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ADAPTIVE NEURO FUZZY INFERENCE SYSTEM FOR MONTHLY GROUNDWATER LEVEL PREDICTION IN AMARAVATHI RIVER MINOR BASIN

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ABSTRACT

Adaptive Neuro Fuzzy Inference System (ANFIS) approach is employed in this present study to observe its applicability on Prediction and Forecasting of monthly Groundwater level Fluctuation in the study area (Amaravathi River Minor Basin). Study area encompasses of heavy abstraction of groundwater due to domestic, industrial and irrigation prospects which will leads in abrupt depletion of groundwater and crises on groundwater utility in future. The specific objectives are developed in the present study is to study the condition of groundwater pattern in the study area though it concern with many practical constraints. ANFI system is one of the developing powerful tools to predict such heavy constrained problem with time series analysis by hybrid technique. First part of the study is to identify the best ANFIS model which will replicate the exact behavior of groundwater system through tuning of parameters by fuzzy subset relationship and satisfying five Statistical measures (RMSE, R^2, CE, COC and MBE) during training and testing processes for the duration of 2005-13. Second part of the study is to forecast the groundwater fluctuation for next one year (2014) from the identified ANFIS model.

Keywords: *Groundwater Modeling, Groundwater fluctuation, ANFIS, Training, Statistical measures, RMSE, Forecasting.*

1. INTRODUCTION

Groundwater is an important source for all human needs. Though the study area has regularized groundwater extraction condition, still some abrupt extractions are going on. This study, serve a primary role to predict the abrupt depletion of groundwater table by adopting ANFIS technique which doesn't required any heavy field exploration techniques. ANFIS is associated with advanced optimization method ie., "hybrid technique" which creates a better data set relationship by neuron connection and fuzzy rules both during forwards and back propagation process.

1.1 Study Area

Amaravathi River basin is located between north latitude $11^0\ 00'$ N and $10^0\ 00'$ N, east longitude $77^0\ 00'$ E and $78^0\ 15'$ 'E. Amaravathi River is originates from Thirumurthimalai in Udumalpet taluk, Coimbatore district and flows through Erode district.

The basin is divided into A1, A2, A3 and A4 sub basins with cumulative area of 174090.95 hectares. The present study area is having heavy abstraction of groundwater due to irrigation, domestic and industrial utilities. The collected data of groundwater fluctuation from year 2005 to 2013 shows the depletion trend, as shown in Figure 1.

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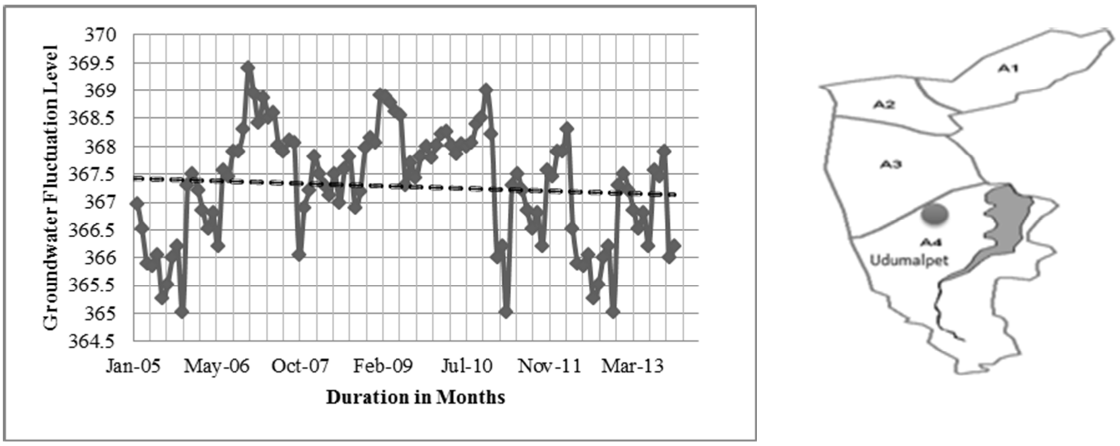

Figure 1: Groundwater Fluctuation Pattern in Amaravathi River Minor Basin (2005-13)

2. OBJECTIVES

- To develop the best ANFIS model which will best fit to the current groundwater fluctuation pattern by hybrid technique through training and testing process after satisfying five statistical measures (Root Mean Square Value, R^2, CE, COC & MSE)
- To Evaluate the prediction level of arrived best model by comparing observed and predicted data
- To generate the possible trend of groundwater fluctuation for next one year (2014)

3. METHODOLOGY

ANFIS structure consists of five layers of processing like, Input, fuzzification, Inferences process, De-fuzzification and Required output as shown in Figure 2.

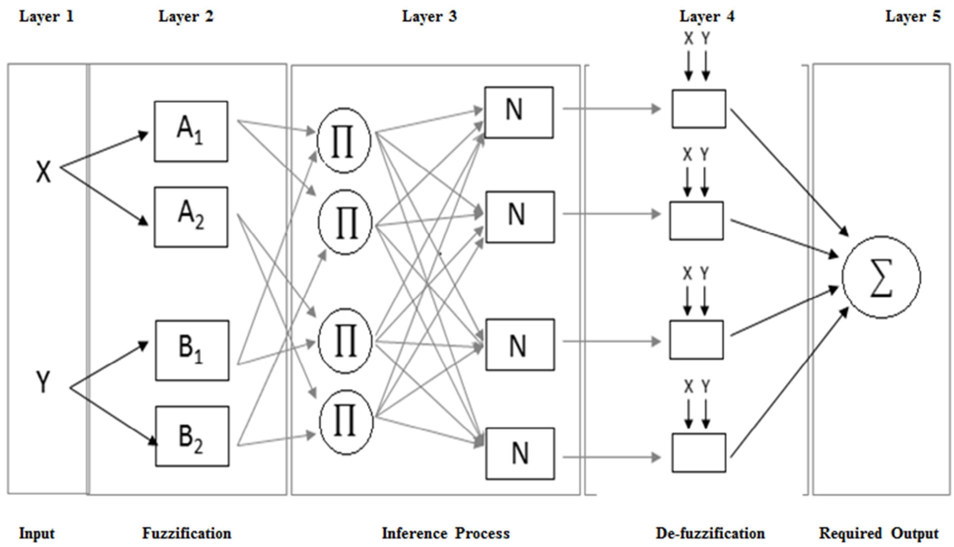

Figure 2: Typical Architecture of ANFI System for Two Input Model

ANFIS process is starts from layer 1 to layer 5. Layer 1 & 2: Input value are fuzzified, Layer 3: Inference process in which the fuzzy rules and membership function are employed for optimization of the model to get best fit, Layer 4&5: cumulative output are generated after defuzzification process, to bring known format of output value for further prediction and forecasting measures.

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The input data for the present study are quantitative measures of groundwater fluctuation rather to language form; hence these data should be fuzzified by relative membership functions according to the real filed condition. Groundwater Recharge, Groundwater Discharge, Groundwater fluctuation level above mean sea level on monthly basis are collected from year 2005 to 2013 for the present study including the duration in which the data are collected.

Collected data are fed in to training process for the period of 2005 to 2010 (Six years), in which the hidden parameters like fuzzy sub set, rules (and/or) are framed according to the field condition. Further, testing /checking process is carried out for the period 2011 to 2013 (Three years), in which the tuned parameters are verified according to its prediction level.

Initially data are fuzzified into fuzzy subset in order to cover the whole deviation of collected data. The subsets are defined by the seasonal variation and hydrological cycle of groundwater pattern in the study area. During data pre-processing, the data were normalized between 0 and 1 using,

$$\mathbf{x_n = (x_i - x_{min}) / (x_{max} - x_{min})}, \ldots\ldots\ldots\ldots (1)$$

where x_n is the normalized value of individual data, x_i is the actual value of individual; data, x_{min} and x_{max} are the minimum and maximum values of the collected data set.

On the basis of available and collected data, the relation between fuzzy inputs and outputs are generated according to field parameter correlation; these are further used to generate fuzzy rules for the analysis. The result obtained from the analysis is in the form of a fuzzy set. This is necessarily to be de-fuzzified to get a required form output which is in the same form of available data through center of area under the curve (ie., centroid method) of de-fuzzification.

4. SENSITIVITY ANALYSIS

The process of sensitivity analysis is to find the model which can be suitable for best replication of present groundwater system by prediction the groundwater fluctuation level during training and testing process. It is essential to have such model for forecasting to next one year time series to know the expected level fluctuation at the same time, to check the condition by comparing with demand from various utility in future.

Four input and one output data analysis is carried out (Duration, Ground water discharge, Ground water recharge and monthly Groundwater level as output for the period 2005-2013) to obtain the good fitting model on the basis of five different statistical measures through mamdani fuzzy inference system and hybrid optimization method. Averaging testing error produced by different Membership Functions (MF) in ANFIS model during training and testing process with constant epoch level (40) are detailed in Table 1.

From the training result, “Trimf” is performing best on the basis of low Average error emission during the training process. Further this MF is fed in to testing process to know the best fitting trend to observed value of groundwater fluctuation level. Average error produced by “Trimf” during testing process is detailed in Table 2.

Table 1: Average Training Error for Different MF for Different ANFIS Model Performance

Process	No of MFs	MFs type Input	MFs Output	Epoch	Average Testing Error
Training	3 3 3	Trimf	Linear	40	0.39961
Training	4 4 4	Trimf	Linear	40	0.32905
Training	6 6 6	Trimf	Linear	40	**0.24519**
Training	3 3 3	Trapmf	Linear	40	0.46757
Training	4 4 4	Trapmf	Linear	40	0.37800
Training	6 6 6	Trapmf	Linear	40	**0.32585**
Training	3 3 3	Gaussmf	Linear	40	0.38408
Training	4 4 4	Gaussmf	Linear	40	0.35894

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Training	6 6 6	Gaussmf	Linear	40	**0.26721**
Training	3 3 3	Gabellmf	Linear	40	0.39815
Training	4 4 4	Gabellmf	Linear	40	0.36453
Training	6 6 6	Gabellmf	Linear	**40**	**0.27816**
Training	3 3 3	Gauss2mg	Linear	40	0.42086
Training	4 4 4	Gauss2mg	Linear	40	0.36733
Training	6 6 6	Gauss2mg	Linear	40	**0.25165**
Training	3 3 3	Pimf	Linear	40	0.50784
Training	4 4 4	Pimf	Linear	40	0.36971
Training	6 6 6	Pimf	Linear	40	**0.32583**
Training	3 3 3	dsigmf	Linear	40	0.40417
Training	4 4 4	dsigmf	Linear	40	0.35750
Training	6 6 6	dsigmf	Linear	40	**0.24695**
Training	3 3 3	psigmf	Linear	40	0.40419
Training	4 4 4	psigmf	Linear	40	0.35746
Training	6 6 6	psigmf	Linear	**40**	**0.25010**

Table 2: Average Testing Error for Different MF for Different ANFIS Model Performance

Process	No of MFs	MFs type Input	MFs Output	Epoch	Average Testing Error
Training	3 4 5	Trimf	Linear	40	0.39425
	4 3 5	Trimf	Linear	40	0.32868
	5 4 3	Trimf	Linear	40	0.33731
	5 5 5	Trimf	Linear	40	0.33074
	5 6 5	Trimf	Linear	40	0.33142
	5 5 6	Trimf	Linear	40	0.33627
	4 3 3	Trimf	Linear	40	0.32508
	6 6 6	Trimf	Linear	40	0.24519
	6 5 5	Trimf	Linear	40	0.23588
	6 4 4	Trimf	Linear	40	0.25743
	6 3 3	Trimf	Linear	40	**0.23368**
	3 6 3	Trimf	Linear	40	0.40233
	3 3 6	Trimf	Linear	40	0.39868

Based on the observation from sensitive analysis, ANFIS model performance is to the level of satisfactory in Triangular Membership Function at 6:3:3. More in epoch and level of rules will always lead to increase in accuracy level of prediction. The results of various ANFIS membership are detailed in Figure 3. Further the model prediction are verified by five different statistical measure like Root mean Square error (RMSE), R-square, Coefficient of Correlation (COC), Mean Squared error (MSE) and Coefficient of Efficiency (COE) in order to obtain the optimum model which will further useful in the process of forecasting to next one time series (one year).

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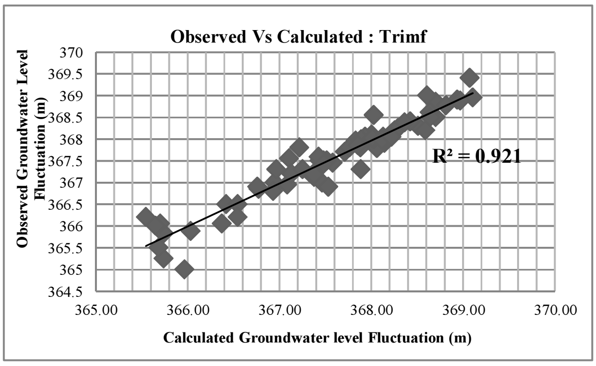
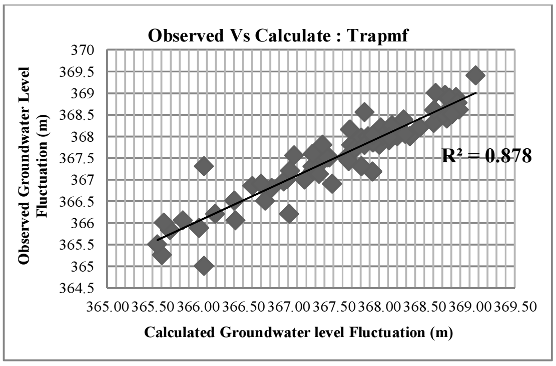
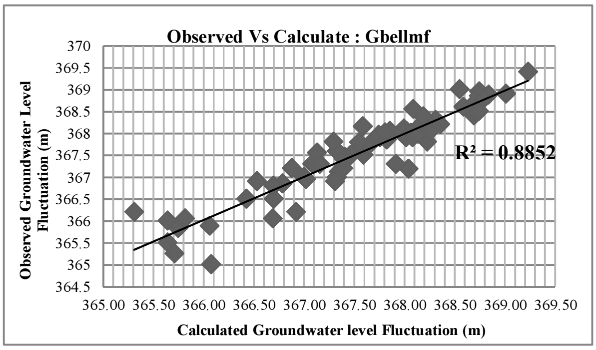


3(a)



3(b)



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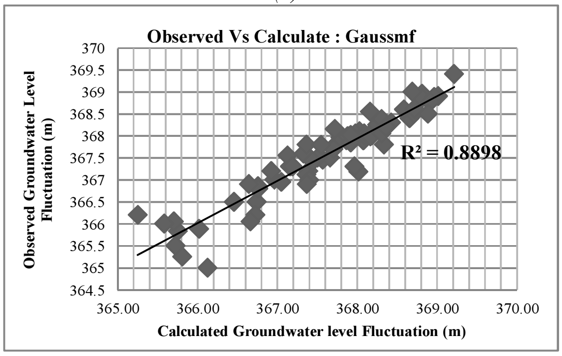

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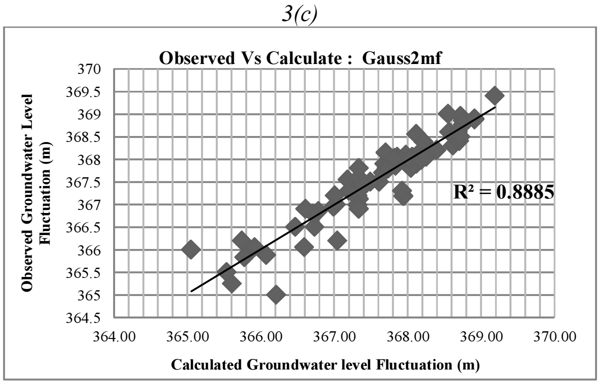
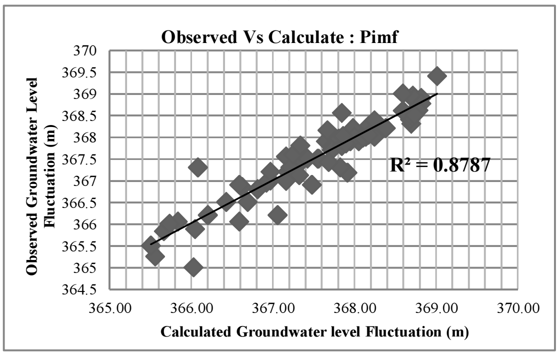
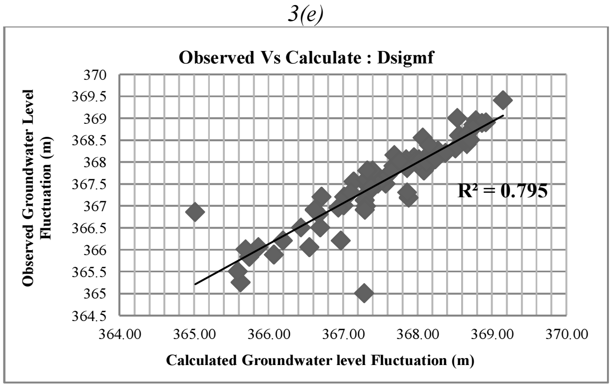


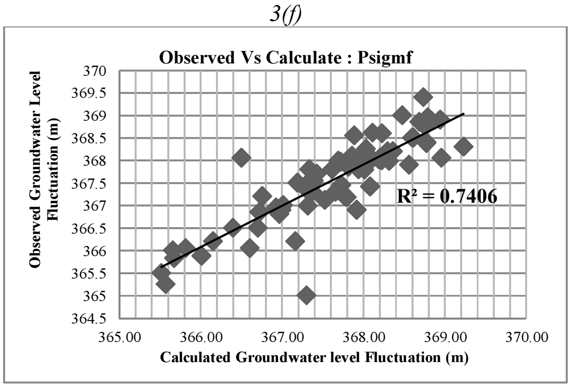
3(e)



3(f)



3(g)



3(h)

Figure 3 : Goodness Fit by Arrived Optimum Membership Functions by Comparing Observed Vs Calculated { 3(a): Trimf, 3(b): Trapmf, 3(c): Gbellmf, 3(d): Gaussmf, 3(e): Gauss2mf , 3(f): Pimf, 3(g): Dsigmf, 3(h): Psigmf }

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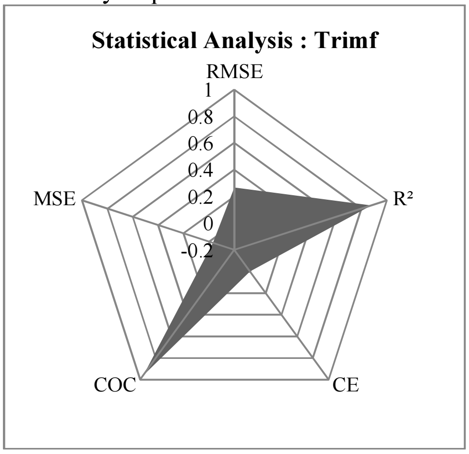
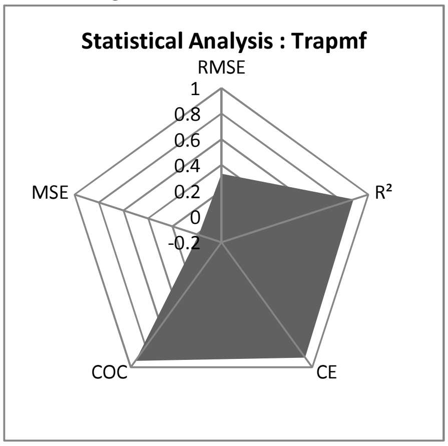
Goodness fit analysis clearly notated the Membership Function which has comparatively more accuracy in prediction of observed value is "Trimf". The results obtained during other statistical measures are detailed by Radar chart is shown in Figure 4.



4(a)



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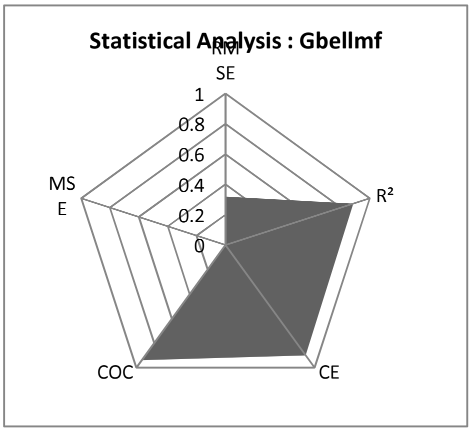
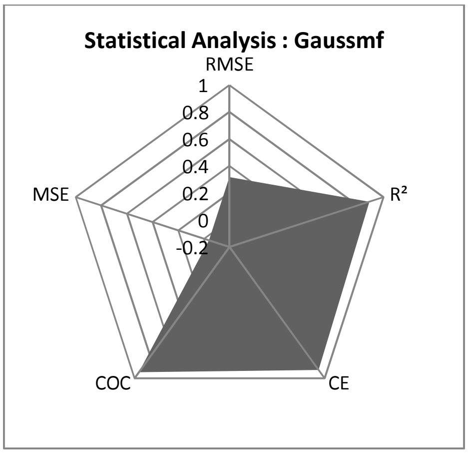
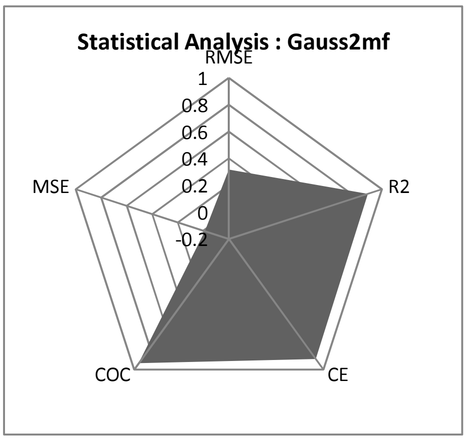


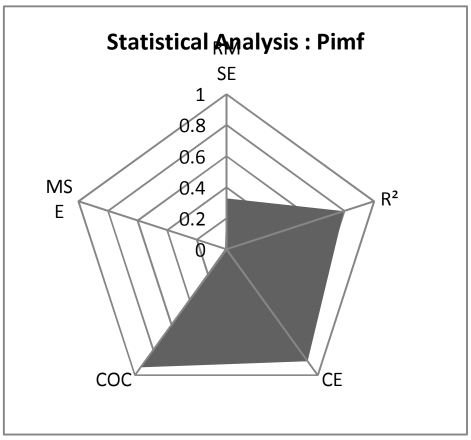
4(c)



4(d)



4(e)



4(f)

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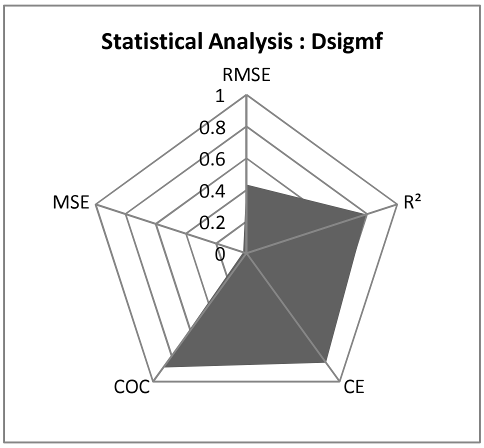
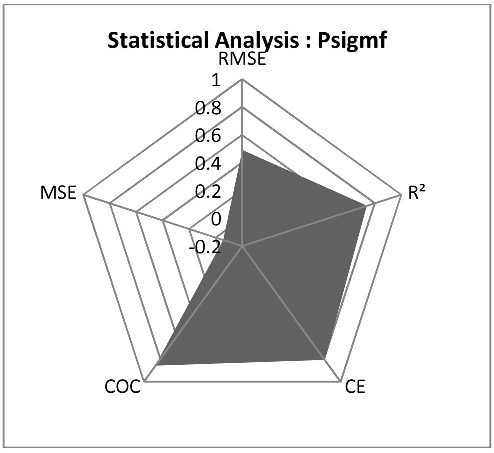


4(g)



4(h)

Figure 4 : Goodness Fit by Arrived Optimum Membership Functions by Statistical Measures(Radar Chart) { 4(a): Trimf, 4(b): Trapmf, 4(c): Gbellmf, 4(d): Gaussmf, 4(e): Gauss2mf , 4(f): Pimf, 4(g): Dsigmf, 4(h): Psigmf }

5. FORECASTING

The arrived best optimum model (Trimf: 6 3 3) is used for forecasting of groundwater fluctuation to one time step (2014) as shown in Figure 5. The result shows the decrement trend of groundwater level with the same level of groundwater recharge.

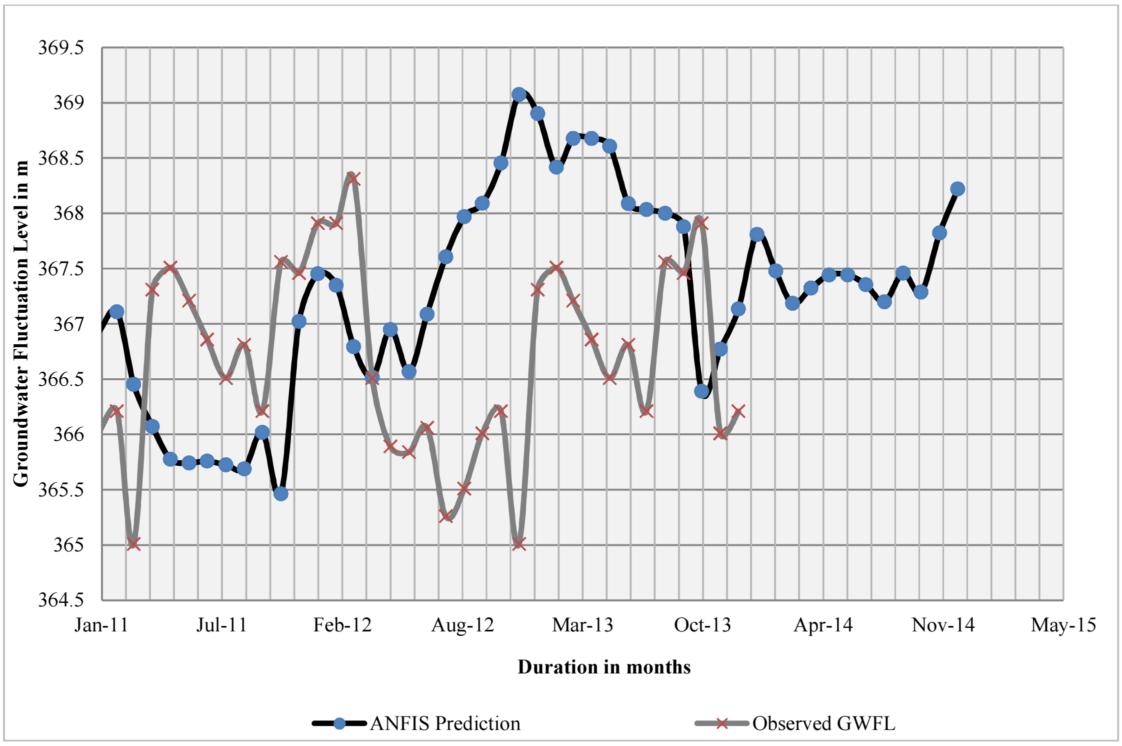


Figure 5: One Time Step Forecasting of Groundwater Fluctuation (2014)

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6. CONCLUSION

Based on the performance of the model, the following points are concluded.

- The proposed model is the best fit by the hybrid technique with 6:3:3 membership function
- The sensitivity of the arrived optimum models are satisfied under five level of statistical measures
- The forecasted model performance exactly replicate the current situation of groundwater system
- The proposed model is further useful to forecast under different scenario in order to develop the various management policies

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