APPLICATION OF FUZZY LOGIC TO SALINE WATER INTRUSION INTO COASTAL AQUIFERS

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ABSTRACT: Aquifers are the principal source of fresh water. The demand of groundwater has escalated in recent years due to population growth and is expected to continue in the future. The aquifers near the sea are commonly intruded by seawater. In the present study an attempt is made to apply Fuzzy Logic to study the progression of seawater intrusion into coastal aquifers of Vakadumandal of Nellore District, A.P., India. Wells spread over in the study area are selected and the various chemical parameters comprising of Calcium, Magnesium, Sodium, Potassium, Bi-carbonate and Chloride were analysed. Membership functions were developed for the chemical parameters and the weighted fuzzy value was found for all the wells which indicate the degree of contamination due to seawater intrusion.

Key Words: Coastal aquifer, groundwater, salinity, seawater intrusion, membership function, fuzzy logic.

I.INTRODUCTION:

Coastal aquifers constitute an important source of water, especially in arid and semi-arid zones. In many coastal areas, the development and management of fresh groundwater resources are seriously constrained by the presence of seawater intrusion. Seawater intrusion is a natural phenomenon that occurs as a consequence of the density contrast between fresh and saline groundwater. Normally, the denser saline water forms a deep wedge that is separated from the fresh water body by a transition zone of variable density. Seawater-freshwater interface in the coastal aquifers is in the form of a transition zone. Even this transition zone is not static, but fluctuates by the influence of several factors like precipitation, exploitation of fresh groundwater, tidal waves, cyclonic storms, tidal marshes etc. Problems arise when saline water from the deep saline wedge enters pumping wells and affects the water quality. Most commonly, this occurs at individual wells where heavy pumping lowers the fresh water potential in the immediate vicinity of the well and causes saline water to be drawn upwards to the well, a phenomenon known as upconing. The other reasons that are attributed to seawater intrusion are, when permeable formations outcrop into a body of seawater and when there is a landward hydraulic gradient. Therefore, studies on coastal aquifers have become important to efficiently and effectively meet the growing demands of groundwater.

Extensive research has been carried out and much progress has been made in understanding the various mechanisms that govern seawater intrusion. The dominant factors are the flow regime in the aquifer above the intruding seawater wedge, the variable density and hydrodynamic dispersion. A large number of field investigations have been conducted in many parts of the World, providing a basis for understanding the complicated mechanisms that cause seawater intrusion and affect the shape of the zone of transition from fresh water to seawater. Subrahmanya Kumar C.S.V. et al (2003) have studied the seawater contamination zones by chemical parameters in Nellore District, A.P. Ravi Prakash, S. et al (1996), has made a study on dilineation of salt-water contamination zones and Babu Rao P. (1996) studied problems on salinity ingress in coastal aquifers of A.P.

Groundwater is essentially six-component aqueous system comprising of calcium, magnesium, sodium, potassium, bicarbonate and chloride. In the past, a clear-cut definition as to what constituted a 100% seawater intrusion has not been putforth. This can be attributed mainly due to the uncertainity that prevails in the analysis of these parameters. Under this vague situation, fuzzy logic approach provides the best solution. In fuzzy logic method, the boundary between the two extremities of logic is a gradual transition rather than abrupt. It is this unique character of fuzzy logic approach that makes it the best for seawater intrusion studies.

2. AREA OF STUDY:

Vakadumandal of Nellore district, A.P has been considered for studying seawater intrusion as the mandal is located along the coast of Bay of Bengal. Vakadumandal is bounded between $13^0$30' – $15^0$6' N latitudes and $75^0$5' – $80^0$5' E longitudes at an altitude of 18.69m above the sea level .The geology of study area constitutes sand bed and limestone.

3. EVALUATION METHODOLOGY:

Fuzzy logic is a mathematical method used to characterize and propagate uncertainty and inaccuracy in data and functional relationships. The concept of fuzzy logic was introduced by Zadeh (Zadeh, 1965) as an extension of Boolean logic to enable modelling of uncertainity. Fuzzy logic introduces a concept of partial truth-values, that lie between "completely true" and "completely false". The central concept of fuzzy logic is the membership function, which represents numerically the degree to which an element belongs to a set. In a classical set, a sharp or unambiguous distinction exists between the members and non-members of a set, while in a fuzzy set, the distinction between members and non-members is gradual. An element can be a member of a set to a certain degree. The degree to which a member is an element of a set is called the membership degree. Similar to traditional logic, in fuzzy logic membership values can be combined through operations on fuzzy sets, such as union, intersection and complement. The steps involved in the study is shown in the flow chart (Fig. 1)

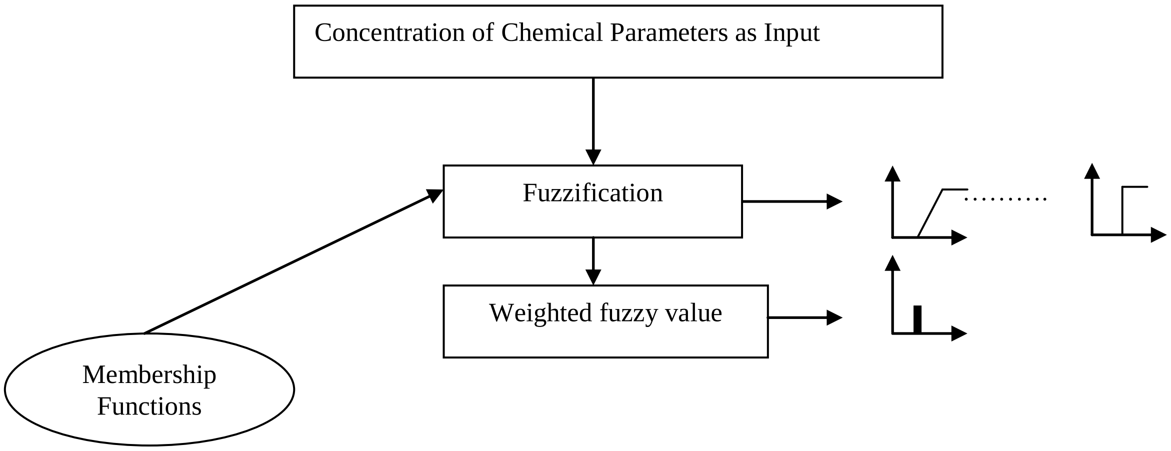

Fig.1: Schematic Representation of Saline Water Intrusion Study

Groundwater is essentially a six component aqua system of calcium, magnesium, sodium, potassium, chloride and alkalinity. The water samples from various wells which are spread over in the study area are collected. The water samples are analyzed for chemical parameters such as calcium, magnesium, sodium, potassium, bi-carbonate and chloride using standard methods. The relative concentration levels of these parameters will decide the extent of salinity.

The membership functions of various chemical parameters such as calcium, magnesium, sodium, potassium, chloride and alkalinity are formulated taking into account the values of permissible and excessive limits of the chemical parameters in ppm as shown in Figure.2 to Figure.7.The membership function for the parameters were assumed to be linear between the permissible and excessive limits. This function suits the problem from the point of view of simplicity, convenience, speed and efficiency.

The membership values for various chemical parameters are found out for the known concentrations. The membership values for various chemical parameters are combined by individual weightage factors to get the weighted fuzzy value.

Let C_i be the fuzzy value expressing the concentration of the component 'i' in the water sample, $W_i$be the weightage factor expressing the significance of the component 'i' in determining the extent of seawater intrusion, F_i be the weighted fuzzy value expressing the seawater intrusion, then

$$F_i = \sum_{i=1}^{n} W_i C_i \Big/ \sum_{i=1}^{n} W_i \qquad (1)$$

Where, n = number of chemical parameters taken into consideration
In order to estimate the weightage factor $W_i$for each parameter, some empirical relations between various parameters for seawater studies are considered which are as follows:

Ca / Mg	=	0.18
Cl/TA	=	200
TA / TH	=	1

Base exchange index i.e.

[Cl - (`Na+ K)] / Cl = 0.11

Using the above relations the computed weightages are as follows:

Magnesium	=	0.149	Total alkalinity	=	0.261
Sodium and potassium	=	46.507	Chloride	=	52.255

The weighted fuzzy values are calculated for all the wells from Equation (1) which indicate the degree of seawater intrusion. The fuzzy values and the weighted fuzzy values for the wells considered in the study area are shown in Table 1.

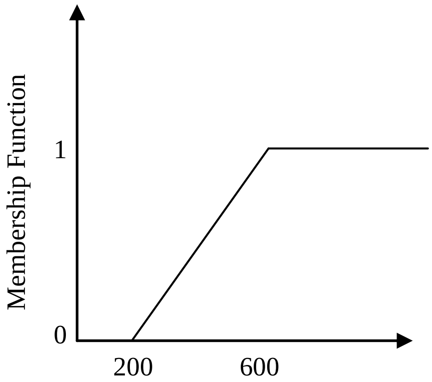

Fig. 2. Membership Function for Chloride

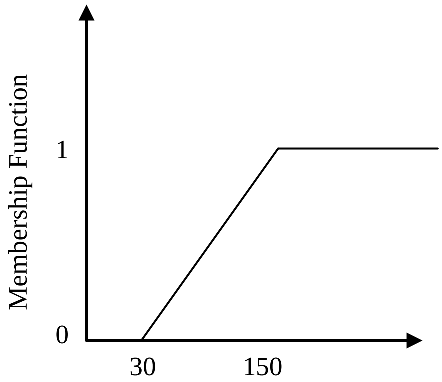

Fig. 3. Membership Function for Magnesium

4.RESULTS:

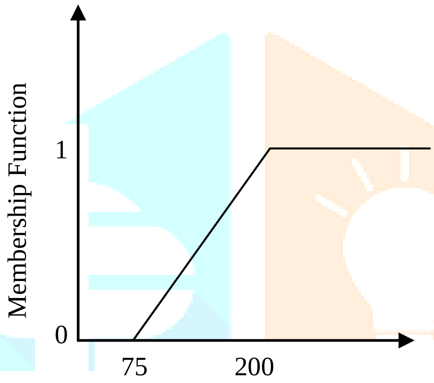

Fig. 4. Membership Function for Calcium

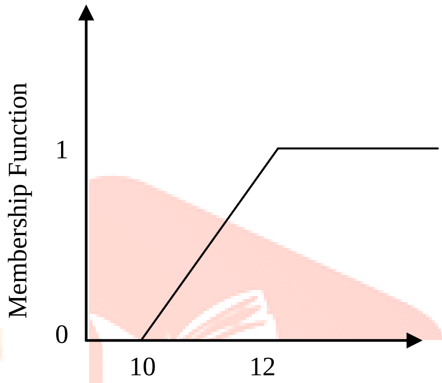

Fig. 5. Membership Function for Potassium

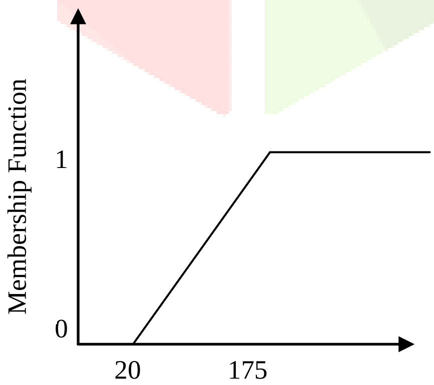

Fig. 6. Membership Function for Sodium

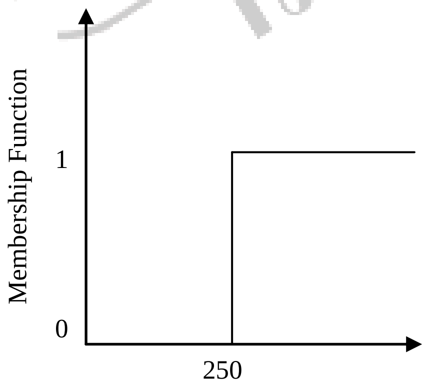

Fig. 7. Membership Function for Total Alkalinity

Table 1: Fuzzy values for chemical parameters

S. No	Name of the sample station	Magnesium	Calcium	Total alkalinity	Sodium	Potassium	Chloride	Weighted fuzzy value
1	Pamanji	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	Valamedu	0.90	0.88	1.0	0.90	0.90	0.91	0.91

3	Nagarru	1.0	1.0	1.0	1.0	1.0	1.0	1.0
4	Gemini Kothapalem	0.88	0.95	1.0	0.89	0.90	0.92	0.91
5	Molaganuru	0.51	0.50	1.0	0.49	0.50	0.51	0.51
6	Gagnapalem	0.78	0.78	1.0	0.75	0.76	0.79	0.78
7	Andalamala	0.95	0.86	0.1	0.88	0.90	0.91	0.90
8	Budidalavayu	0.92	0.81	1.0	0.75	0.79	0.98	0.87
9	Peddacheruvu	0.97	0.86	1.0	0.93	0.93	0.98	0.96
10	Nellipudi	0.72	0.65	1.0	0.66	0.66	0.68	0.68
11	Kottacheruvu	0.55	0.58	1.0	0.45	0.47	0.50	0.49
12	Gundkuru	0.77	0.67	1.0	0.68	0.69	0.72	0.71
13	Kalluru	0.89	0.80	1.0	0.83	0.83	0.85	0.84
14	Pallapalem	0.82	0.73	1.0	0.60	0.69	0.71	0.70
15	Uttarapalem	0.51	0.48	1.0	0.46	0.49	0.52	0.50
16	Durgavaram	0.73	0.67	1.0	0.69	0.70	0.69	0.70
17	Thirumuru	0.67	0.70	1.0	0.62	0.63	0.63	0.63
18	Konduru	0.76	0.81	1.0	0.69	0.69	0.70	0.70
19	Jammala	0.70	0.77	1.0	0.70	0.69	0.70	0.70
20	Duggavaram	0.97	0.98	1.0	0.93	0.92	0.8	0.93
21	Dugarajupatnam	1.0	1.0	1.0	1.0	1.0	1.0	1.0
22	Rayapadupalem	1.0	1.0	1.0	1.0	1.0	1.0	1.0
23	Pamblipalem	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	Raviguntapalem	0.80	0.85	1.0	0.80	0.80	0.84	0.82
25	Chebettivaripalem	0.81	0.83	1.0	0.76	0.79	0.62	0.8
26	Pambali	0.97	0.95	1.0	0.94	0.94	0.95	0.94
27	Kottapalem	0.88	0.95	1.0	0.91	0.90	0.65	0.91
28	Nidigurti	0.70	0.60	1.0	0.62	0.64	0.55	0.64
29	Vallamedu	0.66	0.60	1.0	0.65	0.64	0.65	0.65
30	Nimmavaripeta	0.90	0.90	1.0	0.91	0.91	0.89	0.90
31	Munapalem	1.0	1.0	1.0	1.0	1.0	1.0	1.0
32	Vadapalem	1.0	1.0	1.0	1.0	1.0	1.0	1.0
33	Gollapalem	0.8	0.79	1.0	0.80	0.82	0.79	0.80
34	Mulapadva	1.0	1.0	1.0	1.0	1.0	1.0	1.0

5. CONCLUSIONS AND DISCUSSIONS:

1. The results indicate that the groundwater is contaminated in areas near the sea coast and the extent of salinity in the groundwatergradually declines as the distance increases from the seacoast. This can be emphasized from the fact that the weighted fuzzy values for the wells near the sea exhibited higher values when compared to the weighted fuzzy values for most of the wells which are away from the coast. Thisclearly indicates that the chief source of contamination in the area of study is seawater.

2. Fuzzy logic method was proved to be a more effective and precise way of studying the degree of contamination of groundwater due to seawater intrusion into coastal aquifers.

3. The inhabitants of the study area depend locally on the groundwater for their daily use.However the results clearly indicate thatseawater intrusion has occurred heavily, which has made the groundwater unfit for human use.

Other alternatives proposed to combat seawater intrusion are:

a) Application of artificial recharge methods.
b) Provision of proper water supply scheme
c) Construction of barrage across Swarnamukhi River.

4. Construction of groundwater dams may be another option to curb saline water intrusion.

5.Recharge pits may be dug near the seashore and if recharging is done by fresh water, the salinity can be kept at low concentration. This method was found successful in Southern California, USA.

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