Fuzzy MCDM approach for addressing composite index of water and air pollution potential of industries

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Abstract

Urbanization and industrialization with minimal focus on environmental pollution has resulted in rapid degradation of natural environment. A fresh look at the pollution control strategies is, therefore, necessary. An attempt has been made to address the problem and a new formalism is proposed for ranking of industries based on their water and air pollution potential. Vagueness in the perception of environmental experts for ranking the techno-scientific parameters in linguistic terms for the specific usage, coupled with imprecision in parametric data calls for the application of fuzzy modeling. The case study relates to the application of Fuzzy Multi Criteria Decision Making (FMCDM) for ranking different types of industries located in the State of Gujarat, India. The paper highlights the feasibility of approach for ranking the industries on basis of its pollution potential.

1. Prologue

The industrial policies of developing countries mainly focus on the pursuit of economic growth with inadequate importance to environmental pollution issues. Focus on the growth and pursuit of economic excellence, with inadequate importance to environmental pollution issues results in ever increasing pollution levels, which are primarily responsible for impairing natural environment. The permissible limits prescribed by the regulatory agencies allow industries to discharge their wastes in the natural environment thereby allowing its impairment to a minimum level. Depletion of water flows in rivers over a period of time and the ever-increasing pollution load in the natural bodies is a matter of serious concern. In the absence of adequate dilution, the industry discharging its waste within the prescribed pollution norms also contributes its share towards overall environmental degradation. The situation is not far different in case of the parameters relating to air, land and noise pollution. Expressing permissible limits of pollution parameters on dichotomous scale (Yes/No) now needs a paradigm shift from crisp (Permissible OR Not Permissible) to fuzzy values (Permissible AND Not Permissible). According to Hipel et al. (1993), a decision problem is said to be complex and difficult, if there exist multiple criteria – both qualitative and quantitative in nature. An attempt has been made to formulate a fuzzy model employing Fuzzy Multiple Criteria Decision Making (FMCDM) approach, with a view to rank different types of industries based on their water and air pollution potential.

2. Objectives

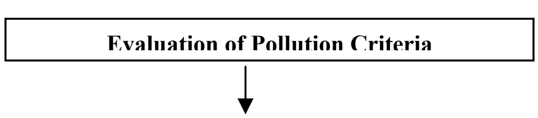
Development of protocol for ranking of different types of industries based on their environmental pollution potential with recourse to fuzzy set theory with a case study.

3. Fuzzy multi-criteria decision making (FMCDM) modeling

Many attempts have been made to study different methods of ranking alternatives under fuzzy environment during the last few decades. Jain [15, 16] proposed a method of using the concept of membership level, whereas Baldwin and Guild [7] indicated that the above two methods suffer from some difficulties for comparing the alternatives and havedisadvantages. Adamo introduced α-preference rule using the concept of α-level set .Chang indicated that the method proposed by Adamo [8] may lead to an inappropriate choice and went on to introduce preference function concept of an alternative. A complete review of fuzzy numbers ranking methods was presented by Bortolan et. al. [3].Hagemeister et. al.[13] developed a methodology for hazard ranking of landfills using fuzzy composite programming, this paper presents methodology to assess the environmental and public health hazard posed by an unregulated landfill when available data is imprecise, uncertain or subjective. Raj et. al. was used a concept of maximizing set and minimizing set for ranking alternatives with fuzzy weights [14]. A more recent study by Singh et. al. [2] highlights a fuzzy framework for contractor selection; this paper presents a systematic procedure based on fuzzy set theory to evaluate the capability of a contractor to deliver the project as per the owner's requirement. The approach developed for the ranking of industries based on their environmental pollution potential, is somewhat analogous to the procedure suggested by Singh et. al. [2]. The methodology discussed here has been successfully used for ranking of same type of industries [17] considering seven linguistic variables of Saaty (1977). For the evaluation of the modern concept of uncertainty the readers can refer the publication of a seminal paper by Lotfi A. Zadeh on fuzzy sets [10]. In his paper, Zadeh introduced a theory of objects–fuzzy sets – with boundaries that are not precise [4].

3.1 Methodology

Figure 1 portrays an overview of the fuzzy decision framework to rank industries, which is self-explanatory. Identification of environmental experts is of prime importance. The parameters identified for defining pollution potential of industry by the experts are listed in Table2. The importance weight for each of the criteria mentioned above is developed by consulting environmental experts. To describe the level of performance on decision criteria Saaty (1977) developed fuzzy numbers for seven linguistic variables. For the proposed study for evaluation of pollution potential of industries four fuzzy numbers are predefined to describe the level of performance on decision criteria. Four linguistic variables are used because it is convenient for an expert to distinguish subjectively between four alternatives. Table 1 shows the linguistics variables and fuzzy numbers used in this study. Figure 2 shows the graphical presentation of fuzzy numbers for the linguistics variables.



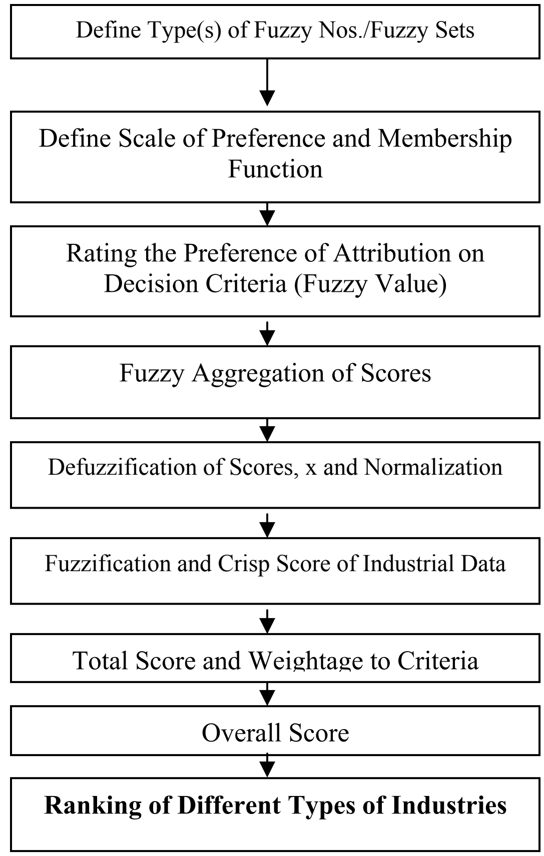


Figure 1. Fuzzy decision framework for industrial ranking

Table 1. Linguistics variables and fuzzy numbers

Linguistics Variables	Fuzzy Numbers
VI (Very Important)	(0.72,0.86,1.00,1.00)
I (Important)	(0.43,0.57,0.72,0.86)
A (Average)	(0.14,0.29,0.43,0.57)
NI (Not Important)	(0.00,0.00,0.14,0.29)

The importance weight factors are computed for sub criteria (parameters) of water pollution (Suspended Solids, Color, TDS, BOD, COD, Oil & grease, Chlorides, Sulphates, Ammoniacal Nitrogen, Phosphates, Nickel,

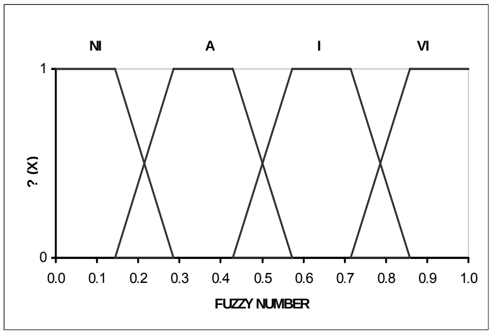


Figure 2 Graphical presentation of fuzzy numbers for linguistics variables

Phenolic compounds, Sulphides, Fluorides, Zinc, Arsenic, Cadmium, Chromium, Copper, Cyanides, Selenium, Lead, Mercury, Iron and Bio-assay) and sub criteria of air pollution (SPM , SOx , NOx, Cl_2 and HCl). Table 2 shows experts' opinion for sub criteria of water pollution.

Using the equation (1) given below, average fuzzy number for all environmental experts' opinion can be expressed as

$$A_{ij}^{k} = \left(\frac{1}{p}\right) \otimes \left(a_{i1}^{k} \oplus a_{i2}^{k} \oplus \ldots \oplus a_{ip}^{k}\right) \text{ for } j = 1, 2, \ldots p \quad (1)$$

Where a_{ij}^{k} is a fuzzy number (weight) assigned to a parameter by Environmental Experts for the decision criterion C_k and p is the number of experts involved in the evaluation process. Using equation 1 the matrix given above can be further simplified to calculate the average fuzzy number.

The linguistic variables as assigned by the experts are converted to fuzzy numbers used in the above expressions through Table 1 and Figure 2. Now, the defuzzified values for the sub criteria are obtained by using equation (2).

$e = (x_1 + x_2 + x_3 + x_4) / 4$ (2)

For details about different types of fuzzy numbers, membership functions, aggregation and defuzzification methods, interested readers may refer Zimmerman (1985), Klir and Folger (1988) and Kaufmann and Gupta (1991). Table 3 shows Average Fuzzy Number based on experts' perception. The normalized weight for each sub criterion of water pollution is obtained by dividing the scores of each sub criteria (C_{ij}) by the total of all sub-criterion ($\sum C_{ij}$). The next step is to convert the parametric values of wastewater generated and stack emissions to the fuzzy numbers (membership functions) based on the specified statutory norms. Figure 3 shows Fuzzy set for Not Acceptable (membership function one) for wastewater parameter Chemical Oxygen Demand (COD). Similarly, fuzzy sets for other parameters of water pollution and air pollution can be developed.

Table 1. Experts' opinion

Sub Criteria	EE1	EE2	EE3	EE4	EE5
SS, mg/l	I	I	A	A	A
Color, Co-pt	A	A	A	A	A
TDS, mg/l	I	I	VI	I	I
BOD, mg/l	VI	VI	VI	VI	VI
COD, mg/l	VI	VI	VI	VI	VI
Oil & grease, mg/l	I	A	I	A	A
Chlorides, mg/l	A	A	I	A	I
Sulphates, mg/l	A	I	I	A	A
Ammonical Nitrogen, mg/l	NI	NI	NI	A	NI
Phosphates, mg/l	A	I	I	A	A
Nickel, mg/l	NI	NI	NI	A	A
Phenolic Compounds, mg/l	A	A	NI	NI	A
Sulphides, mg/l	A	A	I	A	I
Fluorides, mg/l	A	NI	NI	NI	A
Zinc, mg/l	A	A	NI	NI	NI
Arsenic, mg/l	A	A	NI	NI	NI
Cadmium, mg/l	NI	NI	NI	A	A
Chromium, mg/l	A	NI	NI	NI	A
Copper, mg/l	A	NI	NI	NI	A
Cyanides, mg/l	A	A	NI	NI	NI
Selenium, mg/l	NI	NI	NI	A	A
Lead, mg/l	A	NI	NI	NI	A
Mercury, mg/l	A	A	NI	NI	NI
Iron, mg/l	A	NI	NI	NI	A
Bio-assay, %	I	I	A	A	A

EE- Environmental Expert

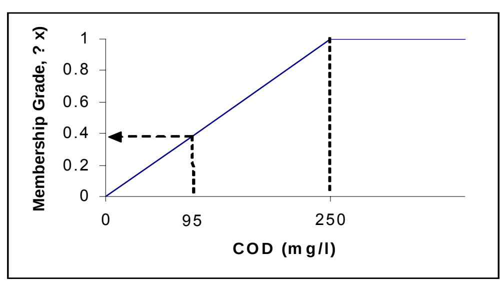


Figure 3. Pollution Parameter Chemical Oxygen Demand (COD): Fuzzy Set for Not Acceptable

Table 2. Average fuzzy number

Sub Criteria					Avg (Ck)
SS	0.256	0.402	0.546	0.686	0.473
Color	0.140	0.290	0.430	0.570	0.358
TDS	0.488	0.628	0.776	0.888	0.695
BOD	0.720	0.860	1.000	1.000	0.895
COD	0.720	0.860	1.000	1.000	0.895
Oil & grease	0.256	0.402	0.546	0.686	0.473
Chlorides	0.256	0.402	0.546	0.686	0.473
Sulphates	0.256	0.402	0.546	0.686	0.473
Amm.Nitro.	0.028	0.058	0.198	0.346	0.158
Phosphates	0.256	0.402	0.546	0.686	0.473
Nickel	0.056	0.116	0.256	0.402	0.208
Phe.Comp.	0.084	0.174	0.314	0.458	0.258
Sulphides	0.256	0.402	0.546	0.686	0.473
Fluorides	0.056	0.116	0.256	0.402	0.208
Zinc	0.056	0.116	0.256	0.402	0.208
Arsenic	0.056	0.116	0.256	0.402	0.208
Cadmium	0.056	0.116	0.256	0.402	0.208
Chromium	0.056	0.116	0.256	0.402	0.208
Copper	0.056	0.116	0.256	0.402	0.208
Cyanides	0.056	0.116	0.256	0.402	0.208
Selenium	0.056	0.116	0.256	0.402	0.208
Lead	0.056	0.116	0.256	0.402	0.208
Mercury	0.056	0.116	0.256	0.402	0.208
Iron	0.056	0.116	0.256	0.402	0.208
Bio-assay, %	0.256	0.402	0.546	0.686	0.473

Fuzzy decision matrix for sub criterion C_{15} (COD) can be written as

$$X_{C_{15}} = \begin{bmatrix} \mu_1\ \mu_2\ \mu_3\ \ldots\mu_n \\ (a_1,a_2,a_3,\ldots a_n,) \\ (b_1,b_2,b_3,\ldots b_n,) \\ (c_1,c_2,c_3,\ldots c_n,) \end{bmatrix} \begin{vmatrix} \\ I_1 \\ I_2 \\ I_n \end{vmatrix}$$

Where $a_1, a_2, a_3 \ldots a_n$, $b_1, b_2, b_3 \ldots b_n$ and $c_1, c_2, c_3 \ldots c_n$ are fuzzy values of COD obtained from seasonal monitoring for Industry 1, Industry 2 and Industry n respectively.

The crisp scores on the sub criterion C_{15} for each industry can be obtained using following equation.

Industry 1= $(a_1 + a_2 + a_3 .. a_n)/n$, Industry2 = $(b_1 + b_2 + b_3 .. b_n)/n$ and Industry n $=(c_1 + c_2 + c_3 .. c_n)/n$

Similarly, crisp scores can be computed for the other sub criteria of water pollution and air pollution. Using simple additive weighing method (Hwang and Yoon 1981), the total scores (TS) for each industry can be calculated as follows.

$$TS = \sum \left(X_k \otimes W(C_k) \right) \text{for } k = 1,2,3.. (2)$$

Where,

$W(C_{ki})$ = weight or the importance value of the sub criterion k and

X_k = crisp score of the industry data against the sub criterion k.

Using pollution potential importance weight for both the criteria (such that their summation is equal to 1), an overall score (OS) for the industries can be calculated as follows.

$$OS = \sum (TS_{ki} \otimes W(C_{ki}))\ for k = 1,2,3 and i = 1,2,..n. (3)$$

Where,

TS_{ki} = total score of the industry i against the criterion k

$W(C_{ki})$ = weight or the importance value of the criterion k for industry I = $TS_{ki} / \sum TS_{ki}$

4. Case Study

The case study relates to the available wastewater generation and air emission characteristics from three chemical industries, three thermal power station units and three dying & printing textile industries located in Gujarat State, India. Table 4 shows the effluent characteristics of the treated wastewater and the effluent characteristics of the treated wastewater and the stack emissions for above mentioned industries monitored for winter (M_1), summer (M_2) and rainy season (M_3).

The parametric values of wastewater generation and stack emissions are converted to the fuzzy numbers (membership functions) based on the specified statutory norms (see figure 3). For example for 95 mg/l COD normalized value is 0.38. Similarly, normalized values of wastewater characteristics and stack emissions for all industries have been worked out.

Table 4. Effluent characteristics of wastewater and stack emissions

Sub Criteria	GPCB* limit	Industry 1			Industry 2			Industry 3		
		M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
Chemical Industries										
Water Pollution										
SS, mg/l	100	114.0	95.0	65.0	75	85	50	20	30	40
TDS, mg/l	2100	4500	4225	4775	2175	2640	2591	1110	1200	1235
COD, mg/l	250	75	85	99	88	110	125	89	60	50
BOD, mg/l	30	25	29	31	45	35	32	20	25	18
Chlorides, mg/l	600	275	350.61	500.25	90	125	150	750	100	250
Sulphates, mg/l	1000	1610	1375	1590	0.26	0.00	1.5	600	550	475
Phosphates, mg/l	5	0.00	0.00	0.00	6.0	3.45	6.5	0.00	0.00	0.00
Air Pollution										
SO_X,ppm	100	12.25	13.12	3.4	61.9	80.0	110	15.0	25.0	45.0
NO_X , ppm	50	21.5	30.0	36.0	58.0	49.0	55.0	14.0	35.0	36.0
SPM, mg/Nm^3	150	60.0	55.0	80.0	20.0	175	60.0	175	220	159
Cl_2, mg/Nm^3	9	4.5	3.66	3.91	0.00	0.00	0.00	0.00	0.00	0.00
HCl, mg/Nm^3	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thermal Power Station Units										
Water Pollution										
SS, mg/l	100	16.0	34.0	30.0	57	46	38	32.4	30	28
TDS, mg/l	2100	790	740	812	1054	844	840	876	804	836
BOD, mg/l	30	15.4	18.0	14.0	12	14	14	0.00	0.00	0.00
Phosphates, mg/l	5	2.68	0.97	1.40	1.41	0.98	1.04	0.418	0.700	1.12
Oil & grease ,mg/l	10	1.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total chromium, mg/l	2	0.014	0.012	0.012	0.018	0.012	0.013	0.014	0.012	0.012
Iron, mg/l	1	0.032	0.026	0.028	0.042	0.034	0.032	0.034	0.028	0.032
Air Pollution										
SO_X, ppm	100	3.61	6.22	12.25	12.23	9.21	6.1	4.80	4.20	6.1
NO_X, ppm	50	7.21	6.40	10.4	140	140	132	7.90	7.40	7.20
SPM, mg/Nm^3	150	0.00	7.00	3.8	3.6	3.1	2.4	0.00	0.00	0.00
Dying and Printing Units										
Water Pollution										
SS, mg/l	100	76	51	42	103	48	60	110	86	120
COD, mg/l	250	225.3	338.5	259.6	290	420	270	375	640	410
BOD, mg/l	30	25	35	26	35	54	30	50	79	53
Color, co-pt	100	75	60	65	72	65	45	110	105	90
Ammoniacal Nitrogen, mg/l	50	2.12	1.5	1.78	10.8	10.4	13.51	14.2	8.83	13.9
Oil & grease,mg/l	10	4.2	4.6	1.8	3.2	4.4	1.8	3.4	3.0	4.2
Phenolic Compounds, mg/l	1	0.281	0.360	0.222	0.352	0.318	0.321	0.00	0.00	0.00
Total chromium, mg/l	2	0.046	0.038	0.065	0.049	0.054	0.099	0.120	0.04	0.12
Air Pollution										
SO_X, ppm	100	51.48	40.80	41.5	55.05	42.82	43.62	58.21	52.74	55.25
NO_X ,ppm	50	6.27	6.50	6.60	2.82	2.14	2.41	6.05	6.08	6.11
SPM, mg/Nm^3	150	149	128.3	132.1	117.3	96.1	101.7	148.5	134.06	135.9

For final total score, a unique membership value for each industry for different sub criteria can be obtained by using simple average. Then normalized weight for each sub criterion of water pollution and air pollution for different industries are calculated. Table 5shows normalized weight for sub criteria of water pollution for different types of industries. Matrix is shown for total score of water pollution for same type (chemical)of industries.

Matrix for total score for sub criteria of water pollution

Sub Criteria	I1	I2	I3	W_{Ck1}	W_{Ck2}	W_{Ck3}
SS	0.87	0.70	0.30	0.098	0.098	0.098
TDS	1.00	1.00	0.56	0.143	0.143	0.143
BOD	0.93	1.00	0.70	0.185	0.185	0.185
COD	0.34	0.43	0.27	0.185	0.185	0.185
Chlorides	0.63	0.20	0.53	0.098	0.098	0.098
Sulphates	1.00	0.00	0.54	0.098	0.098	0.098
Phosphates	0.00	0.90	0.00	0.098	0.098	0.098
Bio - assay	0.78	0.69	1.00	0.098	0.098	0.098

Table 5. Normalized weight for sub criteria of water pollution for chemical industries (CI), thermal power station units (TPSU) and dying & printing units (DPU)

Chemical Industries		Thermal Power Station Units		Dying and Printing Units	
Sub Criteria	**Normalized Weight**	**Sub Criteria**	**Normalized Weight**	**Sub Criteria**	**Normalized Weight**
SS	0.098	SS	0.138	SS	0.127
TDS	0.143	TDS	0.203	Colour	0.096
BOD	0.185	BOD	0.262	BOD	0.241
COD	0.185	Oil & grease	0.138	COD	0.241
Chlorides	0.098	Phosphates	0.138	Oil & grease	0.127
Sulphates	0.098	Total chromium	0.061	Ammoniacal Nitrogen	0.042
Phosphates	0.098	Iron	0.061	Phenolic Compounds	0.069
Bio-assay	0.098	--	--	Total chromium	0.056

Using simple additive weighing method (Hwang and Yoon 1981), the total score (TS) for each industry has been calculated and the same is as shown in Table 6.

Table 6. Total score and summation for criteria

Criteria	I1	I2	I3
Water Pollution (C_1)	0.698	0.650	0.490
Air Pollution (C_2)	0.365	0.766	0.604
Σ	**1.063**	**1.416**	**1.094**

Using pollution potential importance weight for both the criteria (such that their summation is equal to 1, see Table 7), an overall score (OS) for the industries has been calculated as follows.

Table 7. Weightage for criteria

Criteria	I1	I2	I3
Water Pollution (C_1)	0.657	0.459	0.448
Air Pollution (C_2)	0.343	0.541	0.552
Σ	**1.000**	**1.000**	**1.000**

Matrix is shown for overall score of water pollution and air pollution. Table 8 shows overall score and ranking for chemical industries.

Matrix for overall score for water and air pollution

$$\begin{bmatrix} \text{Criteria} \\ C1 \\ C2 \end{bmatrix} \begin{bmatrix} I1 & I2 & I3 \\ 0.698 & 0.650 & 0.490 \\ 0.365 & 0.766 & 0.604 \end{bmatrix} \begin{bmatrix} W_{Ck1} & W_{Ck2} & W_{Ck3} \\ 0.657 & 0.459 & 0.448 \\ 0.343 & 0.541 & 0.552 \end{bmatrix}$$

industries (CI)

	I1	I2	I3
Overall Score	0.584	0.713	0.553
Rank	2	1	3

Similarly, overall scores of thermal power station units and dying & printing units are calculated and the same are shown in Table 9.

Table 9. Overall score and ranking for thermal power station units (TPSU) and dying & printing units (DPU)

	I1	I2	I3
Thermal Power Station Units			
Overall Score	0.264	0.351	0.131
Rank	2	1	3
Dying and Printing Units			
Overall Score	0.604	0.597	0.704
Rank	2	3	1

Table 10 shows overall score and ranking for different types of industries.

Table 10. Overall score and ranking for different types of industries

Chemical Industries			Thermal Power Station Units			Dying and Printing Units		
0.584	0.713	0.553	0.264	0.351	0.131	0.604	0.597	0.704
5	**1**	6	8	7	**9**	3	4	2

The authors of this paper developed a methodology for same types of industries and considered Saaty's seven linguistic variables [17]. Table 11 shows overall score and ranking for chemical industries using Saaty's seven linguistic variables.

Table 11. Overall score and ranking for chemical industries using Saaty's seven linguistic variables

	I1	I2	I3
Chemical Industries			
Overall Score	0.473	0.544	0.443
Rank	2	1	3

Sensitivity analysis

In order to check the sensitivity of the model for the given sub criteria, it was proposed to operate the model with SS discharge norms of 50 and 100 mg/l. The ranking was obtained for three chemical industries and the same is shown in Table 12.

Table 12. Overall score and ranking of chemical industries (Sensitivity analysis)

GPCB limit	Criteria	I1	I2	I3
50 mg/l	SS	0.624	0.743	0.565
100 mg/l	SS	0.584	0.713	0.553

Comments

As seen from the results (Table 12), the impact potential of an industry increases when the discharge standards for the SS are made more stringent from 100 to 50 mg/l. Moreover, the same is also reflected on the overall score of the industry. However, the ranking of the industry does not change.

5. Discussions

From the results (Table 8 and Table 9), it can be inferred that industry I_2, I_2 and I_3 ranks first in the list of three chemical industries, three thermal power station units and three dying & printing units respectively and are the major contributors in impairing water and air quality while industry I_3, I_3 and I_2 ranks number three in the list of these industries with minimum pollution potential. From the results of different types of industries (Table 10), it can be inferred that chemical industry ranks first in the list of nine industries with high pollution and thermal power station unit ranks number nine in the list of these industries with minimum pollution potential. So this way, it can be possible to do ranking of different types industries on basis of pollution potential and encourage industries entrepreneurs to bring their industries pollution potential at minimum level by controlling pollution to enhance their image in the market.

From the results, using four linguistic variables (Table 8 and Table 9) and using Saaty's seven linguistic variables (Table 11), it can be inferred that by decreasing number of linguistic variables pollution potential of industry is increased but ranking of same type of industries remains same.

The study also reflects that stringent environmental standards increase the pollution potential of industries and industries will have to put more efforts to treat the wastewater and control the air pollution. This can be linked to policy framing based on the principle of **Polluter to Pay,** the decision makers may revisit the concept of Pollution Tax and its variants depending upon the merit of the case and accordingly decide upon the emission norms.

6. Conclusion

The paper demonstrates the use of fuzzy modeling for the ranking of industries based on their environmental pollution potential with a case study. The sensitivity analysis conducted with stringent emission standards concludes that it increases the pollution potential of an industry however; it retains its raking. As the pollution levels in general are on increase, it is opined that the issue of pollution tax should be studied and considered by decision makers of developing countries to control the pollution levels in the environment.

7. Further Scope for research

Here a methodology is developed for pollution potential of industries. For further work the inter relation of sub criteria of water and air pollution can be considered to see the effect on ranking of industries. Some of the other issues of relevance include, fuzzy rule based systems, linkage between the increased concentration of the pollution parameters and imposing pollution tax, willingness to pay and alike.

8. References

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