Spatial analysis of CO and PM_{10} pollutants in Tehran city

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ABSTRACT

Nowadays, air pollution in cities with regard to its harmful outcomes has been turned into one of the serious challenges in urban management. Pollutants as Carbon monoxide, sulfur dioxide, and the aerosols that are known to be among the most important factors related to heart, vascular, and lung disease, have underlined public welfare and health, and the organizations concerned with community health undertake remarkable expenses for disease coming out of these pollutants per year. Awareness of the air situation and its quality over periods and the process of air pollutants' changes in locations, and especially detection of high risk places can play an important and efficient role in urban health management and land use policy-making. In this paper, for the prediction of the possibility of occurring a pollutant in different locations, based on location information, one modern method of analysis entitled indicator kriging method is introduced. Since, nowadays, CO and PM_{10} are the two major pollutants in Tehran city, using the mentioned method, the probability of occurrence of each of them in Dey 1390 along with their accuracy is being measured and then a map is provided for the possible occurrence of these pollutants over the whole city of Tehran.

Key word: Air Pollution; Indicator Kriging; Map of Occurring Air Pollution; PM_{10}; CO

INTRODUCTION

Air pollution, produced by human and biological activities, is associated with the fabric of modern life. Since nowadays in spite of the widening of cities and the population growth, the number of industrial units is being increased, this issue has been turned into a controversial topic. The importance of the issue is enhanced when the pollution endangers public welfare and even the health of community's individuals and causes the exacerbation in respiratory disease and the production of different types of cancer. For this reason some rules have been established in different countries and attempts has been made to determine the permitted and safe limit for different air pollutants and to suggest suitable strategies for their resolution.

Today, most of the capital cities in the world are facing air pollution phenomenon. Increased combustion of fossil fuels in the last century is responsible for the progressive change in the atmospheric composition[1]. Tehran city, as one of those capital cities, is not an exception and because of the uncontrolled population growth, immigration, no correct planning in the years before, and not paying attention to environmental issues for developing cities, Tehran has encountered multiple problems including air pollution in a way that the studies conducted in relation to the effects of Tehran air pollutants' on health, has shown that the rate of heart and respiratory attacks' increase is in the hours when pollutants' concentrations in the air increases [2&3].

Considering the statistics and the reports done by the air quality control organization, the main air pollutants in Tehran are NO_2, SO_2, CO, PM_{10}, and O_3. Reported by the country's environment protection agency and based on some six year's data (1378-1383), all the pollutants' level were higher than the permitted level [4]. This research concentrates on PM10 and CO pollutants because these are critical pollutant in Tehran. In addition, since the air pollution problem is exacerbated every year because of the temperature inversion problem in the cooling of the air in autumn and winter, in this study, these two pollutants' situation has been considered in Dey [3].

As the air pollutant gases' concentration is being influenced by environmental factors, the probability of pollution will not be uniform across Tehran. The purpose of this study is to provide the map for the probability of occurring air pollution for different pollutants and in the cold period of the year in Tehran (when the probability of occurrence of temperature inversion phenomenon increases), through utilizing the map, the possibility of detecting high risk places and as a result, the sources generating pollution in those points is provided for controlling air pollution for urban health managers. For this purpose we use an indicator kriging(IK) method.

IK is a geostatistical technique used to approximate the conditional cumulative distribution function (ccdf) at each point based on the correlation structure of indicator transformed data points [5].

This statistical technique was introduced by Journel in 1983 and right from its introduction, it has been the focus of interest among a many of researchers, especially the geologists [6]. For example it has been applied in the lithological classification of rocks in 1997 [7] and in the estimation of contamination probability in groundwater aquifers in 1996[8].

In recent years, this model is used for data analysis in most fields so that Goovaerts has investigated theoretical basis of indicator kriging in 2009 and has used it in geology data analysis [9].

Guimaraes in 2011, in a study in Brazil, using indicator kriging prepared a map for the prevalence of Schistosomiasis disease. These maps give the community's health authorities the possibility of control and the prevention of this disease's transfer [10].

In many countries, this model is used for analyzing data related to air pollution. In 2009, Shad, et al, using indicator kriging and fuzzy kriging prepared the map for the probability of occurrence of PM_{10} for Tehran [11]. In 2010, Garcia et al, utilizing geostatistical methods and considering cut point 42ppb provided the possibility map for the occurrence of O_3 pollutant for Badajez city (located in southwest Spain) and it helped them detect high risk places there [12].

In 2010, Martin et al, using indicator kriging prepared the map of the probability of occurrence of pollution in Spain for O_3, PM_{10}, and NO_2 pollutants [13].

MATERIALS AND METHODS

The place of focus in this research is Tehran city which is located at the southern range of Alborz Mountain. Alborz heights and Bibi Shahrbanu Mountain, form the northern and eastern parts of the city, respectively. But the western and southern parts of Tehran are not that much high, therefore, mountain dams in north and east prevent wasted materials, brought forth by the western winds into the city climate, to go out and this causes that the urban air be polluted especially in the central and eastern areas. Since the prevailing winds in Tehran have western direction and that most of the industries are stationed in the western part so it can be expected that the urban air be frequently polluted [14].

The data utilized in the present study include all data recorded by pollution measurement stations that are placed in different areas in Tehran and are collected and registered by the Tehran air quality control organization and Tehran air pollution monitoring center in Dey 1390. Figure 1 shows the geographical locations of pollution measurement stations in Tehran.

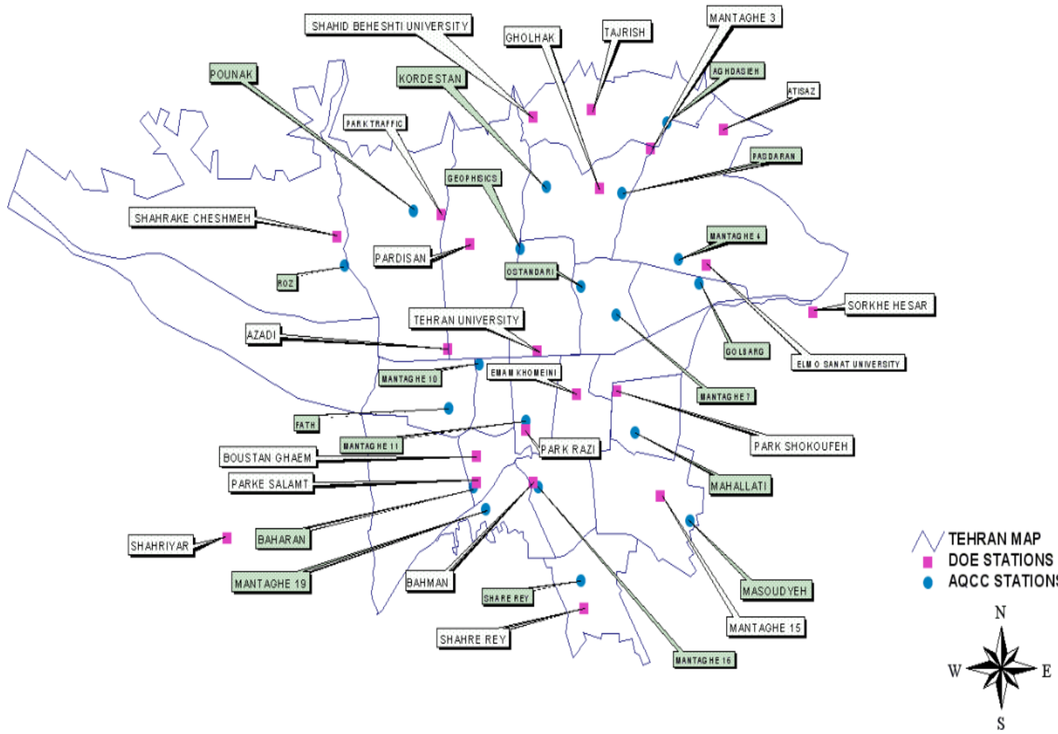


Figure 1. Location of pollution measurement stations in Tehran

Data analysis

Kriging is a predictor method in spatial analysis particularly geostatistical data. In this method for estimating in a certain point, nearer observations are given more weight and far observations are less weighted. In addition, the weights are determined in a way that the estimation variance becomes the minimum.

Suppose that predicting variable Z(.), in s_0 based on $Z(s_1),\ldots, Z(s_n)$ values from the random field of Z(.) that are observed in $s_1,\ldots s_n$, is being considered. In kriging method $Z(s_0)$ in the form of linear combination $\hat{Z}(s_0)=\sum_{i=1}^{n}\lambda_i Z(s_i)$ through selecting coefficients of λ_i, k, are estimated in a way that they be evenly unbiased and have the minimum variance [15]. One type of kriging is indicator kriging that is used for analyzing spatial binary data. Suppose, $I=(I(s_1),\ldots,I(s_n))$ are spatial binary data that are produced through some transformations of indicator spatial data $Z = (Z(s_1),\ldots,Z(s_n))$ in $\{s_1,\ldots, s_n\}$ locations with z cut point as:

$$I(s_i; z) = \begin{cases} 1 \ if\ Z(si) > z \\ 0 \ if\ Z(si) \le z \end{cases} \quad i= 1,\ldots n$$

In 1993 Cressie showed that minimizing the squared mean of prediction error $E\{I(s_0,z)-\hat{I}(s_0,z)\}^2$, results in optimal prediction of:

$$\begin{aligned}\hat{I}(s_0, z) &= E\,(I(s_0, z) \mid \text{data adjacent point } s_0)\\ &= p(I(s_0, z) = 1 \mid \text{data adjacent point } s_0)\\ &= p\,(Z(s_0) \le z \mid \text{data adjacent point } s_0)\\ &= F_{z(s0)}\,(Z \mid \text{data adjacent point } s_0)\end{aligned}$$

To estimate this probability, complicated techniques are required that depends on the statistical distribution of data in the desired points. Geostatistic branch in spatial statistics consists of techniques that use non-linear functions for data in order to estimate $p(Z(s_0) \le z \mid$ data adjacent to point s0) that was introduced for the first time by Journel in 1983 for this purpose [16]. Indicator kriging is a nonparametrical method i.e., in this method there is no need for making certain assumptions regarding data distribution[17]. The other important point of interest is that unlike the other methods, this method is applicable for skewed data without need to correct the skewness [9&18]. This technique transforms the variable measured on a continuous scale into several indicator variables and assigns each a value of zero and one.

Indicator kriging explained as a nonlinear method is in fact a linear Kriging of non-linear transformations and determines the probability of a variable becoming more or less than an identified limit[19]. In this technique the estimation of the value of the random binary field in a certain point s_0 on the basis of spatial indicator data is

$$\hat{I}(s_0, z) = \hat{F}(s_0; z|(n)) = \sum_{i=1}^{n} \lambda_i(z) I(s_i, z)$$

in which $\lambda_i(z)$ are indicator kriging weights. The condition $\sum_{i=1}^{n} \lambda_i(z) = 1$ that ensures predictor unbiasedness, is provided through minimizing the squared predictor error. In this method for modeling the spatial correlation, experimental semi-variogram is used as:

$$\hat{\gamma}_I(h; z_k) = \frac{1}{2N(h)} \sum_{\alpha=1}^{N(h)} [i(s_\alpha; z_k) - i(s_\alpha + h; z_k)]^2$$

where N(h) is the number of paired samples that are in a h distance from each other [16]. In case we have more than one cut point, indicator kriging is called multiple indicator kriging [20].

For evaluating the predictions made by indicator kriging, most often root mean square criterion is used:

$$RMSPE = \sqrt{\frac{1}{n} \sum_{j=1}^{n} e_{(-i)}^2}$$

When the root mean square of prediction error becomes a minor value, the predictions made will enjoy enough validity[16&21]. For drawing probability maps and their accuracy as well, Arc Gis software version 10 is used in this research.

RESULTS

In table 1, the considered variables in this research and their descriptions are provided. Since in indicator kriging method, the selection of cut points is required, there is always this criticism that by making the data binary, much of the information is missed.

Table 1. Descriptive statistics for the variables studied

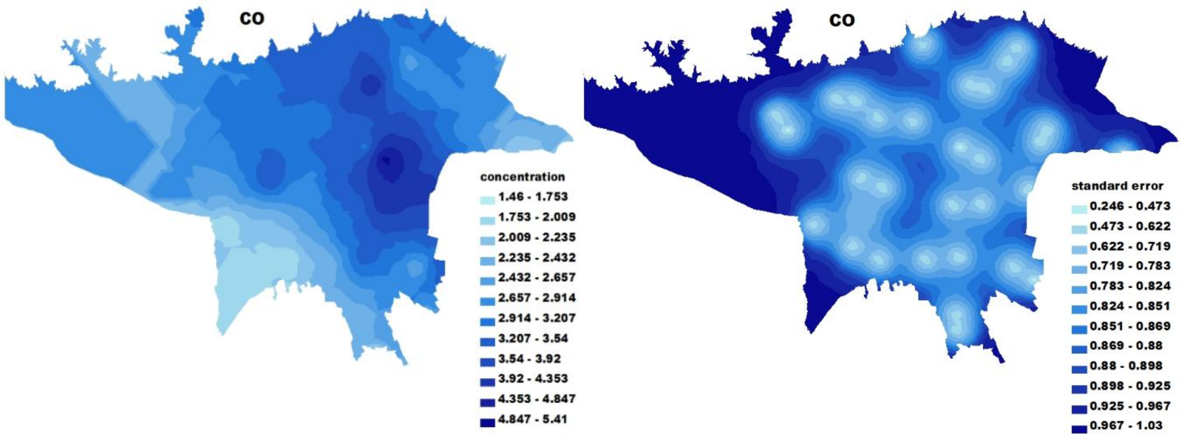
	CO	**PM10**
Mean	2.99	79.03
Standard deviation	.93	36.91
Minimum	1.46	37.91
Maximum	5.41	122.67
First quartile	2.25	60.98
Second quartile	2.98	79.56
Third quartile	3.26	91.71

For solving this problem usually more than one cut point is considered. So that in this research, the quartiles stated in the above table are regarded as cut points for each variable.

First, using Arc Gis10, the experimental indicator variogram was investigated in four geographical directions, 0, 45, 90, and 135 degrees, and the isotropy was confirmed. Then using indicator kriging and ordinary kriging, the data were analyzed. In ordinary kriging method, using the available samples and through interpolation, the pollutants' concentrations are estimated in all parts of the city and by indicator kriging, the probability of passing of pollutants' concentrations beyond the certain boarders (quartiles).

The results of fitting of ordinary and indicator kriging that include the map of predicting each pollutant's concentration along with the related accuracy map, and the map of predicting the probability of pollution occurrence (for each pollutant and for different cut points (quartiles)) together with the accuracy map of related prediction for all the city is provided in the figures 2 to 5 below.

In figure 2 map (a) represents that the more the color range tends to dark blue, the more the CO pollutant's concentration and the zone is more polluted of that pollutant. So based on the results of ordinary kriging method, CO pollutant's concentration is more in the eastern and northern parts of Tehran than in the other parts and these areas are polluted than others. Furthermore, with the help of the offered SDs in map (b) for the predictions made through this method, the



(a) (b)

Figure 2. The mapping of CO pollutant concentration degree (a) along with its accuracy (b)

accuracy of the predictions made can be estimated. In the way that the more the color range becomes nearer to dark blue, standard deviations become greater and the results' accuracy decreases. As is evident in map (b), standard deviation is greater in western parts than in the other parts, therefore, the accuracy of the predictions is less in these zones than in others. Tha maps (a_1), (a_2), and (a_3) show that the more the color range tends toward dark blue, the possibility of the passing of CO from cut points of 2.25 ppm, 2.98 ppm, and3.26 ppm increases and the place becomes more polluted with regard to that pollutant. So based on the results from indicator kriging, the probability of pollution occurrence, considering CO is more for each of the cut points mentioned in Tehran east and north in comparison with other areas of the city and these parts are more polluted than the others. In addition maps (b_1), (b_2), and (b_3) represent that since the standard deviation is great in western area, predictions in this part have lesser accuracy. It can be understood from map (a) that the PM_{10} pollutant's concentration is more in eastern and south western parts in comparison with the other parts of the city and these areas are more polluted than the rest. Furthermore, with the help of the standard deviations offered in map (b), it is observed that the standard deviation is greater in western parts than in other parts, so the accuracy of results in these areas are lesser than in other parts. Considering map (a_1) it is found that the probability of PM_{10} pollutant's concentration passing the 60.98 $\mu g/m^3$ cut point in eastern and western areas is more than in other areas. Maps (a_2) and (a_3) also show that the probability of passing of this concentration beyond the 78.84 $\mu g/m^3$ and 91.71 $\mu g/m^3$ cut points in eastern and south western areas is more than other parts. In addition, maps (b_1), (b_2), and (b_3) represent that since the standard deviation is great in west, the predictions have lesser accuracy in these areas.

For evaluating the predictions made by this method, cross-validation criterion is used, the results of which is presented in tables 2 and 3.

As it is evident, except in one, all of these values are all small and near to zero that shows the prediction power of the methods.

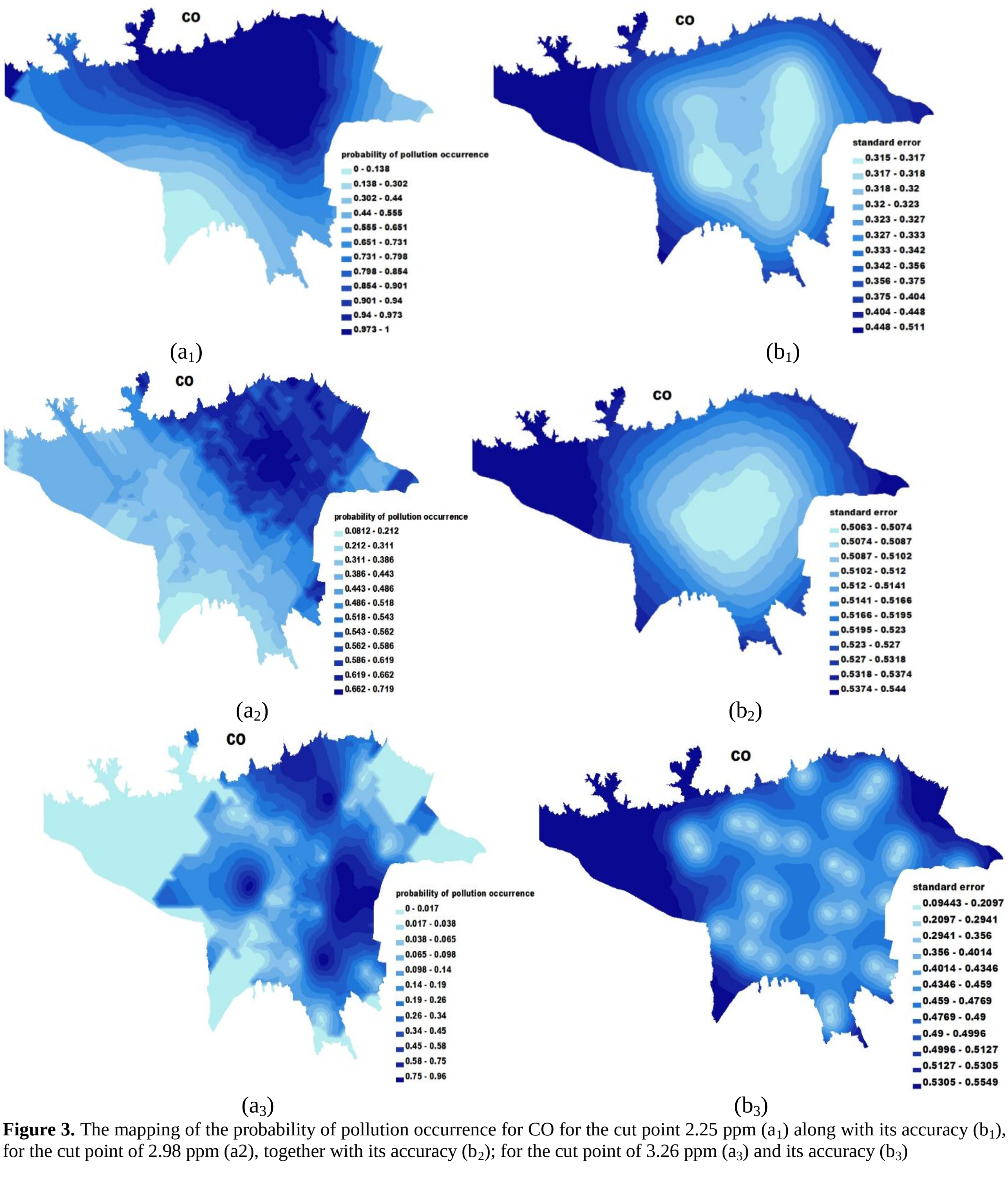
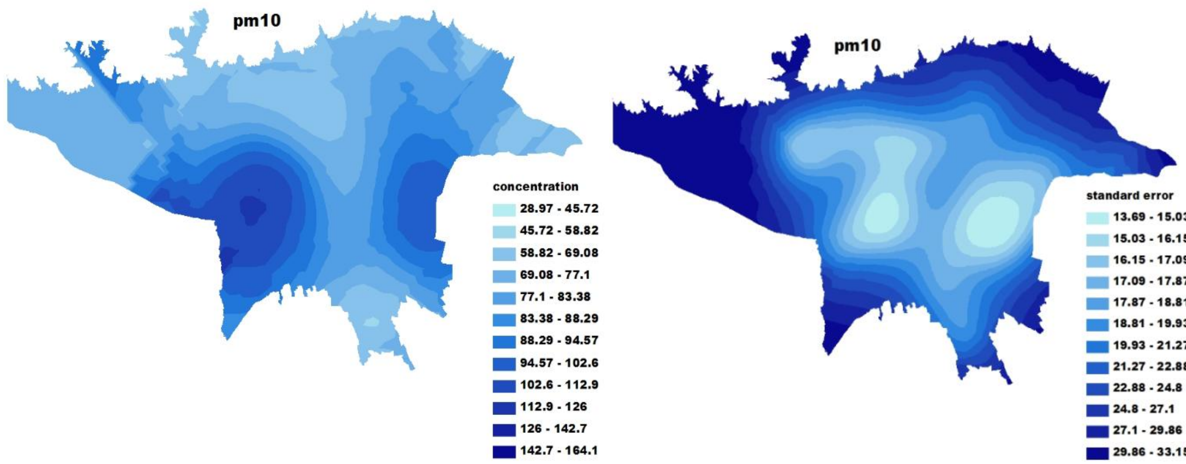
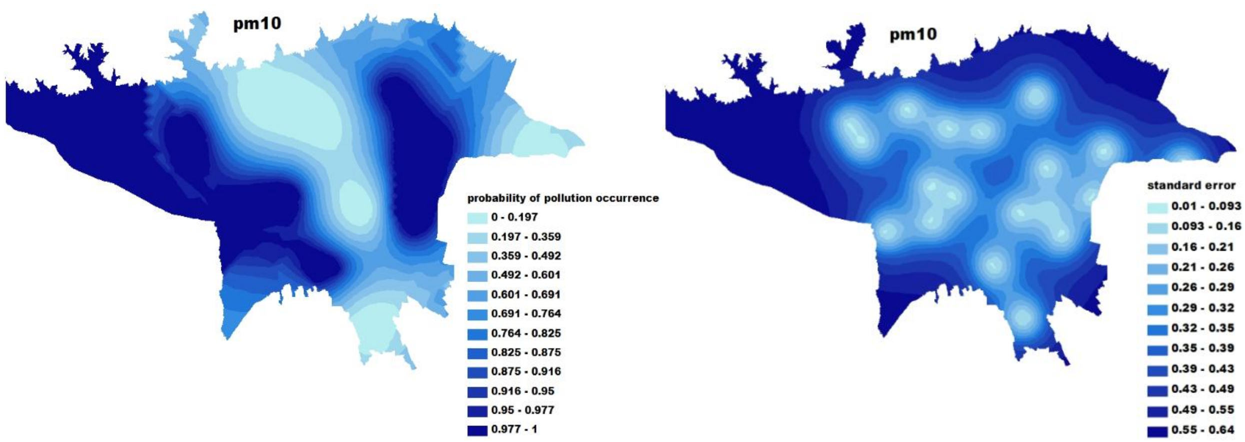


Figure 3. The mapping of the probability of pollution occurrence for CO for the cut point 2.25 ppm (a_1) along with its accuracy (b_1), for the cut point of 2.98 ppm (a2), together with its accuracy (b_2); for the cut point of 3.26 ppm (a_3) and its accuracy (b_3)

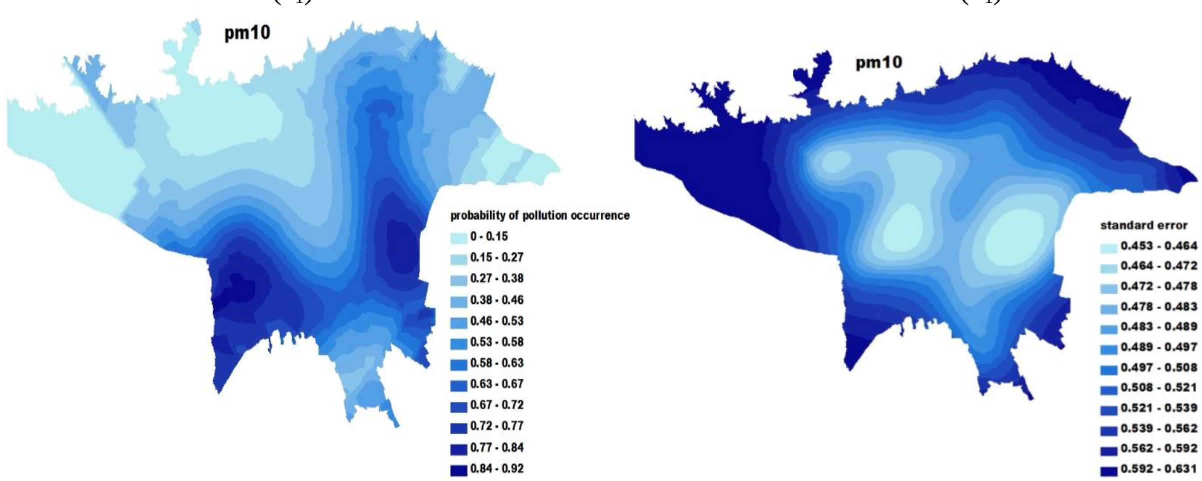


(a) (b)

Figure 4. The mapping of estimating the PM10 pollutant's concentration (a) with its accuracy (b)

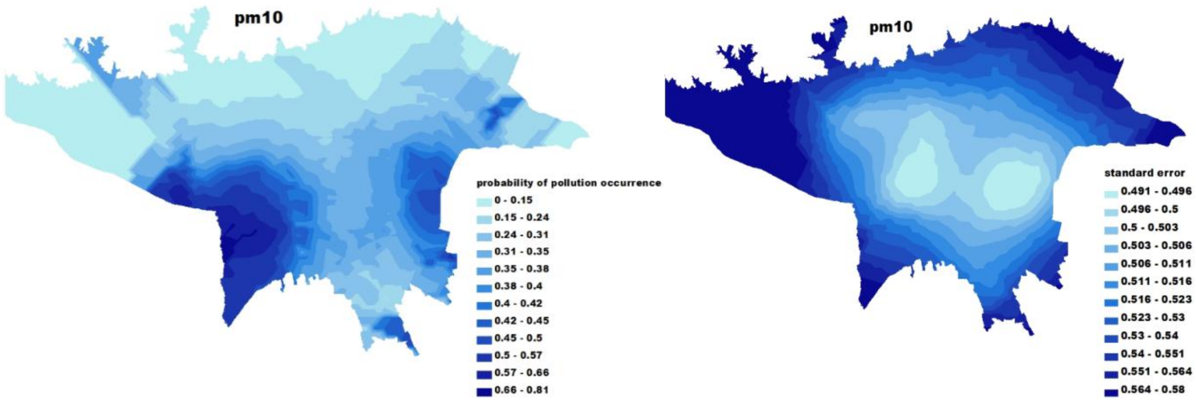


(a_1) (b_1)



(a_2) (b_2)

Figure 5. The mapping of the probability of pollution occurrence for PM_{10} for the cut point 60.98 $\mu g/m^3$ (a_1) along with its accuracy (b_1), for the cut point of 79.56 $\mu g/m^3$ (a2), together with its accuracy (b_2); for the cut point of 91.71 $\mu g/m^3$ (a_3) and its accuracy (b_3)



(a_3) (b_3)

Figure 5 continued. The mapping of the probability of pollution occurrence for PM_{10} for the cut point 60.98 µg/m^3 (a_1) along with its accuracy (b_1), for the cut point of 79.56 µg/m^3 (a2), together with its accuracy (b_2); for the cut point of 91.71 µg/m^3 (a_3) and its accuracy (b_3)

Table 2. Cross-validation standards done through ordinary kriging method

	Squared mean root of prediction error
CO	.81
PM_{10}	27.76

Table 3. Cross-validation criterion done through marking indicator kriging method

	Squared mean root of prediction error
cut point 2.25 for CO	.3822
cut point 2.98 for CO	.5074
cut point 3.26 for CO	.4594
cut point 58.79 for PM_{10}	.4656
cut point 78.84 for PM_{10}	.51
cut point 100.02 for PM_{10}	.45

DISCUSSION

The purpose of this research was the mapping of the concentration of the main air pollutants in Tehran city and also the preparation of the map of passing these pollutants' concentrations beyond the certain cut points in Dey 1390, while in most studies conducted on the area of air pollution in Iran, the focus is on the interpolation of the pollutants' concentration and not on the interpolation of the possibility of their occurrence. Since the number of pollution measurement stations were very few when those studies were done, it seems not logical to compare their results with the result of present study. Considering the studies done by the researcher, up to now, just one study has been carried out (Shad et al., 2009) in Iran investigating the probability of air pollution considering PM_{10} in Tehran that albeit, a different approach has been taken in it than the present research, in that study fuzzy indicator kriging and indicator kriging were compared. According to the result of that research, central and eastern parts are more polluted.

Considering the maps derived from both ordinary kriging and indicator kriging, it is found that the results derived from both methods are roughly in line with each other i.e., in places where the pollutant's concentration is high, the probability of the pollution for that pollutant is also high.

With regard to figure 1, the pollution measurement stations are more centralized in Tehran, but the dispersion is more in the marginal parts and particularly in western parts of Tehran. This factor leads to low accuracy predictions in these locations, contrary to it; the predictions made by the central zones have the most accuracy. The results of cross-validation criterion in table 2 confirms this issue as well; because these standards have the lowest values for the CO pollutant having the maximum sample size.

So it can be claimed that great distances among the pollution measurement stations, reduces spatial dependence among the samples and causes the results from some other places to have not enough accuracy.

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