a mountainous region of a tropical island. Journal of hydrologic engineering. 2010;16(4):371-83.
37. Ahadi S, Roshani M, Tadari M, Torbatian S. Annual report on the ambient air quality of Tehran, 2015-2016 (1394). Tehran Air Quality Control Company (TAQCC), No. QM95/02/01(U)/01. Tehran, Iran.