Int. J. Hum. Capital Urban Manage., 1(4): 295-300, Autumn 2016
DOI: 10.22034/ijhcum.2016.04.007

CASE STUDY

Estimation of exposure to fine particulate air pollution using GIS-based modeling approach in an urban area in Tehran

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Received 8 June 2016; revised 14 August 2016; accepted 26 September 2016; available online 1 October 2016

ABSTRACT: In many industrialized areas, the highest concentration of particulate matter, as a major concern on public health, is being felt worldwide problem. Since the air pollution assessment and its evaluation with considering spatial dispersion analysis because of various factors are complex, in this paper, GIS-based modeling approach was utilized to zoning $PM_{2.5}$ dispersion over Tehran, during one year, from 21 March 2014 to 20 March 2015. The RBF method was applied to obtain the zoning maps and determining the highest concentration of $PM_{2.5}$ in the 22 Tehran's regions for each season. The $RMSE_{min}$ values according to the number of neighbors and types of functions in the radial basis function method, including completely regularized spline, Spline with tension, Multiquadric function, Inverse multiquadric function, and Thin-plate spline for each month have been assessed. By performing analysis on the errors, the numbers of neighbors were estimated. The numbers of neighbors in the model for each function were varied from 2 to 30. The results indicate that the models with 3 and 4 neighbors have the best performance with the lowest RMSE values with using RBF method. The highest $PM_{2.5}$ concentrations have been occurred in the summer and winter especially at the center, south, and in some cases at northeast of the city.

KEYWORDS: *Air pollution; Completely regularized spline (CRS); Inverse multiquadric function (IMF); Multiquadric function (MF); $PM_{2.5}$ concentrations; Radial basis function (RBF) method; $RMSE_{min}$; Spline with tension (SWT); Tehran's regions; Thin-plate spline (TPS)*

INTRODUCTION

Over the past few decades, the issue of particular matter (PM) had increasing negative impacts on human health and environment, due to population growth, energy utilization, global urbanization and industrialization all over the worlds (Zhang *et al*., 2012; Liu *et al*., 2013; Han *et al*., 2014; Hu *et al*., 2014; Huang *et al*., 2014; Lary *et al*., 2014; Lin *et al*., 2014; Song *et al*., 2015; Wang and Ogawa, 2015; Trizio *et al*., 2016). The coarse particles are mixture of various materials which may include metals, ions, minerals, organic content, PAH, soot, microorganism, etc. The air quality index with considering PM has exceeded the standard values at more regions in Tehran as an industrialized area.

The researches in the air pollution fields have indicated that an effective solution to dispersion modeling of PM is the application and implementation of a geographic information system (GIS) in which measured data after analyzing can be used for obtaining the zoning maps (Cyrys *et al*., 2005; Saleh, 2014).

In recent years, inhabitants of metropolitan Tehran have suffered air pollution in high levels, as well as serious environmental damages causing increase of mortality in a steady state. (Nayeb Yazdi, 2015). In this study, to assess environmental air pollution through

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Tehran city, monthly recorded $PM_{2.5}$ concentration datasets, during one year, from 21 March 2014 to 20 March, 2015 have been collected. To normalize huge number of data, avoiding less effective values, the lag effects are filtered and the concentration data have been implemented on rush hour values upon weighted coefficient. To develop spatial dispersion maps of $PM_{2.5}$ over Tehran using radial basis function (RBF) method and evaluation the sensitivity of its parameters, the authors used the monthly average concentration of $PM_{2.5}$. Accordingly, GIS technics help determine the highest levels of $PM_{2.5}$ concentrations in the Tehran's regions.

MATERIALS AND METHODS

Case Study

Tehran city with a population of around 9 million is the capital of Iran and center of Tehran province. (Statistical Centre of Iran, 2012) Tehran Meteorological Station specifications with longitude of 51.23N and latitude of 35.44E with a height of 1419 meters from the sea level have been considered in this research. (Vakili *et al.* 2015) This city has been divided into 22 districts, as the largest city and urban area across Iran, the 2nd-largest city in Western Asia, and the 3rd-largest in the Middle East. (WHC; 2016, Memarianfard *et al.*, 2017) The annual mean rainfall is about 230 mm during four seasons of year. The average annual temperature is 17-°C. The maximum yearly temperature is 39°C in summer and -6 °C in winter. The annual mean humidity is 40% and the highest monthly average humidity is 65% in January and the lowest mean is 24% in July and August. (Alizadeh-Choobari *et al*., 2016a; Alizadeh-Choobari *et al*., 2016b; Lalehpour, 2016) This so wide range of yearly climate changes makes the overall environmental situation complicated in Tehran. Some of effective factors making the situation complicated are: The climatological and topographical conditions of the city which is surrounded from North and East sides by mountains, contributing to low winds and low rainfall. On the other side, lack of the rationalized and justified public transportation system, time wasting administrative serviceability, old system of bureaucracy, mostly use of fossil fuel for heating and energy, obsolete transport vehicle technology and high average life of a vehicle fleet, the large number of private cars, minibuses, buses, vans, trucks, and motorcycles, low fuel prices subsidized by the government causing little incentive for fuel conservation, low quality of fuels, low proportion of trees and green areas, litter incomplete burning during nights at city sides, general heavy traffic due to poor urban planning, not observing the traffic rules by the public which has contributed to congested road space, poor municipality knowledge and training level, and finally, the economic and social problems caused in part by the population growth due to the immigration to the capital, and unsatisfactory levels of public awareness on environmental issues. (Lalehpour, 2016; Redzuan *et al*., 2013) There are 22 climatological stations to measure and monitoring air pollutants, across Tehran. Unfortunately, only 19 stations are able to measure $PM_{2.5}$ emissions. (Memarianfard *et al.*, 2017) The geographical map of Tehran and the locations of the ambient air pollution Monitoring stations with considering $PM_{2.5}$ have been shown in Fig. 1.

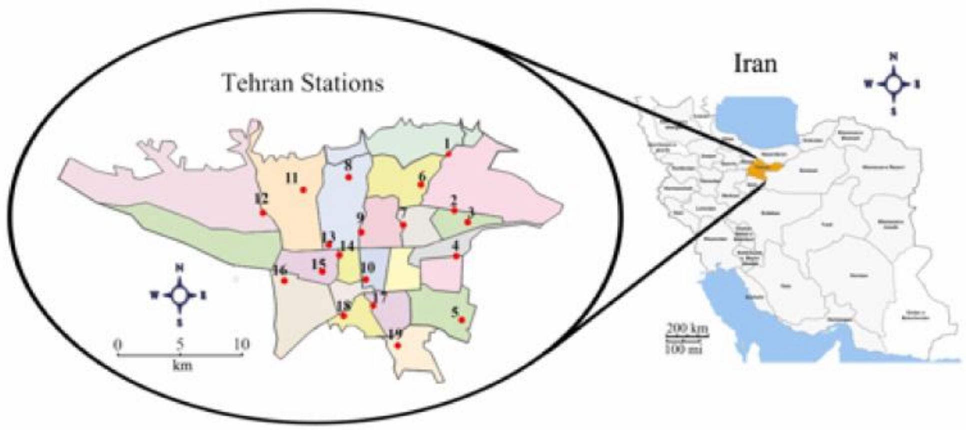

Fig. 1: The study area of research performance and air pollution monitoring stations in Tehran City

Method scheme

To assess environmental air pollution through Tehran city, during one year, from 21 March 2014 to 20 March 2015, monthly recorded $PM_{2.5}$ concentrations have been collected. To normalize huge number of data, avoiding less effective values, the lag effects are filtered and the concentrations have been implemented on rush hour values upon weighted coefficient. To develop spatial dispersion maps of $PM_{2.5}$ over Tehran using RBF method and evaluation the sensitivity of its functions, the authors used the monthly average concentrations of $PM_{2.5}$.

The RBF interpolation fits a minimum-curvature surface through the input points using piece-wise functions. Conceptually, just like a rubber sheet that is bent around the sample points, it fits a mathematical function to specified number of nearest points exactly. At the same time, it ensures that the joints between one part of the curve and another are continuous through averaging, while minimizing the total curvature of the surface. This method is the best for gently varying surfaces such as elevation, water table heights, or pollution concentrations.

In the RBF network, the Gaussian function is often used as the nonlinear transfer function in the hidden layer (Lu *et al.*, 2004).

RESULTS AND DISCUSSION

In this research, the $RMSE_{min}$ values according to the number of neighbors and types of functions in the RBF method, such as completely regularized spline (CRS), Spline with tension (SWT), Multiquadric function (MF), Inverse multiquadric function (IMF), and Thin-plate spline (TPS) for each month have been assessed. Results of the $RMSE_{min}$ assessment versus the number of neighbors and types of functions, such as CRS, SWT, MF, IMF, and TPS are shown in Fig. 2 and the corresponding values are presented in Table 1.

Also, Fig. 3 shows number of $RMSE_{min}$ for each number of neighbors with regards to all types of stated functions.

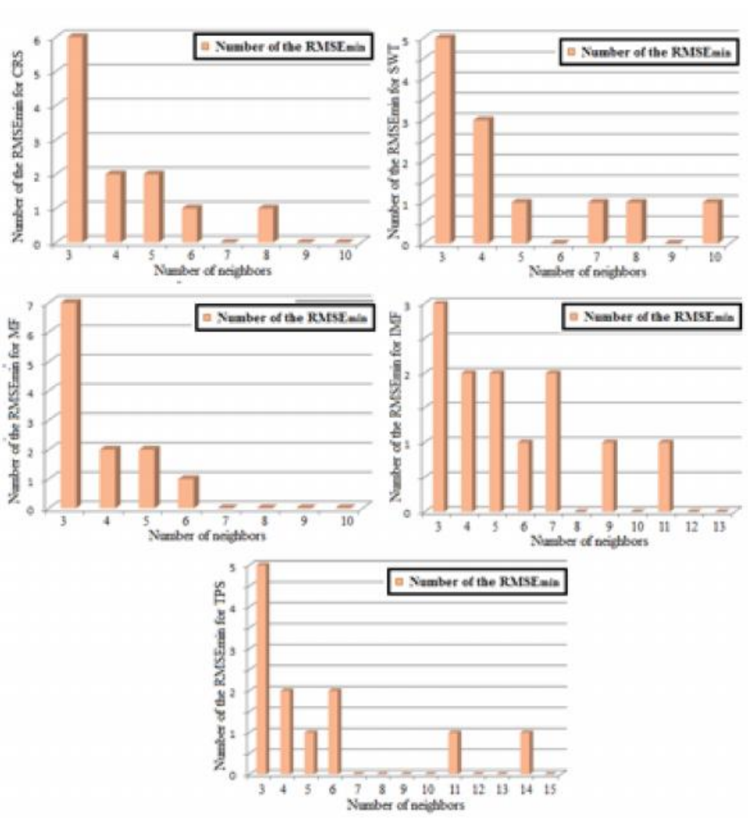

Fig. 2: Results of the $RMSE_{min}$ assessment versus number of neighbors and type of functions, including CRS, SWT, MF, IMF and TPS

Obviously, neighbor number 3 can be introduced as the best case due to presenting the maximum number of minimum root of mean square errors. In this research, the results of the zoning maps modeling of fine particulate air pollution using GIS-based method with considering $PM_{2.5}$ have been presented. For calculation purposes, RBF application was utilized to obtain Tehran's zoning maps. The spatial dispersion of $PM_{2.5}$ concentrations contours maps upon the use of RBF method during the months of summer seasons in Tehran's regions are shown in Fig. 4. Also, similar maps for the 3 months of winter are shown in Fig. 5. Clearly, the most critical zones for these two season times are at the center, south, and in some cases at northeast of the Tehran city, while the clean area are north, north-west, and in some cases across north-east zones due to the existing fresh wind entrance and circulation path.

Table 1: Total number of the $RMSE_{min}$ versus five functions: CRS, SWT, MF, IMF, and TPS and the number of neighbors from 3 to 15

Number of neighbors	CRS	SWT	MF	IMF	TPS	Total
3	6	5	7	3	5	26
4	2	3	2	2	2	11
5	2	1	2	2	1	8
6	1	0	1	1	2	5
7	0	1	0	2	0	3
8	1	1	0	0	0	2
9	0	0	0	1	0	1
10	0	1	0	0	0	1
11	0	0	0	1	1	2
12	0	0	0	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	1	1
15	0	0	0	0	0	0

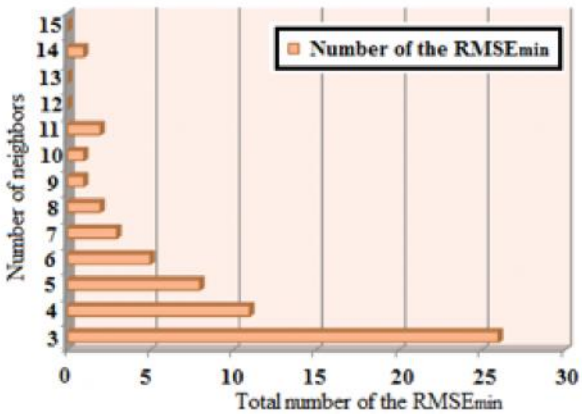

Fig. 3: Results of the $RMSE_{min}$ assessment with considering number of neighbors and total number of the $RMSE_{min}$ for all types of functions, including CRS, SWT, MF, IMF, and TPS.

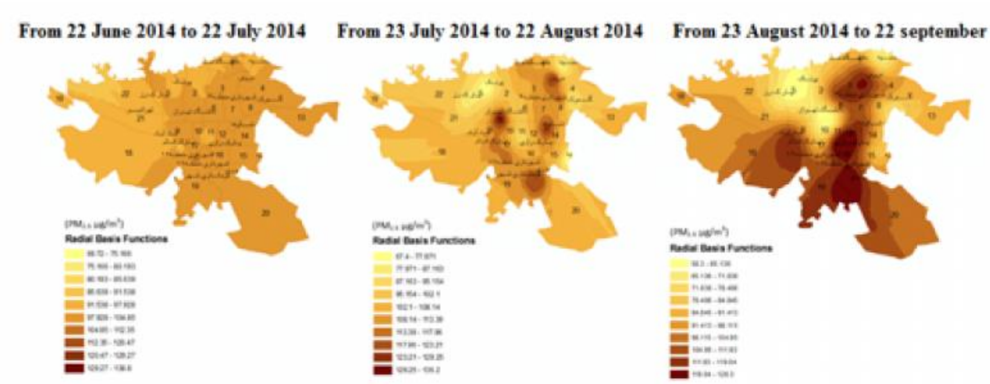

Fig. 4: Model results of fine particulate air pollution contours map using RBF-based approach for $PM_{2.5}$ monthly averaged for three months of summer season in Tehran

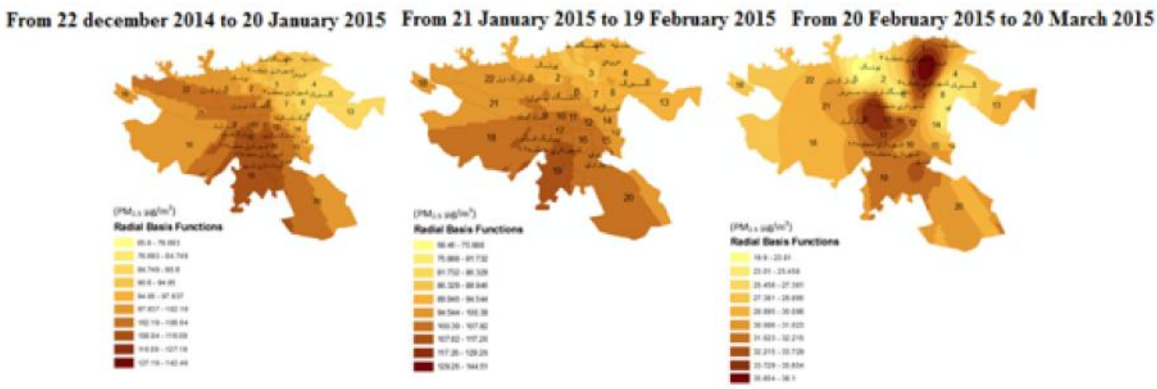

Fig. 5: Model results of fine particulate air pollution contours map using RBF-based approach for $PM_{2.5}$ monthly averaged for three months of winter season in Tehran

CONCLUSION

A GIS-based method was proposed for developing the zoning maps can be used as an idea for presenting distribution of air pollution over an industrialized city. In this research, the proposed model results are as $PM_{2.5}$ concentrations contours maps across any city, presenting averaged values during a certain period of times or at any certain specific time lead to control zonal urban air quality of cities.

Upon the use of certain numerical algorithms, by performing analysis on the errors, the numbers of neighbors corresponds to number of $RMSE_{min}$ were estimated to carry out the case of neighbor with maximum number of $RMSE_{min}$ participating in error estimation. The numbers of neighbors in the model for each function introduced as RBF were varied from 2 to 30. The model results indicate that the case with 3 and 4 neighbors have the best performance with the lowest RMSE values and the most number of $RMSE_{min}$ with using proposed functions.

According to proposed method, the highest $PM_{2.5}$ concentrations have been carried out and presented in the summer and winter times, especially at the center, south, and in some cases at northeast of the Tehran city which are the most critical zonal and times.

ACKNOWLEDGEMENT

The authors would like to thank the *anonymous reviewers* for their valuable comments and suggestions to improve the manuscript.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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