ECOPERSIA. 2018;6(2):91-100

Sensitivity Analysis of Meteorological Parameters and Instability Indices on Concentration of Carbon Monoxide, Particulate Matter, and Air Quality Index in Tehran

ARTICLE INFO

Article Type
Original Research

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How to cite this article
Farhadi R, Hadavifar M, Moeinaddini M, Amintoosi M. Sensitivity Analysis of Meteorological Parameters and Instability Indices on Concentration of Carbon Monoxide, Particulate Matter, and Air Quality Index in Tehran.ECOPERSIA. 2018;6(2):91-100.

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Article History
Received: October 6, 2017
Accepted: January 23, 2018
ePublished: June 26, 2018

ABSTRACT

Aims Nowadays, dangerous chemical pollutants by a numerous of natural and synthetic sources are produced and released to the environment. These pollutants have short-term and long-term effects on human health. The purpose of this paper is to examine the impact of climate parameters and instability indices on air pollution in Tehran-Iran.

Materials & Methods To evaluate the impact of meteorological parameters and indices of stability and instability on sensitivity analysis in Tehran-Iran, the Sharif University monitoring station was selected for air sampling and analysis. Sampling was performed from March 2011 to July 2012 in Tehran.

Findings Results of sensitivity analysis showed that average daily change of the concentration of pollutants throughout the year was very different and intensively influenced by meteorological parameters. Results showed that wind direction (WD) (82%) and relative humidity (32%) and temperature (20%) have the most influence on the concentration values of pollutants carbon monoxide (CO), particulate matter (PM10), and air quality index (AQI). The highest concentrations of CO occurred in summer and lowest in winter, and maximum concentration of PM10 was in autumn, and its lowest concentration was in spring. Results revealed that the lowest average of AQI occurred in the spring, while in autumn, winter, and summer have almost equal values, but in winter AQI has slightly higher values.

Conclusion According to the results of this research in Sharif station Tehran, the WD has the highest impact percentage (82%) on the concentration of pollutants. The highest concentrations of CO occurred in summer, and maximum concentration of PM10 was in autumn.

Keywords Air Pollution; Coefficient Correlation; Meteorological Parameters; Sensitivity Analysis; Stability and Instability Indices

CITATION LINKS

[1] Sources of chemical contaminants and routes into the freshwater ... [2] Short term effects of criteria air pollutants on daily mortality in ... [3] Air quality biomonitoring: Assessment of air pollution genotoxicity ... [4] Air pollution, its origin and ... [5] Assessment of human health impact from exposure ... [6] Urban air quality management-A ... [7] Quantifying the air pollutants emission reduction during the 2008 Olympic ... [8] Environmental policy design and dynamic nonpoint-source ... [9] Assessment and prediction of tropospheric ozone concentration levels using artificial neural ... [10] Regression and multilayer perceptron-based models to forecast hourly ... [11] Forecasting urban PM_{10} and $PM_{2.5}$ pollution episodes in ... [12] PM_{10} emission forecasting using artificial neural networks and genetic ... [13] Seasonal modeling of $PM_{2.5}$ in California's San Joaquin ... [14] A multisite-ultipollutant air quality ... [15] Application of fuzzy time series models for forecasting ... [16] Decision tree methods: Applications for classification and ... [17] High performance computing of data for a new sensitivity analysis ... [18] A comparison of methods for uncertainty and sensitivity analysis applied to ... [19] Monitoring of criteria air pollutants in Bursa ... [20] Urban climate and air pollution in ... [21] Sensitivity analysis of a mathematical model for photochemical ... [22] Air pollution modelling, sensitivity analysis and parallel ... [23] Preparing input data for sensitivity analysis of an air pollution model by ... [24] Selection of the most significant variables of air ... [25] Dust storm monitoring using HYSPLIT model and NDDI (Case study: Southern ... [26] Emulation and sensitivity analysis of the community Multiscale Air Quality ... [27] Sensitivity analysis in complex ... [28] Influence of humidity on the initial ... [29] Investigation of PM_{10} concentration trend ... [30] Characterization of criteria air ... [31] Air quality effects of an urban ... [32] PM_{10} pollution: Its prediction ... [33] Relative humidity and moisture ... [34] Diurnal and seasonal variations ... [35] Seasonal variations in surface ... [36] Explaining the high PM_{10} concentrations ... [37] Influence of meteorological ...

Introduction

Hazardous air pollutants produced by numerous natural sources and manmade activities.[1] Releasing of these pollutants into the environment ultimately cause adverse effects on human health and the environment.[2] Today, many major cities and metropolises around the world are facing environmental problems, which are headed by unfavorable air quality resulting exposure of citizens to the polluted air.[3] Air quality is closely related to the quality of life which evaluates the air quality status.[4] Air quality index (AQI) is calculated with most important pollutant including sulfur oxides, ozone, nitrogen oxides, carbon monoxide (CO), and particulate matter (PM10).[5] Based on the results, all these pollutants (solid, liquid, and gas) are considered to be of serious risks to human health.[6] Due to the adverse effects of various contaminants, the air quality controlling policies is one of the most important requirements for public health.[7] Hence, quality control and formulation of appropriate policies to reduce the amount of pollutants need to be considered. Forecasting of air pollution patterns is a necessary item to reduce and prevent the enhanced pollution and critical air quality.[8] Using of models predicting the concentration of pollutants for next day, authorities can make proper decisions based on some limiting roles of urban air pollution.[9] Predicting can be done with modeling involving a lot of models to predict air pollution such as autoregressive integrated moving average,[10] regression,[11] weather research and forecasting model with chemistry,[12] neural networks,[13] community multi-scale air quality model (CMAQ),[14] gray model,[15] and fuzzy inference system.[16] In all of these methods, the choice of input variables plays an important role in the accuracy of the model and results.[17] One of the ways applied to understand the impact of independent parameters on the dependent parameters is sensitivity analysis.[18] The effects of the metrological parameter on aerosols and atmospheric pollutants have been studied in many countries. Tasdemir *et al*. [19] investigated of the concentration of SO_2 and NO in 1 year in the city of Bursa. Their studies showed that the correlation between the concentration of these pollutants and meteorological parameters had a weak correlation. While another study in Shanghai surveyed the total suspended particle and SO_2 concentration with meteorological parameters.[20] This survey showed that the distribution of pollutants affected by meteorological conditions such as wind direction (WD) that has a rarefaction effect on SO_2 concentration. The daily change of wind speed (WS) is opposite to SO_2 concentration. Tilden and Seinfeld [21] used sensitivity analysis by a mathematical model for photochemical air pollutant and concluded that predicted NO, RHC, and O_3 concentrations were found to be relatively insensitive to uncertainties in the values of the relative humidity (RH). Roskilde *et al.* [22] used sensitivity analysis and parallel implementation for air pollution modeling. Their results showed that the sensitivity analysis requires numerous model experiments and variation of the corresponding parameters. They mentioned that it is a huge computational task and its efficient parallel implementation is primary importance for sensitivity analysis. Tzvetan *et al.* [23] for preparing input data for sensitivity analysis of an air pollution model uses high-performance supercomputers and algorithms. There were a number of uncertain internal parameters, especially in the chemistry–emission sub-model. Azid *et al*.[24] applied sensitivity analysis for selection of the most significant variable of air pollutant in Malaysia. Khamooshi *et al.* [25] modeled the dust storms using the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model and Normalized Difference Drought Index (NDDI) in Bushehr, Fasa, and Shiraz cities in Iran. The results of this study showed that western winds cause maximum peak dust entering the region. Furthermore, this study showed that the atmospheric patterns and NDDI index are a suitable feature for detecting the paths of storms caused by suspended particles. Results of tracing wind flow in the fiercest dusty day using HYSPLIT model indicated that dust masses originated from the western parts of Iraq and eastern Syria and transported by the northwest winds of the region. This study revealed that PM10 and CO were the most significant parameters in ambient air. Beddows *et al.*[26] used of emulation and sensitivity analysis of the CMAQ model for a UK ozone pollution episode. The result showed how the influence of different input uncertainties changed during the episode. They revealed spatiotemporal patterns of model sensitivities with NO and isoprene emissions, NO_2 photolysis, ozone BCs, and deposition velocity being among the most influential input uncertainties.

Instability indices

Lifting condensation level (LCL)

LCL is elevation that surface air will reach to dew point and consequently be saturated when rises in free or forced status. This index plays a significant role in determining atmospheric parameters.[27]

Showalter index (SI)

This index is expressed by Showalter as follows:

$$SHOW = T_{E500} - T_{P500} \quad (1)$$

In this relation SHOW is SI (°C), TE500 and TP500 are ambient temperature and parcel air temperature (°C), respectively, at pressure of 500 hpa. In general, values positive this index indicates stability, 0 to −4 show marginal instability, −4 to −7 indicates the large instability, and if the calculated values be >−8 or less, extreme instability occurs and consequently parcel air will climb further.[28]

Total totals index (TT)

TTI is an index that assesses the strength of the storm. This index is obtained from the following equation:

$$TT = (T_{850} - T_{500}) + (T_{d850} - T_{500}) \quad (2)$$

Where T and Td are ambient temperature and temperature of dew point, respectively, at the considered level.

In the present study, we surveyed sensitivity analysis of more effective meteorological parameters and stability and instability indices on the concentration of CO, PM10, and AQI in outdoor air of Tehran-Iran. This work has investigated the effect of stability and instability indices on the air pollution for the first time. However, meteorological parameters widely used for predicting air pollutions by other authors

Materials and Methods

Area study

Tehran has been considered as most polluted cities in the world. It was located at latitude 35°43′00″ north and longitude 51°24′00″ east in the south of the Alborz mountains that cover an area about 730 km^2. This city based on municipal divisions has 22 regions [29].

Several factors are affecting on air pollution of Tehran that among them geographical (the surrounding mountains especially the Alborz Mountain range) and meteorological factors including temperature inversion and the movement of vehicles are important. Figure 1 shows the geographical location and meteorological stations (including 22 regions) of Tehran-Iran.

Collecting data

In general, data were including meteorological parameters of Mehrabad station, which collected from Iran's meteorological organization and pollutant concentration and stability and instability indices were obtained from Mehrabad air quality controlling station, and CO and PM10 pollutant concentration data and AQI collected from Sharif station as air quality control agency of Tehran according to Table 1 that had been measured from March 2011 to July 2012. Based on the dataset, correlation analysis to analyze the interactions between pollutants and meteorological factors was used that also concluded the main factors.

Methodology

Sensitivity analysis

The sensitivity analysis implies to study of affected output variables by the input variables in the statistical model [30]. In other words, a way to change the entries in a statistical model for an organized, systematic model that can predict the effects of this change in output. Variance-based sensitivity analysis approach has been proposed for determination error of input parameters that affecting the output results of air pollution model.[18] To determine the most important

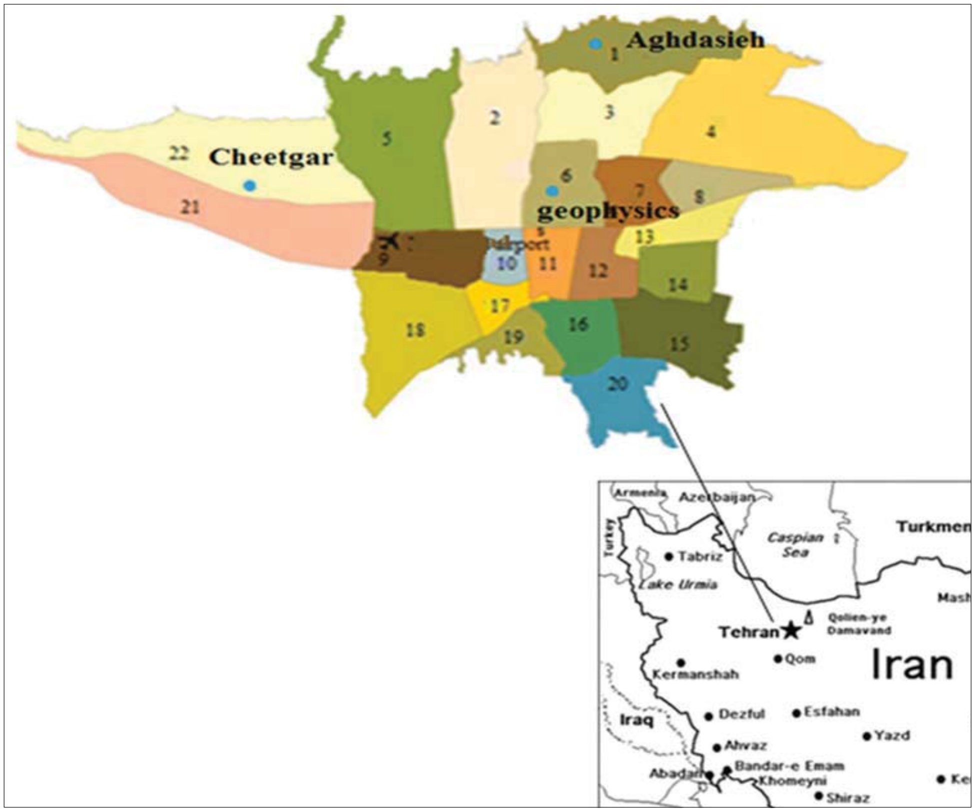

Figure 1: The geographical location and meteorological stations of Tehran city

Table 1: Description of variable input parameters and indices for sensitivity analysis

Main variables	Detailed variables
Meteorological parameters	Wind speed (WS): Meters per second (m/s)
	Wind direction (WD), degrees from true North
	Temperature (T), dry bulb temperature, °C
	Relative humidity (RH), (%)
Pollutant concentration	PM10 (particulate matter)
	CO (carbon monoxide)
	AQI (air quality index)
Instability index	LCL (lifted condensation level)
	SI (Showalter index)
	TT (Total totals index)

factors affecting the concentration of PM10 and CO and AQI index Pearson correlation coefficient was used in SPSS.16 software. In this case, the metrological variables associated with the value of AQI index, PM10 and CO introduced to the software and the effect of each meteorological parameters and stability and instability indices on the concentration of CO and PM10 and AQI index was evaluated. The Pearson correlation test was used to investigate the relationship and impacts between variables.

Statistical analysis

At first, the normality of the data was evaluated using Kolmogorov–Smirnov test. Normality was performed using the Box-Cox Convert onto data revealing that the concentration of pollutants in the study station did not have a normal distribution ($P < 0.05$). To investigate significant differences between concentrations of pollutants in the studied seasons and to show contaminants small differences Duncan test was selected. All of the analysis were conducted with the SPSS Software. Finally, to investigate the correlation coefficient between the concentration of pollutants and meteorological parameters and stability and instability indices regression analysis was performed with Sigma plot software.

Findings

Sensitivity analysis of parameters

For sensitivity analysis, the relationships between input parameters determined using Pearson correlation coefficient, and after that, the percentage effect of each of these parameters on the output was measured. The parameters that have the greatest impact on the outcome were identified as the most sensitive and important input variables. As shown in Figure 2a-c, WD with the effect of 82% and RH with 32% and temperature (T) with 20% had the greatest impact onto air pollution indices (CO, PM10, and AQI). The highest concentration of pollutants occurs in low RH. In other words, increase in dryness of the air has been associated with an increase in the amount of pollutants. Furthermore, minimum emissions of pollutants occur at high RH.

Pollutant concentration in terms of season

According to Table 2, the results of Duncan test showed that the highest concentration or average concentration of CO occurred in summer and lowest value seen in winter. This is may be due to the effect of Tehran-Karaj highway locating in the west of Tehran with speed limit of 120 kph. This highway is the main source of CO producing from motor vehicles traveling in this highway and increased traffic, leads to further increase of CO.

Correlation between parameters and linear regression

Table 3 shows the results of the regression modeling for CO, PM10, and AQI at the studied

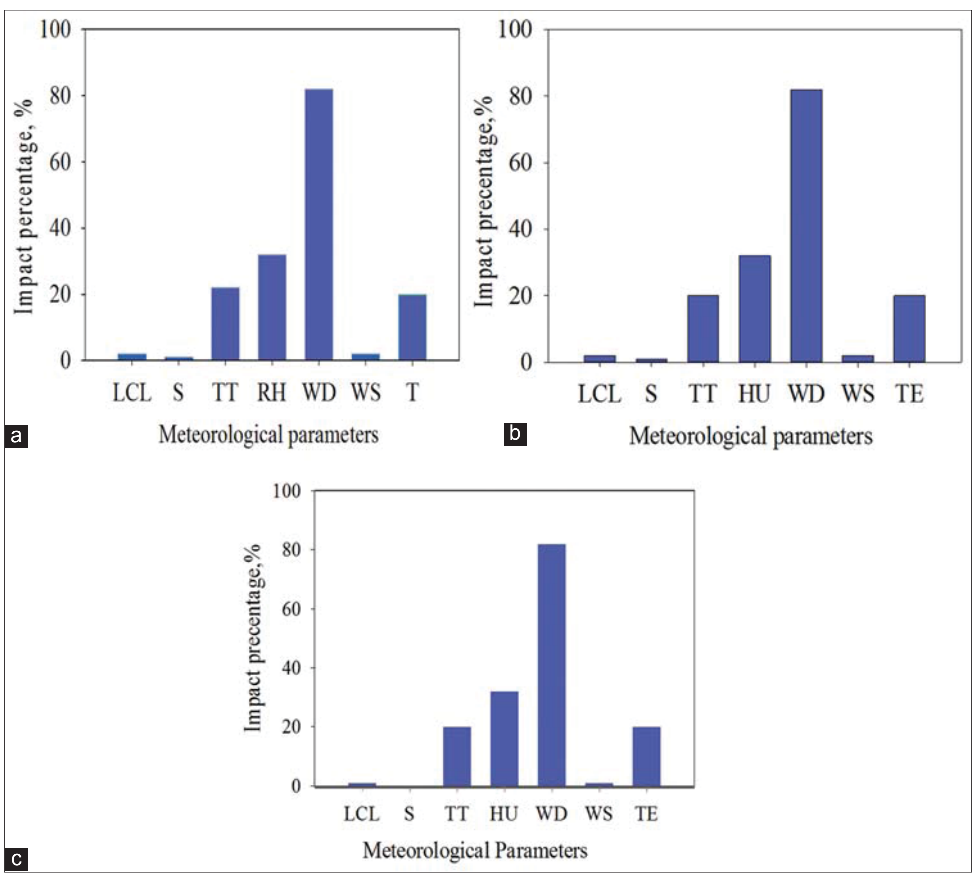

Figure 2: Percentage impact of meteorological parameters on the concentration of particulate matter (a), carbon monoxide (b), and air quality index (c) (base sensitivity analysis)

Table 2: Means of CO, PM10, and AQI for groups in homogeneous subsets based on observed means (base Duncan test)

Indices of air pollution	Season	Number of samples	Subset	
			1	2
CO	Winter	90	0.2333	
	Spring	186	0.2538	0.2538
	Autumn	90	0.2709	0.2709
	Summer	133		0.2889
	Sig.		0.063	0.083
PM10	Winter	186	0.2663	
	Spring	90		0.3603
	Autumn	133		0.3771
	Summer	90		0.3814
	Sig.		1.000	0.07
AQI	Winter	186	0.1192	
	Spring	133		0.1484
	Autumn	90		0.1654
	Summer	90		0.1657
	Sig.		1.000	0.144

CO: Carbon monoxide, PM10: Particulate matter, AQI: Air quality index

air pollution station. As Table 3 and Figure 3a show, the highest correlation occurred between PM10 and LCL with R2 value of 0.71. While the lowest correlation belonging to PM10 and humidity with a correlation value of 0.0128 (Figure 3b). In general, there was a greater correlation between PM10 and instability indices compare to meteorological parameters. As seen in Figure 3c, the highest correlation belongs to CO and LCL (R^2 = 0.0036) and according to Figure 3d the lowest correlation belonging to CO and WD with R^2 value of 0.0001 that this means no correlation exists between these parameters. Furthermore, from data of Table 3 concluded that a greater correlation was seen between CO and instability indices compared to meteorological parameters. Finally, Figure 3e shows, the highest correlation occurs between AQI and S with R square value of 0.0061 and the lowest correlation belonging to AQI and WD with a correlation value of 0.0001 (Figure 3f). The correlation between PM10 and instability indices had the highest value among all parameters. Finally, we understood that all three pollutants had a greater correlation with stability and instability indices compared to meteorological parameters and among three pollutants highest correlation coefficient with the parameters belonged to PM10 that affecting on parameters more than other pollutants. In general, correlation coefficients of <0.05 recommended as no correlation occurs between the parameters and the concentration of pollutants. In this case only a correlation observed between PM10 with instability indices of LCL and S and also between AQI with instability index of S. This may be due to this fact that linear regression analysis is not reliable for this item and should use predicting models such as neural network or hybrid models that are both more flexible and show logically nonlinear relationships between the parameters.

Discussion

In this study, sensitivity analysis and linear regression model were used to investigate the effect of meteorological parameters and instability indices on the concentration of pollutants. The parameters that had the greatest impact were sensitive and important inputs. Wind direction, humidity and temperature had the most effect on air pollutants (CO, PM10 and AQI). In linear regression model for CO, LCL instability index has the highest correlation coefficient. Also, the highest correlation coefficient of PM10

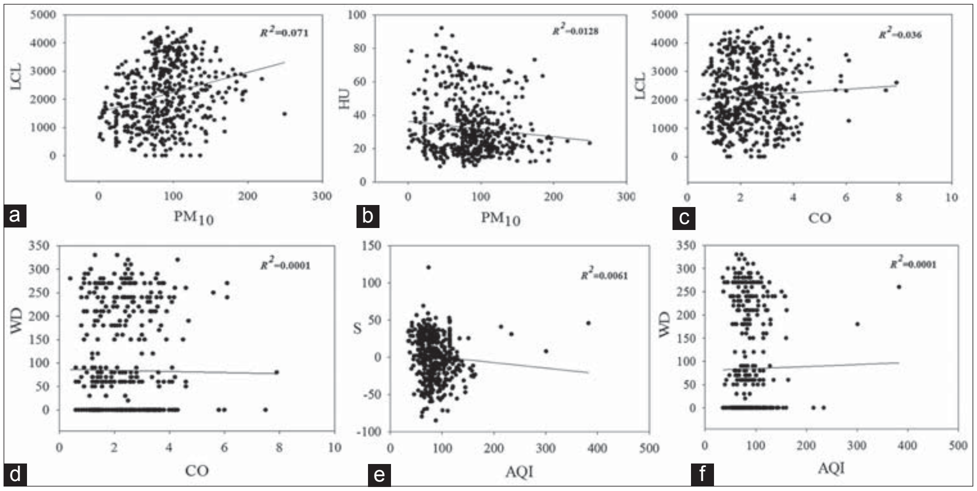

Figure 3: (a-f) Highest and lowest correlations coefficient between indices of air pollution (particulate matter, carbon monoxide, and air quality index) and meteorological parameters (base regression analysis)

Table 3: Correlation of CO, PM10, and AQI index with meteorological parameters and stability and instability indices (base coloration coefficient)

Indices of air pollution	Meteorological parameters and stability and instability indices						
	Temperature	Wind speed	Wind direction	Humidity	TT	SI	LCL
CO	0.0279	0.011	0.0001	0.0281	0.0018	0.0029	0.0036
PM10	0.042	0.0152	0.0048	0.0128	0.052	0.66	0.71
AQI	0.0138	0.002	0.0001	0.021	0.005	0. 61	0.0034

CO: Carbon monoxide, PM10: Particulate matter, AQI: Air quality index, SI: Showalter index, LCL: Lifted condensation level, TT: Total totals index

was with LCL that show the PM10 highly correlation with instability indices compared to meteorological parameters. Finally, the highest correlation coefficient AQI was with S as an instability index. We found that all three pollutants had higher correlation coefficients with instability indices compared to meteorological parameters. On the other hand, the highest correlation coefficient between the three pollutants with parameters was related to PM10. In total, the correlation coefficient between the three pollutants with the parameters was weak, which may be due to the fact that there may be a series of nonlinear relations between the parameters that the regression model cannot show due to its linearity. For this reason, a non-linear flexible model such as neural network or hybrid models should be used for better fitness.

Nazari *et al.*[29] emphasized that with increasing temperature, dominant wind percentage, WS and reducing the RH, rainfall, and percentage of slow winds, the concentration of PM10 increases. Wind plays an important role in the dispersion of pollutants. Although Tehran WD is from the west to the east, most industries are located in western are of Tehran causing high concentrations of contaminants. Pollutant concentration incensement happened when effective and sweeping wind not blown and atmospheric conditions are stable and out of normal conditions. On the other hand, increasing consumption of fossil fuels causes to increase temperature and concentration of contaminants. Guo *et al.*,[30] in during 2014–2015, investigated the characterization of criteria air pollutants in Beijing. They concluded that warm winds from the south assisted the PM accumulation, while fast and cold winds from the northwest helped move the pollutants out of the city.

Dijkema *et al.* [31] mentioned that a lowering of the maximum speed limit from 100 to 80 kph had reduced traffic-related air pollution in the vicinity of highways. Accelerating and decelerating of vehicles due to high traffic in peak hours causing to an enormous release of CO onto ambient air. On the other hand, the lack of urban green spaces can effect on temperate surface inversion reducing precipitation and washing down the pollutants [32]. The western winds make a turbulent that reduces Tehran air pollutants usually blow in very low speed. Just 30% of dominant winds are faster than 5 meters per second usually blow in early spring and late summer causing to clean air.[33] The geographical location of Tehran basically creates the local winds in altitude of 150–800 m. These winds contributing about 2.66% of all winds blowing in Tehran, but they do not have enough speed and power to clean the air because of such speed and altitude. Christine *et al.*[34] investigated diurnal and seasonal variations of NO, NO_2, and PM2.5. They concluded that pollutant concentration in the urban and suburban area is higher in fall and winter. In fact, WS increases pollutant concentration. In the present study, this fact that the peak of PM10 concentrations occurred in autumn probably may be due to increasing fuel consumption and sustainability of air because of temperature inversions. Meteorological conditions, increasing coldness and WS that increases dust (mostly originated from vicinity area of Tehran) are the most important factors affecting increasing of PM10. Existing of various industries in the western areas of Tehran in the direction of the dominant wind as well as emissions from old vehicles is reasons for the increase of reported PM10 in the air of Tehran.[32] Ghaffari and Nouri[33] in their study about RH and moisture convergence in dusty days in the Alvand mountains stated that the movement of suspended particles from Iraq and other countries to the east and southeast of Iran usually occurs in warm seasons and also stated that the highest suspended particles of the atmosphere depends on WS and particle size. Shyam *et al.*[35] studied seasonal variations in surface ozone and its precursors over an urban site in India. The result showed that most concentration of O_3 was in fall and winter because of larger value precursor gases and lowest concentration was in summer because of monsoon period. Magdalena and Katarzyna[36] studied the high PM10 concentrations observed in Polish urban areas. They concluded that the highest concentrations of PM10 occurred in January. However, the main reason was either related to regional background pollution (in the central part of the country) and with local emission sources (in the southern part). The occurrence of high PM10 concentrations is most commonly associated with the influence of high-pressure systems that brought extremely cold and stable air masses from east to south of Europe. Their analyses showed industrial point sources had the biggest (up to 70–80%) contribution in PM10 levels on the days with maximum PM pollution, while remote and residential/traffic sources determined the air quality in the early stages of the episodes. In our study, the lowest average of AQI index seen in the spring, while in autumn, winter, and summer have almost equal values, but in winter AQI has a higher value. In agreement with other studies, the highest concentration of CO occurred in the summer, and the highest concentration of PM10 was in the fall.

Husseini and Hejazi[37] surveyed the effects of meteorological parameters (WD, WS, temperature, pressure, and sunshine) on the concentration of pollutants (SO_2, CO, NOX, and O_3) by statistical analysis in Tehran. The results showed that there was a significant correlation between CO and meteorological parameters (high pressure, high temperature, sunshine, and WS).

Conclusion

The air pollution fundamentally influenced by meteorological parameters. Results of the sensitivity analysis showed that the highest effect percentage of meteorological parameters on the emissions of CO, PM10, and AQI index are WD (82%), RH (32%), and temperature (20%). WD is more important because of movement of pollutants to out of city boundaries. The highest concentration or average concentration of CO was in summer, and lowest was in winter. The peak concentration of PM10 in the autumn was greater than other seasons and in the spring, had less value. The highest concentration of AQI was in the winter and then autumn and its lowest value seen in spring.

Acknowledgments
Authors appreciate the sponsorship of the Ministry of Science, Research and Technology of Iran and financial supports of Hakim Sabzevari University.

Ethical Permissions
Authors confirm that the research will be conducted in line with all University, legal and local ethical standards.

Conflicts of Interest
There are no conflicts of interest with respect to the Hakim Sabzevari University.

Authors' Contributions
Each of the authors contributed to the development of the paper.

Funding/Support
Hakim Sabzevari University funding is gratefully acknowledged.

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