ASSESSMENT OF AIR POLLUTION LEVEL AT ADAMAWA STATE UNIVERSITY MUBI USING FUZZY INFERENCES SYSTEM MODEL

Supported by tetfund

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Received: September 14, 2024 Accepted: November 28, 2024

Abstract: In recent years, air pollution has emerged as a significant environmental issue, particularly in urban areas. This article presents an analysis of air pollution levels in the vicinity of Adamawa State University, employing an innovative fuzzy inference system model to quantify and assess pollution levels and their implications for public health and the environment. A Mandani-type fuzzy logic model is developed based on two input variables (CO_2 and NO_2) and the output variable (air quality index, AQI), using fuzzy logic toolbox of MATLAB. In particular, the specific objectives of this paper are to develop a fuzzy rule-based model and to analyze the system-generated surfaces. Different weighting factors were then assigned to each pollutant according to its priority. Triangular membership functions were employed for classifications and the final index consisted of twenty-five inference rules. The results obtained shown that the air quality of the study area is excellent based on the air quality index classification by the Environmental Protection Agency (EPA) which is appropriate for outdoor activities. Improving carbon dioxide (CO_2) and nitrogen dioxide (NO_2) concentration levels in the atmosphere requires a multi-faceted approach involving the use of renewable energy source such as solar and wind, Implement energy-efficient appliances and LEDs in households, invest in tree planting and forest conservation efforts to absorb CO_2 from the atmosphere, encourage urban greening initiatives, such as community gardens and green roofs, and use of electric or hybrid vehicles.

Keywords: Air Pollution, Air Quality Index, Carbon dioxide, Fuzzy inference system, Mandani-type fuzzy, Nitrogen dioxide

Introduction

The need to have a clean, dry, and healthy environment cannot be over-emphasized as polluted air adversely affects the health of humans and animals and causes plant and material damage. Air pollution can be referred to as any atmospheric condition in which certain substances are present in such concentrations that they can produce undesirable effects on man and his environment (Abhatia, 2014). These substances include gases (oxides of Sulphur, oxides of nitrogen, oxide of carbon, hydrocarbons, etc) particulate matter (smoke, dust, fumes, etc), radioactive materials, and many others. Increasing demographic pressure allied with increased developmental activities are factors responsible for generating more copious emissions than the air can assimilate. According to Medugu (2023), protection against detrimental effects of polluted air should be handled with reliable information on the level at which pollutant are present. The principal gasses of concern in air pollution control are Sulphur oxides (SOX_2, SO_3), nitrogen oxide (NO, NO_2), carbon oxides (CO, CO_2), organic and inorganic acidic gases, and hydrocarbons (Ajit, 2013).

Carbon dioxide (CO_2) is generally not considered an air pollutant but, because of its increased global background concentration, its influence on global climatic patterns is of great concern. It is generated from incomplete combustion of fossil fuels. Due to deforestation, the rate of CO_2 absorption by the plants is reduced and so the amount of CO_2 in the air is increasing. It is most active in raising the atmospheric temperature. The amount of CO_2 in the air is 0.033%. A slight increase of it will raise the atmospheric temperature which may be dangerous for the earth's climate and the living world (Barry and Chorley, 2012). The use of alternative energy resources and extensive afforestation may be able to maintain the CO_2 balance.

Nitrogen dioxide (NO_2) is a brown pungent gas with an irritating odour which can be detected at a concentration of about 0.12 ppm. It absorbs sunlight and initiates a series of photochemical reactions. Small concentrations of NO_2 have been detected in the lower stratosphere, NO2 is probably produced by the oxidation of NO by ozone. Nitrogen dioxide is of major concern as a pollutant; it is emitted by fuel combustion and nitric acid plants. NO_2 irritates the alveoli of the lungs. NO_2 combines with moisture to form nitric acid and can cause damage as acid rain. NO_2 at a concentration of 0.5 ppm for 10-12 days causes suppressed growth. At concentrations higher than 1ppm it causes a reduction in the yield of fruits. If combined with unburned hydrocarbons it forms photochemical smog which is very harmful to plants (Abbasi, 2010).

Methods based on the fuzzy set's theory should be applied in the context of environmental numbers. The boundaries between an acceptable and an unacceptable concentration are not to be considered as sharp, but as fuzzy, with implications for subsequent action plans (Dunea, et al. 2011). Previous studies have used various approaches to predict the air quality index (AQI). In this study, we focus on a fuzzy inference system (FIS) to predict the AQI value. According to Chaudhari and Patil (2014), the FIS approach has an expressive output strength without difficulty in understanding the results and manipulating the goal. FIS can capture converting environment as a professional information and without problems. The very first application of this technique was to control a steam engine and the result obtained was as good as when controlled by experienced human operators.

Guleda Onkal-Engin et al (2004) provide a methodology for urban air quality using fuzzy synthetic evaluation techniques in the European part of Istanbul. Air pollutant data such as Sulphur Dioxide (SO_2), Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Ozone (O_3), and total suspended particulate matter (PM) collected at five different air quality monitoring stations located in the western part of Istanbul was used in this evaluation. The results obtained were compared to those applied to the EPA air quality index and concluded that these techniques are relatively suitable for urban air quality management. Alieldin, et al. (2016) makes use of Fuzzy Logic to Assess the Environmental Quality of Urban Development. The researchers manage the uncertainties associated with decision-making processes by employing fuzzy logic in obtaining precisely enumerated, quantified, and computerized assessment results for Mansoura Waterfront. The concentrations of carbon oxides (CO and CO_2) and suspended particulate matter at Benue Cement Company (BCC) and Tse-Kucha community were investigated by Abdulkarim, et al. (2007). Results obtained show that concentrations of carbon dioxide of 34.40ppm, 39.50 ppm, 48.50 ppm, 78.55 ppm, 65.25 ppm, 26.80 ppm and 29.5 ppm for quarry, raw mill, cement mill, Kiln, packing house, limestone stockpile and Tse-Kucha community respectively were below the maximum standard natural concentration of CO in atmosphere of 600ppm while concentrations of CO (1.25ppm - 4.00ppm) measured in all the sample stations were below the Nigerian Ambient Air Quality Standards (NAAQS) and WHO max limit of 10 ppm - 20 ppm for an 8-hourly average time.

The use of fuzzy numbers is proposed as a suitable technique for handling environmental criteria and tackling decisions made under uncertainty (Saeedi, et al. 2008). Fuzzy logic was successfully applied for various air quality assessments and predictions (Dunea, 2008; Oprea, et al., 2010). The literature shows that fuzzy inference systems are frequently considered for short-term forecasting applied to emissions control or AQI computations. These methods have some advantages over deterministic approaches (Dunea, et al. 2011). Danladi, *et al.*, (2016) presents a solution methodology, using fuzzy logic approach for short term load forecasting (STLF) for Adamawa State University, Mubi. The proposed methodology utilized fuzzy reasoning decision rules that use the nonlinear relationships between inputs and outputs. The fuzzy logic model was developed in the Simulink environment of a MATLAB software. The model developed was able to forecast a day ahead load (kW) and it they observed that weather parameter (temperature) has significant impact on electrical load.

In this paper, a fuzzy rule-based model is designed to assess the air quality of Boni Haruna Campus, Adamawa State University Mubi, based on two input variables (CO_2 and NO_2) and the output variable (air quality index, AQI) using fuzzy logic toolbox of MATLAB. In particular, the specific objectives are to develop a Mandani-type fuzzy logic model and to analyze the system-generated surfaces.

Materials and Method

Materials

A portable gas monitor (model CE-89/336/EEC by Crown Instrument Ltd Oxon, United Kingdom) and Matlab software.

Study Area

The study is carried out in Boni Haruna Campus of Adamawa State University located in Mubi town, in the Northern Senatorial District of Adamawa State, Nigeria. Mubi is geographically located within latitude 10.27 and longitude 13.28 and has an elevation of 1906 feet above sea level situated at the foot of the Mandara mountains separating Nigeria from the republic of Cameroun.

Data Collection

Air quality data were collected directly from the sampling location through a manual control monitoring gas detector, which automatically measures and records the concentration of CO_2 and NO_2 level presence in the atmosphere at the study location. Data were collected for twelve hours at an interval of one hour (that is, from 8 am to 7 pm).

Experimental design

Fuzzy Inferences System Model

In this study, two main pollutants were taken into account for calculating the air quality index (AQI) for Boni Haruna Campus, Adamawa State University Mubi (i.e. NO_2 and CO_2). These two pollutants' levels are crisp inputs for our FIS model, while AQI is the output variable.

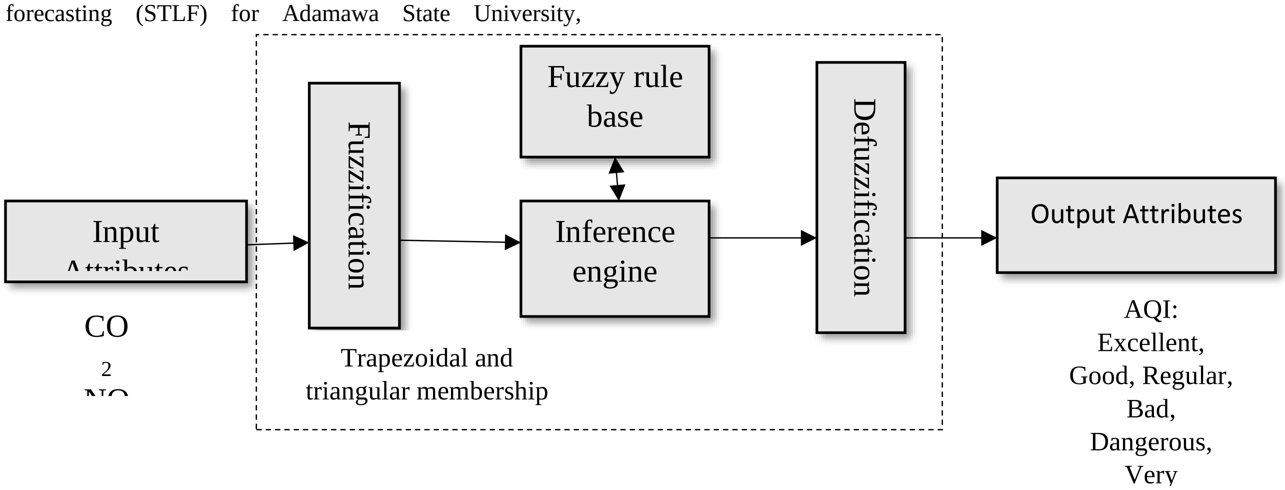

Figure 1: Fuzzy inference model for the air quality determination

Fuzzification is the process of making a crisp quantity fuzzy. The operation interprets real crisp input or else measured values into linguistic ideas using appropriate membership functions. In this study, a triangular membership function was utilized to standardize the crisp for its simplicity and computational performance.

The categorization levels of the air quality metrics are shown in Tables 1 and 2 below, which are mainly based on reported works (Carbajal-Hernandez et al. 2012; Dionova et al. 2020; EPA 2014; Katushabe et al. 2021).

Table 1: Threshold point for air pollution

AQI	Excellent 0-50	Good 51-100	Regular 101-150	Bad 151-200	Dangerous 201-300
CO2(ppm)	Very low 0-300	Low 301-600	Medium 601-1000	High 1001-1700	Very high 1701-2700
NO2(ppm)	Very low 0.000-0.105	Low 0.106-0.210	Medium 0.211-0.315	High 0.316-0.420	Very high >0.420

The harmful effects of air pollutants on human health may be divided into the following categories by air quality regulations (Carbajal-Hernandez et al. 2012):

• Excellent: Conditions are appropriate for practicing outdoor activities.
• Good: It is possible to participate in outdoor activities.
• Regular: Outdoor activities should be avoided since they may hurt population health, particularly among young and old persons
• Bad: There are increased negative health impacts on the community as a whole, especially among young and old persons
• Dangerous: There could be a significant negative impact on the general public's health.

Moreover, the associated fuzzy membership values are described as follows:

• The concentration of NO_2 (β): very low, low, medium, high, and very high.
• The concentration of CO_2 (α): very low, low, medium, high, and very high.

The AQI is categorized and approximated as the output of the following membership values: excellent, good regular, bad, and dangerous.

The input presented in Table 1 is utilized to determine the corresponding membership function for each pollutant type based on the range of values for each category.

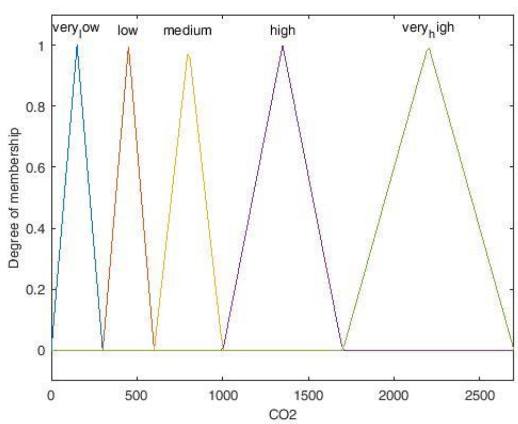

Figure 2: Input membership function of CO_2

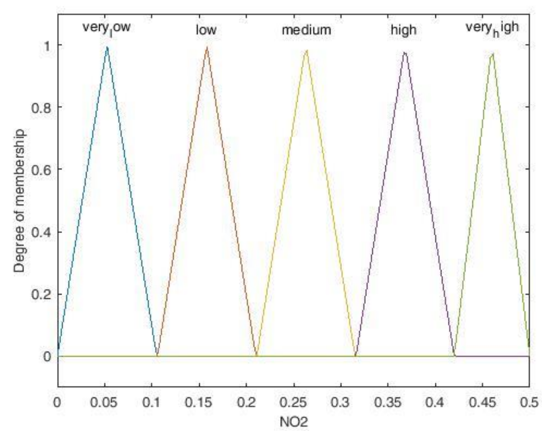

Figure 3: Input membership function of NO_2

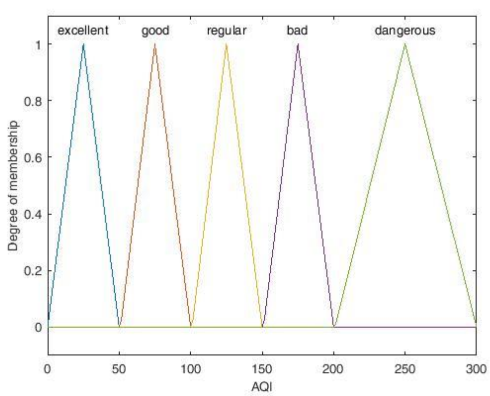

Figure 4: Output membership function

The probable combination of membership functions influences the number of defined fuzzy rules which can be obtained with the following formula (Cavallaro 2015):

Number of possible fuzzy rules = N^M

where: M = number of parameters., N = the number of linguistic terms per input parameter.

In our case, $5^2 = 25$ rules.

Table 2: Rule base

Input parameters		Output parameter
CO_2	NO_2	AQI for Boni Haruna Campus
Very Low	Very Low	Excellent
Very low	Low	Good
Very low	Medium	Regular
Very low	High	Bad
Very low	Very high	Dangerous
Low	Very low	Good
Low	Low	Good
Low	Medium	Regular
Low	High	Bad
Low	Very high	Dangerous
Medium	Very low	Regular
Medium	Low	Regular
Medium	Medium	Regular
Medium	High	Bad
Medium	Very high	Dangerous
High	Very low	Dangerous
High	Low	Dangerous
High	Medium	Dangerous
High	High	Dangerous
High	Very high	Dangerous
Very high	Very low	Dangerous
Very high	Low	Dangerous
Very high	Medium	Dangerous
Very high	High	Dangerous
Very high	Very high	Dangerous

Table 2 shows the 25 rules for two inputs (CO_2 and NO_2) with five categories for each input (i.e., very low, low, medium, high, very high) and five categories for the AQI output (i.e., excellent, good, regular, bad, dangerous) utilized in the study. For instance, if we pick the first line, the reading of the input is as follows:

"IF CO_2 is very low AND NO_2 is very low THEN AQI is excellent".

Finally, the defuzzification step constitutes a decisional phase that makes it possible to transform a fuzzy value of a variable into a real value. The center of gravity (COG) approach was employed in the current study since it is considered to be the most frequent and relevant defuzzification technique. The COG returns the center of the area under the curve formed by the output fuzzy function (Carbajal-Hernandez et al. 2012).

Results and Discussion

Air quality has been assessed using a set of 12 measurements for each air quality parameter (day-time of information). The results of AQI using Mamdani Fuzzy Inference System is shown in table 3 below. The values are obtained based on the 25 "If-Then" rules that are mentioned earlier. The status in the linguistic value is all "Excellent", i.e. condition is appropriate for practicing outdoor activities (Table 1) based on these two-air pollutants used in the study area.

Table 3: Result output of AQI from MATLAB (Mamdani Status)

INPUTS		MATLAB (Mamdani Status)	
		OUTPUT	LINGUISTIC VALUE
CO2	NO2	AQI	
28.9	0.0336	25.2	Excellent
28.91	0.0378	25.2	Excellent
28.91	0.0357	25.2	Excellent
28.92	0.0357	25.2	Excellent
28.68	0.0126	25.2	Excellent
28.57	0.0084	25.1	Excellent
28.45	0.0063	25.0	Excellent
28.33	0.0042	25.5	Excellent
28.27	0.0252	25.2	Excellent

28.27	0.0231	25.2	Excellent
28.17	0.021	25.2	Excellent
28.17	0.0189	25.2	Excellent

Moreover, as shown in Fig. 6 below, the surface view demonstrates how the output AQI is affected by CO_2 and NO_2 levels in the air. The three-dimensional surface view is used to see how one value of the outputs is dependent on one or two values of the input data. The *X* and *Y*-axes correspond to the input values of air pollutants, while the *Z*-axis indicates the AQI output value. The plot indicates that when one of the air pollutant input concentrations rises, corresponds to an increase in the AQI.

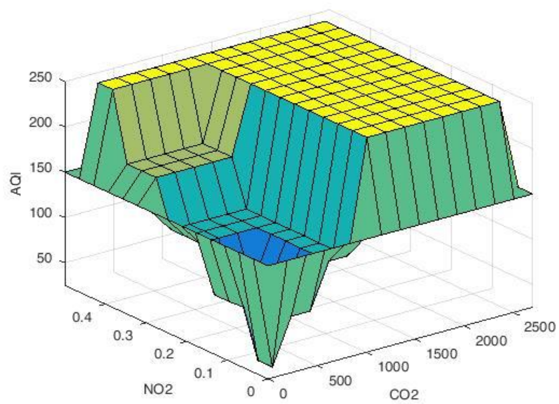

Figure 6: Surface viewer of the model

Conclusion

The concepts underlying fuzzy technology are successfully used in air quality modeling, allowing an alternative approach to solving specific environmental problems when the objectives or constraints are not precisely defined. By integrating two pollutant time series into a single indicator, the FIS provided a better and more comprehensive image of the air pollution status within the area of interest compared to classical pollution reports using individual pollutant concentrations. The air pollution level of Boni Haruna Campus (ADSU) Mubi has been successfully determined and was found to be excellent based on the Air quality index classification which is appropriate for outdoor activities. In future it might be possible to analyze the data by using other fuzzy inference system approaches, such as Sugeno Fuzzy Inference System. Improving carbon dioxide (CO_2) and nitrogen dioxide (NO_2) concentration levels in the atmosphere requires a multi-faceted approach involving the use of renewable energy source such as solar and wind, Implement energy-efficient appliances and LEDs in households, invest in tree planting and forest conservation efforts to absorb CO_2 from the atmosphere, encourage urban greening initiatives, such as community gardens and green roofs, and use of electric or hybrid vehicles.

Acknowledgments

The authors are grateful to the management of Federal Polytechnic Mubi for their financial assistants and providing equipment for the measurement of the air pollutant. Also, to the department of Physics, Adamawa state University Mubi for their support in carryout the research.

Conflict of Interest

I confirm that this work is original and has not been submitted elsewhere.

References

Abbasi, T. and Abbasi, S.A., 2021, October. Pollution and Its Control: A Historical Perspective. In *International Conference on Advances and Innovations in Recycling Engineering* (pp. 15-33). Singapore: Springer Nature Singapore.

Abdulkarim, B.I., Chiroma, T.M. and JOSEPH, T., 2007. Assessment of CO, CO2 and suspended particulate matter emissions. *Leonardo Electronic Journal of Practices and Technologies*, *11*, pp.109-116.

Ajit, K. S., 2013. *Weather and climate (Climatology).* Kalyani publishers. India

Alieldin, A.T., Sheta, S.A.A. and Hegazy, I.R., 2020. Adoption of Fuzzy Logic to assess the Environmental Quality of Urban Development. *MEJ-Mansoura Engineering Journal*, *41*(2), pp.9-14.

Barry, R.G. and Chorley, R.J., 2009. *Atmosphere, weather and climate*. Routledge.

Bhatia, S.C., 2001. Environmental pollution and control in chemical process industries. *Khanna ub,, Delhi*, pp.365-391.

Carbajal-Hernández, J.J., Sánchez-Fernández, L.P., Carrasco-Ochoa, J.A. and Martínez-Trinidad, J.F., 2012. Assessment and prediction of air quality using fuzzy logic and autoregressive models. *Atmospheric Environment*, *60*, pp.37-50.

Cavallaro, F., 2015. A Takagi-Sugeno fuzzy inference system for developing a sustainability index of biomass. *Sustainability*, *7*(9), pp.12359-12371.

Chaudhari, S.R. and Patil, M.E., 2014. Comparative analysis of fuzzy inference systems for air conditioner. *International Journal of Advanced computer research*, *4*(4), p.922.

Danladi, A.., Puwu, M.I., Michael, Y. and Garkida, B.M., 2016. Use of fuzzy logic to investigate weather parameter impact on electrical load based on short term forecasting. *Nigerian Journal of Technology*, *35*(3), pp.562-567.

Dionova, B.W., Mohammed, M.N., Al-Zubaidi, S. and Yusuf, E., 2020. Environment indoor air quality assessment using fuzzy inference system. *Ict Express*, *6*(3), pp.185-194.

Dunea, D., 2008. Developing an expert system applied for air quality assessments, *The Scientific Bulletin of the Electrical Engineering Faculty, Bibliotheca Publishing House*.

Dunea, D., Pohoata, A.A. and Lungu, E., 2011. Fuzzy inference systems for estimation of air quality index. *ROMAI J*, *7*(2), pp.63-70.

EPA., 2014 Technical Assistance Document for the Reporting of Daily Air Quality. Retrieved from: https:// www. epa. gov/ sites/default/ files/ 2014-

08/documents/care your air. pdf. Accessed 20 Dec 2023

Katushabe, C., Kumaran, S. and Masabo, E., 2021. Fuzzy based prediction model for air quality monitoring for Kampala city in East Africa. *Applied System Innovation*, *4*(3), p.44.

Onkal-Engin, G., Demir, I. and Hiz, H., 2004. Assessment of urban air quality in Istanbul using fuzzy synthetic evaluation. *Atmospheric Environment*, *38*(23), pp.3809-3815.

Oprea, M. and Dunea, D., 2010. SBC-MEDIU: A multi-expert system for environmental diagnosis. *Environmental Engineering and Management Journal*, *9*(2), pp.205-213.

Medugu, D.W., 2012. Concentration of air particulate matter at cattle market in Mubi, Nigeria. Adamawa State University Journal of Scientific Research. Pp. 48-55.

Saeedi, M., Fakhraee, H. and Sadrabadi, M.R., 2008. A fuzzy modified gaussian air pollution dispersion model.