"Takagi-Sugeno Fuzzy Rule Based Air Pollution Index"

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Abstract:
Fuzzy logic uses fuzzy rules, which are uncertain, non-descriptive, undefined, and linguistic. The developed fuzzy model by Takagi and Sugeno is illustrated by fuzzy logic if-then rules, which can be characterized by the general input-output relation of a nonlinear system. "In this paper, a methodology will be illustrated by using "Takagi-Sugeno fuzzy logic rule-based system to develop an Air Pollution Index." An air pollution index defined as a system that can convert the weightage of individual air pollution-related parameter (Sulphur dioxide (SOx), Nitrogen dioxide (NOx), Carbon monoxide (CO), and particulate matter (PM) into a single numerical value or crisp set value. To easily understand linguistic air quality indicators, which includes the combined effect of all the air pollutants parameter, is proposed as a new air pollution quality index using fuzzy logic. A model is developed to find fuzzy logic air pollution index (FLAPI) with input variable with their membership function. NOx, SOx, CO, and PM. The nature of the curve for membership function is considered triangular with four membership function.

Key words- ***Fuzzy logic, membership function, Air Pollution Index, Takagi-Sugeno Modeling.***

I. Introduction

Fuzzy inferences system is a suitable numerical operating tool with a rule-based system to treat various linguistic information which is affected by uncertainty and inaccuracy. Crisp set based evaluated air quality index contains the best-identified parameters, and then used for forecasting and decision-making if they are supported by the necessary input data. Fuzzy logic has an actual theory of ordinary actuation which one and all meet every day. Fuzzy logic is used in uncertainty environments so that connoisseur experimentation can be rehabilitated into numerical languages. By utilizing fuzzy logic, it is conceivable to amplify the use of decision making. It is probably to use for quantifying air pollutant risk, dangerous industries and high-risk area by a continuous value between 0 and 1.

Zadeh (1965) first presented the idea of the fuzzy set hypothesis. A fuzzy set can be characterized mathematically or numerically by assigning to every conceivable individual in the universe of discourse a value representing to its review of participation in the fuzzy set. Strategies used in the fuzzy sets between a satisfactory and an unsuitable concentration is not be considered as sharp, yet as fuzzy, with suggestions for consequent activity designs. The utilization of fuzzy numbers is proposed as a reasonable strategy for taking care of environmental criteria and handling decision made under uncertainty or vulnerability. Fuzzy membership function values are frequently represented by real-number values running in the closed interim somewhere in the range of 0 and 1. A fuzzy number contrasts from the crisp number as far as its membership value. In classical set hypothesis, the membership function of a number is 1 inside the limits of the set and is 0 outside. A fuzzy number may have a few diverse membership values inside an interval of 0 and 1.

Air contamination is an outstanding environmental issue related to urban regions around the globe. An "Air Pollution Index" (API) might be characterized as a single number for detailing the air quality concerning its impacts on human health.

Fundamentally, an AQI or API is developed to express the levels of at least one air contaminations, over different basic averaging periods, against a reference. The national air quality measures will typically use as the reference for the index. A system of air quality monitoring stations will be set up to quantify encompassing convergences of customary contaminations at fixed intervals. Some observing stations are situated at the roadside to gauge road level concentrations.

In these last years' several works have been conducted for the assessment of Air quality, several models were developed for the air quality assessment and their environmental impacts. Various air quality indexes were developed and are used for describing air quality. For example Oak Ridge Air Quality Index (ORAQI), Mitre Air Quality Index (MAQI), Extreme Value Index (EVI), Ontaria Air Pollution Index (API), Green's Combined Index (CI), Combustion Products Index (CPI), Air Quality Index (AQI), P index, etc.

All these indices vary in terms of the number of parameters used and the methodology used for obtaining the value of the index. In India, the pollution control authority (Central Pollution Control Board, CPCB, New Delhi), has classified areas into different zones based on the activities like industrial, commercial, residential, sensitive and set standards for the permissible values of criteria pollutants (Indian Air Quality Standard, 2009) in each zone. (Cavallaro F., 2012) Fuzzy logic is a reasonable numerical methodology to treat data of altogether different nature, which is incompletely influenced by instability and subjectivity. (Ashok Deshpande, 2014) Introduced two need-based research studies refer to air and water quality index. The first study refers to fuzzy air quality description in Pimpri-Chinchwad Municipal Corporation (PCMC) monitoring location, while the other relates to linguistic classification of water quality with the degree of certainty in PCMC area, India.

(Abhishek Upadhyay, 2014) Developed an approach to determine fuzzy air quality based on the observed air pollution concentration. The proposed technique is a multi-poison conglomeration strategy with fluctuating weighting and can consider subjective components like affectability and populace thickness. The centralizations of the five air contamination parameters (O_3, CO, SO_2, NO_2, and PM10) were utilized to build up the model for air quality appraisal. (Daniel Dunea, 2011) The created approach was given a dependable strategy in surveying the Air Quality Index (AQI) by utilizing fuzzy logic. Air quality assessment was carried out at Romanian, where input variables SO_2, NO_2 and PM10 are considered. (Dashore, 2011) In this study, a fuzzy inference system was used to calculate the air quality index of atmosphere to suggest the outdoor activities of the human. (Daniela Romanoa, 2004) Discussed two different theories and applied to evaluate air emissions uncertainty. Design a fuzzy simulation to quantify air pollution, and the pollutants parameter were considered SO_2, NO_2, CO, and PM.

(Fisher, 2006) Design the simple and complex model for evaluating air quality reviewed, suggested a flexible approach to decide environmental quality having a lot of uncertainty. (Xiaoliang Zhao, 2010) They defined a city air system, assessment elements and there uncertainty. City air quality factor was formulated by using trapezium function. The weightage factors are given by using Entropy technology to design a fuzzy logic model based air quality assessment system. (Cavallaro F., 2012) Successfully applied fuzzy logic in the environmental field and designed the environmental quality indices (EQI).

A specific element of air is considered using 6 intervals of pollutant concentrations such as sulfur dioxide, nitrogen dioxide, Ozone, Carbon monoxide and particulate matter. At least three or four specific air components are generally presented to calculate AQI. Fuzzy logic is successfully applied for quantifying various air qualities.

The aim of this paper to develop a methodology based on Takagi-Sugeno fuzzy inferences system for the design and the subsequent assessment of air pollution indexes. It is a multitalented methodology which enables the design of detailed indexes to evaluate the quality of the air compartment from different perspectives depending on the attributes and properties included in the index. Fuzzy Logic Air Pollution Index (FLAPI) is estimated using four pollutants (SO_x, NO_x, CO, and PM) and therefore one fuzzy set for each pollutant and one for FLAPI is developed. The final value of the FLAPI is obtained as a result of a fuzzy inference procedure based on the zero-order method of Takagi and Sugeno.

II. Takagi - Sugeno Fuzzy inferences system

The objective of this work is to develop a programme for quantifying Air Pollution Index by using Takagi-Sugeno fuzzy rule based system. In the design of a framework that controls a procedure whose input-output relations are characterized by an arrangement of fuzzy control rules, e.g., IF-THEN rules. Fuzzy rationale thinking contains two sorts of data. The primary concerns the linguistic marks and membership functions to assign the input and output factors. The second type of data is concerned with rule-base which helps to processes to fuzzy inputs to fuzzy values to outputs. Fuzzy inferences system (FIS) is made out of three squares. The primary, fuzzification, converts crisp value input to a linguistic variable using the membership functions kept in the knowledge base. The second block, the Fuzzy Inference Engine is allocated the assignment of assessing the input's level of membership to the fuzzy output sets using the fuzzy rule base. At last, the defuzzifier block changes the fuzzy output into a crisp value.

III. Stage 1

Program to find Nitrogen Oxides, Sulphur Dioxides, and Carbon monoxide Group-1 Index

Three input variables are considered namely SO_x, NO_x, and CO in (Nitrogen Oxides, Sulphur Dioxides, and Carbon monoxide Group-1) NSC_Group-1 to get FLAPI. The nature of the graph for membership function is considered as triangular. Four linguistic variables are considered as membership functions which are clean, moderate, poor and harmful. The membership function linguistic values ranges vary from 0 to 100 and truth value (membership function) varies from 0 to 1. AND and OR operators are used to formulate rules in Sugeno model by using the fuzzy tool in Matlab.

i. Nitrogen Oxides (NO_x)

Table 1: Membership Function for NO_x

Sr. No.	Membership Function for NO_x	µg/m³
1	Clean	[0, 0, 35]
2	Moderate	[30, 45, 60]
3	Poor	[55, 65, 75]
4	Harmful	[70, 100, 100]

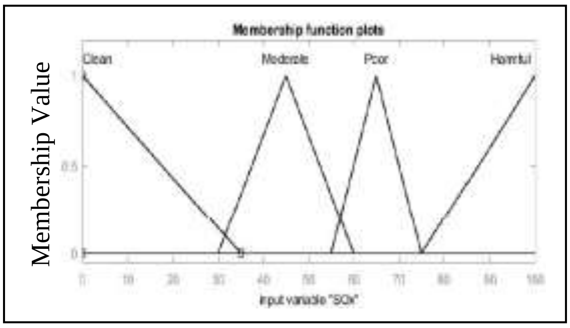

Figure 1: Fuzzy Set for Input Variable "NO_x" (µg/m³)

ii. Sulphur Dioxides (SO_x)

Table 2: Membership function for SO_x

Sr. No.	Membership Function for SO_x	μg/m³
1	Clean	[0, 0, 35]
2	Moderate	[30, 45, 60]
3	Poor	[55, 65, 75]
4	Harmful	[70, 100, 100]

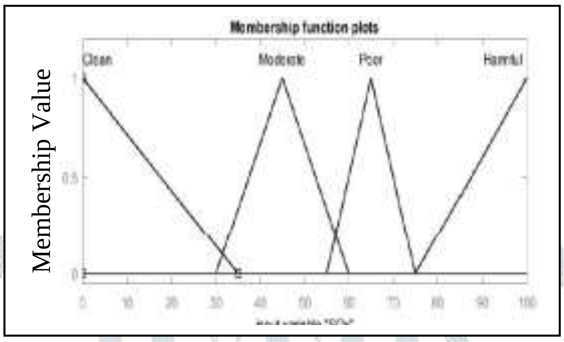

Figure 2: Fuzzy Set for Input Variable SO_x (μg/m³)

iii. Carbon monoxide (CO)

Table 3: Membership function for CO

Sr. No.	Membership Function for SO_2	mg/m³
1	Clean	[0, 0, 3]
2	Moderate	[2.5, 3.5, 4.5]
3	Poor	[4.2, 5.5, 6.5]
4	Harmful	[6, 10, 10]

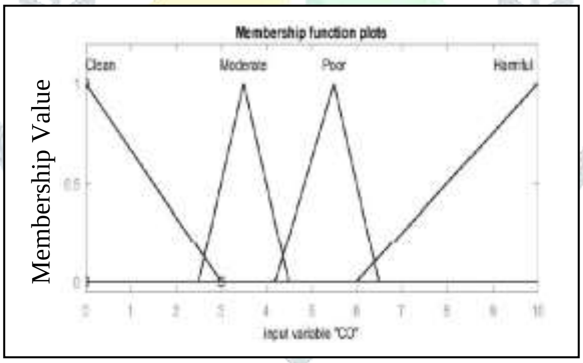

Figure 3: Fuzzy Set for Variable "CO"

Based on the concentration of SO_x, ambient air can be defined as clean, moderate, poor and harmful. It can be seen in Figure 2 that the fuzzy set SO_x for moderate air varies from 30 to 60 μg/m³. The first value (30μg/m³) is the minimum with zero membership value, next 45μg/m³ with unit membership value and then the membership value falls to zero at 60μg/m³. The Y-Axis represents membership function for this set. The plotted graph is shown that value 33μg/m³ is in both sets: clean and moderate, but its degree of membership in both the set varies. This kind of classification is more apt for describing the air quality as it considers variability.

iv. Output Variable with Membership Function

Table 4: Membership Function for Output (NSC_GR-1)

Sr. No.	Membership Function for SO_x	Index Value
1	Clean	[25]
2	Moderate	[50]
3	Poor	[75]
4	Harmful	[100]

Figure 4: Output Variable Membership Function for "NSC_Gr-1"

IV. Rules for NSC_Gr-1

Rules can be expressed in the form of the natural language like IF antecedent, THEN consequent. For example:

Rule 1: **IF** {NO_2 is harmful OR SO_2 is harmful, OR CO is harmful}
THEN {air is harmful}.

Once the fuzzy variables and membership functions are described the if-then fuzzy rule base can be defined. The number of fuzzy rules defined depends on the possible combination of membership functions. FIS with I-input variables has R=P.J rules, where P is the number of linguistic terms per input variable.

For NSC_Gr-1 evaluation, considered three pollutants, and 21 rules are formed to cover all possible set of combination of NO_x, SO_x and CO. Fuzzy numbers are operated using a Sugeno type fuzzy inference system. Figure 5 shows the Adaptive Neuro-Fuzzy Inference System (ANFIS), Figure 6 shows the rule-based fuzzy inference system for the NSC_Gr-1 mode land surface view is shown in Figure 7. The first step is to identify all the rules in which each parameter value falls. Based on these membership values and operators (OR / AND), the fuzzy output set is implicated. The implicated output from each rule is then aggregated and defuzzified to obtain the value of NSC_Gr-1 and its class.

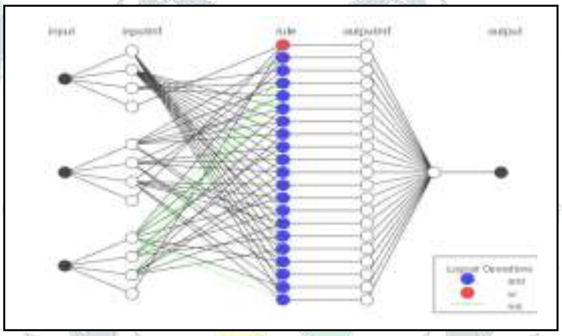

Figure 5: ANFIS Output System for NSC_Gr-1

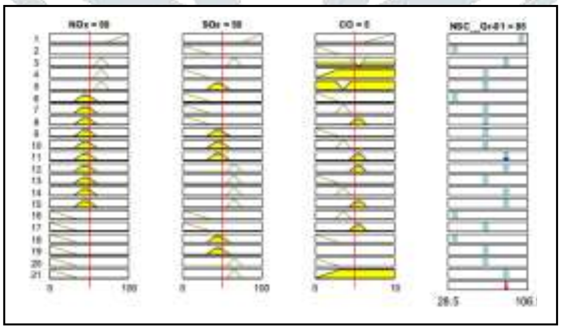

Figure 6: Input and Output Rule View of Rule Base Fuzzy Inference System

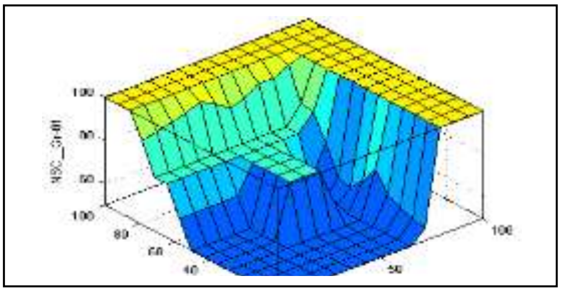

Figure 7: Generated Surface for NSC_Gr-1

V. Stage 2

Program for Fuzzy Logic Air Pollution Index (FLAPI)

As all the parameters to determine FLAPI could not be considered in the first stage, the remaining parameters particulate matter is considered in the next stage. The output of stage-1, NSC_ Gr-1, is considered as an input variable in stage-2 to accommodate the effect of 'NO_x,' 'SO_x' and 'CO' to find final FLAPI. FLAPI output value between 0–100, index value NSC_Group-1and PM is selected as input variables to find final Fuzzy Logic Air Pollution Index.

i. Air Pollution Index Group-1 (NSC_Gr-1)

Table 5: Membership Function for Air pollution Index Group-1

Sr. No.	Membership Function for NSC Index Value	Values
1	Clean	[0, 0, 40]
2	Moderate	[35, 46,60]
3	Poor	[55 65 75]
4	Harmful	[70, 100, 100]

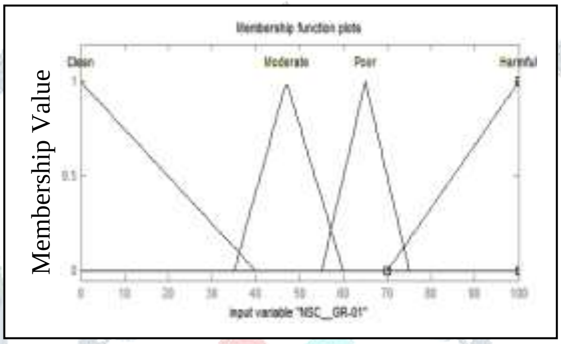

Figure 8: Input Variable Membership Function for NSC_Gr-1

ii. Particulate Matter

Table 6: Membership Function for PM

Sr. No.	Membership Function for PM (µg/m³)	Values
1	Clean	[0, 0,40]
2	Moderate	[30,45, 65]
3	Poor	[60, 75, 90]
4	Harmful	[85, 125, 125]

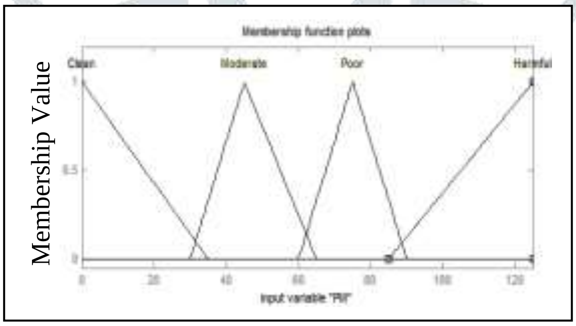

Figure 9: Input Variable Membership Function for PM

iii. Output Variable with Membership Function

Table 7: Membership Function for FLAPI output

Sr. No.	Membership Function	Index Values
1	Clean	[25]
2	Moderate	[50]
3	Poor	[75]
4	Harmful	[100]

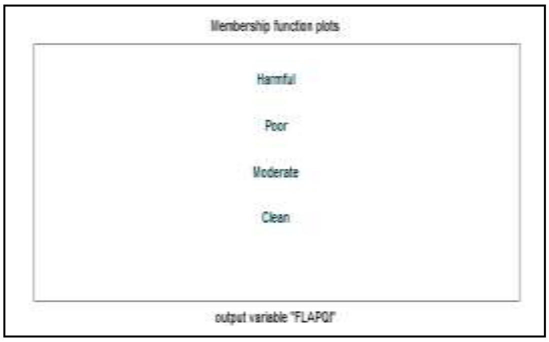

Figure 10: Output Variable Membership Function for FLAPI

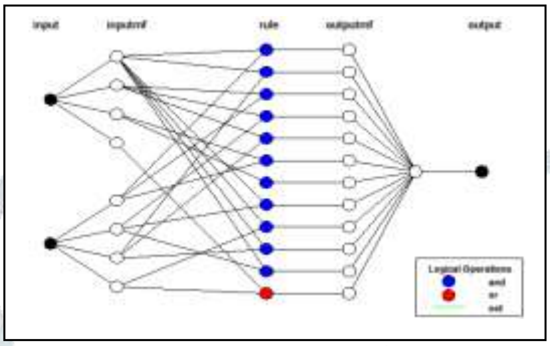

Figure 11: ANFIS Output System for FLAPQI

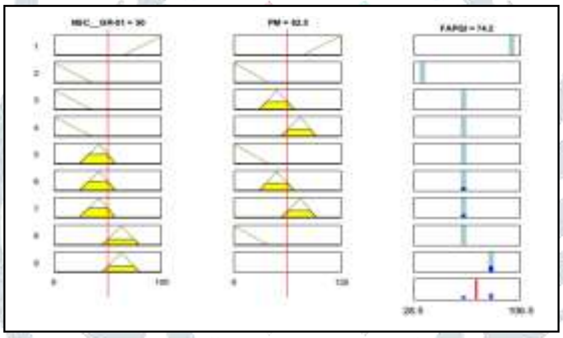

Figure 12: Input and Output Graphical View of Rule Base Fuzzy Inference System

For FLAPI evaluation two inputs NSC_Gr-1 and PM are considered and 12 rules are formed to cover all possible set of combination of air. Fuzzy numbers are operated using a Sugeno type fuzzy inference system. Figure 11 shows the Adaptive Neuro-Fuzzy Inference System (ANFIS), Figure 12 shows the rule-based fuzzy inference system for the FLAPI, surface view is shown in Figure 13. Rule-based fuzzy inference framework shows the final value of all input variables. The rules have finalized by professional acquaintance and the air parameter values which affect the human health.

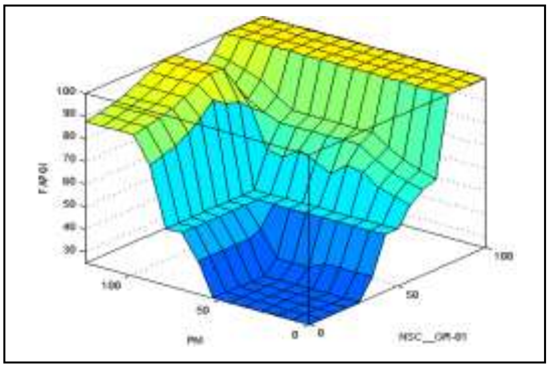

Figure 13: Generated Surface for FLAPI by Rule-Based Fuzzy Inference System

VI. Testing:

Considering the data from table 8, it is noticeable that on first day all the parameters are within the limit, and the corresponding descriptor is moderate air quality. On second day, NO_x, CO, and SO_x are within the limit; however the particulate matter below 10 micrometers median size (RPM) exceeds the limit of 100 μg/m³ and may cause health problems, but the corresponding air quality descriptor is still moderate. Similarly, on day 3, SO_x, CO, and RPM are within the limit; however the NO_x level has exceeded the limit of 80 μg/m³ still the air quality descriptor remains moderate. On day 4, NO_x, SO_x, and CO within the limit, limit still the air quality descriptor remains poor.

This indicates that the AQI, which is supposed to provide the combined indication of air quality using the value of the individual parameter, fails if the two parameters are at the two extremes. When any one of the pollutant parameter value reaches its highest regulatory level, it should indicate harmful air quality irrespective of other parameter values.

Table 8: Ambient Air Quality Parameter, AQI and FLAPI for Four Days

Pollutant	24 hourly average concentration (μg/m³)			
	Day 1	Day 2	Day 3	Day 4
NO_2	37	15	90	40
SO_2	38	15	15	45
RPM	78	124	30	75
CO (mg/m³)	2	3	2.5	1.5
AQI	49	49	48	50
Air quality class	Moderate	Moderate	Moderate	Poor
FLAPI	50	100	100	50
Air pollution class	Moderate	Harmful	Harmful	Moderate

VII. Conclusion:

On the basis of the above data, it is concluded that aqi based on crisp set theory has limitations viz., step function and eclipsing, the developed methodology overcomes both these constraints. Fuzzy set eliminates the problem of the step function and the problem of eclipsing is solved by using the rule based system. In this study, we propose an air quality index by takagi-sugeno fuzzy rule base system to evaluate air quality of different reasons. Fuzzy air pollution index was calculated by using parameter SOx, NOx, co, and pm. The study shows the way of decision making when the inputs are undefined and use linguistic variable.

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