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Efficacy of Degree of Reliability and Computing with words in Fuzzy Description of Air Quality

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Abstract: ***Communicating the information to the policy makers and the public at large is by indices. The US Environmental Protection Agency (EPA) formulated a uniform Air Quality Index (AQI), for the use of state and local agencies but there has been no general acceptance of the method. Many countries have devised their own methods for describing air quality. The paper is an attempt to compare the following three methods for air quality classification using the available air quality parametric data in three Indian cities and prove the efficiency of degree of reliability and computing with words in fuzzy description of air quality. These methods include: 1. conventional US-EPA -AQI, 2. Fuzzy Air Quality Index (FAQI) using Fuzzy Inference System and 3. Fuzzy logic based method proposed by Deshpande using the concept of degree of match, without computing AQI and straightway describing air quality in various linguistic terms with some degree of certainty attached to each term. The first two methods fail to capture the uncertainty which is resident in the pollutant data. In these two methods first, the air quality is computed as a number and then described in linguistic terms, unlike human thinking. The study reveals that the air quality description using the third formalism is comparable to the two AQI and FAQI methods. In addition the advantage of the third method is that, it attaches degree of certainty to each linguistic class. In spite of variability in the perception of the experts there are no visible changes in the final results using the third method which could be considered as somewhat like fuzzy- stat modeling. In our view, fuzzy logic is a human centric logic and its potential needs to be practically exploited***

Keywords: Degree of Match, Degree of Certainty, Linguistic term, Convex Normalized Fuzzy Number, Fuzzy Rule Base System

1. Introduction

Air is the prime resource for sustenance of life. Clean air is essential to maintain balance of life on this planet- not just humans, but wildlife, vegetation, water and soil. Ambient air quality refers to the quality of outdoor air in our surrounding environment. Every day, the average person inhales about 20,000 liters of air. Every time we breathe, we risk inhaling dangerous chemicals that have found their way into the air. The automobile is a primary source of hazardous air pollution. Vehicular emissions are of particular concern since these are ground level sources and thus have the maximum impact on the general population. The health effects caused by vehicular pollution in cities are indicated through increasing incidences of cough, headache, nausea, irritation of eyes, and various bronchial and respiratory diseases like simple bronchitis, Chronic Obstructive Pulmonary Disease (COPD), Asthma, Allergic Rhinitis and Conjunctivitis and Heart Attack.

The US Environmental Protection Agency (EPA) formulated a uniform Air Quality Index (AQI), for the use of state and local agencies [6]. Air quality indices (AQI) are numbers used by government agencies to characterize the quality of the air at a given location. As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly severe adverse health effects. The Maharashtra Pollution Control Board monitors three pollutants viz. Respirable Suspended Particulate Matter (PM_{10}), Oxides of Nitrogen (NO_x) and Oxides of Sulphur (SO_x) [7]. The deficiencies in modelling perceptions of the experts about the permissible limits and the uncertainty in the parametric data of air pollutants have motivated the researchers to initiate efforts on application of soft computing techniques for the estimation of air quality indices.

Mohammad Hossien et al. [3] computed Fuzzy-AQI using Fuzzy Inference System (FIS) and arrived at Fuzzy Air Quality Index (FAQI). The author developed a comprehensive tool for classification of air quality and tends to produce accurate results. They claim the indexing system to be useful, reliable, and suitable for consideration by the local authorities in air quality assessment and management schemes. Deshpande, et al. [4] in Degree of Certainty (DC) approach proposed a novel concept of describing air quality straightway in linguistic terms similar to that of fuzzy thinking of human brain which invariably, does not work with numerical values. The author further attaches a degree of certainty to each linguistic term to ensure the confidence level. The two issues addressed via case study in the paper are:

1) Comparison between the results of AQI and FAQI with the DM approach.
2) Can the variability in the expert's perception in the form of fuzzy sets and the rule base, result into a large difference in the output?

This paper is organized as follows: Section I introduces the concept of indexing system and literature review. Section II presents the three methods for computing AQI. The utility of the methods listed in earlier section is demonstrated in Section III with a case study that relates to fuzzy air quality description with the available air quality data for Pune, Mumbai and Navi Mumbai cities. Section IV discusses on the results. The concluding remarks and scope for further research are stated in Section V and Section VI respectively. Section VII lists the references.

2. Methodology

Fig. 1 depicts some of the facets of the three methods. The computational procedure of these method used in a case

study, in order to achieve the twin objectives stated in section 1, is very briefly discussed:

2.1 Conventional Air Quality Index (AQI)

Computation of AQI requires an air pollutant concentration from a monitor or model. The function used to convert from air pollutant concentration to AQI varies by pollutant, and is different in different countries. Air quality index values are divided into ranges, and each range is assigned a descriptor and a colour code. The pollutant with the highest concentration is considered as the "responsible pollutant". The AQI value for individual pollutant can be computed using the following formula (1):

$$\frac{(I_{high} - I_{low})}{(C - C_{low})} * (C_{high} - C_{low}) + I_{low} \rightarrow (1)$$

where I = Index for pollutant, C = the pollutant concentration, C_{low}= the concentration breakpoint that is ≤ C, C_{high}= the concentration breakpoint that is ≥ C, I_{low}= the index breakpoint corresponding to C_{low}, I_{high}= the index breakpoint corresponding to C_{high}.

2.2 Fuzzy Air Quality Index (FAQI)

Different weighting factors were assigned to each pollutant according to its priority and trapezoidal membership functions were defined for classifications and the final index consisted of 84 inference rules. At the first step, the pollutants were processed by the inference system and normalized, thus resulting in the FAQI. Each of the 84 rules had only one antecedent in order for the weight assignment to be facilitated. The structure of the fuzzy rules applied is as follows: If PM_{10} is Very Good then FAQI is *Good*. The classical fuzzy inference system (Mamdani) was used, which proved to be the best method for capturing expert's knowledge base. The weighting factors were assigned to the pollutants in accordance with the experts knowledge based on the medical evidence available for the health effects of the air pollutants. Thus PM_{10} and NO_x were assigned maximum weights as these are the two pollutants emitted due to vehicular pollution.

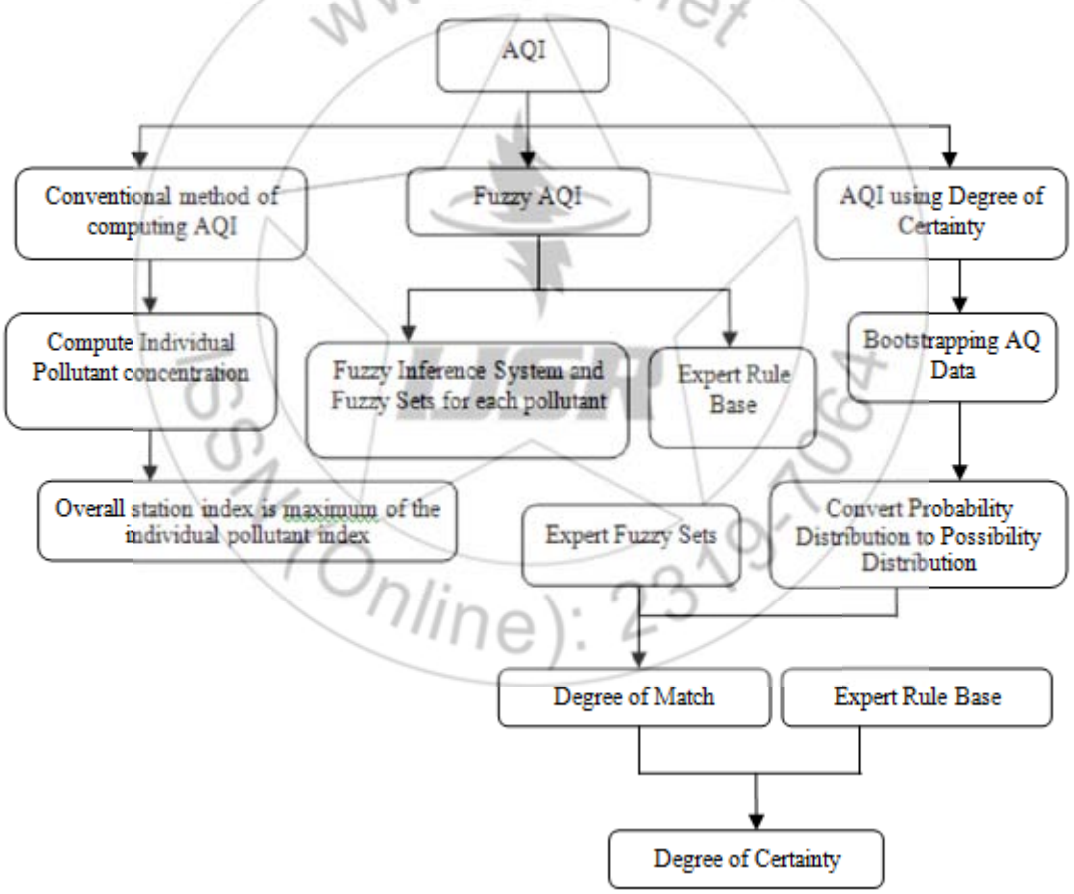

Figure 1: Framework for computing AQI

2.3 Type 1 Fuzzy Inference System (FIS) with Degree of Match

This novel method proceeds with the fuzzy sets for the three pollutants and the rule base obtained from the air quality experts. Many a times, collected data from the sampling locations is inadequate for carrying out statistical analysis. In such a situation, the defined statistical technique- a *bootstrap method* could be employed which ensures reliability of the data. Based on the data obtained using bootstrap method, probability distribution fitting to air quality parametric data was carried out.

As we intend to compare probability distribution with the convex fuzzy sets drawn for the selected parameters, it is necessary to transform probability distribution into possibility distribution of the parametric data, using the concept of Convex Normalized Fuzzy Number (CNFN).

Probability distribution can be transformed into a CNFN with membership grade function $\mu_A(x)$ thereby characterizing the dynamic behaviour of the pollutants into a possibility distribution. Uncertainty in the expert's perception – could be termed as epistemic uncertainty, is modelled by constructing fuzzy sets/ fuzzy numbers. The normal distribution plot is converted into possibility distribution(A) and fuzzy set for the sub attribute(A') characterizing linguistic terms are matched to arrive at a measure called Degree of Match which is defined as

$$DM(AA') = \int \mu_{A \cap A'}(x)\, dx \,/\, \int \mu_{A'(x)},\ x \in X \quad \rightarrow (2)$$

in the above 'x ' denotes the Universe, and μ A $\cap$ A', x is membership grade for A $\cap$ A'.

If A and A' are the discrete possibility distributions and the measure is defined as

$$DM(AA') = \sum \mu_{A \cap A'}(x) \,/\, \sum \mu_{A'(x)},\ x \in X \quad \rightarrow (3)$$

The computational scheme of Degree of Match (DM) can be used with a view to estimate matching between expert's perception and the antecedent part of the rule, in order to describe air quality fuzzily with certain degree of certainty. The degree of match of each classification rule indicates the certainty value of classification, in the present case: air quality. The greater the degree of match, the greater is the possibility that air quality is classified in that class.

A set of fuzzy rules is constructed for classifying air quality as: *very good, good, fair, poor and very poor* in order to aggregate the set of attributes. Each rule has an antecedent propositions connected together using AND operator, resulting in some consequences. These linguistic descriptions are invariably imprecise / vague / fuzzy keeping in view the inadequate information on the health implications of each parameter on the users and the aggregated effect of all the parameters on human health. A fuzzy rule based system can be developed for the knowledge representation or reasoning process. Following are the sample **rules** stored in the knowledge base. The rules are processed using conjunction and disjunction operators. The optimal acceptance strategy is usually that for which the degree of assertion is the maximum.

1. If PM_{10} is <Good> and
NO_2 is <Poor> and
SO_x is <Good> then Air Quality is ***Good***

2. If PM_{10} is <Fair> and
NO_2 is <Good> and
SO_x is <Fair> then Air Quality is ***Fair***

3. Case Study

The case study relates to fuzzy description of air quality with the available air quality data from five monitoring stations in Pune city viz. Karve Road, Swargate, Nal Stop, Bhosari and PCMC, three monitoring stations in Mumbai viz. Sion, Mulund and Bandra and Four monitoring stations in Navi Mumbai viz. Vashi, Airoli, Nerul and Mahape. Figure 2 is a map indicating locations of Pune and Mumbai cities in Maharashtra, India.

The phenomenal increase in the number of two wheelers has caused a serious problem of vehicular air pollution in Pune and Mumbai cities. The total pollution load in Pune city is due to 1784740 vehicles is 479 tons per day. The vehicular pollution due to 2 wheelers is the maximum which is 30.28 % of the total pollution load. . Fig. 3 depicts the progressive increase in the registered vehicle statistics of Pune and

Figure 2: Map of Pune and Mumbai, Maharashtra, India

Mumbai cities. In one of the locations in Pune alone, diesel driven three wheelers plying on narrow roads are around 60 percent of the total number of vehicles registered, emitting around total pollution load of 36 tonnes/day in a congested area with high rise buildings occupying very high population density.

The number of petrol driven two wheelers and mostly diesel driven three wheelers, without catalytic converter passing through Karve Road intersection were 64965 and 13523 vehicles/day, respectively during the study carried out by the author in Jan 2015.

Total Pollution load in Mumbai city due to 1784740 vehicles is 665 tonnes per day. Pollution due to cars is the maximum which is 28.94 % of the total pollution load. The two wheelers are the main cause of vehicle pollution in Pune city and diesel driven four wheelers (cars) are the main cause

Table 1: AQI Results obtained using three methods

City	Location	Conventional AQI	FAQI	AQI with Degree of Match		
				Expert 1	Expert 2	Expert 3
Pune	Karve Rd.	85.41 (Fair)	97.8 (Fair)	0.23 (Fair)	0.60 (Fair)	0.60 (Good)
	Swargate	91 (Fair)	109 (Fair)	0.90 (Fair)	1.00 (Fair)	0.86 (Fair)
	Nal Stop	86.67 (Fair)	100 (Fair)	0.59 (Fair)	0.73 (Fair)	0.65 (Fair)
	Bhosari	100.38 (Poor)	119 (Poor)	0.53 (Poor)	0.30 (Poor)	0.30 (Fair)
	PCMC	151.13 (Very Poor)	179 (Very Poor)	1.00 (Very Poor)	0.92 (Very Poor)	0.92 (Poor)
Mumbai	Sion	338.56 (Very Poor)	301 (Very Poor)	0. 47 (Very Poor)	0.55 (Very Poor)	0.55 (Very Poor)
	Mulund	156.64 (Very Poor)	160 (Very Poor)	0.52 (Very Poor)	0.70 (Very Poor)	0.70 (Very Poor)
	Bandra	234.39 (Very Poor)	302 (Very poor)	1.00 (Very Poor)	1.00 (Very Poor)	1.00 (Very Poor)
Navi Mumbai	Vashi	158 Very	160 (Very	0.72 (Very	0.91 (Very	0.91 (Very

		Poor)	Poor)	Poor)	Poor)	Poor)
	Airoli	129 (Poor)	112 (Poor)	0.43 (Poor)	0.73 (Poor)	0.35 (Very Poor)
	Nerul	88.5 (Fair)	70.1 (Fair)	0.25 (Fair)	0.60 (Fair)	0.60 (Fair)
	Mahape	111.13 (Poor)	112 (Poor)	0.38 (Poor)	0.70 (Poor)	0.70 (Poor)

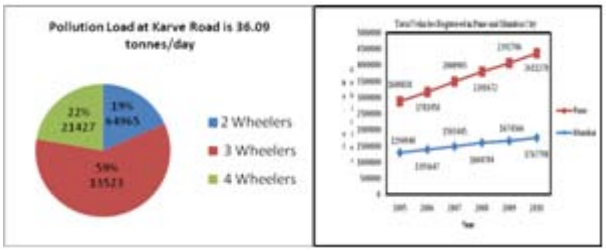

Figure 3: Number of vehicles registered in Pune and Mumbai city & Pollution load at Karve Road

of pollution in Mumbai city. The auto exhaust pollutants viz. PM_{10} and NO_x are of great concern to the environmentalists.

Indian National Ambient Monitoring Programme (NAMP), all the pollutants are not measured. However, it was necessary to monitor at least three pollutants in order to compute air quality index (AQI). The parametric data for the month of November was considered in the analysis as this is one of the worst months in winter when temperature inversion could be observed. The individual pollutant concentration was computed and finally the maximum of the three individual pollutants is described as the overall station index for the air quality. With the help of MATLAB (7.0), Fuzzy Logic Toolbox, the fuzzy air quality index was computed by specifying the fuzzy sets for the three pollutants and the if-then rules specified by the experts. Fuzzy Inference System was developed and final FAQI was obtained.

The important objective of the paper is to compare the results of the DM approach with the AQI and FAQI, considering the perception of three air quality experts.

4. Results and Discussion

Table 1 portrays the three methods of computing AQI for various monitoring stations in Pune, Mumbai and Navi Mumbai.

A closer look of the results obtained in Table 1 infers the following:

1. The results obtained using the new formalism known as DM method (in this sequel method 3) is almost comparable with that of the results of AQI and FAQI.
2. There has been a common belief that there is a great variability in the experts' perception. On this aspect, the authors (particularly the third author) is of the view that the implementation of the DM formalism could be done by a team of experts , one of the team member should necessarily be a domain expert with over two/ three decades of experience in dealing with such system. He will direct the team to identify the experts for the task in hand. In this present study, the air pollution experts selected have over two decades of experience. However, there was some variability in their perception which is evident form the fuzzy sets and fuzzy rules, In spite of such a reality, there was no visible change in the final results.
3. AQI and FAQI are computed using a single value estimate and that is a mean value. DM method uses the concept of convex normalized fuzzy number and proceeds with the computations of directly describing air quality with a degree of certainty attached to each linguistic term.
4. To conclude, we strongly recommend the use of DM approach as it directly describe air quality in linguistic terms with degree of certainty attached to each description which is absent in the AQI and FAQI. The human brain does not think of number and then describe any quality. We, therefore, once again reiterate that fuzzy logic is human centric logic and its potential in its practical use need to be fully exploited.

5. Concluding Remarks

Though the strength of the Degree of Match formalism has been demonstrated with an exhaustive case study, there might not be a wide acceptance in the international community as the traditional approaches are in use, and these also do not have general acceptance, internationally. Resistance is likely. In many regions, such as the United States and EU, both decision makers and members of the public seem more comfortable with the current system—in which government agencies avoid confronting uncertainties by setting guidelines that are crisp and often fail to communicate uncertainty. Perhaps someday a more comprehensive approach that includes exposure surveys, toxicological data, and epidemiological studies coupled with fuzzy logic based modeling will be developed toward resolving some of the conflict, divisiveness, and controversy in the current regulatory paradigm.

What is more important is to suggest a policy frame work to bring down- especially vehicular pollution in urban settings in all the countries. Over 50 % of the total vehicular traffic plying on Indian roads is two / three wheeler auto vehicles. The study reveals that the toxic gas emissions from two wheeler (gas or petrol or diesel driven) and three wheeler vehicles (mainly diesel driven) with no catalytic converter installed, are on increase and is a major source pollution in urban cites in the developing countries.

There have been concerted efforts being made, world over, on the reduction of Green House Gases (GHG). Nevertheless, if the global warming or climate change is of serious concern, humankind should try to refrain from using any automobile that produces greenhouse gases, and look for new viable options. How to reduce these auto exhaust emissions in urban cities under the present circumstances? There is no simple answer. Here are some useful suggestions:

It is well known that electric cars, with a few limitations, can produce miniscule greenhouse or pollutant gases during use. However, they do produce these gases during the production

stage. A systematic loss/ gain analysis for the electric vehicle (EV) as clean energy option in transportation sector could be investigated.

The first step to reduce vehicular pollution is by replacing diesel/ petrol vehicles by two/three EV's, followed by introducing electric cars in place of petrol/ CNG/ diesel driven four wheelers on city roads.. A five years phased program should be initiated after the successful trials on city/ town road, especially in developing countries. There are some issues relating to electric cars, such as: recharging time for a battery, disposal of the used batteries, and alike. Majority of these issues could be resolved involving all the stakeholders in the decision process. The efforts on practice oriented research are an urgent need of the hour if toxic vehicular emissions and their health impacts is an issue of serious concern to the policy makers, and public at large.

6. Future Scope for Research

Type 2 FIS using multiple experts for air quality classification will also be attempted in order to enhance the credibility of fuzzy logic based formalism in air quality classification. Air pollution and its health effects will be studied using evidence theory and fuzzy set theory.

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