ORIGINAL ARTICLE

Determination of Dispersion and Zoning of Air Pollutants in Tehran Using AERMOD Model: A Case Study of District 2 of Tehran, Iran

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Abstract

Background: Cities, as population centers, face increasingly diverse environmental problems. Hence, there is an urgent need for a healthy environment by eliminating the emission of various life-threatening air pollutants with different origins. The present study aimed to determine the air pollution zones using the AERMOD model and provide a strategic management plan to reduce air pollution in District 2 of Tehran, Iran.

Methods: In this study, the air pollutant dispersion was evaluated by the AERMOD model exploiting spatial analysis (interpolation) and field measurements. The samples were collected from 32 places in the North, South, Central, East and West of District 2 of Tehran. Air quality indices, including ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide were analyzed in the experiments. Zoning and mapping of dispersion maps and spatial analysis were performed by ArcGIS.10 software using inverse distance weighted interpolation methods in the study area.

Results: According to the results, the highest concentrations of sulfur dioxide, nitrogen dioxide, ozone, and carbon monoxide pollutants were related to stations 28, 26, 15 and 15 with values of 10.9, 54.6, 32.8, and 31.9 ppb, corresponding to the southern, eastern, southern, and southwestern regions in Sharif, Punak, and Kuy-e Nasr neighborhoods, respectively.

Conclusion: Based on the statistical tests of correlation coefficient, normalized mean error, and normalized mean bias, all the calculated results confirmed the accuracy of constructed model and that the modeling would not have sufficient accuracy and performance without the implementation of AERMAP.

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Introduction

Cities, as population centers, face numerous and varied environmental problems (Sadigh et al., 2021; Mostofie et al., 2014). Hence, there is an urgent need for a healthy environment by eliminating the occurrence of various types of pollution (Sadigh et al., 2020).[1] The 20-Year National Vision of the Islamic Republic of Iran, in line with Article 5 of the Constitution, emphasizes the importance of urban environmental issues and integrated urban management.[2] However, most human activities have contributed to air pollution due to population growth, urban development, presence of various industries (such as power plants, refineries, steel mills, etc.), motor vehicles, and the construction of residential and commercial complexes.[3] Accordingly, the share of fixed and mobile sources related to air pollution in different cities of Iran has been announced 10-15% and 85-90%, respectively.[4] Therefore, increasing urban traffic has endangered humans by emitting some air pollutants such as ozone (O_3), nitrous oxide (NO_X), carbon monoxide (CO), particulate matter (PM), and sulfur dioxide (SO_2) due to the combustion of fossil fuels, the effects of which are evident in terms of physical and mental health of people and increased economic losses.[5]

Numerous epidemiological studies have emphasized the correlation between air pollution and public health, pointing out that long-term exposure to ambient air pollution has led to the onset and exacerbation of respiratory diseases.[6] Recently, these effects have been highlighted on a global scale, especially in developing countries and with the extent of industrialization.[7] According to environmental studies, 70% of deaths in Tehran are due to cardiovascular and respiratory diseases that are directly or indirectly related to air pollution.[8]

Due to the great advances in mathematical models in the field of Environmental impact assessment (EIA) of air pollution, it can be noted that GIS has been very powerful in monitoring and managing air quality and comparing inverse distance weighted (IDW) interpolation methods (kriging); also, AERMOD is very useful as one of the Gaussian models in modeling pollutant dispersion.[9]

In the middle atmospheric and topographic conditions, Gaussian mass model can provide acceptable results. This type of modeling is applied for most of the dispersion models. Some Gaussian models of air pollution include SCREENS, ISCLT, ISCST, PLUMES, and CTDMPLUS. The PLUMES model is widely used to estimate the concentration of pollutants or their settling flux due to a wide range of pollution sources. Industrial source complex long term (ISCLT) is a pollutant dispersion model, similar to the ISCST model, in which building effect analysis is also added. Among these, the AERMOD model is the next version of the air pollutant dispersion model. In 1991, the American Meteorological Society (AMS) and the US Environmental Protection Agency (USEPA) established a joint group with a specific goal. Accordingly, given that advances in the meteorological boundary layer, a new dispersion model was developed and ISC3 algorithms were updated with advanced modeling techniques, resulting in the development of the advanced AERMOD model. The greater success of the AERMOD model in generating dispersions for the buoyancy mode is the release of long chimneys with a more complex topography compared to ISC3.[10] Therefore, AERMOD is one of the USEPA-approved software that is among the preferred models recommended by this organization; it means that the use of this software is preferable to other air pollution dispersion modeling software.

Mohan et al. (2011) showed that the use of AERMOD in determining air quality can measure PM with the least differentiation of modeling outcomes.[11] Seangkiatiyuth et al. (2011) made an attempt to model the impact of NO_2 emissions from a cement complex in Bangkok, Thailand using AERMOD.[12] Mokhtar et al. (2014) assessed the health risks of SO_2 from coal-fired power plants using AERMOD.[13] Gibson et al. (2017) examined the linear sources of SO_2 and NO_x with the AERMOD model in Nova Scotia, Canada.[14]

Kesarkar et al. (2007), in a case study, modeled PM10 dispersion in Pune, India, where the required AERMOD meteorological characteristics were calculated using the Weather Research and Forecasting (WRF) model. This case study was performed, assuming that the land is flat and has an area of 25×25 km^2, with a modeling network distance of one kilometer.[15] Zhang et al. (2008) conducted a case study in the city of Hangzhou in southern China, in which the dispersion of three SO_2, NO_x and PM_{10} pollutants from fossil fuels and industrial production processes was modeled by the AERMOD model, and then the obtained results were compared by the data collected from seven monitoring stations.[16] Mazur et al. (2009) modeled the ambient air total gaseous mercury concentrations in the vicinity of coal-fired power plants in Alberta, Canada, in an area of 60×60 km^2, with 169 receptors using AERMOD model, and compared the results with the values recorded at two monitoring stations.[17] In a case study, Zou et al. (2010) investigated the performance of AERMOD in estimating SO2 concentrations in Dallas and Ellis counties in Texas. The performance of the AERMOD model was evaluated at different time scales.[18]

The purpose of this study was to explain the validity of air pollutant dispersion modeling with IDW interpolation methods and field measurements of air quality indices using statistical relationships. Finally, modeling was carried out by the AERMODE and air pollutant zoning by the ArcGIS.

Methods

This is a descriptive-analytical. Necessary analyses were performed by collecting the required data and modeling them using GIS software.

Study Area

The District 2 of Tehran consists of 9 regions and 21 neighborhoods, is adjacent to districts 10, 9, 6, 5, 3 and 1, and is located in the middle and northern domains of the city with an area of 47.1 square kilometers and a population of 692,579. Figure 1 shows the geographical coordinates of sampling stations in location.

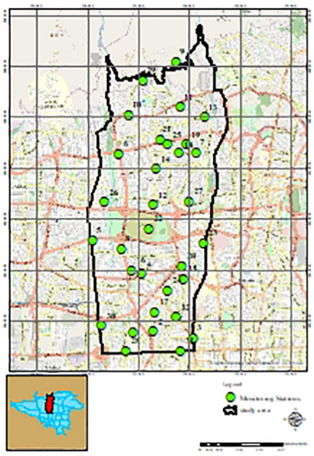

Figure 1: Sampling stations in District 2 of Tehran Municipality

Experiments

The main pollutants of CO, O_3, NO_2 and SO_2 were measured according to national standards and international methods.[19] In order to fully cover the geographical area, the stations were selected by identifying and being close to point sources such as gas stations, parks, bus and taxi terminals, schools, and hospitals. Precise air pollution dispersion in 32 points were included as follows: 8 points in the southern regions (including stations 1, 28 and 30 in Tarasht neighborhood, stations 2 and 17 in Shadmehr neighborhood, stations 3 and 31 in Tohid neighborhood, and station 32 in Tehran Villa neighborhood); 8 points in the northern regions (including station 9 in Kuhsar neighborhood, station 29 in Shahrak-e Mokhaberat neighborhood, station 10 in Farahzad neighborhood, stations 11 and 13 in Saadatabad neighborhood, and stations 19, 21 and 25 in Darya neighborhood); 6 points in the central regions (including stations 12 and 14 in Ivanak neighborhood, station 16 in Shahrak-e Azmayesh neighborhood, station 22 in Pardisan neighborhood, station 24 in Tehran Villa neighborhood, station 4 in Shahrak-e Azmayesh); 4 points in the western regions (including stations 5 in Shahrak-e Homa dneighborhood, stations 6, 26 in Sepehr neighborhood, station 8 in Khorram Rudi neighborhood); and 6 points in the eastern regions (including station 7 in Modiriat neighborhood, station 15 in Patris neighborhood, stations 27 and 18 in Shahrak-e Gharb neighborhood, stations 20 and 23 in Kuy-e Nasr neighborhood). Considering geographic data and environmental information and integrating them with air quality data, zoning and mapping of dispersion maps and spatial analysis were performed by ArcGIS.10 software using the IDW method in the study area.[20] The main requirements of the AERMOD model included input file containing information on pollutant emission sources, receptor position, specifications of meteorological files, and model output. Atmospheric data and recorded quality control statistics at Chitgar synoptic weather station (2017) were employed as well. In the AERMET preprocessor, information on hourly surface observations and upper air data were used for preprocessing. The preprocessors of three surface properties (surface roughness, albedo, and Bowen ratio) were introduced as input to determine these required values on a seasonal and annual basis. Pollutant modeling was estimated based on their conditions in 8-hour, 24-hour, and annual averages.

In order to validate the AERMOD model, in this study, 32 receptors were identified to assess the modeling results and field measurement values, and the assessments were performed by the statistical parameters proposed by the USEPA, as follows:

Correlation Coefficient (CCOF)

The CCOF parameter, according to Equation 1, shows the correlation between the model output results and the field measurement data; the closer it is to 1, the better the accuracy of the model results.

$$CCOF = \frac{\sum_{i=1}^{N}(X_i-\bar{X})(Y_i-\bar{Y})}{\left(\sum_{i=1}^{N}(X_i-\bar{X})^2 \sum_{i=1}^{N}(Y_i-\bar{Y})^2\right)^{1/2}} \quad \text{Equation (1)}$$

Where, Xi: model output data, Yi: monitoring field data, $\bar{X}$: mean model output data, $\bar{Y}$: mean field data, N: the total number measured and the range of its changes (+1 ~ −1).

Normalized Mean Bias (NMB) and Normalized Mean Error (NME)

In order to evaluate the performance of the model for the modeling of pollutants, the U.S. EPA benchmarks are ≥15% for NMB and ≥30% for NME.

$$NMB = \frac{\sum_{i=1}^{N}(X_i-Y_i)}{\sum_{i=1}^{N}Y_i} \quad \text{Equation (2)}$$

The range of changes in NMB is -1 ~ + ∞.

$$NME = \frac{\sum_{i=1}^{N}|X_i-Y_i|}{\sum_{i=1}^{N}Y_i} \quad \text{Equation (3)}$$

The range of changes in NME is 0 ~ + ∞.

Cross Validation method was applied to evaluate the accuracy of the interpolation method and the final maps obtained through interpolation of sample points.[21] As for the process of testing and evaluating the constructed model in this method, each point was excluded from the list once in a row during point interpolation and did not participate in interpolation. In the next step, after creating the model, the variable parameter of this point was compared with the variable parameter of the prediction model, and its error was calculated subsequently. This step continues until all points are evaluated once. Finally, the accuracy of the final model is obtained by calculating the RMSE value based on Equation (4).[22]

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left[Z(si) - z(si)\right]$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[Z(Si) - z(si)\right]^2} \quad \text{Equation (4)}$$

Where, Z (Si) stands for the predicted value, z (si) for the actual value, i^{th} point for the assessment of points, n for the number of assessment points, ME for the mean prediction error, i for the number of assessment point and Si for the position of i^{th} assessment point. The ME value accounts for the bias value of the predicted model, which should be close to zero, and the RMSE value should be minimal.

Results

Table 1 shows the results of field measurements of air pollutant concentrations in the studied stations and the measured pollutant concentrations. According to the measurement of SO_2 concentration, the highest concentrations were 10.9, 10.7, 10.3 and 10.2 ppb at stations 28, 1, 2 and 30, respectively, corresponding to the south of the study area in Sharif, Daryan-e-No and Tohid neighborhoods. The lowest concentration was reported to be 5.1 ppb at stations 5 and 25. The highest concentrations of NO_2 pollutants were 54.6 and 52.7 ppb at stations 26 and 6, respectively, east of the study area in the Punak area, and the lowest concentration was reported to be 2.1 ppb at station 28 south of the study area. The highest concentrations of O_3 pollutant were 32.8, 32.2, 31.3 and 31.2 ppb at stations 15, 28, 23 and 20, respectively, in the southwest and south of the study area in Kuy-e Nasr and Sharif neighborhoods; the lowest O_3 concentration was 19.1 ppb at station 31 in Tohid neighborhood. The highest concentrations of CO pollutants were 31.9, 30.8 and 30.6 ppb at stations 15, 20, 23 and 28 in Kuy-e Nasr and Sharif neighborhoods, and the lowest concentrations of this pollutant were 16.3 and 16.6 ppb at stations 25 and 21 in Saadatabad and Asmanha neighborhoods in the northern part of the map.

AERMOD Modeling System

In the AERMET preprocessor, the meteorological data were used as the mean level of rainfall, cloud cover, atmospheric pressure, and ratio of air pressure to the surface of the high seas as surface characteristics,

Table 1: Concentrations of pollutants measured in this study

Stations	Parameters (ppb)				Stations	Parameters (ppb)			
Number	CO	O_3	NO_2	SO_2	Number	CO	O_3	NO_2	SO_2
1	29.3	30.6	3.1	10.7	17	24	23.8	14	9.9
2	19.6	19.8	7	10.3	18	17.1	27.7	51	5.2
3	28.7	27.6	27.2	9.7	19	16.9	27.7	50.9	5.2
4	26.5	26.2	24.9	9.2	20	30.8	31.3	34.8	8.6
5	25.4	27.1	41.7	7.8	21	16.6	20.4	51.5	5.1
6	22.6	26.8	52.7	6.4	22	25.9	26.4	37.3	7.9
7	18.6	21.9	48.8	5.7	23	30.8	31.2	37.9	8.2
8	25.9	26.4	34.1	8.4	24	28.3	28.4	27.1	9.1
9	19.5	22.3	48	6.4	25	16.3	20.2	51.8	5.1
10	20.7	24.1	49.6	6.2	26	24.3	28.7	54.6	6.5
11	17.6	21	49.9	5.5	27	25.1	26	41.8	7.2
12	24.2	25.5	42.4	7.2	28	30.6	32.2	2.1	10.9
13	19	21.8	48	6	29	20.4	23.4	48.3	6.2
14	19.5	22.8	48.7	5.9	30	26.7	27	15.7	10.2
15	31.9	32.8	35.1	8.7	31	21.2	19.1	15.9	9.8
16	26.3	26.1	26	9.1	32	26.8	26.7	23.9	9.4

Table 2: Monthly levels of atmospheric variables in 2017 at Chitgar station (Source: Iran Meteorological Organization)

Variable/month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Wind speed	1.21	1.86	2.22	2.46	2.62	1.81	1.65	1.48	1.71	1.73	1.27	1.03
Temperature	4.4	6.8	11.58	17.73	23.61	29.31	31.40	31.25	27.13	20.72	11.71	6.67
Relative humidity	60	48	40	37	28	23	25	24	24	30	47	62

Table 3: Surface parameters used in this study

	Surface roughness (meters)	Bowen ratio (dimensionless)	Albedo (dimensionless)
Mean	1	1.625	0.27
Spring	1	1.5	0.35
Summer	1	1	0.14
Fall	1	2	0.16
Winter	1	2	0.18

and dew point temperature, temperature, wind direction and speed, as well as humidity percentage for preprocessing, as displayed in Table 2. Table 3 shows the surface parameters as input for modeling pollutants.

Calculating the concentration of CO, O_3, NO_2 and SO_2 pollutants (in ppb) in AERMOD and GIS software showed that higher concentrations of CO indicate the accumulation of this pollutant in the study range of 25 to 138 ppm in 1-hour state and from 10 to 54 ppm in 8-hour state. The O_3 concentrations range from 12 to 139 ppb in the 8-hour state and from 4.68 to 54.8 ppb in the annual state. The highest NO_2 concentrations are obtained from about 6.5 to 46 ppb for the 1-hour state and from about 2 to 18 ppb for the annual state. The highest concentration of this pollutant in the 24-hour state is from 3.5 to 55.5 ppb.

Zoning with IDW Interpolation Method

The zoning map in Figures 2-5 shows the concentrations of CO, O_3, NO_2 and SO_2 (in ppm) in the region. The highest CO concentration in the zoning map is obtained from about 24.5 to 32 ppm, and the lowest from about 16 to 24 ppm. In the zoning maps, the highest O_3 concentration is around 27 to 31 ppb and the lowest is around 21 to 24 ppb. The highest NO_2 concentration is obtained from about 37 to 55 ppb and the lowest from about 2 to 20 ppb. The highest SO_2 concentration was obtained from about 9 to 11 ppb and the lowest from about 5 to 7 ppb.

According to Table 4, the comparison of predicted concentrations at the ground surface obtained from the sources with the results obtained from the measurements at the monitoring stations in 2018 showed that the modeling could be useful to determine the dispersion of pollutants in the study area.

According to Figure 4, the lowest concentration of NO_2 in the northern part was noticeable due to the presence of altitudes and wind currents, as well as less

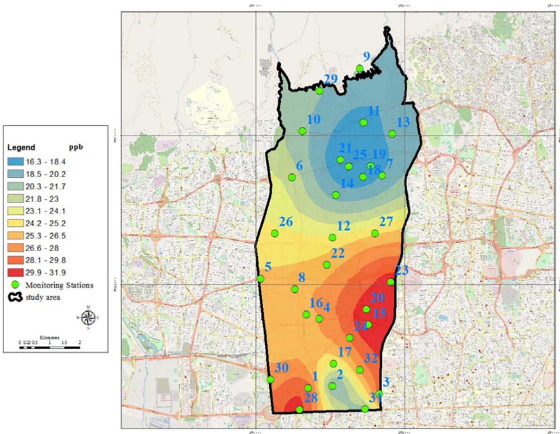

Figure 2: Interpolation map for CO pollutant concentration (ppm) in district 2 of Tehran, Iran

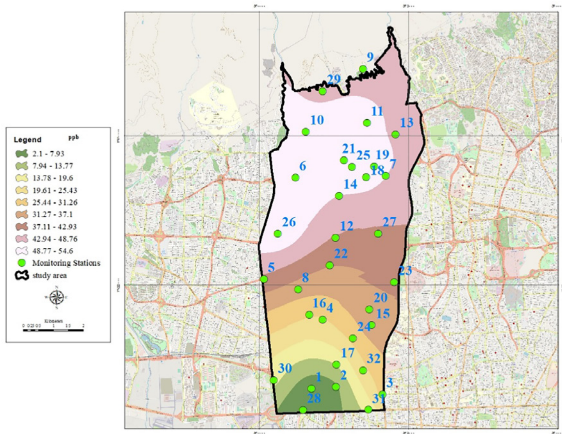

Figure 3: Interpolation map for O_3 pollutant concentration (ppb) in district 2 of Tehran, Iran

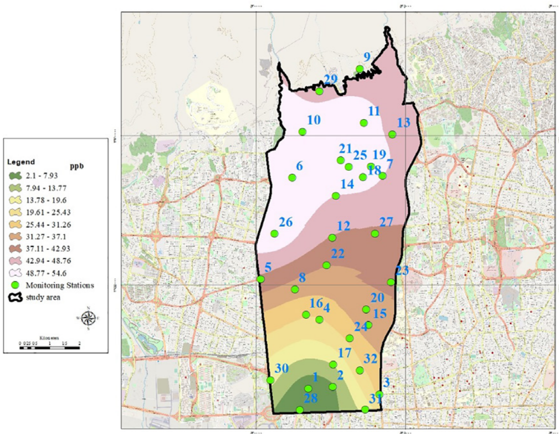

Figure 4: Interpolation map for NO_2 concentration (ppb) in district 2 of Tehran, Iran

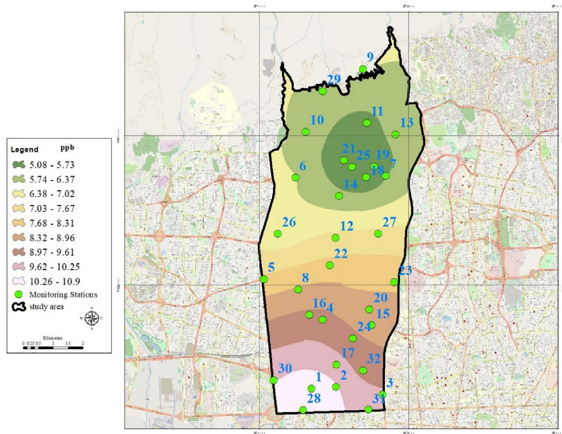

Figure 5: Interpolation map for SO_2 concentration (ppb) in district 2 of Tehran, Iran

Table 4: Validation of model outcomes for pollutants

Statistical parameters	Optimal range of model accuracy	Pollutants			
		CO	O_3	NO_2	SO_2
CCOF	~1	0.85	0.87	0.91	0.89
NMB (%)	−~+∞	-0.32	-0.38	-0.41	-0.36
NME (%)	0~+∞	0.54	0.51	0.39	0.38

Table 5: Clean Air Standard (WHO, 2015)

Pollutants	Mean duration	Standard	Number of items higher than standard in AERMOD model zoning
Carbon monoxide (CO)	1 hour	35000	2
	8 hours	9000	3
Sulfur dioxide (SO_2)	24 hours	37	1
	1 year	7	2
Nitrogen dioxide (NO_2)	1 hour	100	0
	8 hours	53	0
Ozone (O_3)	24 hours	70	1
	1 year	5.7	3

vehicle traffic, so that in the southern part and other areas, due to high traffic and lack of air movement, an increase in its concentration was observed. This pollutant was not found in any of the areas above the standard definition of clean air in Table 5.[23]

Discussion

The severity of CO pollution in the south of the region was observed in Sharif and Daryan-e-No neighborhoods due to incomplete combustion of fuels, which is consistent with other similar studies.[24] Considering the existence of Alstom power plant and the main and busy routes of Azadi and Tohid streets and Yadegar-e Imam highway, due to the prevailing wind and urban fine texture of this region, an increase in the concentration of this pollutant is not unexpected. Similar studies have confirmed these results.[25] According to Figure 2, the concentration of CO has decreased to the north of the region in the neighborhoods of Faraz, Parvaz, Farahzad and Saadatabad due to the altitude of these areas. It should be noted that the concentration of pollutants in other areas also decreases with distance from the streets, which is the result of concentrations from different linear sources, and is consistent with the findings of Zhang and Batterman in 2010.[26] Ashrafi et al. (2012) determined and modeled the dispersion of volatile organic compounds evaporated from storage tanks located in Assaluyeh, Iran, and found that the highest concentrations occur at all-time averages, at an altitude of 20m above the ground; however, in the first half of 2009, the northwest wind and in the second half of 2009 the southeast wind affected the region more.[27] According to Table 5, the regions with unauthorized air pollution with CO concentration are noticeable in a period of 8 hours. High concentrations of O_3 are evident in the southern part of Sharif and Daryan-e-No neighborhoods, which have decreased to the north of the region (Figure 3). The sources of this pollutant are vehicles and transportation systems, which is consistent with Chen et al.'s results in 2020.[28] The significant increase in NO_2 concentration was observed due to the proximity of this region to District 9 of Tehran Municipality and the presence of busy streets and highways in this region, as well as the prevailing wind direction from west to east. In particular, the highest concentration of this pollutant was observed in the central part of Shahrak-e Gharb area due to increased traffic and proximity to Shahid Hemmat Highway, which has heavy traffic during many hours of the day and night, in line with a study by Mohseni Nameghi in 2013.[29]

Figure 5 also shows the highest concentration of SO_2 in the southern part of the region and in Tarasht and Sharif neighborhoods; the concentration of this pollutant decreases gradually towards the center and north of the region. Some of the factors that increase this pollutant in these areas can be attributed to the existence of small workshops and high traffic of Azadi and Yadegar streets and Sheikh Fazl-allah Nouri Expressway; this is in line with the findings of Sun et al.'s study in 2018.[30] Increasing fossil fuel consumption and weather inversion in cold seasons has a significant effect on increasing the concentration of this pollutant on an annual basis, which is consistent with the results of studies by Trinh et al. in 2019.[31] According to Table 5, the annual NO_2 concentration in two regions and the 24-hour concentration in one region was higher than the standard. The results of the present study indicated higher concentrations of accumulation of these pollutants in Sharif and Daryan-e-No, Tarasht and Kuy-e Nasr neighborhoods in the south of the study area due to the fine texture of these regions, increased traffic, increased traffic of motor vehicles and proximity to other municipal regions, and high traffic of the mentioned regions. Statistical evaluations of CCOF, NMB, and NME were consistent with the results of validation measurements of the studied parameters around District 2 of Tehran Municipality, which is in line with the results of the studies carried out by Jafarigol et al. in 2016.[32]

Conclusion

In this study, the IDW method had the most appropriate ME, indicating the lowest bias compared to other methods used due to the process of predicting unknown points based on spatial correlation in this method and heterogeneity of known points in the present study.

Conflict of interest: None declared.

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