Original Article

Spatial Analysis and Source Identification of PM_{10} Particle Matter in Yazd

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Received: 2015/11/12 **Accepted:** 2016/02/15

Abstract

Introduction: This study aimed to spatially analyze PM_{10} concentrations in the ambient air in Yazd during two seasons, and mapping by the using Kriging interpolation method. Moreover, different factors affecting the concentrations of PM_{10}were marked and standards were also investigated.

Materials and Methods: Measurement of PM_{10} particulates was performed by the monitoring device HAZ-DUST EPAM 5000. In the present study, 13 sampling stations were identified in various areas of the city in order to take samples of PM_{10} in winter and spring in 2013. Eventually, Arc GIS software, kriging interpolation method and spatial autocorrelation were used for PM_{10} spatial distribution.

Results: The spring seasonal mean of PM_{10} (155µg/m^3) was reported to be higher than its amount in winter (27.87µg/m^3). At 11 stations (out of 13 stations), PM_{10}concentrations were higher than the WHO standards in winter. Seasonal mean of PM_{10} concentrations in spring exceeded WHO standards in all stations. Particulate matter levels were higher in high-traffic and old areas compared to other regions. RMSE index was reported 45.493 and 56.525 in winter and spring, respectively.

Conclusion: PM_{10} concentration revealed the random spatial pattern in the two seasons. This study revealed traffic and historical places affecting the PM_{10} concentration.

Key words: GIS; kriging; Particulate matters;

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Introduction

Regarding the cities expansion and population increase, every year, thousands of mortalities are fixed by the acute effects of air pollution. The major cause of this pollution can be excessive traffic and vehicles used in the industrial development, which can lead to increased consumption of fossil fuels and consequently, the impure air will be ascending. Despite the fact that the presence of very low concentrations of air pollutants within the standard ranges should not have adverse effects on human health, it can be harmful to the sensitive groups [1]. However, pollution due to fuel combustion process in the developed countries has significantly decreased during recent years and the new air pollutants have newly emerged as the greatest health concerns in the urban areas such as ozone, NO_2, as well as changes in the distribution and size of particulate matters. Some of these particles are produced by the incomplete combustion of fossil fuels which can pollute the soil through precipitation after emitting into the atmosphere. On the other hand, environmental pollution caused by industrial activities, such as Petrochemical, Oil and similar industries occur in the soil [2]. Epidemiological studies show that air pollution in cities in the past two decades has led to breathing problems, heart disease, chronic bronchitis and even mortality [3]. Results of different studies indicate biological mechanisms of pollutants that affect human health, have not been yet clearly identified, which are likely to be the result of pollutants oxidation potential from two directions: the direct effects on the cellular components of the airways and the oxidation of the activated intracellular routes[4]. WHO's reports show that particulates smaller than 10 microns and SO_2 can cause respiratory and cardiovascular diseases such as asthma, bronchitis, heart attacks, lung function interference and even mortality, as mortality caused by particulate matters smaller than 10 microns in some cities in Europe consequently causes an increase of 6% in mortality [5]because of an increase in the concentration of 10 micrograms per cubic meter. Different methods have been introduced in order to estimate air pollution, among which integrating air pollution monitoring station data by spatial analysis methods can be mentioned[6]. Kriging model can be placed among the most commonly used methods of spatial analysis. This interpolation method is based on regression, which not only focuses on the distance between the measured points, but it also focuses on the correlation between the measured points [7, 8]. In a study conducted on air quality in Mashhad, Akbari et al.[7], using IDW interpolation method based on the PSI index,proposed that the air quality was very unhealthy and dangerous in Spring 2008, and the unhealthy situation was generally reported in all the seasons. In the present study, particulate matters and carbon monoxide were used to determine the PSI index. In another

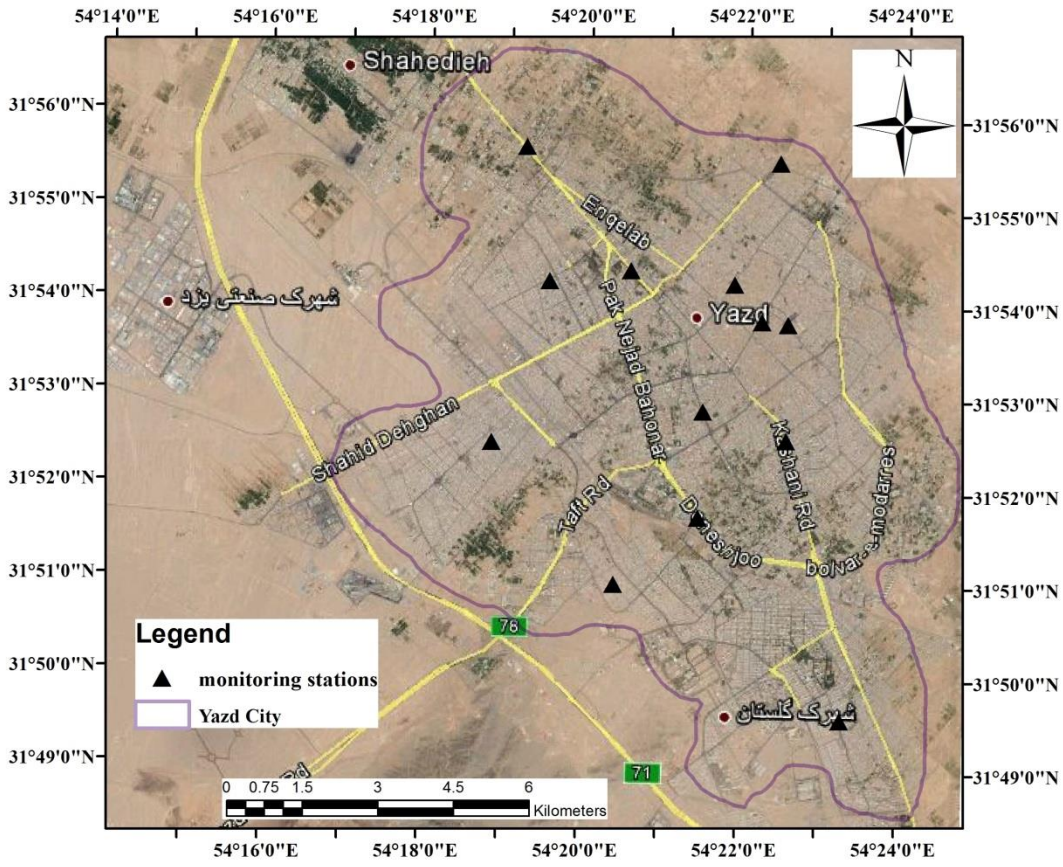
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study conducted by Jahanshiri in Mashhad in 2008 [9], the concentration of carbon monoxide and particulate matters were reported higher than the other pollutants. In fact,This study was aimed to do a spatial analysis of PM_{10} concentrations in the ambient air of Yazd in the winter and spring and mapping via using Kriging interpolation method. Finally, different factors affecting the concentrations of PM_{10}have been marked and some standards have been investigated.

Materials and Methods

The Study Area

Yazd is the most populous city as well as the political and administrative capital of Yazd province which is located at latitude of 54º and longitude of 31º in the center of Iran. The population in Yazd is 560,000, of which, 500,000 people live in the urban areas and the rural population is about 60,000. The climate is hot and dry with a desert situation and the annual rainfall is 50 mm. Figure 1 shows the area under investigation and the sampling points.



Figure(1) Study area and sampling location

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Data collection

Measurement of PM_{10} was performed by the monitoring device HAZ-DUST EPAM 5000. This device has the capability to quickly respond and record the information related to harmful particles that can affect respiratory system. Regarding weight studies, according to EPA and TEOM, this device measured individual particles to measure the particulate separator with 47 mm filters, measured in two ways: light and weighting. Display of measured data and the ability to transfer information directly, graphic profiles of measured data and set up in less than 15 seconds can be named as the advantages of the device. The sampled air is passed through an optical sensor, and then the sampled air passes through a 7 mm weighted filter that installed exactly after the optimal sensor. The filter is designed according to EPA standards. Using the device is really simple, which can be quickly set up used to measure PM_1, $PM_{2.5}$, PM_{10}, and TSP. Thirteen sampling stations were selected done in the open air, according to EPA standards at a distance of 20 meters from the street and other sources of pollution at an elevation of 15 meters above the ground level. Sampling locations were selected based on proximity to the industrial areas, a low-traffic area, an area with continuous traffic, high traffic area and suburb. In the winter and spring of 2013, the samples were taken randomly for one week per month and finally the seasonal mean of PM_{10} was used in regard with modeling and spatial analysis.

Spatial Analysis

To analyze spatial data related to the PM_{10}concentrationin the air, Yazd software Arc GIS 10.1 was used produced by ESRI Company. To assess the arrangement of PM10 concentration data in space, to see whether their distribution is arbitrary or not, and to show the correlation between points and spatial changeability of the studied phenomena (air quality), autocorrelation analysis (Moran's index) of the model was utilized.

Kriging Method

Kriging is an interpolation technique in which the surrounding measured values are weighted to derive a predicted value for an unmeasured location. The weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points. Kriging is regarded unique among the interpolation methods in that it provides an easy method for characterizing the variance, or the precision of predictions. As a matter of fact, it is based on the regionalized variable theory, which assumes that the spatial variation in the data being modeled is homogeneous across the surface. That is, the same pattern of variation can be observed at all locations on the surface [10]. In general, the success of this method in the interpolation of variables, totally depends on the chosen model with semivariogram experimental data. If the chosen model is not sufficiently accurate, interpolation results cannot be appropriate. In some cases, due to such reasons as lack of spatial harmonic general structure, low accuracy

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of data and spatial heterogeneity of the data, the results of this approach are not sufficiently accurate. To investigate the changes in the spatial and temporal concentration of PM_{10} in the air of Yazd, ordinary kriging method was used, which uses spatial correlation phenomena structure for estimating spatial distribution. The ordinary kriging method can be considered in regard with interpolation of each point in the specified range of points. It should be noted that coordinates of the points are sampled in the UTM system. General equation is as follows:

(1) $$Z*(xi) = \sum_{i=1}^{n} \lambda i \, z(xi)$$

Where Z*(xi) is grade estimation, iλ is weight or importance relative units of i and z (xi) is the value of measured variable.

Evaluating the Correctness of Used Model and Variogram

Model validation was performed using the following evaluation criteria (11):

(2) $$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(q_i - \hat{q}_i)^2}$$

(3) $$\%\,RMSE = \left(\frac{RMSE}{\mu}\right) \times 100$$

Where *n* is the number of data, *qi* is the measured value, $\hat{q}i$ is the value predicted by the model and μ is the mean of each factor being measured. The RMSE (Root Mean Square Error) can be applied in optimal estimation or in a case where both the estimated and measured values are equal to zero. The smaller the RMSE, the safer the predictive interpolation method will be. Since RMSE is sensitive to outlier data, RMSE% can be used. Acceptable RMSE% is 40 and RMSE% higher than 70% is a sign of uncertainty in estimating the large variations between the estimated and measured values (12).

Results

PM_{10} Concentration

A statistical summary of the sampling sites in Yazd is given in Table 1. Based on the information given in this Table, PM_{10} seasonal average concentration in spring (155µg/m3) is more than its amount in winter (27.87µg/m3). The maximum concentration of pollutants was observed at the Station No. 9 (297µg/m^3) in the spring, whereas the lowest concentration of PM_{10} was at the Station No. 3 in winter (µg/ m35. 8).

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Table 1: Summary statistics for PM_{10} air sampling stations in Yazd

Number of sampling stations	Name of sampling stations	Zone of sampling	PM_{10} Conc µg/m^3 (Winter)	PM_{10} Conc µg/m^3 (Spring)
1	Jomhouri Blvd	Industrial	71.5	57
2	Azad shahr	Industrial	91	163.5
3	Navab Blvd	Suburb	8.5	83
4	Motahari	Suburb	10	104
5	Golesorkh	Suburb	190	240.5
6	Imam St	Traffic jams	243	242
7	Taleghani Blvd	Traffic jams	21	122
8	Ta'avon	Traffic jams	24	120
9	Mahdi St	Continuous traffic	176	297
10	Kashani	Continuous traffic	71.5	146
11	Imam shahr	Continuous traffic	31	125
12	Razmandegan	Low traffic	148	216
13	Dashti Blvd	Low traffic	49	99
-	Mean	-	87.27	155
-	Minimum	-	8.5	57
-	Maximum	-	243	297

Spatial Distribution

Various semivariograms, two logarithmic methods and Box-Cox were used to normalize the data through spatial analysis and PM_{10} mapping via kriging method. Finally, based on the lowest RMSE, hole-effect semivariogram was applied for the data related to the winter (figure 2) and K-Bessel semivariogram along with Box-Cox normalization method was used for the data related to the spring (figure 3). Figures 4 and 5 demonstrate mapping of PM10 concentrations in winter and spring, respectively. Due to the ring road along the northwest to the southwest as well as the presence of industrial estates the city has a higher concentration of particulate matters in West and South West in winter. In spring, in addition to the West and South West, Eastern region also has high concentrations of PM_{10} pollutants. Northeast (sampling stations 5, 6 and 9) is located in the historical context that can raise the amount of pollution in this area in addition to a heavy traffic at Imam Street (Station 6).

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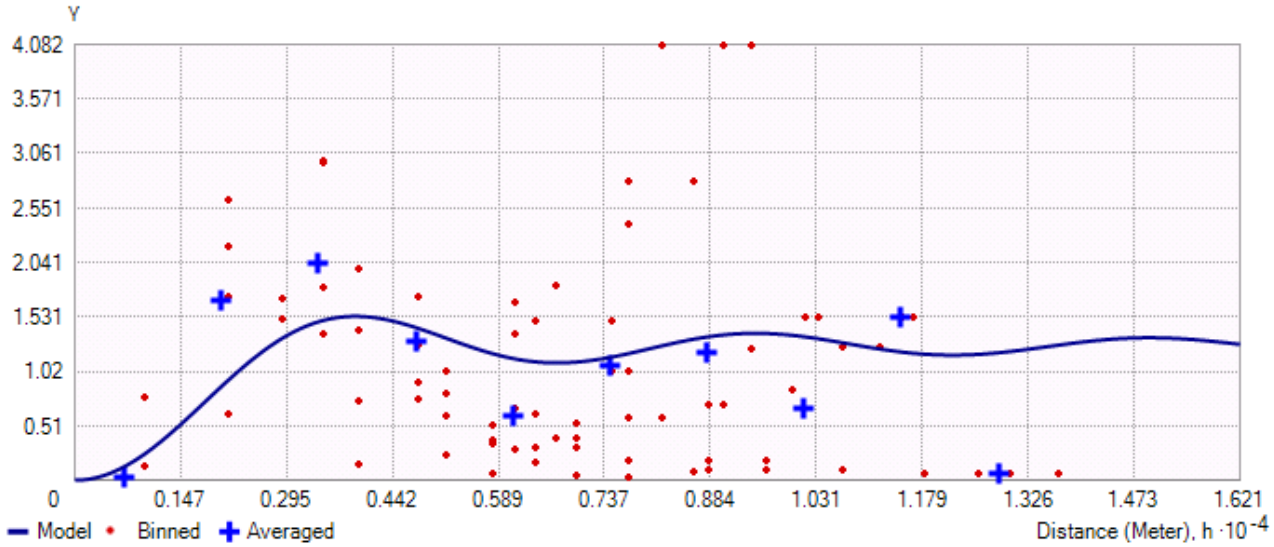


Figure (2) Hole-effect semivariogram for mapping PM_{10} concentration in the winter

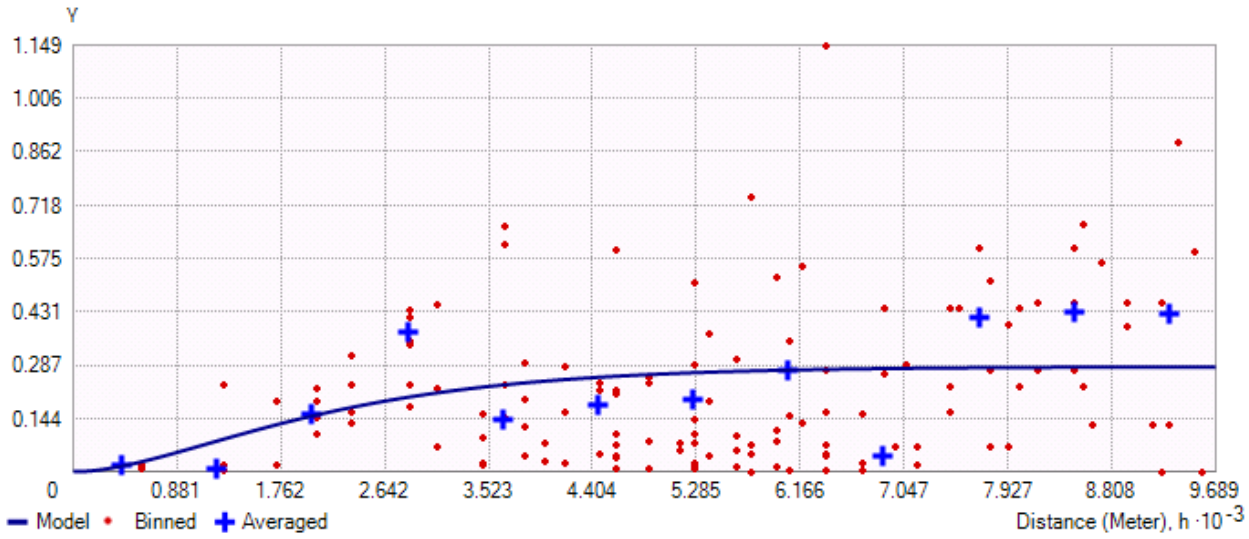


Figure (3) K-Bessel semivariogram for mapping PM_{10} concentration in the spring

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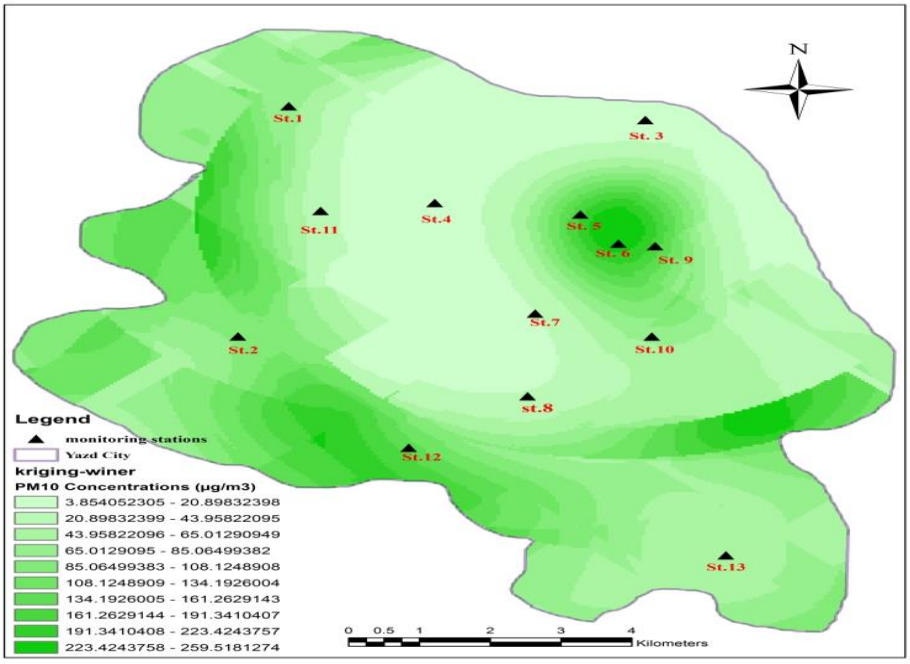


Figure (4). The mapping of PM_{10} concentrations via kriging method in winter

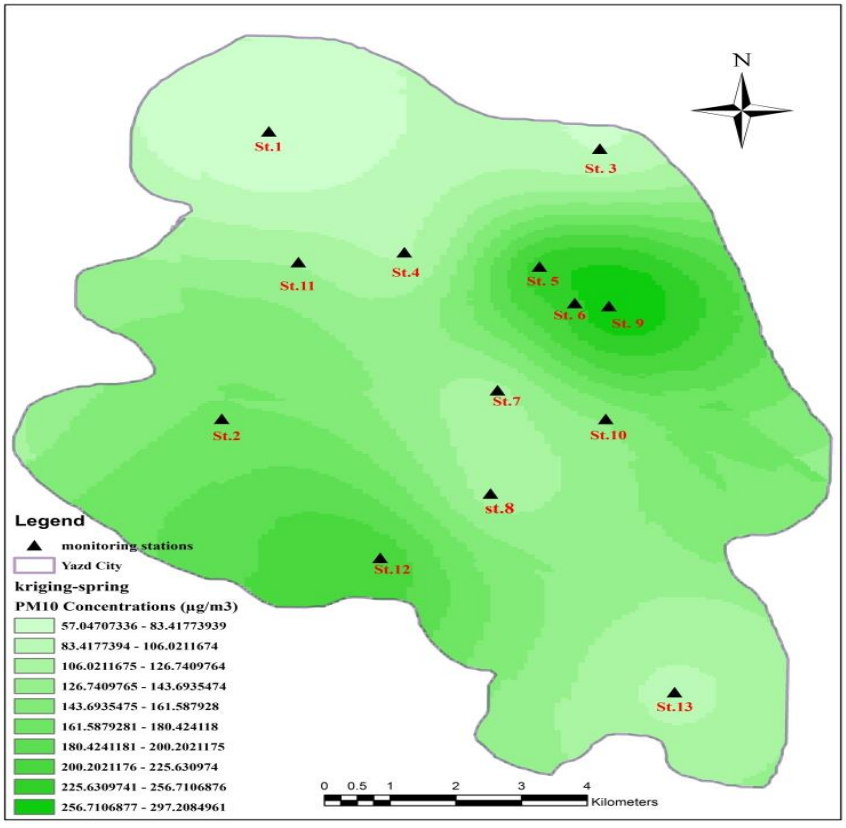


Figure (5). The mapping of PM_{10} concentrations via kriging method in spring

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To study the efficiency of Kriging model for zoning PM_{10} in Yazd, two RMSE and RMSE% indicators were also applied. RMSE values in winter and spring were reported 45.493 and 56.525, respectively. Due to lower data means in sampling sites and the absence of outliers, RMSE values seem to be smaller in the winter. RMSE% values were 52% in the winter and 36% in the spring that indicates an average efficiency of the kriging model with respect to zoning the particulate matter in winter and spring . The nugget to sill ratio was equal to zero for the two seasons.

Spatial Autocorrelations

In the present study, Moran's correlation was utilized. This factor demonstrates that the spatial pattern of the data is cluster-like, disperse, and/or random (See Table 2). Based on this statistical test, PM_{10} was concluded to have a random spatial pattern in winter and summer. Figures 6 and 7 illustrate the graphical Z value range for dispersed (z-score < -1.65), random (-1.65<z-score < 1.65), and clustered (z-score >1.65) spatial distribution patterns in winter and spring, respectively. Hence, the main source of PM_{10} concentration in Yazd seems to be mobile sources. On the other hand, the exhaust emissions might be taken into consideration as the main sources.

Table 2: Spatial autocorrelation (Moran's index) of PM_{10} concentration in Yazd

	Moran's Index	z-score	p-value	Distribution kind
Winter	0.039171	0.868503	0.385119	random
Spring	0.143817	1.608434	0.107740	random

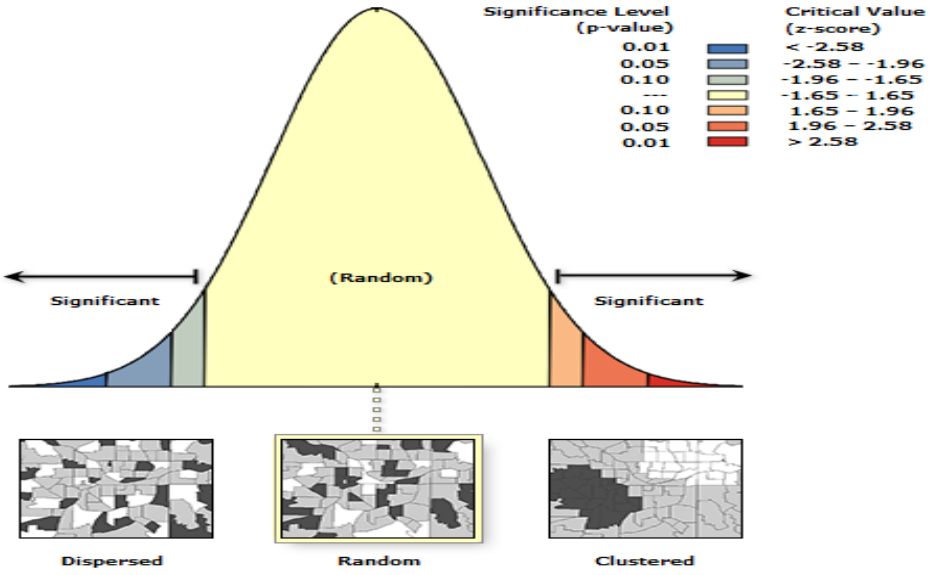


Figure (6) Spatial distribution pattern of PM_{10} concentration in winter

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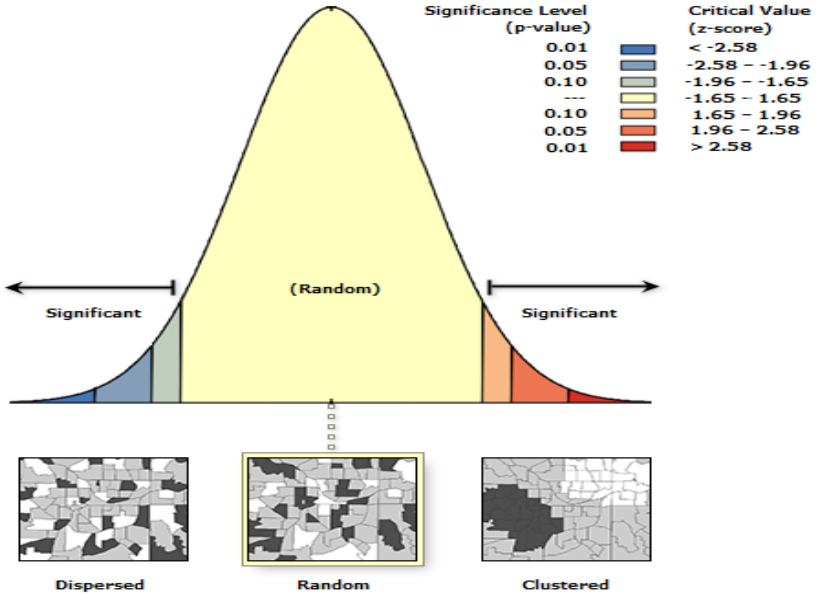


Figure (7) Spatial distribution pattern of PM_{10} concentration in spring

Discussion

Spatial analysis and PM_{10}concentration were studied in winter, in 2013 and in spring in 2014 in Yazd. The study samples were taken from different parts of the city and eventually, zoning was done using Kriging interpolation method. The mean concentration of PM_{10} in the spring was more than its concentration in the winter. Moreover, contaminant concentrations in the areas with heavy traffic and in the historical context of the city, as well as the areas close to the ring road, were held to be higher than the amounts in other areas. PM_{10} concentrations were higher than the WHO standards ($20\mu g/m^3$) [13] in winter at 11 stations out of 13 stations. Seasonal mean of concentrations in spring were exceeding WHO standards in all the stations. At station No.9, the concentration was 14.8 times higher than WHO standards in the spring. Shahsavani et al. [14] analyzed the dust input of the Khoozestan province and realized that the particulate concentration in dusty days increased to 16.5 times more than the standard level in Ahvaz. Hoseinzade et al. (2013) [15] in a study in Hamedan, reported that the mean concentrations of the total suspended particles (TSP), PM_{10} and $PM_{2.5}$ were 16, 7.72 and 4.7 times greater than the World Health Organization (WHO) air quality standard, respectively. Naddafi et al.[16], in a study conducted on the particulate matters in Yazd in 2007, proposed that the concentration of particulates in spring is higher than other seasons of the year that is in accordance with the findings of present study. Jamshidi et al. [17] in a study in 2005 also

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reported that the amount of particulate matter in February and April was reported to be higher than the amounts in the other months of the year. Due to %RMSE, Kringing model had a good performance in zoning PM_{10} in the ambient air. Several studies have revealed that Kringing model has a better performance in air pollution zoning compared to other interpolation methods. It has been demonstrated in a study conducted by Noorpour et al. [18] in Tehran, the spatial and temporal variations of sulfur dioxide, nitrogen dioxide and particulate matter were determined via applying GIS techniques. It is worth mentioning that capability of the ordinary kriging model among different models is much higher than other methods which is used for zoning the air pollution at the conditions where spherical semivaroigram with an RMSE of 17.47 is applied. In a study by Berman et al. [19], to evaluate different models of spatial analysis for zoning the concentration of ozone in America, R^2 and RMSE for the IDW and kriging model were 0.74, 8.163 and 0.79, 6.983, respectively. This study also showed a higher efficiency of Kriging model than IDW method in zoning the air pollution.

Conclusion

The present study demonstrated that traffic and location factors had a significant impact on the amount of particulate matters in the air. Areas with heavy traffic and the ones close to the main streets, as well as historic areas with mud can be influential in the increase of particles concentrations. It was also revealed that the concentration of particles in both winter and spring is higher than the WHO standards. As a result, in order to prevent the adverse effects of these pollutants on the inhabitants of the city, necessary arrangements such as developing the public transportation, replacing the old cars, increasing green areas, restoring historical context and giving health recommendations to people, should be taken into consideration especially on the days with high pollution.

Acknowledgements

The authors are pleased to express their sincerely gratitude to the laboratories at the School of Public Health in Shahid Sadoughi University of Medical Sciences of Yazd and all those who did not withhold their generous assistance to this research.

References

1. De Meij A, Thunis P, Bessagnet B, et al. The sensitivity of the CHIMERE model to emissions reduction scenarios on air quality in Northern Italy. Atmospheric Environment. 2009;43(11):1897-907.
2. Downs SH, Schindler C, Liu L-JS, et al. Reduced exposure to PM10 and attenuated age-related decline in lung function. New England Journal of Medicine. 2007;357(23):2338-47.
3. Fattore E, Paiano V, Borgini A, et al. Human health risk in relation to air quality in two municipalities in an industrialized area of Northern Italy. Environmental research. 2011;111(8):1321-7.

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4. Glinianaia SV, Rankin J, Bell R, et al. Particulate air pollution and fetal health: a systematic review of the epidemiologic evidence. Epidemiology. 2004;15(1):36-45.
5. Pollution WPMA. how it harms health. Fact sheet EURO/04/05, Berlin, Copenhagen, Rome. 2005;4:14.
6. Erxleben J, Elder K, Davis R. Comparison of spatial interpolation methods for estimating snow distribution in the Colorado Rocky Mountains. Hydrological Processes. 2002;16(18):3627-49.
7. Akbari E, Mohammadnia M, Mozaffari Zk. Modeling of Air Pollution in Mashhad City using PSI Index by GIS. National Conference on Air Flow and Pollution University of Tehran 2012 [persian].
8. Diggle P, Moyeed R, Rowlingson B, et al. Childhood malaria in the Gambia: a case-study in model-based geostatistics. Journal of the Royal Statistical Society: Series C (Applied Statistics). 2002;51(4):493-506.
9. Jahangiri M. survey statically and kinetically of air pollution in Mashhad city. mastery of science dissertation in climatology School of geographic and environmental science, Hakim University. 2012. (persian).
10. Xu C-y, Gong L, Jiang T, et al. Analysis of spatial distribution and temporal trend of reference evapotranspiration and pan evaporation in Changjiang (Yangtze River) catchment. Journal of Hydrology. 2006;327(1):81-93.
11. Mehrjardi RT, Jahromi MZ, Heidari A. Spatial Distribution of Groundwater Quality with Geostatistics (Case Study: Yazd-Ardakan Plain) World Applied Sciences Journal. 2008;4(1):09-17.
12. Hengl T, Heuvelink GB, Stein A. A generic framework for spatial prediction of soil variables based on regression-kriging. Geoderma. 2004;120(1):75-93.
13. Rodríguez-Cotto RI, Ortiz-Martínez MG, Rivera-Ramírez E, et al. Particle pollution in Rio de Janeiro, Brazil: Increase and decrease of pro-flammatory cytokines IL-6 and IL-8 in human lung cells. Environmental Pollution. 2014;194:112-20.
14. Shahsavani A, Yarmoradi M, Mesdaghinia A, et al. Analysis of Dust Storms Entering Iran with Emphasis on Khuzestan Province. Hakim Research Journal. 2012;15(3):192-202 [persian].
15. Hoseinzadeh E, Samarghandi MR, Ghorbani Shahna F, et al. Isoconcentration mapping of particulate matter in Hamedan intercity bus stations. Water and Environment Journal. 2013;27(3):418-24.
16. Naddafi K, Ehrampush M, Jafari V, et al. Investigation of total suspended particles and its ingredients in the central part of Yazd. Journal of University of Medical Sciences Health Services of Shahid Sadoughi Yazd. 2008;16(4):21-5[persian].
17. Atafar Z, Eslami A, Pirsaheb M, et al. Investigation of suspended particles pollution in Kermanshah air. Journal of Health in the field. 2015;2(1). [persian] Available in http://journals.sbmu.ac.ir/jhf/article/view/5633.
18. Alireza Norpoor, Feyz MA. Determination of locality and time change in concentration of SO2 , NO2 and particle matter by GIS techniques in Tehran city. Environment logy. 2014;40(3):723- 38.
19. Berman JD, Breysse PN, White RH, et al. Evaluating methods for spatial mapping: Applications for estimating ozone concentrations across the contiguous United States. Environmental Technology & Innovation. 2015;3:1-10.

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