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Risk based Optimal Ranking of Polluted Cities in a Fuzzy Environment: A Case Study

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***Abstract*—The debate on climate change, air pollution and human health risk has reached a steady state. Growing incidence of respiratory diseases in major cities could be attributed to phenomenon increase in air pollution levels due to exhaust from diesel and petrol driven vehicles and also emissions from thermal power plants in or near a city. Though extremely important, initiating mitigation measures for the reduction in air pollution levels in cities is not only expensive but also time consuming. It is, therefore, necessary to devise a suitable mathematical frame work to assist decision makers in ranking of polluted cities based on defined constraints. The paper presents fuzzy logic based formalisms to decide risk based optimal ranking of polluted cities in a fuzzy environment with a case study in Maharashtra State India.**

***Index Terms*— Polluted cities, Fuzzy environment, Risk based optimal ranking, Bellman-Zadeh and Zadeh-Deshpande Methods.**

I. Introduction

The association between green house gases (GHG), climate change, and human health risk is a cause of serious concern. It can be conclusively stated that carbon dioxide is the main contributor to climate change. Human sources include: fossil-fuel-based electrical power generation; fossil fuel combustion in on-road motor vehicles (e.g. cars, trucks, trains); off-road engines (e.g. snow mobiles, gas-powered garden tools); airplanes; marine vessels; space heating in buildings (furnaces); and industrial process.

Though extremely important, initiating mitigation measures for the reduction in air pollution levels in cities is not only expensive but also time consuming. In India, exhaust from diesel and petrol driven vehicles and emissions from thermal power plants in or near a city are the major sources of air pollution. With this backdrop, there is a need to devise a suitable mathematical frame work to assist decision makers in optimal ranking of polluted cities. The paper presents fuzzy logic based formalisms to decide risk based optimal ranking of polluted cities with a case study.

Many a time multiple conflicting constraints need to be evaluated in analysing decisions in our daily lives or in professional settings. We usually weigh multiple constraints implicitly and are contended with the consequences of such decisions that are made based on intuition / perception. For example; permissible level

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of particulate matter ($PM0_{2.5}\mu$) or several other criteria pollutants and other constraints responsible for air pollution. Knowledgeable decisions could be taken by structuring complex problems well and considering multiple criteria explicitly. A variety of approaches and methods have been developed for their application in an array of disciplines, ranging from politics and business to the environment and energy. In this context, the study on the theory and methodology of the fuzzy optimization was proposed by Bellman and Zadeh (BZ) in 1970's [1].

One of the multi criteria methods for air quality classification of polluted cities as high risk, low risk is Zadeh-Deshpande formalism. In our previous work [2], out of twenty four cities in Maharashtra, twelve are classified as high risk cities with varying degree of certainty in numeric terms. These certainty values are further considered as a "Goal" in BZ method in risk based optimal ranking of polluted cities.

The rest of the paper is organized as follows: section II presents the literature review while section III briefly describes the techniques used in the case study and section IV explains the case study. Section V is devoted to results and detailed discussion.

II. Literature Survey

The results of research into the use of fuzzy set based models and methods of multi-criteria decision making for solving power engineering problems were presented by Petr et.al. Two general classes of models related to multi-objective (<*X, M*>models) and multi-attribute (<*X, R*>models) problems are considered. The analysis of, <*X, M*>models is based on the use of the Bellman-Zadeh approach to decision making in a fuzzy environment. Its application conforms to the principle of guaranteed result and provides constructive lines in obtaining harmonious solutions on the basis of analysing associated *maxmin* problems. Several techniques based on fuzzy preference modelling are considered for the analysis of <*X, R*>models. The authors' have reviewed the results associated with the application of these models and methods for solving diverse types of problems of power system and subsystems planning and operation [3]. Peter Ekel et.al. presented results of research and experience in the use of fuzzy set theory methodology for handling and overcoming various forms of uncertainty in the design and control of power systems and subsystems. Approaches to solving fundamental problems of constructing fuzzy estimates of uncertain parameters, comparing alternatives in a fuzzy environment, developing basic principles and methods of mono-criteria and multi-criteria making in a fuzzy environment are briefly described. The results of the paper are of a universal character, have found applications in: the design of distribution systems; optimization of reliability in distribution systems, state estimation, fast analysis, and operation of distribution systems; load systems (power and energy, different levels of territorial, temporal, and situational hierarchy of management) and in industrial power systems (red time control of active load) [4].

III. Techniques Used

A summary of fuzzy logic based formalisms used in the case study are briefly described in this section.

A. Conventional Air Quality Index

The AQI system is based on maximum operator of a function (i.e. selecting the maximum of sub indices of individual pollutants as an overall AQI). An air quality index is defined as an overall scheme that transforms the weighed values of individual air pollution related parameters (for example, pollutant concentrations) into a single number or set of numbers. The result is a set of rules (i.e. most set of equations) that translates parameter values into a more simple form by means of numerical manipulation [5].

B. Bellman-Zadeh Approach

Bellman and Zadeh [1] are the pioneers in applying fuzzy set theory to decision making. In their seminal paper, they opine that each objective can be represented as a fuzzy subset over a set of alternatives *U*. Furthermore, if A; denotes the i^{th} objective, the grade of membership of alternative $u \varepsilon U$ in A_i, $\mu_{Ai}(u)$, denotes the degree to which *u* satisfies the criterion specified by this objective. They then suggest that the objectives be incorporated in a decision function *D*. That is, the overall objective function *D* of a set of objectives $A = \{A_i / i = 1 \ldots\ldots p\}$ can be represented as $D = A_l$ *AND* A_2 *AND* ... *AND* A_p. When no other information is available, the appropriate form to mathematically express the *AND* operation may be the *Min* operator. Thus, the decision function is:

$$D(u) = Min[A_1(u), A_2(u) \ldots\ldots\ldots\ldots A_p(u)] for\ each\ u \in U \qquad (1)$$

The final optimal solution u* satisfies

$$D(u^*) = MaxD(u) for\ each\ u \in U \quad (2)$$

If the individual objectives in the set of objectives do not all have the same importance, the decision function can be expressed as:

$$D(u) = Min_{i=1..p}[a_i A_i(u)] \quad (3)$$

where a_i denotes the weighting coefficients reflecting the relative importance of objective A_i such that :

$$\sum_{i=1}^{n} a_i = 1 \quad (4)$$

It is pertinent to mention that BZ method has been used, in this paper in different setting. The authors have discussed on the application of the method in IV and V Sections.

C. Zadeh-Deshpande Formalism

ZD formalism is composed of Fuzzy logic via Computing with Words (CW) and Type 1 Fuzzy Inference System (FIS) with Degree of Match. A closer look at CAQI, can infer that in this method first a number is calculated and then air quality is described in linguistic terms with no degree of certainty. Human brain does not think in numbers. These limitations of CAQI calls for devising fuzzy logic-based formalism, known as Zadeh–Deshpande (ZD) approach [6;7;8], which is a departure from CAQI wherein air quality is described straightway in linguistic terms with linguistic degree of certainty attached to each description. Uncertainty of uncertainty is modeled using fuzzy logic concepts. Firstly, the uncertainty in the expert's perception is modeled and then the second uncertainty relates to degree of certainty which is modeled by defining fuzzy sets for degree of certainty.

IV. The Study

In CAQI computations only three criteria pollutants were selected by Central Pollution Control Board India, These are PM_{10}, NOx and SOx. The data for these pollutants was fetched from the Maharashtra Pollution Control Board website for winter months from Nov. 2014 to Jan. 2015 for the entire case study. Winter months are critical from air pollution viewpoint as the pollution levels are likely to be at the peak in these months due to temperature inversion phenomenon. Therefore the air quality assessment is based on "World Case Scenario". Based on ZD formalism Aurangabad, Chandrapur, Jalna, Lote, Mumbai, Nagpur, Nanded, Nashik, Pune, Sangli, Solapur and Thane are the twelve air quality monitoring stations (AQMS) in these cities with high risk with varying degree of certainty potential from air quality view point.

As stated, in CAQI and ZD methods only three criteria pollutant viz.; Sulphur Dioxide (SO_2), Oxides of Nitrogen (NO_x), Particulate Matter (PM_{10}), was considered. But there are other factors /constraints which are also responsible for increase in air pollution levels. The combined effects of the aforestated three constraints and other constraints such as: population density, wind velocity, wind direction, temperature, humidity and the capacity/number of thermal power plants in a particular city on air quality of the city was considered in BZ method.

It is true that the turbulent properties of the Atmospheric Boundary Layer (ABL)—such as the diffusivity, mixing, and transport—determine whether pollutants are dispersed and diluted or whether they build up and lead to pollution episodes. Thus, estimating, parameterizing, monitoring, and predicting the structure and behavior of the ABL is crucial to determining air quality [9] In other words: Mixing Height plays an important role in air pollution concentration but its effects will be prominent in cold climate. Therefore, in this study Mixing Height parameter was not considered as one of the constraints in BZ method.

V. Results and Discussion

A. Classification of Air Quality using CAQI and ZD Method:

Table 1 presents the final outcome of the computation carried out for air quality assessment in twelve cities in Maharashtra State. Most of the cities fall under very poor to poor category of air quality with varying degree of certainty using ZD method. Locating industries in or near cities will definitely affect air quality. Super thermal power plant is located near Chandrapur while a cluster of industries are very near to Jalna city. In the light of this observation, the concept of city and industrial development needs to be revisited. Mumbai, Pune and other cities with high air pollution levels could be attributed to exponential increase in vehicular traffic.

TABLE I. CLASSIFICATION OF AIR QUALITY USING CAQI AND ZD METHOD

Sr. No.	Station	ZD Method with DC	CAQI
1	Aurangabad	0.78(VP)	145.87(P)
2	Chandrapur	0.87(VP)	155.06(VP)
3	Jalna	0.85(VP)	228.48(VP)
4	Lote	0.72(VP)	101.00(P)
5	Mumbai	0.92(VP)	167.72(VP)
6	Nagpur	0.89(VP)	100.00(P)
7	Nanded	0.74(VP)	102.00(P)
8	Nashik	0.86(VP)	110.39(P)
9	Pune	0.76(VP)	114.35(P)
10	Sangli	0.84(VP)	152.46(VP)
11	Solapur	0.65(VP)	99.78(P)
12	Thane	0.87(VP)	99.62(P)
VP- Very Poor, P-Poor			

B. Ranking of AQMS using BZ Method:

Assigning Membership Grade: In order to assign membership grade to various constraints following criteria is considered. The first three constraints are Sulphur Dioxide (SO_2), Oxides of Nitrogen (NO_x) and Particulate Matter (PM_{10}). The maximum concentration of these Pollutants for winter months for plotting the data was considered. Figure 1 presents membership computations for PM_{10}. Similar method was applied to SO_2 and NO_X pollutants.

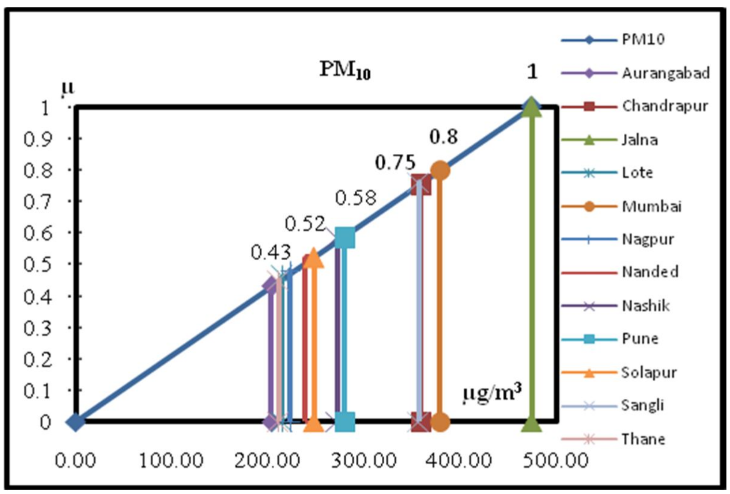

Fig. 1 Assigning Membership Grade to PM_{10}

For the fourth constraint total number of power plants and industries in each city are considered and the city with maximum number of industries is assigned maximum membership grade. Chandrapur and Thane have three and two power plants respectively and so μ=0.8 and μ=0.7 values are assigned. Similarly, Pune, Nanded and Lote have monitoring stations in Maharashtra Industrial Development Corporation (MIDC) area which leads to SO_2 emissions in large concentrations. Table II presents a snapshot of citiwise membership grades for the first three constraints. The DC column obtained by application of ZD formalism now acts as a "Goal" in BZ method for further computations.

Pune and Mumbai are high in vehicular population resulting in high concentration of PM_{10} in the air. In order to assign membership grade to the fifth constraint population density, wind velocity and wind direction are considered. Population in the wind direction has been given highest membership grade and hence Mumbai the most populated city is assigned μ=0.9. As per the null hypothesis constraint 6 was assigned μ= 0.5 with temperature as 32 °C, μ= 0.4 for 31 °C, μ= 0.3 for 30 °C. For the final constraint humidity, μ has been assigned as follows: for humidity between 70 to 79 μ=0.7, 80 to 89 μ=0.8 and so on.

TABLE II. ASSIGNING MEMBERSHIP GRADES TO FIRST THREE CONSTRAINTS

Sr. No.	Station	Goal DC	Constraint1 SO_2	Constraint2 NOx	Constraint3 PM_{10}
1	Aurangabad	0.78	0.24	0.3	0.43
2	Chandrapur	0.87	0.47	0.48	0.75
3	Jalna	0.85	0.20	0.25	1.00
4	Lote	0.72	0.15	0.08	0.46
5	Mumbai	0.92	1.00	1.00	0.80
6	Nagpur	0.89	0.20	0.29	0.48
7	Nanded	0.74	1.00	0.47	0.52
8	Nashik	0.86	0.62	0.23	0.58
9	Pune	0.76	0.6	0.85	0.58
10	Sangli	0.84	0.30	0.49	0.76
11	Solapur	0.65	0.20	0.51	0.52
12	Thane	0.87	0.35	0.18	0.45

Optimal Ranking Of AQMS using BZ formalism: Membership values used in the application of ZD in combination of BZ method are presented in Table III. Table IV finally summaries risk based optimal ranking of polluted cities in Maharashtra State India using ZD and BZ methods. The air quality in all the twelve cities has been classified into high risk category using ZD formalism which is in line with Conventional Air Quality Index (CAQI).

TABLE III. MEMBERSHIP GRADE FOR ZD AND BZ METHOD

Sr. No.	**Station**	**ZD Method**	**BZ Method**
1	Aurangabad	0.78	0.20
2	**Chandrapur**	**0.87**	**0.40**
3	Jalna	0.85	0.20
4	Lote	0.72	0.08
5	**Mumbai**	**0.92**	**0.40**
6	Nagpur	0.89	0.20
7	Nanded	0.74	0.30
8	Nashik	0.86	0.23
9	Pune	0.76	0.30
10	Sangli	0.84	0.20
11	Solapur	0.65	0.20
12	Thane	0.87	0.18

In ZD method, only criteria pollutants were considered. Therefore Mumbai ranks first as the polluted city and Chandrapur as second. In BZ method, most of the other constraints are used in addition to criteria pollutants. As per ZD formalism, Mumbai and Chandrapur are ranked first and second respectively. High concentration of PM_{10} in air can be attributed largely to the emissions from nearby Super Thermal Power Plant. However, heavy vehicular traffic, construction activities, cement roads, untarred roads do contribute to air pollution load. In addition, low temperature and less vertical dispersion during winter months increase the concentration of PM_{10} in Mumbai city. The increase in the number of vehicles has eventually led to alarming levels of emissions as they are caught at the intersections and in the usual snarls during peak rush hours. The flyovers constructed for fast movement of vehicles only added auto exhaust emissions. Industrial units located near cities add to oxides of nitrogen, SO_2, and particulate matter. Chandrapur, Nagpur, Thane and Pune have large number of vehicles plying on road thus resulting in high PM_{10} concentrations. It can be inferred that Chandrapur and Mumbai cities are highly polluted and should be given equal priority to initiate pollution abatement measures. Constraint 4 (location of thermal power plants) is important in case of Chandrapur. BZ method infers Pune cities as ranked second due to hazardous industrial installation and excessive concentrations of PM_{10} due to increase in vehicular traffic. The results presented in the paper are self explanatory. The paper presents a novel combination of Zadeh-Deshpande formalism and Bellman Zadeh method to arrive at risk based optimal ranking of polluted cities in Maharashtra State, India.

TABLE IV. RANKING OF AIR QUALITY MONITORING STATIONS

Ranking of Stations	
ZD Method	**BZ Method**
Mumbai	Chandrapur/Mumbai
Chandrapur	Nanded/Pune
Nagpur/Thane	Nashik
Pune	Aurangabad /Jalna /Nagpur/Sangli/Solapur
Jalna	Thane
Sangli	Lote
Nashik/Nanded	
Lote	
Aurangabad	
Solapur	

VI. CONCLUDING REMARKS

The paper highlights the importance of the combination of Zadeh-Deshpande formalism followed by Bellman –Zadeh method in the estimation of risk based optimal ranking of air quality monitoring stations for initiating pollution mitigation measures in a fuzzy environment. This is basically somewhat like fuzzy optimization problems with consider multiple constraints and a goal (both are expressed in membership functions) to arrive at the ranking of air quality monitoring sites. Ranking of ZD formalism is based on only three criteria pollutants whereas BZ method considers a total of seven constraints to rank AQMS. Hence there is a variation in the ranking of sites by both the methods. Comparing the results of FCM, Mumbai city is the most polluted and is also ranked first in ZD and BZ formalism.

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