Simulation of Water Level using Fuzzy Logic for Sabarmati River

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Abstract – *The present study aims to predict the water level for the study area of Sabarmati river basin at Ahmedabad region. Data-driven water level forecasting models are prepared and discussed. Climatic factors like rainfall, temperature, relative humidity, pan evaporation are used as input. Predicted values are compared with actual data and the optimum model yields appreciable accuracy.*

Key Words: Fuzzy Logic, Water Level, membership function, Rules, MATLAB

1. INTRODUCTION

Water level prediction is an important for environmental protection and flood control. When flood occurs, reliable water level forecasts are used for both early warning system to alert the people and real time control of hydraulic structures like diversion structures, gates, etc. to mitigate flood effects. The predicted values can be provided with a reasonable lead time to do the relief works.

1.1 Study Area

Sabarmati River is one of the major west flowing rivers of India. The Sabarmati basin extends over the states of Rajasthan and Gujarat having an area of 21,674 km^2 with maximum length and width of 300 km and 150 km respectively. The basin is bounded by Aravalli hills in the north and north-east, Rann of Kutch in the west and Gulf of Khambhat in the south.

The Sabarmati basin extends over parts of Udaipur, Sirohi, Pali and Dungarpur districts of Rajasthan, Sabarkantha, Kheda, Ahmedabad, Mehsana, Gandhinagar and Banaskantha districts of Gujarat. In Gujarat, the basin occupies an area of 17,550 km^2 accounting to 81% of total basin area. In Rajasthan, it covers an area of 4,124 km^2 which accounts for 19% of the total basin area. The basin is divided into 2 sub-basins as Sabarmati upper and Sabarmati lower sub-basin.

Table -1: Sabarmati River details

Origin	Village Teput, Udaipur, Rajasthan
Length	371 km
Discharge	Gulf of Khambhat
States and major cities	Rajasthan, Gujarat (Ahmedabad)
Right bank tributaries	Sei, Siri, Dhamni
Left bank tributaries	Wakal, Harnav, Hathimati, Khari, Watrak
Major Dams	Dharoi Dam

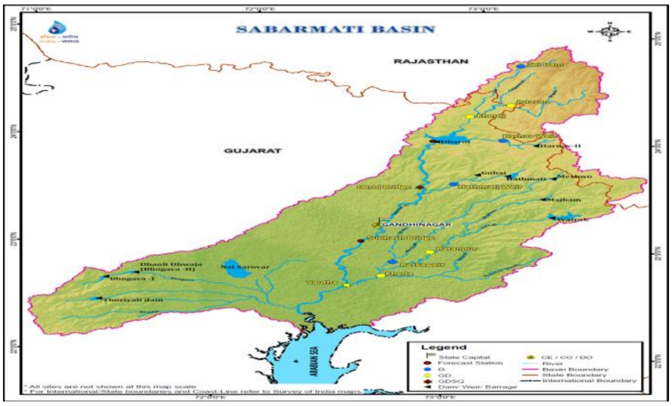

Fig -1: Sabarmati River Basin

2. FUZZY LOGIC

A Fuzzy Logic model is also known as a fuzzy interface system (FIS) or fuzzy controller. Fuzziness in a fuzzy set is characterized by its membership functions. It classifies the element in the set, whether it is discrete or continuous. The membership functions can also by formed by graphical representation. The graphical representation may include different shapes. There are certain restrictions regarding the shapes used. The rules formed to represent the fuzziness in an application are also fuzzy. The shape of the membership function is an important criterion that has to be considered. There are many membership functions that can be used.

Generally linear membership functions are preferred because the fuzzification process and defuzzification process are comparatively easier to perform on linear functions. In the linear membership functions, there are two options as triangular membership functions and the trapezoidal membership functions. Depending upon the requirement and the data set one can choose any of the two membership functions.

2.1 Input Data

The following data has been collected from State Water Data Centre (SWDC), Gandhinagar. The maximum, minimum and average of different climatic factors are shown in Table -1.

Table -2: Data Collected

Data	Max	Min	Average
Rainfall (mm)	59.5	0	5.19
Water Level RL (m)	70	0	33.54
Temperature (^{3}C)	37.3	24.09	30.34
Relative Humidity (%)	98.125	53.125	76.565
Pan Evaporation (mm)	5.57	0.15	2.101

2.2 Data Normalization

It is important to normalize the data so that the range of each variable should lie within the interval (0,1). After data collection, normalization is carried out for each of the variables, i.e. rainfall, water level, temperature, relative humidity and pan evaporation by using following equation:

$$X_{norm} = \frac{Xi - Xmin}{Xmax - Xmin}$$

Where, X_{norm} = normalized value of the observed variable

X_{max} = maximum value of the variable

X_{min} = minimum value of the variable

3. FUZZY LOGIC MODELS

In Fuzzy Logic models, crisp data set is to be converted into fuzzy data by fuzzification process. Then using IF-THEN rules, fuzzified out is to be found out. Then using, defuzzification techniques, fuzzy data is converted into crisp data.

MATLAB fuzzy logic toolbox is used for the development of fuzzy logic system using graphical user interface (GUI).

3.1 MODEL -1

Model -1 consists of 4 input variables as rainfall, temperature, relative humidity and pan evaporation and water level as an output as shown in Fig -1.

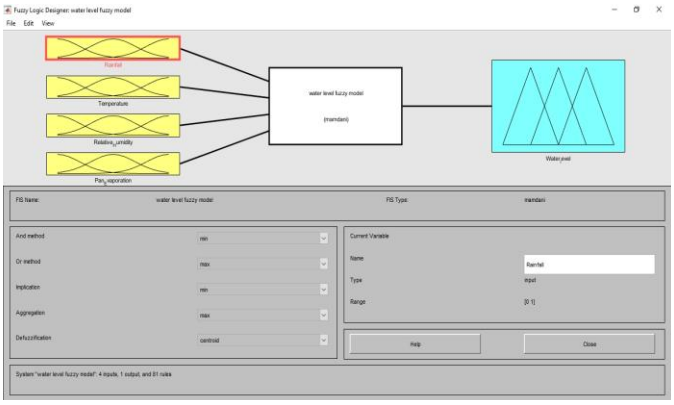

Fig -2: Model 1

The input variables are values are grouped into 3 linguistic variables and output variable values are grouped into 5 linguistic values as shown below:

Rainfall – Low, Medium, High

-0.2 < Rainfall < 0.075: Low Rainfall

0.06 < Rainfall< 0.15: Medium Rainfall

0.01 < Rainfall< 1.2: High Rainfall

Temperature – Low, Medium, High

-0.2 < Temperature < 0.5: Low Temperature

0.3 < Temperature < 0.8: Medium Temperature

0.55 < Temperature < 1.2: High Temperature

Relative Humidity – Low, Medium, High

-0.2 < RH < 0.45: Low Relative Humidity

0.3 < RH < 0.7: Medium Relative Humidity

0.55 < RH < 1.2: High Relative Humidity

Pan Evaporation – Low, Medium, High

-0.2 < PE < 0.55: Low Pan Evaporation

0.4 < PE < 0.85: Medium Pan Evaporation

0.6 < PE < 1.2: High Pan Evaporation

Water level – Very Low, Low, Medium, High, Very High

0.03 < WL < 0.25: Very Low Water Level

0.1 < WL < 0.35: Low Water Level

0.24 < WL < 0.4: Medium Water Level

0.3 < WL < 0.7: High Water Level

0.6 < WL < 0.88: Very High Water Level

Fig -3: Model 1 Membership Functions for input and output variables

Once the membership functions are defined for each input and output variables, now IF-THEN rules are to be defined. These rules transforms the input variables to an output. As the number of variables are more, the number of IF-THEN rules will be more. Formation of rules require an expert knowledge. Some of the rules are defined below:

Ex. IF Rainfall is Low AND Temperature is High AND Relative Humidity is Low AND Pan Evaporation is Low THEN Water Level is Low.

The below figure shows the Fuzzy Rule Viewer for model -1.

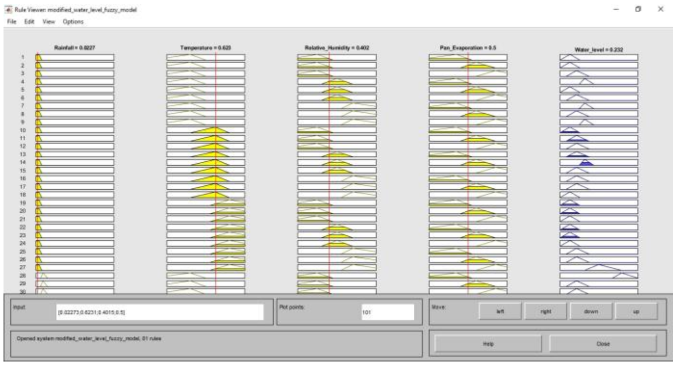

Fig -4: Model 1 Rules

3.2 MODEL -2

Model -2 consists of 2 input variables as rainfall, temperature and water level as an output as shown in Fig -3.

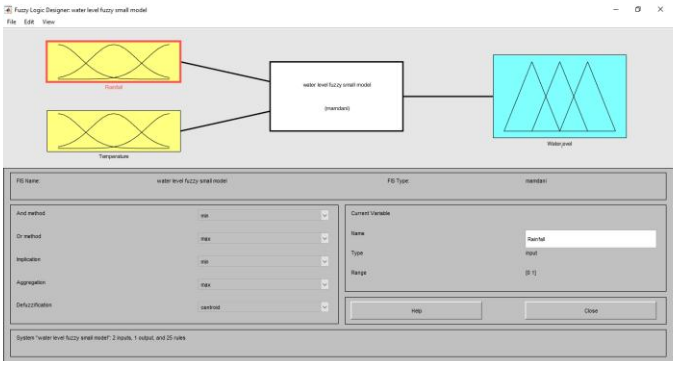

Fig -5: Model 2

The input and output variables are values are grouped into 5 linguistic values as shown below:

Rainfall – Very Low, Low, Medium, High, Very High

-0.2< Rainfall <0.005: Very Low Rainfall

0.02 < Rainfall < 0.07: Low Rainfall

0.06 < Rainfall < 0.1: Medium Rainfall

0.09 < Rainfall < 0.2: High Rainfall

0.15 < Rainfall < 1.2: Very High Rainfall

Temperature – Very Low, Low, Medium, High, Very High

-0.2 < Temperature < 0.3: Very Low Temperature

0.2 < Temperature < 0.4: Low Temperature

0.3 < Temperature < 0.6: Medium Temperature

0.55 < Temperature < 0.8: High Temperature

0.7 < Temperature < 1.2: Very High Temperature

Water level – Very Low, Low, Medium, High, Very High

0.03< WL < 0.25: Very Low Water level

0.1 < WL < 0.35: Low Water level

0.24 < WL < 0.4: Medium Water level

0.3 < WL < 0.7: High Water level

0.6 < WL < 0.88: Very High Water level

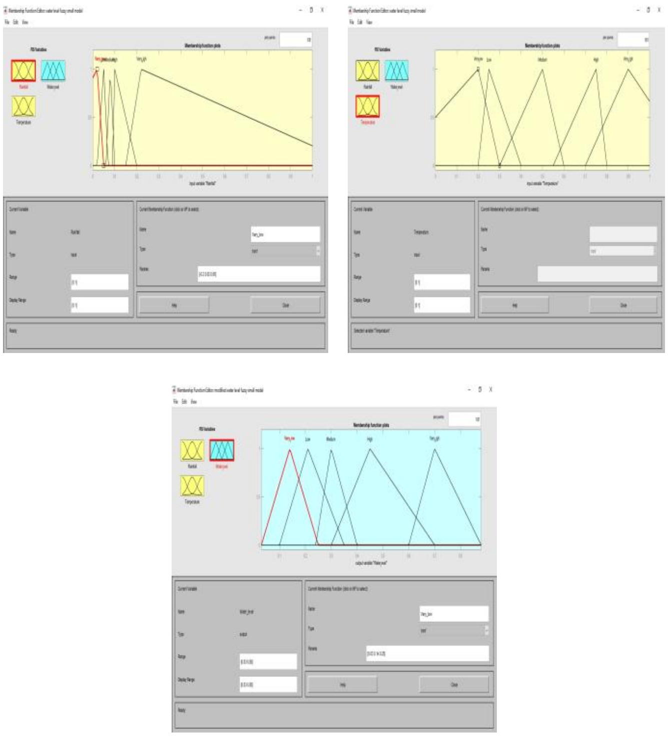

Fig -6: Model 2 Membership Functions for input and output variables

The below figure shows the Rule Viewer for Model -2.

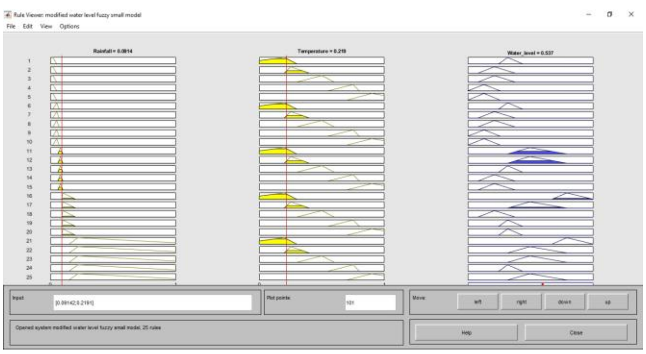

Fig -7: Model 2 Rules

4. RESULTS

The following measure of performance variables are used to measure model outputs:

- MSE (Mean Square Error): It is a measure of how close a fitted line is to data points. It is an average of the squares of the difference between the actual observations and the predicted observations.

$$MSE = \frac{1}{n} * \sum_{i=0}^{n} (Xa - Xp)$$

Where, X_a = Actual value

X_p = Predicted value

- RMSE (Root Mean Square Error): The root mean square error (RMSE) is a very frequently used measure of the differences between predicted value and the actual values. RMSE is defined as the square root of differences between predicted values and observed values. It measures magnitude of the errors.

$$RMSE = \sqrt{\frac{1}{n} * \sum_{i=0}^{n} (Xa - Xp)}$$

- Discrepancy Ratio (D.R.): Discrepancy ratio is defined as the ratio of predicted and actual values. The discrepancy ratio should be 1 for good results.

$$D.R. = \frac{\textit{Predicted Value}}{\textit{Actual Value}}$$

- % error: Percentage error is the difference between the estimated numbers when compared to the actual numbers expressed in percent format.

$$\%\ error = \frac{|\textit{Actual value} - \textit{Predicted value}|}{\textit{Actual Value}} * 100$$

The following results were obtained from the models:

Table -3: Model Results

Model No	MSE	RMSE	D.R.	% error
1	0.028065	0.1675274	0.9618524	0.45366503
2	0.032827	0.1811835	1.0333192	0.61913498

Model -1 has lower MSE and RMSE values. So model -1 yields better results than model -2. The below figure shows the comparison of predicted values with actual values for model - 1.

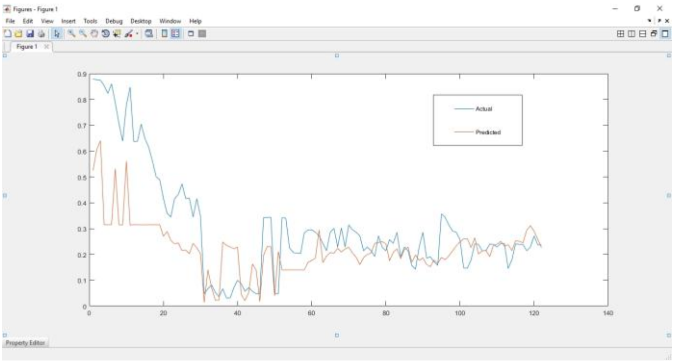

Fig -5: Comparison of actual and predicted values

5. CONCLUSION

In this study, we have tried to predict water level using climatic data as input using Fuzzy Logic. However it is clear from fig -5 that predicted values are slightly differing from actual values. Mean Square Error (MSE), Root Mean Square Error (RMSE), Discrepancy Ratio (D.R.) and % error are used as measure of performance variables. Model -1 is found to be having best result with negligible errors. So we can conclude that as number of input variable increases, the accuracy of the fuzzy model increases.

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