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Comparative Study of ANN and ANFIS for the Prediction of Groundwater Level of a Watershed

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Abstract

Fuzzy set theory, Fuzzy logic and Neural Networks techniques seem very well suited for modeling and controlling a real system. Groundwater is of major importance to civilization, because it is the largest reserve of drinkable water in regions where humans can live. The estimation of the water table elevation is one of the important aspects to understand the mechanism which comprises groundwater resources and to predict what might happen under various possible future conditions. Here, we have developed and compared two different models, Adaptive neuro-fuzzy systems (combination of fuzzy and artificial neural network systems) and Feedfoward Neural Networks systems, for the prediction of groundwater level of a watershed. Using available MATLAB software for both algorithms, the objective is to find which solution performs "better" comparing the performances of the solutions through different parameters for a specific case.

Keywords: ANN, ANFIS, observation wells, MATLAB, groundwater level, watershed.

Introduction

Recently, intelligent soft computational techniques such as Artificial Neural Network (ANN), Fuzzy Inference System (FIS) and (ANFIS) can model superiority of human knowledge features. They also re-establish the process without plenty of analysis. Thus these techniques are attracting great attention in an environment that is obvious with the absence of a simple and well-defined mathematical model. Besides, these models are characterized by nonrandom uncertainties which associated with imprecision and elusiveness in real-time systems. Many researchers have studied the application of neural networks to overcome most of the problems above outlined. The fuzzy set theory is also used to solve uncertainty problems [1]. The use of neural nets in applications is very sparse due to its implicit knowledge representation, the prohibitive computational effort and so on. The key benefit of fuzzy logic is that its knowledge representation is explicit, using simple IF-THEM relations. However, it is at the same time its major limitation. The groundwater level prediction cannot be easily described by artificial explicit knowledge, because it is affected by many unknown parameters. The integration of neural network into the fuzzy logic system makes it possible to learn from the prior obtained data sets[2].

The purposes of this study are to compare the applicability of ANN and ANFIS in predicting groundwater level in Thurinjapuram watershed and to identify the most fitted model to the study area.

Study area

The Thurijapuram watershed covers geographical area of 151.38 sq. km and is located in between 12^{o}12’58” and 12^{o} 21’11” North latitudes and 78^{o}59’45” and 79^{o}9’28” East longitudes (Fig. 1) It is mainly situated in Thiruvannamalai district of Tamilnadu, India. It is mainly located in Thurinjapuram block and partially falls into two other blocks (Chengam and Thiruvannamalai). Thurinjalar is one of the major tributaries of Ponnaiyar Major River originating from Kavuttimalai reserve forest in Chengam Taluk of Tiruvannamalai district. The drainage characteristics are very good. Bedrock is peninsular gneiss of Archean age. The Thurinjapuram area can be classified as ‘‘hard rock terrain’’. The predominant soil types in this river basin are Entiso, Inceptisols, Vertisol and Alfisols. The soil in this minor basin is observed to have good infiltration characteristics. Hence groundwater recharge is possible in this area.

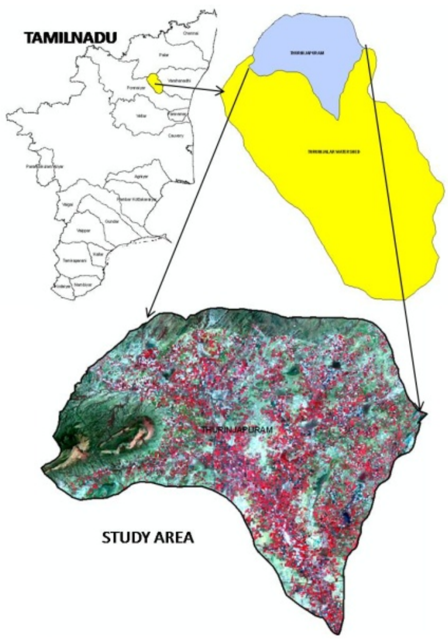

Figure 1: Study area.

The climate is semi-arid. May is the hottest month with a maximum temperature of up to 41° C and December is the coolest month with a maximum of 21.6° C. Hydro meteorological data were collected from Kilnatchipattu weather station maintained by State Ground & Surface Water Resources Data Centre, W.R.O, and P.W.D. The economy of the Thurinjapuram sub watershed depends mainly on agriculture. Data from three observation wells, which have been monitored on a monthly basis by the Department of Groundwater, are available in the Thiruvannamalai Groundwater subdivision.

Data

The input data used for water level prediction are monthly Rainfall and Ground water (level in the observation well) data of Thurinjapuram watershed in Tamilnadu, India, and one month ahead groundwater level as output. For the present study monthly water level data for three observation wells (23112, 23142, and 23143) during 1985 to 2008 has been collected from Thiruvannamalai Groundwater subdivision. In the same period monthly Rainfall data were collected from Kilnatchipattu Raingauge station.

Artificial neural network (ANN)

A feed-forward network is adopted here as this architecture is reported to be suitable for problems based on pattern identification. A network first needs to be trained before interpreting new information. Several different algorithms are available for training of neural networks, but the back-propagation algorithm is the most versatile and robust technique for it provides the most efficient learning procedure for multilayer neural networks. Also, the fact that back-propagation algorithms are especially capable to solve problems of prediction makes them highly popular [3]

During training of the network, data are processed through the network until they reach the output layer (forward pass). In this layer, the output is compared to the measured values (the \true" output). The difference or error between the two is processed back through the network (backward pass) updating the individual weights of the connections and the biases of the individual neurons. The input and output data are mostly represented as vectors called training pairs. The process as mentioned above is repeated for all the training pairs in the data set, until the network error has converged to a threshold minimum defined by a corresponding cost function, usually the root mean squared error (RMSE)[4].

A feed-forward network with back-propagation algorithms was used to predict the groundwater level of a watershed. A number of 192 data were utilized during training session and 84 data were used during testing session. A suitable configuration has to be chosen for the best performance of the network. Out of the different configurations tested, two hidden layer with 12 and 20 hidden neurons produced the best result (Fig3). The log sigmoid function was employed as an activation function. Suitable numbers of epochs have to be assigned to overcome the problem of over fitting and under fitting of data.

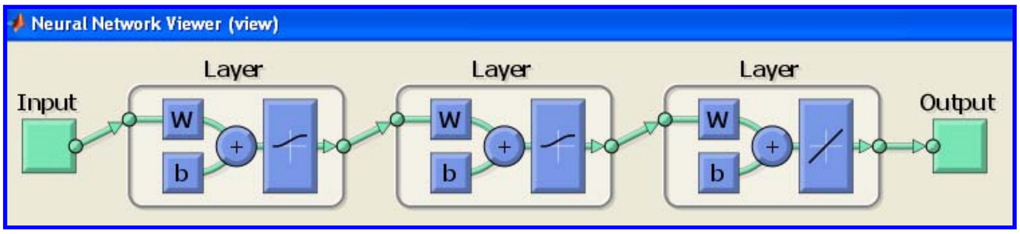

Figure 3: ANN structure for the groundwater level model.

Adaptive Neuro Fuzzy Inference System (ANFIS)

ANFIS was originally proposed by Jang. ANFIS is a fuzzy system trained by an algorithm derived from neural network theory. The algorithm is a hybrid training algorithm based on back propagation and the least squares approach. In this algorithm, the parameters defining the shape of the membership functions are identified by a back propagation algorithm, while the consequent parameters are identified by the least squares method. An ANFIS can be viewed as a special three-layer feed forward neural network. The first layer represents input variables, the hidden layer represents fuzzy rules, and the third layer is an output [5, 6].

For ANFIS model, similar training and testing data sets were used as in ANN model. The membership function of each input was tuned using the hybrid method consisting of back propagation for the parameters associated with the input membership function and the least square estimation for the parameters associated with the output membership functions. The computations of the membership function parameters are facilitated by a gradient vector which provides a measure of how well the FIS system is modeling the input/output data. For a given set of parameters, the numbers of nodes in the training data were found to be 35. Total number of parameters 39 .The numbers of linear parameters and non-linear parameters were found to be 27 and 12 respectively. (Fig4).

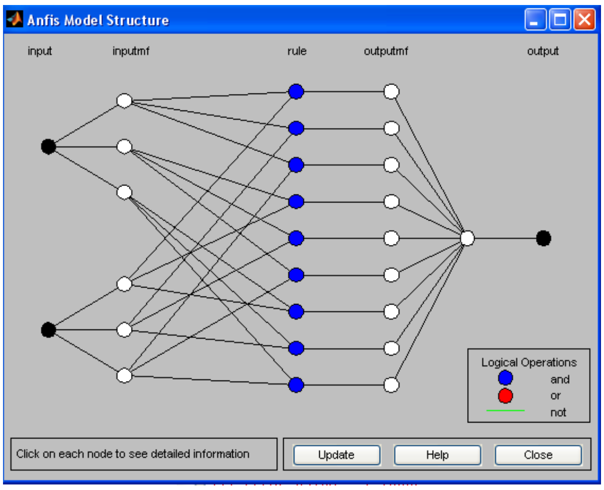

Figure 4: ANFIS structure for the groundwater level model, ANFIS.

Table 1: Network architecture of two models.

ANN model		ANFIS model	
parameters	value	parameters	value
No. of total layers	3	No. of total layers	5
No. of hidden layers	2	No. of input parameters	2
No.of neurons in input layers	2	Type of membership function(MF)	Gaussian
No.of neurons in hidden layers	12 , 20	No. of membership function	3
No. of neurons in output layers	1	Type of output parameter	Linear
Learning rate	0.6	No. of fuzzy rules	9
No. of epochs	2000 to 3000	No. of epochs	150
Error goal	0.001	Error goal	0.01

Comparison of ANN and ANFIS models

Results from two models are presented in this section to access and compare the degree of prediction accuracy and generalization capabilities of the two networks designed in the present problem. The same training and testing data sets were used to train and test both models to extract more solid conclusions from the comparison results.

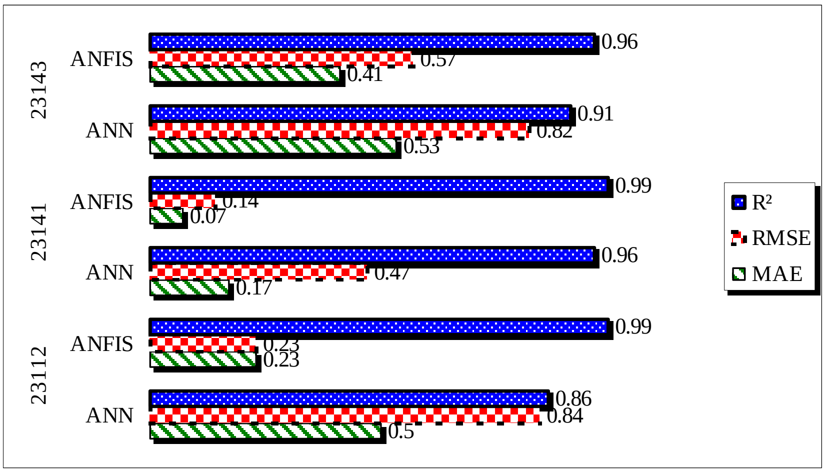

Figure 5: Comparison of ANN and ANFIS error measures for all the three wells.

Mean absolute error (MAE), root mean square error (RMSE) and regression coefficient (R^2) were calculated based on the corresponding measured data. Analysis of data in randomized sets clearly showed that ANFIS model is best fit for predicting the groundwater level in terms of statistical significance as well is given in Fig5.Further, the data were analyzed separately for each independent well point to have a clear comparison of the mean observed and estimated water levels for the two models.

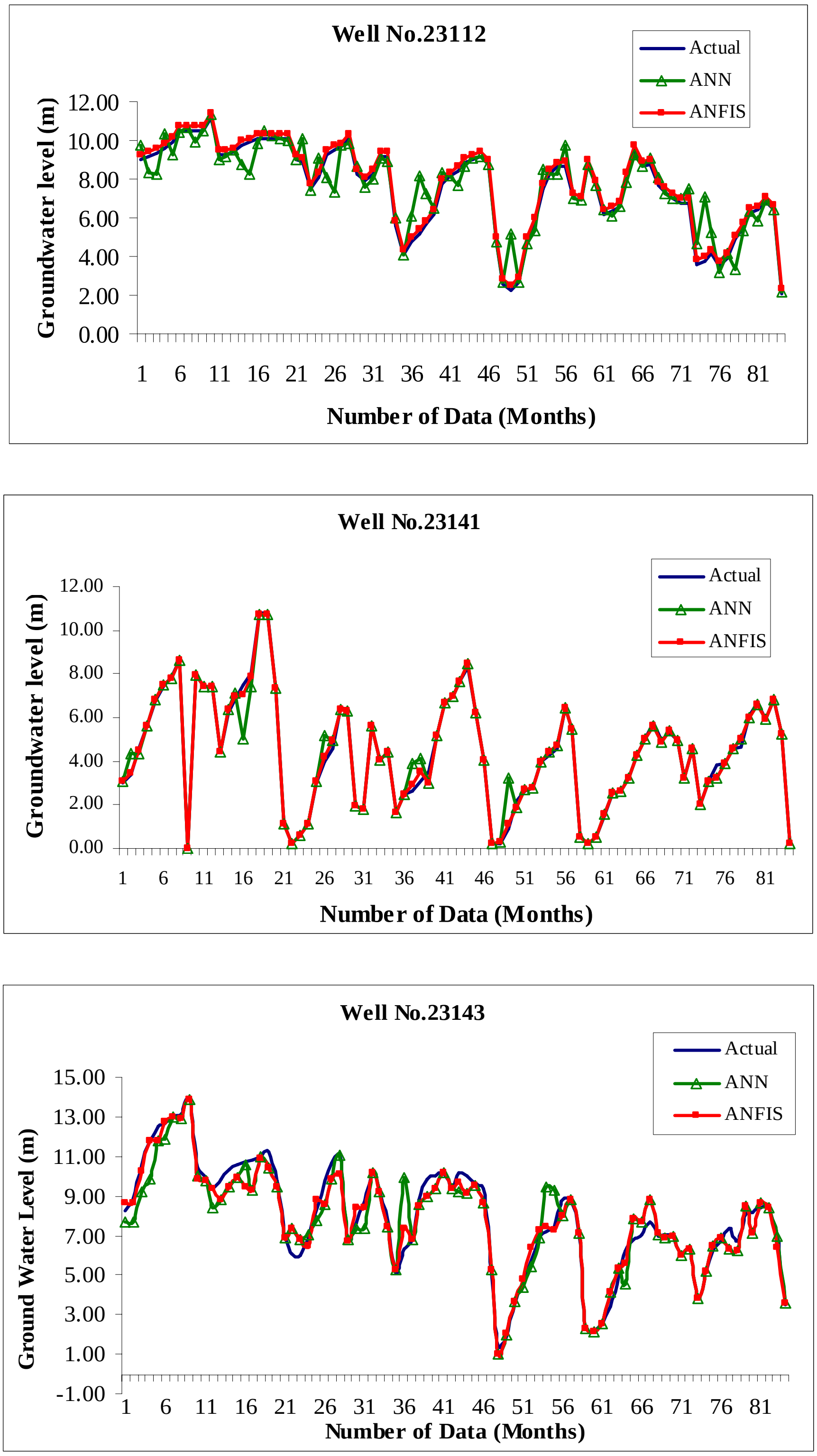

Figure 6: Comparison graph between predictions from two Networks against actual values.

Visual inspection of comparison graph (figure 6) reveals that ANN model shows excellent prediction accuracy for lower values of waterlevel but is unable to maintain its accuracy for higher values, hence losing its generalization capabilities, whereas the ANFIS model maintains its excellent prediction accuracy throughout the range of water level, hence showing consistency and high a degree of generalization capability. From the above discussion it can be concluded that ANFIS model shows better prediction accuracy and better generalization capability in comparison to the ANN model.

Conclusions

In this study, a better forecasting model using ANN and ANFIS has been developed for predicting monthly groundwater level fluctuations in the Thurinjapuram watershed, Tamilnadu, India. The ANFIS method presented in this paper shows a good potential to model complex, nonlinear and multivariate problems. Considering the complexity of the relationship between the input and the output, results obtained are very accurate and encouraging. The lower RMSE obtained by the ANFIS method suggests its good generalization capability. It may be noted that a trial and error procedure has to be performed for ANN model to develop the best network structure, while such a procedure is not required in developing an ANFIS model. Observations made from comparing the results are backed by the fact that results from ANN are largely dependent on architecture of the network, which is very hard to select as it is a complex and time-consuming task. Another limitation that ANN has its inadequate ability to deal with fuzzy and nonlinear data, whereas ANFIS is largely free from both of those limitations. Furthermore, computationally the ANFIS model is more easy and efficient than the ANN model. So the results suggest that the ANFIS method is superior to the ANN method in the modeling and forecasting of groundwater level of a watershed.

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