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Analysis of Groundwater Quality Parameters Using Mamdani Fuzzy Inference System (MFIS)

Payal Prajapati[1], Dr. Falguni Parekh[2]

[1]PG student, Water Resources Engineering and Management Institute, Samiala, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, India

[2]Offg. Director and Associate Professor, Water Resources Engineering and Management Institute, Samiala, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, India

Abstract: ***The quality of groundwater is most important for human and irrigation in any area. For this purpose to analyse the problems of pollution hazards of groundwater and to ascertain its suitability for drinking purpose in Nadiad district. Various methods are used for analysis of groundwater quality but last few decades Mamdani Fuzzy Inference System is widely used which will able to tell about final ground water quality compared to deterministic method. For this study, 509 groundwater wells have been collected in pre monsoon season and 495 groundwater wells have been collected in post monsoon season. Various groundwater parameters viz. EC, TDS, PH, Cl and Ca are used for analyzed groundwater quality. In this paper various membership function viz. Desirable, Acceptable and Not acceptable are used and fuzzy logic rules are defined.. The result showed that only 37 wells are classified in "Desirable" class i.e.7.26%, 286 Wells are in "Acceptable" class i.e. 56.18% and 186 wells are in "Not acceptable" class i.e. 36.54%. in pre monsoon season and only 49 Wells are classified in "Desirable" class i.e. 9.89%, 271 wells are in "Acceptable" Class i.e. 54.74% and 175 Wells are in "Not acceptable" class i.e. 35.35%. in post monsoon season.***

Keywords: Acceptable**,** Fuzzy Logic, Groundwater, MFIS, Quality

1. Introduction

The quality, quantity and availability of drinking water are one of the most important environmental, political and social issues at global level. Groundwater is affected from many factors such as municipal wastage, disposal to nearby water body, discharge the effluent from industries without proper treatment and use of inorganic material in agriculture. The various Physico-chemical parameters of groundwater quality which are greatly influenced by geological formations and anthropogenic activities. Despite the large volume of water that covers the surface of the earth, only 1% is inland fresh and easily available for human use. The qualities of groundwater resources vary naturally and widely depending on climate, season, and geology of bedrock as well as anthropogenic activities. While most people in urban cities of developing countries have to access to piped water, several others still use borehole for domestic and irrigation. Water quality analysis is one of the most important aspects in groundwater studies. The physicochemical parameters of groundwater quality that are greatly influenced by geological formations and anthropogenic activities. Last few decades water quality index (WQI) was used for assessment of water quality using Delphi technique. WQI assesses water quality adding multiplication of the respective weight factor by an appropriated value of each parameter. However WQI exhibit a number of weak points. Mamdani Fuzzy Inference System is widely used during recent years due to its ability to handle the uncertainties in Geoscience and water resources. Groundwater samples are collected from the year 1997 to 2006 for the pre monsoon and post monsoon season of Nadiad taluka. The groundwater quality parameters like EC, TDS, PH, Cl and Ca are used for assessment of water quality.

Parekh and Joshi (2013), carried out a study of Analysis of ground water quality parameters using Mamdani Fuzzy Inference System in Vadodara, Padra and Jambusar talukas and concluded that MFIs is a better toll compared to deterministic approach. Sabir et al. (2012) carried out study of Analysis of ground water using Mamdani Fuzzy Inference System in Yazd Province, Iran and concluded that in MFIS evaluation method, not only the potable water quality is classified as the three forms, but also can easily suggest about final groundwater quality. Dahiya et al.(2007) carried out study of Analysis ground water using Fuzzy synthetic evaluation in Ateli block of southern Haryana and concluded that about 64% water sources were either in "desirable" or "acceptable" category for drinking purposes.

2. Study Area and Data Collection

Gujarat state is located in the Western part of India. In this study, Matar taluka of Kheda district was selected area. The Kheda district is located between 72º32' to 73º37' E longitudinal and between 22º30' to 23º30'North latitude in Gujarat

The data required for water quality analysis in this study have collect from the GERI (Race course), Vadodara for the year 1997 to year 2006 of Matar taluka, Kheda District. For this study 362 wells are selected and five Physico-Chemical parameters viz. EC, TDS, PH, Cl and Ca are collected and analyzed**.**

3. Materials and Method

3.1 Fuzzy logic system

Since past few years have witnessed a rapid growth in the number and variety of application of fuzzy logic. The application rang from consumer products such as cameras, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision – support systems, and portfolio selection.

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To understand the reasons for the growing use of fuzzy logic it is necessary, first, to clarify what is meant by fuzzy logic. Fuzzy logic has two different meaning. In a narrow sense, fuzzy logic is logical system, which is an extension of multivalued logic, but in a wider sense, which is in predominant use today, fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. what is important to recognize is that, even in its narrow sense, the agenda of fuzzy logic is very different both in sprit and substance from the agendas of traditional multivalued logical systems.

3.2 Building system with the fuzzy logic toolbox

In the present study, the GUI (Graphical User Interface) tools are used, which basically consists of five editors to build, edit and view the system, as shown in figur

1) Fuzzy Inference System (FIS) Editor -to handle the high-level issues for the system like number of input and output variables and their names.
2) Membership Function Editor- to define the shapes of all the membership functions associated with each variable.
3) Rule Editor- to edit the list of rules that defines the behaviour of the system.
4) Rule Viewer- to view the fuzzy inference diagram. This viewer is used as a diagnostic to see, for example, which rules are active, or how individual membership function shapes influence the results.
5) Surface Viewer -to view the dependency of one of the outputs on any one or two of the inputs. It generates and plots an output surface map for the system.

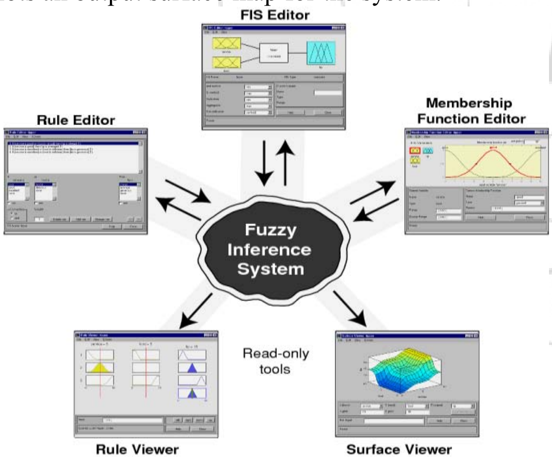

Figure 1: GUI editors in mamdani fuzzy method

3.3 Mamdani fuzzy inference system

Mamdani Fuzzy inference system involves five steps:

1. Fuzzification of the input variable

The first step in building a fuzzy inference system is to determine the degree to which the inputs belong to each of the appropriate fuzzy sets through the membership functions. The input is always a crisp numerical value limited to the universe of discourse of the input variable and the result of Fuzzification is a fuzzy degree of membership.

2. Apply fuzzy operator

Once the inputs are fuzzified, the degree to which each part of the premise has been satisfied for each rule is known. If the premise of a given rule has more than one part, then a fuzzy operator is applied to obtain one number that represents the result of the premises for that rule. The fuzzy logic operators such as the AND or OR operators obey the classical two valued logic. The AND operator can be conjunction (min) of the classical logic or it can be the product (prod) of the two parameters involved in it. Similarly the OR method can be the disjunction operation (max) in the classical logic or it can be the probabilistic OR (probor) method.

3. Apply Implication Method

The fuzzy operator operates on the input fuzzy sets to provide a single value corresponding to the inputs in the premise. The next step is to apply this result on the output membership function to obtain a fuzzy set for the rule. This is done by the implication method. The input for the implication method is a single number resulting from the premise, and the result of implication is a fuzzy set.

4. Aggregation

Aggregation is the unification of the output of each rule by merely joining them. When an input value belongs to the intersection of the two membership functions, fuzzy rules corresponding to both the membership functions are invoked. Each of these rules, after implication, specifies one output fuzzy set. The input of the aggregation process is the list of truncated output function returned by the implication process of each rule. The output of the aggregation process is one fuzzy set for each output variable. The aggregation methods are given by: max (maximum), probor (probabilistic or), and sum (sum of each rules output).

5. Defuzzification

The result obtained from implication is in the form of a fuzzy set. For application, this is defuzzified. The most common defuzzification method is the centroid, largest of maximum, middle of maximum and smallest of maximum. In this study we used centroid method for defuzzification.

4. Results and Analysis

In the deterministic method of water quality assessment 5 qualitative parameters are compared with standard prescribed limits. Then, the results attributed to each parameters are described as “Desirable”, “Acceptable” and “Not Acceptable”. Fuzzy membership functions constructed for all the five parameters are trapezoidal on the basis of expert perception and prescribed limits by World Health Organization which shown in Table 1.

Table 1: The limits prescribed by World Health Organization for the studied parameters

Parameters	World Health organization (WHO)	
	Desirable	Acceptable
EC	1000	2250
TDS	500	1000
PH	7-8.5	6.5 – 9.2
Cl	200	600
Ca	75	200

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For construction of fuzzy model, a total number of 248 rules were developed on the basis of available datasets and experts' perception. In this model, the number of rules depends on the number of inputs and membership functions.

Table 2 shows some of the applied rules for the model. The result of the rules were combined and defuzzified via center of gravity method. on the basis, 509 ground Wells were assessed for pre monsoon season and 495 ground wells were assessed for post monsoon season of Nadiad taluka.

Table 2: some sample rules designed on the expert knowledge basis for the water quality parameters.

Rule No.	*Antecedent part*	*Consequent part*
R_1	If EC=Desirable AND TDS= Desirable AND PH = Desirable AND Cl = Desirable AND Ca = Desirable	Then WQ=Desirable
R_2	If EC=Desirable AND TDS= Desirable AND PH = Acceptable AND Cl = Desirable A ND Ca = Desirable	Then WQ=Desirable
R_3	If EC=Desirable AND TDS= Desirable AND PH = Acceptable AND Cl = Desirable AND Ca = Acceptable	Then WQ=Desirable
R_4	If EC=Acceptable AND TDS = Acceptable AND PH = Acceptable AND Cl = Acceptable AND Ca = Acceptable	Then WQ=Acceptable
R_5	If EC= Not Acceptable AND TDS = Not Acceptable AND PH = Desirable AND Cl = Desirable AND Ca = Acceptable	Then WQ=Not Acceptable

Table 3: Detail on GW quality for Drinking purpose by Using MFIS method and Deterministic method (As per WHO Standards) for post monsoon season of Nadiad taluka.

TW NO.	Decision using MFIS	Decision using deterministic method		
		Desirable	Acceptable	Not Acceptable
373	Acceptable	CL,CA,PH	EC,TDS	
380	Acceptable	CL,CA,PH	EC,TDS	
391	Acceptable		EC, TDS, PH, Cl, Ca	
453	Acceptable	CL,CA,PH	EC,TDS	
455	Not acceptable	PH.Ca	Cl	EC,TDS
459	Not acceptable	PH.Ca	Cl	EC,TDS
463	Acceptable	EC,TDS,CL, CA,TDS		
464	Acceptable	PH.Ca	EC,CL	TDS
467	Acceptable	PH,CA,Cl	EC,TDS	
471	Acceptable	TDS,EC,CL, CA,PH		
595	Acceptable	EC,PH,CL, CA	TDS	
601	Acceptable	Ca, Cl	PH,EC,TDS	
604	Acceptable	Ca, Cl, PH	PH,EC,TDS	
614-I	Acceptable	Ca, Cl, PH	PH,EC,TDS	
634	Acceptable	Ca, Cl, PH	PH,EC,TDS	
635	Acceptable	Ca, PH	EC, Cl	TDS
637	Acceptable	EC, TDS, PH, Cl, Ca		
700	Acceptable		EC, TDS, PH, Cl, Ca	
784	Acceptable	PH, Cl, Ca	EC,TDS	
787	Acceptable	CA, PH	CL	EC,TDS
790	Not Acceptable	PH, Ca		EC, TDS, Cl
1018	Not acceptable	PH,CA	EC,CL	TDS
1019	Not acceptable	Ca, PH	CL	EC,TDS
1020	Acceptable		EC,TDS, CL,CA, PH	
1060	Not acceptable			EC,TDS,CL, CA, PH
1063	Not acceptable	PH,CA	CL	EC,TDS

The distinction in the decision level between the MFIS method and deterministic method is clearly showed in the Tube Well No. 787 and 790. In two samples with the deterministic method Ca and PH are in **desirable** level, Cl is in **acceptable** level and EC and TDS are in **not acceptable** level. While the decision has been taken with MFIS method for these two samples is entirely different. As the sample No. 787 is in **not acceptable** category and the sample No. 790 is in **acceptable** category.

The parameters of sample No. 463 is in **desirable** category, parameters of sample No. 391, 453, 467, 471, 472, 595 and 805 are in **acceptable** category and samples No. 705, 706, 779, 797, 798 and 1019 are in **not acceptable** category according to both methods..

The decision taken with MFIS method, the samples No. 459, 467, 471, 472, 630, 637, 720, 755, 758 and 804 are in **acceptable** category. While decision taken with deterministic method for the same samples are in **desirable** category.

Table 4: Detail on GW quality for Drinking purpose by Using MFIS method and Deterministic method (As per WHO Standards) for post monsoon season of Nadiad taluka.

TW NO.	Decision using MFIS	Decision using deterministic method		
		Desirable	Acceptable	Not Acceptable
373	Acceptable	CL,CA,PH	EC,TDS	
380	Acceptable	CL,CA,PH	EC,TDS	
391	Acceptable		EC, TDS, PH, Cl, Ca	
463	Acceptable	EC,TDS,CL,CA,TDS		
471	Acceptable	TDS,EC,CL,CA,PH		
530	Acceptable		EC, TDS, PH, Cl, Ca	
595	Acceptable	EC,PH,CL, CA	TDS	
755	Not acceptable	PH,CA	Cl	EC,TDS
758	Acceptable	PH,CA	EC,CL	TDS
779	Acceptable	PH, Ca	Cl	EC,TDS
783	Acceptable	PH, Ca	EC,CL	TDS
797	Not acceptable	PH, Ca	Cl	EC,TDS
798	Not acceptable	PH, Ca	Cl	EC,TDS
800	Not acceptable	PH, Ca		EC, TDS, Cl
804	Not acceptable	PH,CA	Cl	EC,TDS
809	Acceptable	Cl, Ca	EC,TDS,PH	
822	Acceptable	Cl, Ca	EC,TDS,PH	
823	Desirable	EC,TDS,CL,CA,PH		
846	Acceptable		EC,TDS,CL,CAPH	

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848	Acceptable	CL,CA,PH	EC,TDS	
852	Not acceptable	PH	Ca	EC,TDS,CL
1018	Not acceptable	PH,CA	EC,CL	TDS
1019	Not acceptable	Ca, PH	CL	EC,TDS
1020	Acceptable		EC,TDS,CL,CA PH	
1480	Not acceptable	PH,CA	EC,CL	TDS
1483	Acceptable		EC,TDS,CL,CA PH	
1503	Acceptable		EC,TDS,CL,CA PH	

The distinction in the decision level between the MFIS method and deterministic method is clearly showed in the Tube Well No. 755 and 779. In two samples with the deterministic method Ca and PH are in **desirable** level, CL is in **acceptable** level and EC and TDS are in **not acceptable** level. While the decision has been taken with MFIS method for these two samples is entirely different. As the sample No. 755 is in **not acceptable** category and the sample No. 779 is in **acceptable** category.

The parameters of sample No. 823 is in **desirable** category, parameters of sample No. 530, 700, 846, 854, 1020, 1071, 1483 and 1503 are in **acceptable** category and samples No. 1060 is in **not acceptable** category according to both methods.

The decision taken with MFIS method, the samples No. 463, 471 and 637 are in **acceptable** category. While decision taken with deterministic method for the same samples are in **desirable** category.

Table 5 : Comparison of the result obtained for the year 2001 and 2006 using MFIS method for various Villages of Nadiad Taluka.

Village	**Well No.**	**Pre Monsoon**		**Post Monsoon**	
		2001	**2006**	**2001**	**2006**
Nadiad	630	Acceptable	Acceptable	Acceptable	Acceptable
Piplata	907	Acceptable	Acceptable	Acceptable	Acceptable
Dabhan	783	Not acceptable	Not acceptable	**Not acceptable**	**Acceptable**
Hathnoli	797	Not acceptable	Not acceptable	**Not acceptable**	**Acceptable**
Gutal	808	Acceptable	Acceptable	**Acceptable**	**Desirable**
Bhumel	705	Not acceptable	Not acceptable	**Acceptable**	**Desirable**
Zarol	836	**Not acceptable**	**Desirable**	**Acceptable**	**Desirable**
Tundel	844	**Acceptable**	**Acceptable**	**Acceptable**	**Desirable**
Dantali	1503	**Acceptable**	**Not acceptable**	**Not acceptable**	**Acceptable**
Vaso	1060	**Not acceptable**	**Acceptable**	Acceptable	Acceptable
Gangapur	1071	Not acceptable	Not acceptable	Not acceptable	Not acceptable
Rampura	720	Acceptable	Acceptable	Acceptable	Acceptable
Bamroli	919	**Acceptable**	**Desirable**	**Not acceptable**	**Desirable**

In this study the results obtained for the year 2006 have compared with the result obtained for the year 2001 using MFIS for the various well of Nadiad Bamroli, Rampura, Gangapur, Piplata, Dabhan, Hathnoli, Gutal, Bhumel, Zarol, Tundel, Vaso and Dantali villages of Nadiad taluka from which the water samples have been collected in pre monsoon and post monsoon season.

Table 5 shows that there is no much changes in **Nadiad, Piplata, Gutal, Tundel, and Rampura villages of Nadiad Taluka** in both Pre monsoon and Post monsoon season. But according to MFIS **Vaso** have become **not acceptable** to **acceptable** category and **Zarol** have become **not acceptable** to **desirable** category. As same **Bamroli** village have become **acceptable** to **desirable** category and **Dantali** have become **acceptable** to not **acceptable** category.

In post monsoon season, **Dabhan, Hathnoli, and Dantali** have become **Not Acceptable** Category to **acceptable** and Bamroli have become **not acceptable** to **desirable** category. As same **Gutal, Bhumel, Zarol and Tundel villages** have become in **acceptable** to **desirable** category.

In pre monsoon season, during year 2001 12.50% of water wells are in desirable Category, 42.61% of water wells are in acceptable category and 44.88% of water wells are in not acceptable category but after 5 years i.e. in year of 2006 14.20% wells are in desirable category, 43.75% water wells are in acceptable category and 42.04% water wells are in not acceptable category

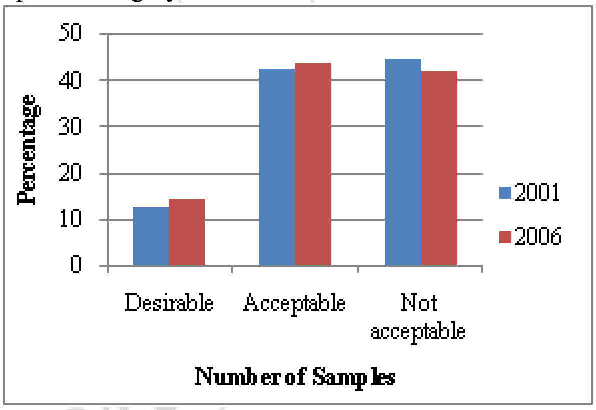

Figure 2: comparative analysis of groundwater quality for pre monsoon in year 2001 and 2006

Looking to this scenario for pre monsoon season of Nadiad taluka, the numbers of wells under not acceptable category are reduced and the numbers of wells under desirable and acceptable category are increased.

In post monsoon season, during year 2001 12.50% of water wells are in desirable Category, 42.61% % of water wells are in acceptable category and 44.66% of water wells are in not acceptable category but after 5 years i.e. in year of 2006 25.33% wells are in desirable category, 38% water wells are in acceptable category and 36% water wells are in not acceptable category.

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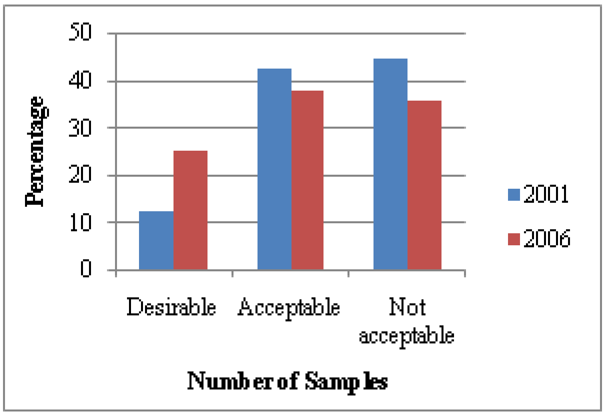

Figure 3: Comparative analysis of groundwater quality for post monsoon in year 2001 and 2006

Looking to this scenario for post monsoon season of Nadiad taluka, the numbers of wells under not acceptable category and acceptable category are reduced.

5. Conclusions

- In this research, applicability of MFIS method was investigated for groundwater quality to drinking purpose and found better in comparison with deterministic method.
- In deterministic method, the quality of each parameters are categorized on the basis of prescribed limits in drinking water given by standards World Health Organization in three form i.e. desirable, acceptable and not-acceptable. It is difficult and obscure to make a decision about of groundwater quality using deterministic methods, but in MFIS evaluation method, not only the potable water quality is classified as the three forms, but also can easily suggest about final groundwater quality.
- In this study, 509 groundwater wells are collected in pre monsoon season of Nadiad taluka, only 37 wells are classified in "Desirable" class i.e.7.26%, 286 Wells are in "Acceptable" class i.e. 56.18% and 186 wells are in "Not acceptable" class i.e. 36.54%.
- In post monsoon season of Nadiad taluka, among 495 groundwater Wells, only 49 Wells are classified in "Desirable" class i.e. 9.89%, 271 wells are in "Acceptable" Class i.e. 54.74% and 175 Wells are in "Not acceptable" class i.e. 35.35%.
- In pre monsoon season, during year 2001 12.50% of water wells are in desirable Category, 42.61% of water wells are in acceptable category and 44.88% of water wells are in not acceptable category but after 5 years i.e. in year of 2006 14.20% wells are in desirable category, 43.75% water wells are in acceptable category and 42.04% water wells are in not acceptable category.
- In post monsoon season, during year 2001 12.50% of water wells are in desirable Category, 42.61% % of water wells are in acceptable category and 44.66% of water wells are in not acceptable category but after 5 years i.e. in year of 2006 25.33% wells are in desirable category, 38% water wells are in acceptable category and 36% water wells are in not acceptable category
- The study reveals that during year 2001, the most of the areas of Nadiad and Matar taluka were grouped in Not Acceptable Category, while in the year 2006, the same area of Nadiad and Matar taluka were grouped in Acceptable Category. This indicates that during 5 years most of the area there is an improvement in groundwater quality in Matar and Nadiad region.
- MFIS is very useful and effective tool in assessment of groundwater quality.

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Author Profile

Dr. Falguni Parekh has completed B.E. (Civil-IWM), M.E. (Civil) in Irrigation Water Management and Ph.D. in Civil Engineering from The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India. She is serving as Offg. Director and Associate Professor in Water Resources Engineering and Management Institute, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda. She has 17 years of teaching and research experience and recognized Ph.D. guide of M.S. University of Baroda. Her research areas are Application of Soft computing techniques in Water Resources Engineering, Benchmarking of Irrigation Projects, Climate change and its impact on Agriculture and Water Resources , Evaluation of Micro Irrigation systems, Ground Water Modeling, Innovation of Low cost Micro Irrigation Systems, Reservoir Operation, Water Conservation Techniques and Rain Water Harvesting and Drought Assessment and Forecasting. She is associated with Professional Bodies like Indian Society of Hydraulics, Indian Water Resources Society, Association of Hydrologists of India, Association of Agrometeorologists, Indian Society of Geomatics. She is Joint secretary of Gujarat Chapter of Association of Hydrologists of India. She has published 44 research papers in Internaional, National Journal and Conferences. She has published two books. She is recipient of two awards for research work.

Payal .D. Prajapati has completed B.E (civil) in Government engineering college Bharuch, M.E (civil) in Irrigation Water Management from The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat India.

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