Development of a Fuzzy Logic Based Model using different Membership and Rules criteria for predicting water consumption using Climatic variables.

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Abstract

This research work highlights the importance of fuzzy model for predicting the water consumption using climatic variables. The developed fuzzy model is based on different rules criteria and different membership function. Mamdani fuzzy inference system is employed for this analysis. this Work is carried out using two membership functions such as triangular and trapezoidal and four different rules criteria such as three, six, nine and twelve rules. Rainfall, Maximum and Minimum temperature and relative humidity were selected as input for predicting water consumption. The model predicted outputs were compared with the actual data. Obtained results reveal that predicted results are almost close to observed data. Performance evaluation is carried out using Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Accuracy and on the basis of the results obtained, it can be suggested that fuzzy model is efficiently capable of predicting water consumption.

Keywords: Climatic variables, Fuzzy Logic, Fuzzy rules, Triangular membership, Trapezoidal membership, Water consumption.

1. INTRODUCTION

Water is treated as valuable resource for all urban development activities. Most of the decision in urban planning and sustainable development are highly dependent on forecasting of water demand. Water scarcity has become a major problem and which affects the economic growth of many countries in the region. Therefore sustainable of water resources is mandatory. An essential component of sustainable water resources planning and management is water demand forecasting. It provide valuable trigger in determining the time and capacity for new water resources development. Hence in order to match supply and demand, proper forecasting of water demand is required.

Climatic behavior prediction is one of the challenging tasks since its variability is directly influence on many sectors such as agriculture, water etc. So it is necessary to determine the relationship among the climatic variables and its influence on these sectors. In this research work, influence of climatic variables such as rainfall, maximum and minimum temperature, Relative Humidity on water consumption is analyzed for an urban area. For this purpose ten years of climatic and water consumption data were collected on monthly basis and it is divided into training and testing pattern. Analysis is carried out using soft computing technique.

Soft computing is an important field which includes fuzzy logic, neural computing, evolutionary computation, machine learning and probabilistic reasoning. Due to their strong learning, cognitive ability and good tolerance of uncertainty and imprecision, soft computing technique have found wide application since Artificial Intelligence plays an important role in modeling and simulation of many convex and complex phenomenons. Hence instead of regression technique soft computing may be advantage because regression is based on assumption of normality and linearity. Hence Fuzzy Logic method is employed in the analysis.

2. Literature Review

Water consumption prediction is essential for planning and management of water resources. In order to balance supply and demand effective planning is necessary. This prediction helps and necessary for both short and long term scenario. As short term relates to climatic seasons and long term requires proper measures to regulate water supply. Hence prediction is necessary.

There are different approaches to water demand forecasting including statistical or mathematical techniques. Aijun et al., (1996) used a rough set approach for water demand prediction to analyze a set of training data and generate decision rules and it was found to be useful for incomplete and deterministic information. Durga Rao (2005) used multicriteria spatial decision explanatory variables for water demand forecasting. Hongwei, et al., (2009) used system dynamic approach for water demand forecasting based on sustainable utilization strategy of the water resources. Herrera et al., (2010) developed predictive models for forecasting hourly water demand using ANN, projection pursuit regression (PPR), multivariate adaptive regression splines (MARS), random forest and support vector regression (SVR).They also used Monte Carlo simulation designed to estimate predictive performance of model obtained on data set and found that support vector regression model is most accurate one followed by MARS, PPR.

Although Conventional time series modeling methods have served the scientific community for a long time and they provide reasonable accuracy, but suffer from the assumption of stationary and linearity (Kermani & Teshnehlab., 2008). Many new methodologies are developed for modeling the data but current trend seems to be model the data rather than physical process. For modeling the data, artificial intelligence techniques (AI) such as fuzzy logic (FL), artificial neural network (ANN) and adaptive neuro fuzzy inference system(ANFIS) are probably the most attractive techniques among the researchers, which is capable of handling imprecise, fuzzy, noise and probabilistic information to solve complex problem in an efficient manner. Altunkaynak et al., (2005) used fuzzy logic approach for water consumption prediction of the Istanbul city, using Takagi Sugeno method for time series data by considering only one lag as input for the analysis. Kermani & Teshnehlab., (2008) used normalized data for water consumption prediction using ANFIS method and also further, auto regressive model is employed for the analysis and they found that ANFIS model is better than autoregressive model. Yurdusev & Firat., (2009) used ANFIS method to forecast monthly water consumption modeling and they have adopted cross correlation method for selection of the input variables. Sen & Altunkaynak., (2009) used Mamdani inference system for modeling of drinking water prediction using different fuzzy sets and rules in the analysis. Also, there were many reports of using ANN in forecasting water demand (Babel & Shinde., 2011, Jain et al 2001, Firat et al 2009 and 2010).

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3. Fuzzy Logic

Lotfi Zadeh (1965) is the founder of Fuzzy logic which is used for wide range of problems covering engineering, process control, image processing, pattern recognition and classification, management, economics and decisions making (Rutkowski 2004). It is good choice to solve many control problems. Sine Fuzzy logic is works on user defined rules and handles imprecise data, it proves to be advantageous. Fuzzy systems is a rule-based systems that works on collection of linguistic rules which can represent the system with accuracy, Fuzzy sets are defined through their membership functions which map the input and output variables from 0 to 1. This may be complete or partial or non membership function. There are two membership functions namely Mamdani and Takagi Sugeno membership function. In this research work Mamdani Fuzzy inference system is employed which expects the output membership functions to be fuzzy sets. In order to enhance the efficiency, Defuzzification process is done. The structure of Mamdani fuzzy Inference system used in the analysis is shown in the figure 1.

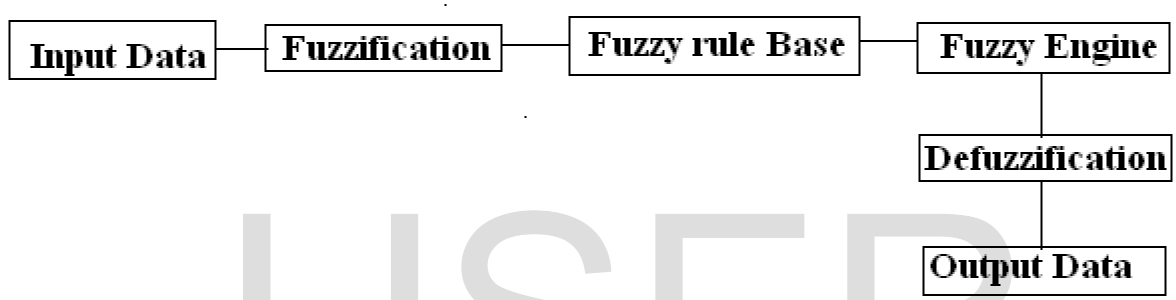


Fig 1: Structure of Mamdani fuzzy Inference System

4. Date and Area of study

The present study includes Yelahanka city, located at $13^0$06'30" to $77^0$34'15" which is a suburban of Bangalore in the state of Karnataka. The city is at a height of about 915m above mean sea level. Due to its higher altitude from mean sea level, it is lush green and has pleasant weather throughout the year. The summer season starts from March to mid-May, with a temperature in the range 20^0- 35^0. At the end of May, the monsoon season starts and lasts until the end of September. There are about 1143mm of rainfall annually. Yelahanka is served by both South west as well as South East monsoon. Winters are mild and last from November to February, with a temperature in the range 14^0 to 24^0. The Monthly variations of Rainfall and water consumption were shown in the figure 2 and 3.

Fig 2: Variation of Monthly Rainfall

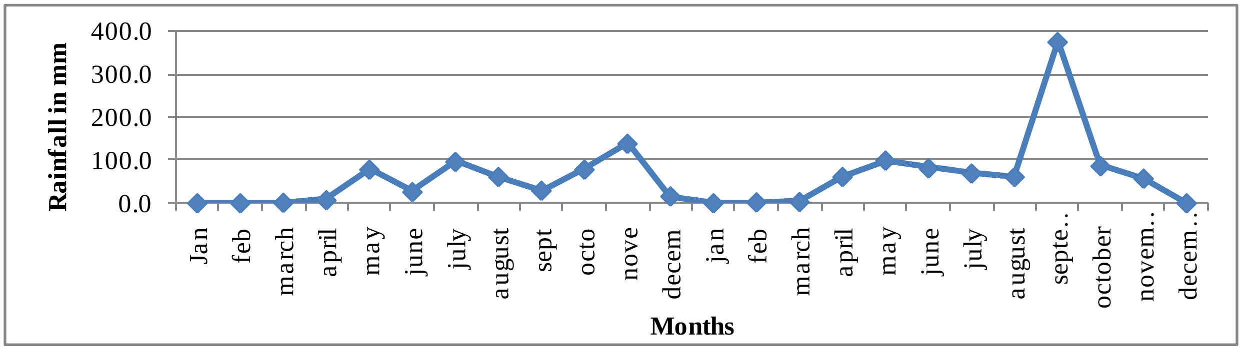
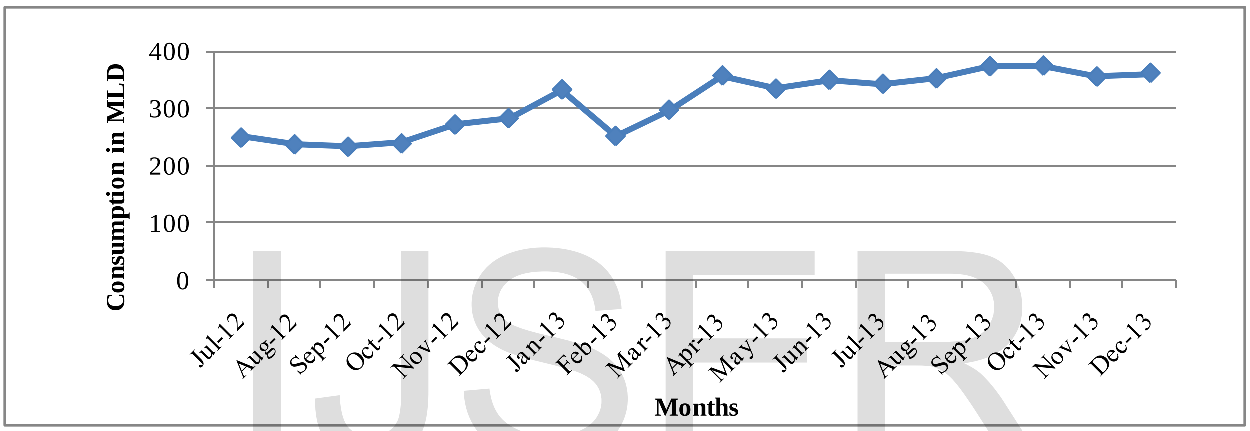


Fig 3: Monthly Water Consumption



The data used in this research were collected from disaster management cell which included rainfall, maximum and minimum temperature, and Relative humidity. The water consumption records are collected from BWSSB for a period of ten years. Structure of the model used in the analysis is as shown below. The selection of input and output variables is done based on correlation coefficient. The structure of the model used in the analysis is shown in the table 1 and the correlation coefficient of all variables was shown in the table 2.

Table 1: Model structure

Types	Model structure
Input	Rainfall, Maximum Temperature Minimum Temperature Relative Humidity
Output	Water Consumption

Table 2: Correlation Coefficient of all the variables

CC	Rainfall	Max-Temp	Min-Temp	Relative Humidity	Water Consumption
Rainfall in mm	1.00	-0.09	0.05	0.34	-0.16
Max-Temp	-0.09	1.00	0.42	-0.09	0.24
Min-Temp	0.05	0.42	1.00	0.16	0.66
Relative Humidity	0.34	-0.09	0.16	1.00	-0.04
Water Consumption	-0.16	0.24	0.66	-0.04	1.00

5. Fuzzy logic modeling of Water consumption prediction

The fuzzy logic model used in this analysis is of mamdani type. it consist of two main components one of which is the knowledge base which control the rules criteria and other is the data base which controls the membership functions. Fuzzy logic start with the fuzzification process, which compares the input variables with membership functions. Initially work is carried out with triangular membership function and it is compared with trapezoidal membership function. Then rules are added to premise part. Four different combinations of rules such as three, six, nine and twelve rules are employed for analysis. Final operation involved the defuzzification process which gives the output in the form of crisp. Centroid defuzzification is employed in the analysis. Figure 4 and 5 shows the triangular and trapezoidal membership application in the analysis. The output operation obtained in the analysis for four input scenario is shown in the figure 6.

Fig 5: shows the usage of triangular membership function for analysis.

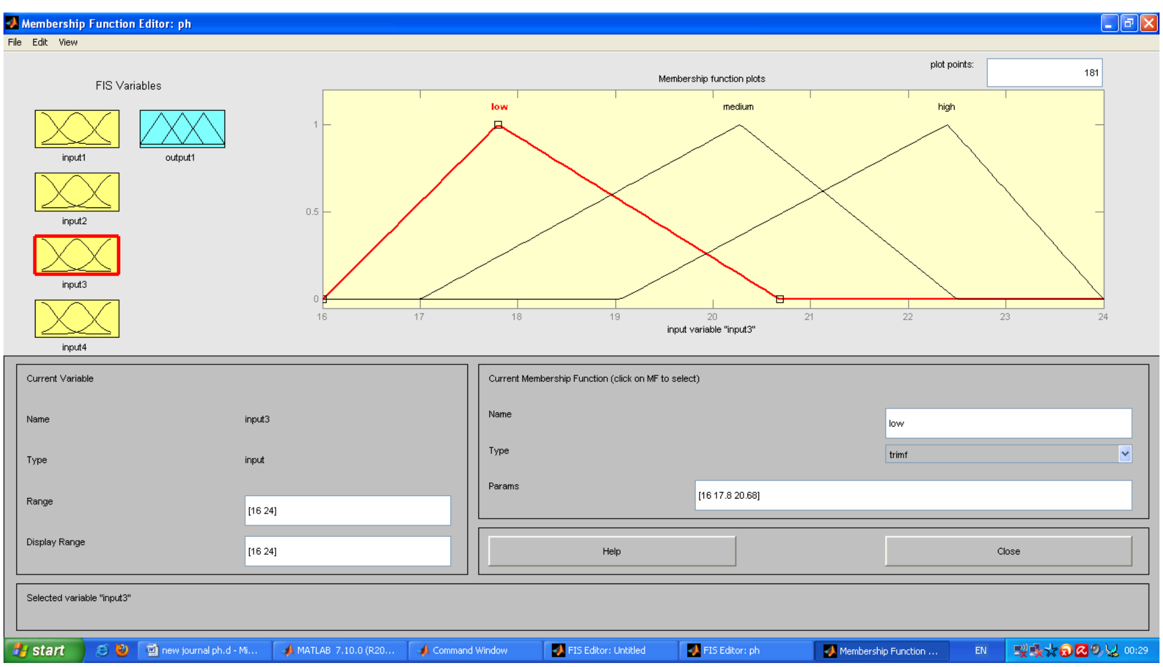


Fig 5: Trapezoidal membership function used in the analysis

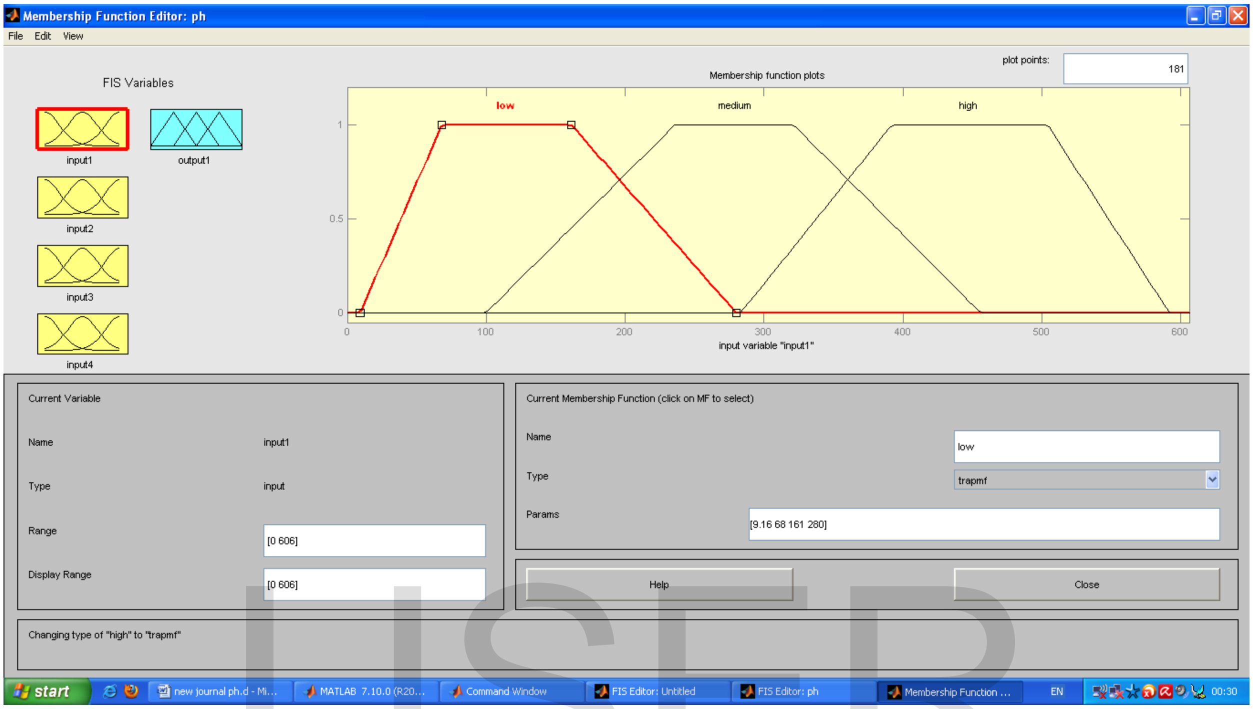
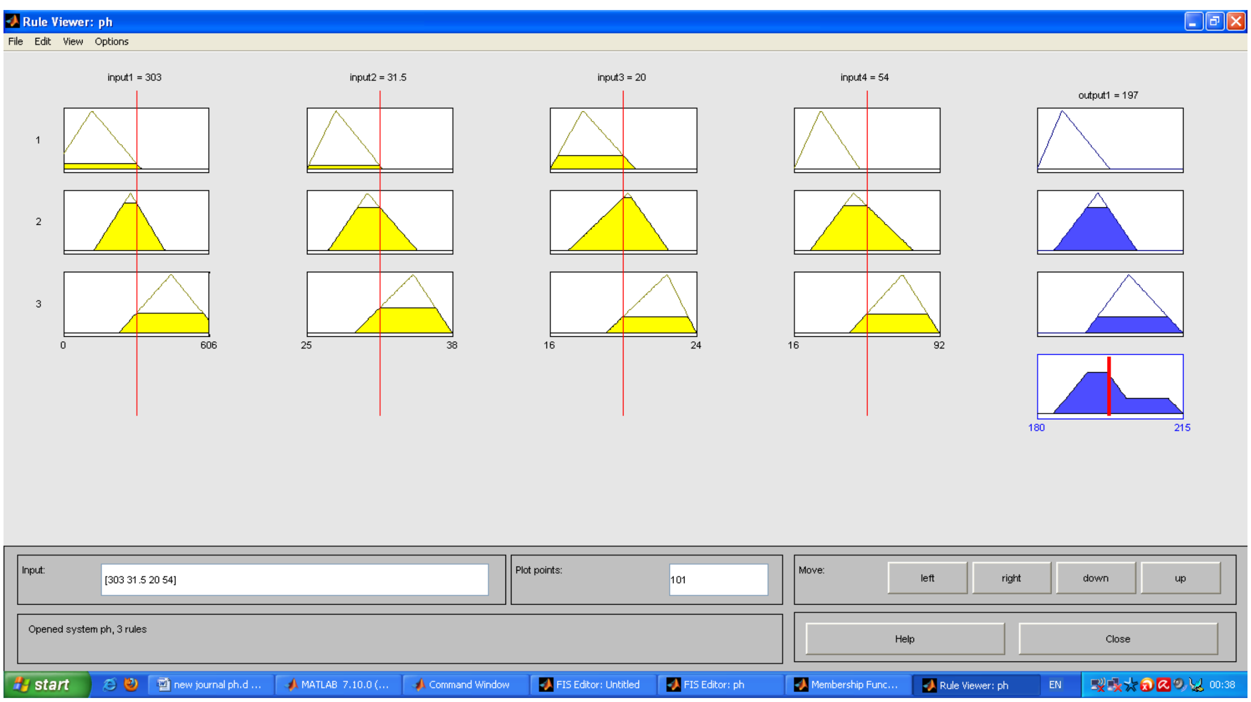


Figure 6: Shows the Input and output operation of fuzzy model



6. Performance Evaluation

Mean Absolute Error (MAE), Root Mean square (RMSE) and Accuracy are the performance evaluation indices used in the analysis. Based on the performance evaluation indices, best model is selected in fuzzy logic.

a) Mean Absolute error (MAE): Smaller the MAE value better will the model result. it is given by the equation :

$$MAE = \frac{observed\ values - predicted\ values}{Number\ of\ observation}$$

b) Root Mean square Error (RMSE): It gives the difference between predicted and observed values. Lower the value betters the result

$$RMSE = \sqrt{\frac{(observed\ -predicted\ )^{2}}{number\ \ of\ observation}}$$

c) Accuracy = 100- RMSE

7. RESULTS AND DISCUSSIONS:

Table 3 shows results of Fuzzy Model. Accuracy of the Fuzzy Model can also be increased by changed different membership function and different rules criteria. Trapezoidal and Triangular Membership were used in the analysis in order to improve the accuracy. From the performance indices it is cleared that triangular membership function is better compare to trapezoidal membership function. Also it is known that since fuzzy model is works on user defined rules, the accuracy of the model can also be increased using different rules criteria. But finding optimal number of rules for which model performs is difficult. There are four different kinds of rules criteria were used in the analysis. Using triangular membership function twelve numbers of rules performed well compare to others types.

Table 3: The results of all membership functions and rules criteria

Membership Type	Type	Three rules	Six rules	Nine rules	Twelve rules
Trapezoidal	RMSE	14.693	25.086	15.271	12.384
	Accuracy	85.307	74.914	84.729	87.616
	MAE	4.242	7.242	4.408	3.575
Triangular	RMSE	14.405	12.673	14.405	10.363

	Accuracy	85.595	87.327	85.595	89.637
	MAE	4.158	3.658	4.158	2.992

8. Conclusion

In this research work water consumption is predicted using fuzzy model. Analysis is carried out using different membership function and rules criteria. From the result it is cleared that triangular membership with twelve rules criteria performed better compared to trapezoidal membership function. Hence it can be conclude that performance of the fuzzy model can be improved using best user defined combined rules and membership function and also which can be used effectively for modeling the water consumption in an urban area.

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