Air Quality Analysis by Using Fuzzy Inference System and Fuzzy C-mean Clustering in Tehran, Iran from 2009-2013

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Abstract

Background: Since the industrial revolution, the rate of industrialization and urbanization has increased dramatically. Regarding this issue, specific regions mostly located in developing countries have been confronted with serious problems, particularly environmental problems among which air pollution is of high importance.

Methods: Eleven parameters, including CO, SO2, PM10, PM2.5, O3, NO2, benzene, toluene, ethyl-benzene, xylene, and 1,3-butadiene, have been accounted over a period of two years (2011-2012) from five monitoring stations located at Tehran, Iran, were assessed by using fuzzy inference system and fuzzy c-mean clustering.

Results: These tools showed that the quality of criteria pollutants between the year 2011 and 2012 did not as much effect the public health as the other pollutants did.

Conclusion: Using the air EPA AQI, the quality of air, and also the managerial plans required to improve the quality can be misled.

Keywords: Fuzzy c-mean clustering, Air quality, Fuzzy inference system, Iran

Introduction

Since the industrial revolution, the rate of industrialization and urbanization has increased dramatically. Regarding this issue, specific regions mostly located in developing countries have been confronted with serious problems, particularly environmental problems among which air pollution is of high importance (1). In order to manage this problem, several tools have been developed. Air quality indices are the most widely used tools which mainly indicate the quality of air in a specific region. In fact, air quality indices are widely used in air quality management schemes. Main air quality index being applied over the world is Air Quality Index or AQI (USEPA, 2009) developed by United States Environmental Protection Agency (2). In this index, one can calculate the quality of air by entering required values of major pollutants (i.e. CO, SO2, PM10, PM2.5, O3, and NO2). Since the air quality indices have been deeply discussed in previously conducted studies, further details can be found (1, 3-8).

As it mentioned earlier, an air quality index not only shows the quality of air, but also can be used to design specific plans in handling air pollution. However, previously developed air quality indices have been mentioned to have main limitations. In a study (1) it was mentioned that the applicability
of USEPA AQI in specific areas which are not similar to United States is limited. This index had been developed based on the quality of air and also the major pollutants in United States. Other limitations not related to the present study are discussed in detail in previously conducted studies (3, 9). Considering the fact that pollutants are being emitted into the air from various sources, it is wise to think that some of the pollutants are indigenous to specific regions. In addition to this, these pollutants are not included in abovementioned index or other air quality indices developed around the world. In conducted study by Sowlat et al. (1) an air quality, namely, fuzzy air quality index was developed. By comparing the result of FAQI with USEPA AQI, they indicated that the major part of pollution is resulted from specific pollutants which are normally ignored in routine assessment of air quality; in other words, the pollution was mostly caused by benzene, toluene, xylene, and ethylbenzen. In other developed indices for assessing water quality, it has also been shown that the quality is mostly rooted from parameters not normally assessed. Considering the fact that an air quality index is a tool by which we are able to make plans so as to manage the problem when it is necessary, the mentioned problem can gravely affect our decision. The major pollutants which are indigenous to specific regions should be studied and indicated. Therefore, to the best of our knowledge, very few studies have been conducted aiming to indicate the local pollutants of different regions around the world.

The present study was aimed to indicate the major pollutants of Tehran, Iran, which is a highly populated area with a total population of approximately 10 million. Eleven parameters, including CO, SO\textsubscript{2}, PM\textsubscript{10}, PM\textsubscript{2.5}, O\textsubscript{3}, NO\textsubscript{2}, benzene, toluene, xylene, and 1,3-butadiene, have been accounted over a period of two years (2011-2012) from five monitoring stations located at Tehran. In fact, we selected these parameters to assess their concentrations and presence over a period of two years so as to find the major air pollutants of Tehran. At first, a set of input-output fuzzy parameters was defined for each mentioned parameter to have it is fuzzy based monthly quality; and also, fuzzy c-mean clustering was used to find the major part of each pollutant in the total quality of air in Tehran, Iran. Furthermore, the number of times, in monthly basis, which each pollutant's level had been higher than its set standard level are extracted in order to have a deep understanding of the quality of air in this area.

**Materials and Methods**

**Fuzzy inference system**

Fuzzy logic, suggested by Zadeh (10), as a tool for which is capable of thinking much more like the way human beings do. Over the past decade, fuzzy logic has been widely used to model and control complex systems (1, 11, 12). To develop a model by using this tool, we are able to use an individual’s existing knowledge and experience as information (13). This property of fuzzy logic can be considered one of its main advantages not considered by other methods. There have been various models developed based on fuzzy logic (1, 11, 12, 14, 15).

We used fuzzy logic to have the fuzzy based quality of each parameter. This process requires knowing three main parts of the fuzzy inference system, including membership functions, fuzzy set operations and inference rules (13). Here, each parameter was assigned to a same output shown in Fig. 1.

A domain called the universe of discourse had been defined for each input and output (Set) divided into subsets and expressed by using linguistic terms. The linguistic terms shown in Fig. 1 were selected based on the terms used to define the air quality in USEPA AQI. We used trapezoidal membership functions based on the following equation and Table 1:

\[
\text{Trapezoidal} : f(x; a, b, c, d) = \begin{cases} 
0 & x < a \text{ or } d < x \\
\frac{(x - a)}{(a - b)} & a \leq x < b \\
1 & b \leq x < c \\
\frac{(d - x)}{(d - c)} & c \leq x \leq d 
\end{cases}
\]

In order to assign each subset to its corresponding subset in the output, fuzzy if-then
rules were defined by extracting experts' knowledge. For each input-output relationship, we defined six rules. Totally 66 rules were defined in this study. The following rules are the examples of what we used in this study:

**Rule 7**: If PM$_{2.5}$ is “low” then Quality is “Moderate”.

**Rule 42**: If SO$_2$ is “extremely high” then Quality is “Hazardous”.

**Rule 13**: If PM$_{10}$ is “moderate” then Quality is “Unhealthy for Sensitive Groups”.

All computations were carried out using the “fuzzy logic toolbox” in MATLAB version 7.9.0.

**Fuzzy c-mean clustering**

Fuzzy c-means (FCM), originally introduced by Bezdek (16), is a technique in each data point belongs to a cluster to some degree that is specified by a membership grade. By using this technique, we are able to group data points, in this case concentrations of abovementioned parameters, into a specific number of different clusters. In fact, the purpose of using this method is to have the best structure regarding the applied data; and also, this method provides us with the ability to partition the data set into groups with similar individuals. The raw concentration of each parameter (monthly average) was entered to the program. We used three cluster because of the trend in the concentration of parameters. In other words, most of the parameters' concentrations were following a same trend individually.

**Case Study**

The present work is a Cross-Sectional study. However, this study was not conducted on the residents of Tehran. In fact, we assessed the concentration and duration of the pollutants over a period of two years. Hence, the group studied in this work was included of eleven parameters (i.e. CO, SO$_2$, PM$_{10}$, PM$_{2.5}$, O$_3$, NO$_2$, benzene, toluene, ethyl-benzene, xylene, and 1, 3-butadiene). The concentration of these pollutants, which are routinely monitored by Air Quality Administration, was collected from five monitoring stations, namely, Aghdasieh, Poonak, Park Roz, Geophysics, and Shahre Rey. Tehran, the capital city of Iran, is one of the most populated cities around the globe with a total population of approximately 12 million. Based on the reports of previously conducted studies, the major sources of air pollution in this city are motor vehicles and industries. High concentrations of air pollutants have been detected in Tehran. Due mainly to prevailing west-to-east winds and also the location of main

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**Fig. 1**: Example of the trapezoidal membership functions for classifying the output.
industries at the west part of this city, wide range of pollutants, especially those with industrial origin (i.e. BTEX and 1,3-butadiene) are present in the air of this region.

Results

Fig. 2 shows the monthly mean concentrations of criteria pollutants at five abovementioned sampling stations. As shown in this figure, monthly averages of these pollutants are mostly lower than set standard levels by EPA. For instance, CO concentrations (Fig. 2a) at different sampling stations, except Shahr-e-Rey, were mostly below the standard level of 9 ppm (USEPA, 1997). In addition, the monthly mean concentrations of other pollutants are shown in Fig. 3. It can be seen from this figure that the mean average concentrations of these pollutants exceed the standard levels in most months of study period. For instance, benzene concentrations (Fig. 3a) are dramatically higher than the standard level of 5 ppb at all sampling stations.

Fig. 2: Monthly mean concentrations of criteria air pollutants for the study period at different sampling stations
Table 1 indicates the individual quality of each pollutant in all the sampling stations derived by using fuzzy inference system. The fuzzy based quality of criteria pollutants cannot be considered as a threat to human health. However, the quality of other pollutants is considerably low. For instance, the quality of benzene and toluene is mostly E and/or F, indicating a hazardous condition.

Based on the results, almost all the clusters deduced for the criteria pollutants centered lower than the set standard level. We analyzed other pollutants as well, shown in Fig. 4, 5, 6, and 7. The concentrations of BTEX and 1,3-butadiene are centered in almost all the sampling stations around the clusters representing the hazardous condition of air quality. In fact, these results show that relying on the index developed by USEPA cannot be a suitable option, since the...
main threat roots from the pollutants not included in that index.

**Discussion**

Based on the results of the present study, it can be implied that the application of EPA AQI is not suitable in regions with different air pollutants. In fact, the application of this index in regions with various sources of air pollutants and different range of pollutants could results in underestimating the quality of air. In other words, EPA AQI is included only with six parameters; whereas, there are many other pollutants emitted from various sources (i.e. industry, and motor vehicles) which are abundantly present in mega cities like Tehran.

In a study conducted by Sowlat et al. (1) this is also insisted on. The index developed by them indicates a more stringent result, in comparison with that of EPA AQI. They reported that this difference is due to the difference in the number of pollutants included in each air quality index. The present study does not aim to consider the total air quality of Tehran, since previously conducted studies have shown that the current AQI index (EPA AQI) is not suitable for indicating the quality of air in this city.

We also tried to further analyze the quality of air between 2011 and 2012 by using fuzzy c-mean clustering. Based on the results, the monthly mean average concentrations of criteria pollutants in all the sampling stations are lower than the standard level. This is also in line with the results of the study conducted by Sowlat et al. (1). If one uses EPA AQI to assess the quality of air between the year 2011 and 2012, the quality of air resulted from using this index would not be what in the reality is. In other words, the results achieved for BTEX and 1, 3 butadiene which are shown in Fig. 4 and 5 for respectively Aghdasieh and Geophysics sampling stations confirm that the quality of air in these years is indeed affected by the parameters not included in the index developed by USEPA.

![Fig. 4: FCM of the monthly mean concentrations of BTEX and 1, 3-butadien pollutants in Aghdasieh (sampling stations)](image-url)
Considering the fact that an air quality index is developed to not only show the quality of air, but also be used as a tool to develop managerial plans, relying on the output of such index can results in completely different outcomes. The real problem can be missed, since the main pollutants are ignored in this index. Annually, a considerable amount of money is spent to improve the quality of air in Tehran. However, this all can be wasted if we do not know where the problem is rooted from.

**Conclusions**

The present study was conducted with the aim of assessing the main air pollutants of Tehran, Iran between 2011 and 2012. A broad range of air pollutants exist in the environments jeopardizing the health of human beings. It showed that the main pollutants of this city are not what general public believes. In fact, the main threats come from the pollutants which are not currently included in the air quality index developed by USEPA. In the present work, eleven parameters were assessed by using fuzzy inference system and fuzzy c-mean clustering. These tools showed that the quality of criteria pollutants between the year 2011 and 2012 did not as much effect the public health as the other pollutants did. It is clear that by using the air EPA AQI, the quality of air, and also the managerial plans required to improve the quality can be misled.
Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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### Table 1: Fuzzy sets and linguistic terms for the inputs and the output

| Intervals                          | 1, 3-butadiene (ppb) | Benzene (ppb) | Toluene (ppb) | Ethylbenzene (ppb) |
|------------------------------------|---------------------|---------------|---------------|-------------------|
| Good                               | a 0 b 200 c 250     | a 0 b 2 c 3.5| a 0 b 0.004   | a 0 b 0.6 c 0.6  |
| Moderate                           | 200 250 460 500     | 2 3.5 5 6    | 0.004 0.006  | 0.01 0.011 0.015 |
| Unhealthy for Sensitive Groups     | 460 500 600 650     | 5 6 8 10    | 0.01 0.011   | 0.017 1 1.5 3 4  |
| Unhealthy                          | 600 650 1000 1100   | 8 10 12 15  | 0.015 0.017  | 0.03 0.037 3 4 6 8|
| Very Unhealthy                     | 1000 1100 1500 1550 | 12 15 25 30 | 0.03 0.037 0.1| 0.12 6 8 15 20 |
| Hazardous                          | 1500 1550 2000 2000 | 25 30 50 50  | 0.1 0.12 1   | 1 15 20 30 30  |

### Table 1: Continued

| Xylene (ppb) | PM$_{2.5}$ (µg/m$^3$) 0-180 | PM$_{10}$ (µg/m$^3$) 0-600 | Criteria Group CO (ppm) 0-50 | O$_3$ (ppb) 0-600 | SO$_2$ (ppb) 0-100 |
|--------------|-----------------------------|-----------------------------|------------------------------|-----------------|-------------------|
| a            | b                            | c                            | d                            | a               | b                 | c       | d       |
| 0            | 0                            | 12                           | 18                           | 0               | 0                 | 20      | 30      | 35     | 120   | 30     | 150   | 110   | 150   | 150   | 100   | 150   | 150   | 150   | 150   | 150   |
| 12           | 18                           | 35                           | 20                           | 30              | 50                | 60      | 25      | 75     | 125   | 175    |
| 30           | 35                           | 45                           | 50                           | 80              | 90                | 125     | 175     | 225    | 275   | 8      | 10     | 11     | 13     | 115    | 135    | 135    | 135    | 135    | 135    |
| 45           | 50                           | 60                           | 70                           | 80              | 90                | 110     | 120     | 225    | 275   | 375    | 11     | 13     | 14     | 20     | 155    | 175    | 190    | 210    | 200    | 240    |
| 60           | 70                           | 100                          | 110                          | 120             | 140               | 150     | 150     | 35     | 190   | 210    | 380    | 430    | 280    | 350    | 550    | 650    |
| 100          | 110                          | 150                          | 150                          | 150             | 180               | 180     | 180     | 40     | 600   | 435    | 600    | 600    | 50    | 380    | 430    | 600    | 600    | 550    |

### Table 1: Continued

| NO$_2$ (ppb) 0-2000 | Output Quality 0-500 |
|---------------------|----------------------|
| a                   | b                    | c                   | d                   |
| 0                   | 0                    | 6                   | 120                 | 0                   | 0                   | 40                 | 60                 |
| 60                  | 120                  | 180                 | 240                 | 40                  | 60                  | 90                 | 110                |
| 180                 | 240                  | 280                 | 340                 | 90                  | 110                 | 140                | 160                | 190                | 210                |
| 280                 | 340                  | 600                 | 700                 | 140                 | 160                 | 190                | 210                | 270                | 320                |
| 600                 | 700                  | 1100                | 1400                | 190                 | 210                 | 270                | 320                | 500                |
| 1100                | 1400                 | 2000                | 2000                | 270                 | 320                 | 500                |

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