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Air quality assessment using a weighted Fuzzy Inference System

Miguel Ángel Olvera-García, José J. Carbajal-Hernández *, Luis P. Sánchez-Fernández, Ignacio Hernández-Bautista

Centro de Investigación en Computación, Instituto Politécnico Nacional, Av. Juan de Dios Bátiz s/n, Nueva Industrial Vallejo, Gustavo A. Madero, México D.F., C.P. 07738, Mexico

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ABSTRACT

Air pollution is a current monitored problem in areas with high population density such as big cities. In this sense, environmental modelling should be accurate in order to generate better air quality evaluations; but in consequence they are complex. Nowadays, the artificial intelligence based on heuristic methods allows assessing air quality parametres, providing a partial solution to this problem. Accordingly, this paper proposes a new evaluation model using fuzzy inferences combined with an Analytic Hierarchy Process, providing a new air quality index. Environmental parametres ($PM_{2.5}$, PM_{10}, O_3, CO, NO_2 and SO_2) are evaluated according to toxicological levels and then, a fuzzy reasoning process assesses different air quality situations. Additionally, individual weights are computed and assigned according to the pollutant importance on the air evaluation. Finally, the model proposed considers five score stages: *excellent*, *good*, *regular*, *bad* and *dangerous*, based on data from the Mexico City Atmospheric Monitoring System (SIMAT). Experimental results show a good performance of the proposed air quality index against those in literature, providing better assessments when weights are assigned according to an importance level in atmosphere pollution.

1. Introduction

People living in big cities suffer air pollution, which has daily negative effects on their health, generating several respiratory diseases, in which severe cases can be fatal. The main sources of air pollution are industrial combustion processes and automobile emissions (Bartra et al., 2007). In Mexico City about 5 million cars are used daily, emitting annually into the atmosphere approximately 1.6 million tons of carbon monoxide, around 895,369 tons of total organic compounds (300,000 tons of hydrocarbons released into the atmosphere through evaporation and poor combustion), 239,132 tons of nitrogen oxides (including 90,000 tons of nitrogen dioxide), 34,677 tons of particles matter smaller than 10 μm, 9451 tons of particles matter smaller than 2.5 μm and 4867 tons of dioxide sulphur. Both, particles matter smaller than 10 μm and ozone are the most abundant pollutants in the Mexico City Valley area and they are beyond permissible limits (SEDEMA, 2014). According to this problem, in Mexico, several government agencies measure the amount of air pollutants using an indicator known as the IMECA (Metropolitan Index of Air Quality), which allows the Ministry of Environment of the Mexico City in coordination with the National Institute of Ecology and Climate Change (SEDEMA, 2014; INECC, 2014), to obtain the necessary information for decision making and issuing necessary environmental alerts. Other international organizations have implemented similar methodologies for air pollutant assessment and monitoring such as the Environmental Protection Agency in United States (USEPA, 2009) and the Pan American Health Organization (PAHO, 2015).

Human permissible limits, are in a ranges set and are used to calculate the IMECA index. They are defined by toxicity level tests and measure the impact of air pollution on the health of people as a whole. Although, the damage that each pollutant causes separately is known (NADF-009-AIRE, 2006, WHO, 1987), without inferring if all parametres have the same harmful possibilities as is considered in the IMECA and other similar indexes. Alternatively, other methodologies have been proposed for evaluating air quality using computational models such as fuzzy logic (Liu et al., 2009; Upadhyaya and Dashore, 2010, 2011; Alhanafy et al., 2010; Sowlat et al., 2011; Wang and Chen, 2015), artificial neural networks (Ordieresa et al., 2005; Salazar, 2007; Coman et al., 2008; Feng et al., 2013; Mishra and Goyal, 2016), associative memories (Ruiz et al., 1995), support vector machines (Wang et al., 2008), factor analysis (Bishoi et al., 2009), Bayesian models (Yong et al., 2008), amongst others. Sen et al. (2015); Yadav et al. (2014) and Carbajal et al. (2012) propose air quality assessment models using Fuzzy Inference Systems in their respective works, classifying potentially harmful situations by handling uncertainty and subjectivity through a Fuzzy Inference System. Nevertheless, these models do not properly handle uncertainty, subjectivity and individual importance that are implicit in environmental parametre behaviours, avoiding the proper integration of individual evaluations, giving to each of them the same importance,

* Corresponding author.
E-mail addresses: ma.olvera58@gmail.com (M.Á. Olvera-García), jcarbajalh@cic.ipn.mx (J.J. Carbajal-Hernández), lsanchez@cic.ipn.mx (L.P. Sánchez-Fernández), ignaciohb@gmail.com (I. Hernández-Bautista).

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since each air quality parametre has a different affectation on population health.

Recent works for air quality assessment using fuzzy logic and combining an Analytic Hierarchy Process (AHP) have been developed, providing different solutions (Valipour and Montazar, 2012c, Upadhyay et al., 2014, Akkaya et al., 2015). In Abdullah and Khalid (2012), a fuzzy analysis is used for generating weights that are multiplied to different parametre indexes. Then, the air quality index is obtained by the sum of the particular results using an AHP. In this case, there is not an experimental analysis phase of this work. Gorai et al. (2015, 2014) and propose air quality models based on a similar work to Abdullah and Khalid (2012), where parametre weights are built using a fuzzy model and by analysing environmental patterns. Finally, an AHP is applied for computing the output scores. Those works provide a good solution for evaluating atmosphere pollution; moreover, the main gap is the lack of a reasoning process which is able to detect negative situations according to the parametre behaviours. Also, only using an AHP model in environmental assessments generates a particular issue, in which the global score is highly influenced by the parametre with the highest weight.

In this work, the authors hypothesised that a parametre priority assignment based on a Fuzzy Inference System will generate better air quality assessments, as there are pollutants with major health affectations since they have more importance in air pollution. In this sense, the combination of a reasoning system with a weighment process, will involve the importance of the pollutant with a potential crisis detection modelling, increasing the effectiveness of the assessment to generate more accurate evaluations that can be reflected in an air quality index (AQI).

In the present study, the proposed models are applied for analysing the air quality of Mexico City and its Metropolitan area, where pollutants are assessed for establishing an indicator for good or bad air quality. In order to introduce the reader to the methodology structure, the rest of this paper has been organized as follows: in Section 2, pollutants and their main characteristics in air quality assessment are explained. In Section 3, a Fuzzy Inference System for air quality assessment is proposed; additionally a numerical example is given for a better understanding of our proposal. Section 4 explains the priority assignment process, giving the new air quality index. Section 5 shows some experiments using real environments, where the proposed index is compared against other similar air quality indexes given in literature and by international organizations; this section shows the performance and efficiency of our proposal. Finally, Section 6 provides our conclusion and future research directions.

2. Air quality requirements

2.1. Study area

The Mexico Valley area encompasses Mexico City and some towns belonging to the Mexico State (Metropolitan area). Mexico City includes more than eight million inhabitants and more than 20 million for the Metropolitan area. The Mexico Valley has an area of 9600 km^2 and has a minimum altitude of 2240 m (7349 ft) above sea level. It is surrounded by mountains and volcanoes that reach elevations of over 5000 m. This area is located in the Trans-Mexican Volcanic Belt and the high plateaus of south-central Mexico (INEGI, 2010). The Mexico City Valley air pollution problems depend of different factors such as the wind, weather, population and industry. Usually a greenhouse effect is present due to the topography of the area (Fig. 1).

Air quality analysis in the Mexico Valley is made through the Mexican Ministry of Environment (SEDEMA, 2014) according to the Atmospheric Monitoring System called SIMAT (2014), which monitors the urban air pollution daily using an air quality index known as the IMECA. This index was designed using as an information base, the methodology of the Agency for United States Environmental Protection Agency (USEPA, 2015) and since 1982, it has been used as the official standard. The SIMAT is composed of four environmental monitoring networks such as: a) the Automatic Air Quality Monitoring Network (RAMA, 2015), which consists of 30 environmental stations; b) the Manual Network for Atmospheric Monitoring (REDMA, 2015), which consists of 12 monitoring stations; c) the Atmospheric Storage Network (REDDA, 2015), with 16 sampling stations where environmental measurements are made every six days and d) the Solar Radiation and Meteorology Network (REDMET, 2015), which operates 16 stations providing information on meteorological parametres to develop forecasting and dispersion models, analysing the pollutants movement in time (Fig. 2).

2.2. Air quality parametres

The air quality assessment is based on the pollutant concentration levels, which can damage population health depending of the toxicity and exposure time (Wang et al., 2011). In this case, six key pollutants have been studied in the urban area: ozone (O_3), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), particulate matter smaller than 10 and 2.5 μm (PM_{10} and $PM_{2.5}$). Although NO_x and SO_x parametres represent a better set of pollutants to be analysed, the SIMAT only measures NO_2 and SO_2 concentrations. The aim of this work is to be an alternative of the SIMAT evaluations for validating the air quality assessment. In this sense, no data information about NO_x and SO_x measurements can be obtained from the monitoring stations. In air quality assessment, the damage caused by each parametre is perfectly known, generating different problems on the health of people, so they should be treated separately. In order to understand the negative effects of the pollutants involved in the atmosphere, Table 1 shows some considerations about their human health interaction.

Environmental parametres are assessed by their toxicity levels and negative effects concerning good air quality. According to this, national and international organizations have implemented some classification levels, which define the criteria to be considered in the air quality assessment. This work is based on the USEPA and IMECA toxicity levels in order to be compatible with their air quality scores, having a direct correspondence between the FIS, the IMECA and USEPA outputs and toxicity levels. For this reason, classification levels were selected from the IMECA proposal. Table 2 contains those classifications that have been considered by the IMECA and the USEPA indexes (NADF-009-AIRE, 2006; USEPA, 2009). This will be helpful when a comparison between indexes is made, having the same final score range and being compatible to both indexes in the evaluation of the air quality of the Mexico City Valley. More details about the IMECA index can be consulted in Appendix A.

2.3. Air quality classification

According to governmental standards, air quality levels have been defined according to their negative effects on human health. In this sense, as the IMECA index was created to evaluate and classify the environmental set of parametres according to their limits, the categories defined by the Mexican Ministry of Environment have been proposed to be used, which gives some recommendations for making any outdoor activity (SEDEMA, 2014). In its website, the latest evaluations of air quality through the IMECA index are calculated and displayed across several monitoring stations and by assigning a specific colour, corresponding to a classification level. In this sense, five categories have been defined for assessing the air quality as follows:

a) *Good*: it is appropriated to perform outdoor activities;
b) *Regular*: outdoor activities can be performed; however, children, elderly and sick people can be affected.
c) *Bad*: outdoor activities should be avoided. Children and older adults with cardiovascular diseases such as asthma can be affected by the bad air quality condition. Therefore, be attentive to information on air quality and medical recommendations.