Temporal Analysis of Water Quality Evaluation using Fuzzy Logic and Ideal Point Analysis

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Abstract: ***Water quality assurance is the pre-requisite for the maintenance of congenial environment and an index of health and well being of a society. There are multiple cross elastic criterions that influence water quality with respect to physico-chemical and biological parameters like temperature, ph, Turbidity, BOD,COD, chlorides, nitrates and nitrogen…etc. The variations and uncertainty of these characteristics is more prominent in spatial and temporal frames. An attempt is made in the study to assess the water quality at different locations in an urban area relative to the different study locations that serves as an index to prioritize the worst pollution prone locations. A temporal analysis of the water quality in conducted to assess the variations in different seasons of the year. Fuzzy Logic system and Ideal Point Analysis are used as decision support analyzers in evaluating the parameters in a defined framework. Sensitivity analysis is conducted to assess the robustness of the model frame work. This approach can serve as a quality assurance tool for taking appropriate control strategies by government to achieve sustainable environment that leads to social, economic and environmental benefits.***

Keywords: Congenial environment, Decision support analysers, Fuzzy logic, and Sensitivity analysis.

1. Introduction

Groundwater quality is one of the most important aspects in water resource studies [1,2]. It is largely controlled by discharge recharge pattern, nature of the host and associated rocks as well as contaminated activities [3, 4, 5] The analyzed chemical parameters of groundwater have important role in classifying and assessing water quality. As the distribution of surface water is so uneven in many parts of the country the dependence on ground water is almost total. This paper studies the quality of ground water and prioritization is done to know the best quality of ground water in the city of Hyderabad.

2. Hypothesis

The ground water continues to exploit at ever increasing rates, especially in rapidly expanding urban areas of the country. Depending on various natural and cultural factors, the quality of ground water in terms of its physical, chemicals and organic characteristics is variable, determining its suitability for different purpose like domestic, agricultural or industrial. The parameters for measurement of the quality are primarily based on physical and chemical characteristic. The quality assessment is multifaceted with multiple characteristics to obtain best quality of ground water in the urban areas. The analysis of these multiple characteristics in a relative platform involves an uncertainty, by which the quality is worst effected by certain parameters can best be analyzed by fuzzy interface approach. Fuzzy multi criteria analysis approach provides an ideal solution in uncertain situations and it has been attempted by number of researchers for prioritization analysis in different situations. This study attempts to conceptualize fuzzy multi criteria analysis to analyze the best quality of ground water in the areas of Hyderabad and identify the critical land use that has worst ground water quality.

3. Objectives of the study

The objectives framed in the study are as follows:

1. To develop framework for ground water quality assessment for urban areas considering the physical and chemical characteristics.
2. Identification of area that pose a significant threat to ground water quality in the urban areas
3. Conceptualization of fuzzy multi criteria approach and development of fuzzy interface system to analyze the worst and best water quality of ground water.

4. Methodology

Figure 1 shows the outline of the fuzzy interface system. The system consists of input phase where the characteristics based on physical and chemical impurities in the urban area and characteristics are derived through the geochemical laboratory as per the standard procedure for American public health association[6]. The crisp input data is obtained from the laboratory test for the samples collected from different areas of city and is standardized with a linear additive function. The fuzzification of the quality characteristics activates the linguistic variables which forms an input to the fuzzy interface. This interface is a decision support system where the rules provided by experts and Multi criteria evaluation set up analyze the input forms. The MCE used is the Ideal point analyses that derives the separation measure from the ideal point.

4.1 Concept of fuzzy interface system

The fuzzy set theory was proposed by Zadeh, L. A[6]. in 1965, to represent the uncertainty involved in any situation in linguistic terms. A fuzzy number $\tilde{A}$ is a fuzzy set, and its membership function is $\mu_{\tilde{A}}(x) : R \rightarrow [0,1]$ [Dubois & Prade

(1978)[7]; Yeou-Geng Hsu et al. (2003)[8]; Mei-Fang Chen et al.(2003)][9], where ‘x’ represents the criteria. A linear membership function is the widely used and the corresponding fuzzy numbers are called Triangular Fuzzy Numbers (TFNs). TFNs are the special class of fuzzy numbers whose membership is defined by three real numbers (l, m, n) i.e. $\mu_{\tilde{A}}(x) = (l,m,n)$, which is pictorially shown in Fig. 1. The TFNs can be expressed as follows.

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{(x-l)}{(m-l)}, & l \le x \le m, \\ \dfrac{(n-x)}{(n-m)}, & m \le x \le n, \\ 0, & \text{Otherwise;} \end{cases} \quad (1)$$

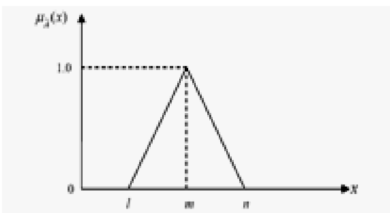

Figure. 1 Concept of fuzzy interface system

5. Study area

In present study 310 ground water samples were collected from bore wells located in parts of the city.

Table 1. List of study sites in Hyderabad city

Zones	*Name of the Zone*	*Name of the area*
A1	Kapra	Kapra, Cherlapalli, Mallapur, Nacharam
A2	Uppal	Uppal, Habsiguda, Kothapet, Ramanthapur
A3	LB nagar	Mansoorabad, Hayathnagar, Vansathalipuram, Karmanghat, Gaddiannaram, Rama Krishna Puram
A4	Sarrornagar	Moosarambagh, Saidabad, I.S.Sadan, Santoshnagar, Riyasat Nagar, Kanchanbagh, Barkas, Chandrayan gutta, Jangammet, Uppuguda, Old Malakpet, Akberbagh
A5	Falakuma	Nawabsaheb Kunta, Jahanuma, Kishanbagh, Ramnaspura, Dhoolpet, Begum Bazar, Puranapul
A6	Rajendra nagar	Attapur, Mylardevpally, Shivarampally
A7	Mehdipatnam	Red Hills, Mallepally, Chintalbasti, Vijayanagar Colony, Ahmed Nagar, Nanalnagar, Tolichowli, Lunger House, Muradnagar, Asifnagar, Ziaguda
A8	Gunfoundry	Sultan Bazar, Jambagh
A9	Amberpet	Himayathnagar, Kachiguda, Barkatpura, Golnaka, Bagh Amberpet, Nallakunta, Vidyanagar, Bagh Lingampally, Adikmet, Ramnagar, Musheerabad, Kavadiguda, Domalguda, Gandhinagar
A10	Jubilee Hills	Khairtabad, Panjagutta, Somajiguda, Ameerpet, Sanathnagar, Erragadda, Vengalrao Nagar, Srinagar Colony, Banjara Hills, Yousufguda, Rahamath Nagar, Borabanda, Jubilee Hills.
A11	Serilingam pally	Gachibowli, Hafeezpet, Chanda Nagar
A12	Ramchandrapuram	Rama Chandra Puram, Patancheruvu
A13	Kukatpally	KPHB Colony, Moosapet, Mothinagar, Fathe Nagar, Old Bowenpally, Kukatpally, Vivekananda Nagar Colony, Hydernagar
A14	Qutubullapur	Gajula Ramaram, Jagadgiri gutta, Chintal, Shapur Nagar, Suraram Colony, Jeedimetla, Qutubullapur.
A15	Alwal	Alwal, Macha Bollaram, Yapral
A16	Secunderabad	Defence Colony, Moula Ali, Safilguda, Gautham Nagar, Old Malkajgiri
A17	Malkajgiri	Tarnaka, Mettuguda, Mettuguda, Boudha Nagar, Chilkalguda, Padmarao Nagar, Bansilalpet, Ramgopal pet, Begumpet, Marredpally, Addagutta

6. Application of methodology

6.1 Data collection

Primary data has been collected through field investigations as well as expert opinion surveys. The opinion of selected experts from all over city has been sought to ascertain the influence of different characteristics on the ground water. The criteria’s considered are with respect to three severity levels namely low, medium and high. Further they were asked to indicate their preferences regarding the influence of severity of various parameters in terms of linguistic variables such as Negligible (N), Low (L), Moderate (M), High (H) and Very High (VH) as it would be difficult to express the weights in quantifiable terms. The responses given by a group of 15 experts have been summarized and presented in Table 2.

Table 2. Summary of Experts Opinions

Parameters	*Experts Opinions*														
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
PH	H	M	M	H	VH	VH	H	M	H	VH	VH	H	VH	H	VH
EC(Us/cm)	M	H	H	M	VH	H	M	VH	M	H	VH	M	H	VH	H
TDS(mg/l)	L	M	L	M	H	M	M	L	H	M	H	M	M	H	L
Na^+(mg/l)	M	L	M	N	M	N	L	M	N	L	M	N	M	L	M
K^+(mg/l)	M	H	M	VH	H	M	VH	H	M	H	VH	M	H	VH	H
Mg^{++}(mg/l)	L	M	L	H	M	L	H	L	H	M	VH	M	VH	M	VH
Ca^{++}(mg/l)	N	L	H	N	M	L	H	N	VH	M	L	H	N	M	L
Cl^-(mg/l)	H	VH	VH	H	VH	H	VH	H	VH	VH	H	VH	H	VH	VH
So4(mg/l)	H	M	VH	H	M	VH	H	VH	VH	M	H	VH	VH	H	H
HCO3(mg/l)	M	H	VH	H	M	VH	M	H	VH	H	VH	M	H	VH	M
NO3(mg/l)	M	VH	H	M	VH	H	VH	M	VH	H	M	H	VH	M	H
F^+(mg/l)	H	VH	H	M	VH	M	H	M	H	VH	H	VH	H	M	VH
TH	M	H	VH	VH	VH	H	H	VH	H	H	VH	H	VH	H	VH
SAR	H	M	VH	H	VH	M	VH	H	VH	M	VH	H	VH	VH	H

N=Negligible; L= Low; M=Medium; H =High ; VH= Very High;

6.2 Fuzzy interface system prioritization process

Phase-1:

Data collected in the field is being normalized in the scale of 0 to 100 with respect to the maximum value in the series through a simple normalization (Linear additive function) as shown below.

Normalized Data Point = (Data Point) x 100 / (Mode of the Data Series) (2)

Further, these values are being arranged into 10 groups with a uniform interval of 10 and ratings have is given.

Normalized value	0-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Rating	1	2	3	4	5	6	7	8	9	10

The rating matrix are being arranged in a matrix form named as Rating matrix$(R_{ij})_{nXm}$ with each row representing alternative ($A_1, A_2 \ldots\ldots A_{18}$) and each column representing criteria.

Phase-2:

The linguistic variables utilized for expressing the criteria's have been expressed as TFNs. TFNs assigned for various linguistic variables are shown in Table 3.

Table 3. Triangular Fuzzy Numbers (TFNs) for Linguistic Variables

Linguistic Variable	*TFN*
Negligible	(0,0,1)
Low	(0,0.1,0.3)
Medium	(0.3,0.5,0.7)
High	(0.7,0.9,1)
Very High	(0.9,1,1)

Phase-3:

Experts opinion available for the various Criteria's in the form of linguistic variable as presented in Table are being converted into fuzzy numbers. To normalize differences existing in expert opinion, simple average of fuzzy numbers for all the linguistic variables has been calculated and the corresponding weights are being worked out and presented in the Table 4. Fuzzy weights for all criteria can be expressed in the form of following row matrix $w=(w_1, w_2 \ldots\ldots\ldots\ldots w_m)$ (3)

Where, $w_1, w_2 \ldots\ldots\ldots\ldots w_m$ are the fuzzy weights for all criteria expressed in Triangular Fuzzy Numbers i.e $w_j = (w_{j1}, w_{j2}, w_{j3})$ $\forall$ j= 1, 2, 3…….M

Table 4 . Fuzzy Weights

Criteria	*Fuzzy Weight*
PH	0.7 0.9 0.9
EC(Us/cm)	0.62 0.793 0.9
TDS(mg/l)	0.33 0.5 0.67
Na^+(mg/l)	0.14 0.26 0.43
K^+(mg/l)	0.62 0.793 0.9
Mg^{++}(mg/l)	0.42 0.573 0.713
Ca^{++}(mg/l)	0.26 0.373 0.513
Cl^-(mg/l)	0.82 1 1
So^4(mg/l)	0.7 0.9 0.94
HCO^3(mg/l)	0.633 0.8 0.9
NO^3(mg/l)	0.633 0.8 0.9
F^+(mg/l)	0.66 0.827 0.92
TH	0.767 0.92 0.98
SAR	0.713 0.867 0.94

Phase-4:

Fuzzy evaluation value (p_i) is then calculated by multiplying the rating matrix with the weight matrix and summed up for all the areas an example is represented in table 5. This process is mathematically expressed as follows.

$p_i = \sum_{j=1}^{M} R_{ij} * W_j, \quad \forall\ i=1,2,\ldots\ldots N \quad \text{and} \quad \forall j= 1,2,3\ldots\ldots M \qquad (4)$

Table 5. Fuzzy Evaluation values

A1	*29.807*	*38.265*	*42.278*
Ai….j	………	…………	……………
A17	35.613	45.937	51.587

Phase-5:

To establish the relative preference of all the Areas, difference between all combinations of the fuzzy values has been computed shown in table 6. This is mathematically expressed as

$F_{ij} = (Sm_i - Sm_j) \quad \forall i= 1 \text{ to } N \quad \forall j= 1 \text{ to } N \quad \text{and} \quad i \neq j \qquad (5)$

It is noted that a_1, a_2 are triangular fuzzy numbers and hence $(a_i - a_j)$ are also triangular fuzzy numbers. A sample of these values is presented below.

Table 6. Fuzzy Evaluation values

A1-A2	*-81.024*	*-60.71*	*-34.962*
A2-A3	17.664	46.545	70.615
Ai-Aj	…….	…………	………..
A15-A16	-30.024	-14.451	2.546
A16-A17	-10.228	7.534	24.551

Phase-6:

The fuzzy Preference relation matrix (E) has been developed, to know the degree of preference of Areas a_i over the a_j.

$$E = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1N} \\ e_{21} & e_{22} & \cdots & e_{2N} \\ \cdots & \cdots & \cdots & \cdots \\ e_{N1} & e_{N2} & \cdots & e_{NN} \end{bmatrix}$$

Where, e_{ij} is the real number indicates the degree of preference between the respective i^{th} and j^{th} areas. It has been calculated using positive (A^{+}_{ij}) and negative (A^{-}_{ij}) of difference between two fuzzy values $(a_i - a_j)$.

$e_{ij} = A^{+}_{ij} / (A^{+}_{ij} + A^{-}_{ij})$ Where $(A^{+}_{ij} + A^{-}_{ij})$ =Total area of $(a_i - a_j)$. (7)

Positive and negative areas have been computed using the membership function (UFij (x)) of the values $(Sm_i - Sm_j)$. An example of computation of e_{ij} is shown below in fig 4. For example, if the

$F_{12} = (a_1 - a_2) = (-)$

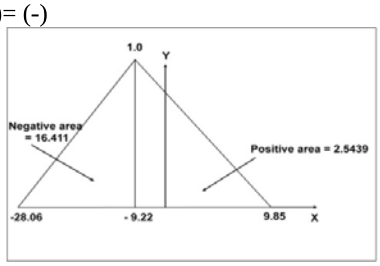

Figure 2. Computation of e_{ij}

Total area from fig=18.955;
Positive area=2.5439;
Negative area=16.411;

$e_{12} = (2.5439/18.955) = 0.13$

Here $e_{ij} = 0.5$ and $e_{ij} + e_{ji} = 1.0$, if $e_{ij} > 0.5$ the area A_i is to be given priority over stretch A_j and vice versa.

Phase-7:

Priority Index (PI) for all the Areas is computed from the fuzzy preference relation matrix using the following mathematical form.

$(PI)_i = \sum_{j=1}^{n} (e_{ij} - 0.5) \quad \forall\ i = 1 \text{ to } N \qquad (8)$

Based on the PI, all the areas have been ranked and presented in Table 7. The prioritization process, as explained in the above stages is quite complex and cumbersome due to a number of areas and criterion. Hence, a code has been developed in MATLAB and being used in the present study.

Table 7. Ranking of different areas

Area	*Desig.*	*Rank*
Kapra	A1	3
Uppal	A2	17
LB nagar	A3	9
Sarrornagar	A4	11
Falakuma	A5	13
Rajendra nagar	A6	6
Mehdipatnam	A7	4
Gunfoundry	A8	8
Amberpet	A9	2
Jubilee Hills	A10	1
Serilingam pally	A11	14
Ramchandrapuram	A12	15
Kukatpally	A13	12
Qutubullapur	A14	16
Alwal	A15	5
Secunderabad	A16	10
Malkajgiri	A17	7

The lowest rank indicates the area were the water quality is worst when compared to other areas.

7. Conclusions

The following conclusions have been drawn from the present work.

- The centre which has the highest Priority Index (PI) will be given top priority and vice versa.
- On the basis of hydro chemical studies, it may be concluded that the quality of groundwater in certain parts of Hyderabad city is affected and not fit for human consumption.
- In the study area, many of ionic concentrations in the groundwater are at higher levels indicating that they are problematic in one way or the other, if they are consumed without proper treatment.

- It is significant to note that ground waters of variable quality exist in this area and the quality of the groundwater is being deteriorated in some parts. This is mainly because of percolation from sewage, waste disposal sites and industrial effluents.
- Therefore, it is advisable that constant monitoring and proper treatment of groundwater is essential, as prerequisite for use of these waters for drinking purpose because of excessive amounts of fluoride and nitrate concentration in the groundwater of the area.
- •As the waters are of very hard type, they may pose problem for domestic use also, in particular washing of clothes because of their adverse action with soap and hence, water softening processes for removal of excess hardness is needed. If this is not feasible, it is recommended that these waters may be used only for some industrial and other purposes.

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