Mamdani Fuzzy Based Prediction of Rainfall Fuzzy Rainfall Index

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Abstract. This study attempts to investigate the link between rainfall and climatic large-scale synoptic patterns. Here, we employed the fuzzy inference system (FIS) to forecast rainfall. Six linguistic variables were considered as an input for the proposed system, split into two FIS. Average Mean Temperature (degree celsius), Mean Wind velocity (KM-PH), and Evapotranspiration (mm/day) belong to FIS1. In contrast, Relative humidity (%), Season, and Mean sun shines (hrs/day) belong to FIS2, and each model has three triangular membership functions, excluding the season variable. It has four bi-membership functions: summer, winter, South West, and North East. The output models have four memberships function Very high, High, Normal, Low, and Very Low for FIS1 and FIS2; respectively. The IF-THEN rules were assigned based on the individual significance of linguistic variables for rainfall and from expert opinion for the model FIS1, FIS2 and FRFI, In this article, we had implemented 72 numbers of possible rules, moreover model results can be reviewed into surface 3D-Plot. The implication of each variable with output such as FIS1, FIS2, and FRFI was addressed. Finally, predicted values were compared with the actual rainfall data. Thus, the proposed model would be expected rainfall at a reasonable accuracy. All the implementation has been done in MATLAB7 Fuzzy toolbox.

Keywords: Fuzzy rainfall index · Fuzzification · Defuzzification · If-then rules · Surface plot · Regression

1 Introduction

Seasonal rainfall predictions may be extremely useful for management and conservation, such as reservoir operations, agricultural practices, and flood response. Effective water resource planning and management are required to mitigate this. In the short term, this mandates a thorough understanding of the next season. In the long run, credible estimates

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of future unpredictability and change are required [1] [2]. The fuzzy technique was easy and produced a definitive result from partial, ambiguous, or inaccurate information [3] [8]. Fuzzy logic theory and fuzzy set theory are effective tools for reflecting imprecision and uncertainty in decision-making [4] [5]. In recent years, many authors have been focusing in soft computing area like fuzzy inference system for many meteorological problems such as rainfall event prediction using rule base fuzzy basic inference system, Annual Rainfall forecasting by using Mamdani fuzzy inference system, Fuzzy rule-based classification of atmospheric circulation patterns, Fuzzy based decision support system for irrigation system management, Hazard rating of Debris flow Evapotranspiration sites in hillside communities of Ershai Township Changhua country, Taiwan, a mode for predicting rainfall by fuzzy set theory using USDA Scan data, Fuzzy rule-based flood forecasting mode of Jaidha river basin, Dhemaji, Assam.[6] [7]. If-Then rules based model has evaluated for fog formation over Delhi, and the results were found to be appreciably good [11]. In their works, they considered five parameters such as Total cloud cover, relative humidity, wind direction, temperature, and surface pressure as input variables for their model, and the obtained results were validated by using the brier score and the friction score [10]. Fuzzy based models for the estimation of rainfall; in their work, few parameters such as temperature, humidity, wind speed, and solar radiation have been considered, and the results can be inferred that the predicted rainfall results are closer to actual rainfall data [8] [9] [12]. a fuzzy-based approach has been exploited for Weather forecasting. Their experimental parameters were humidity, temperature, and rainfall; according to statistical analysis, they were made membership function for each variable [13]. It is inferred that it is not mandatory to have a demarcation line for the classification of the forecasting objects [15, 16]; for instance, rainfall prediction was divided into three grades rareness, normality, and plenty of rainfall respectively; thus, said to be fuzziness have followed IF-THEN rule base, for instance, if WP is very high AND TP is lower THEN RF is moderate in which very high, lower and moderate were linguistic variables [9][10]. Fuzzy rules could easily be programmed and fuzzy models can be transparent since rules are based on structure. In this present study, we have aimed to design a fuzzy model for predicting rainfall, and this model can produce a single index, the expected rainfall value [14, 17] .

2 Methodology and Materials

2.1 Study Area

The Perambalur district is lies between 10°54’ and 11°30’ North Latitude and 78°40’ and 79°30’ East Longitude, the mean height of the selected study area is 252m above sea level and the normal rain fall of the district is 908 mm, the observed data can be acquired between latitude of 11°13′32" and longitude of 78°52′32" with an altitude of 118 m at velar basin, south of Cauvery, Various parameters like Average Wind velocity, Average Temperature, Evapotranspiration, Relative humidity, mean sun shines and rainfall was measured. The maximum annual rainfall was obtained during the southeast monsoon period; the normal rainfall of the study area is 908 mm.The model can be evaluated from March to December 2010 since it contains sufficient data. The Evapotranspiration values for the observation period is 4.43, Maximum, Min, Median, and Standard deviation are

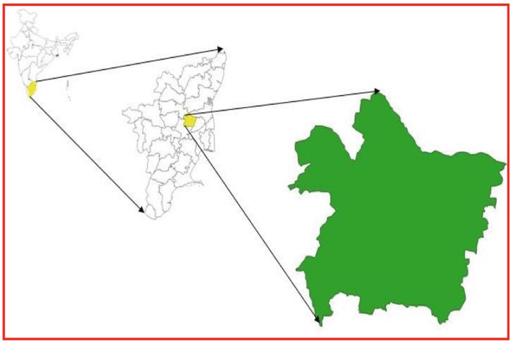

Fig. 1. Location of the study area

Table 1. Statistical analysis of variables

Variables	Mean	Max	Min	Median	Standard deviation
Evapotranspiration(mm/day)	4.43	6.52	0	5.12	2.017
Relative humidity (%)	62.74	80	51.1	59.25	9.672
Mean Sun shine hours per day	5.94	9.13	4.19	5.38	1.909
Mean Windvelocity in KMPH	6.99	12.2	2.59	6.79	3.082
Mean temperature in∘C	26.26	30.6	21.0	26.48	3.092

6.52, 0, 5.12 and 2.017, and the mean Relative humidity value for the observation is 62.4, Maximum, Min, Median, and Standard deviation are 80, 51.1, 59.25 and 9.67, Similarly, Statistical analysis of other variables as shown in Table 1.

2.2 Fuzzy Rule-Based System (FRBS) for Prediction of Rainfall

The development of the fuzzy model to predict the rainfall index involves the following steps. The proposed model started with the preparation of linguistic parameters, The proposed Mamdani fuzzy model for rainfall index is shown in Fig. 2. The first fuzzy model has three input variables (Temperature, Wind speed, and Evapotranspiration) and the Second Fuzzy model has three input variables (Relative humidity, Season, and Sunshines). OG1 and OG2 are the output of FIS1 and FIS2, respectively. The output values can be obtained from aggregated in the subsequent model. The relationship between input and work can be represented as follows. FIS1 = f (Temperature, Wind speed, Evapotranspiration), FIS2 = f (Relative humidity, Season, Sunshines), FRFI = f (FIS1, FIS2). The second and most crucial step is assigning ranges for all the variables which have been used for the model; Table 2 shows the linguistic variables and their fuzzy intervals.

Parameter, assigning a membership function for each variable is essential. In this study, the triangular membership function is most suitable for input and output parameters since computational is most straightforward in manner, which is represented in

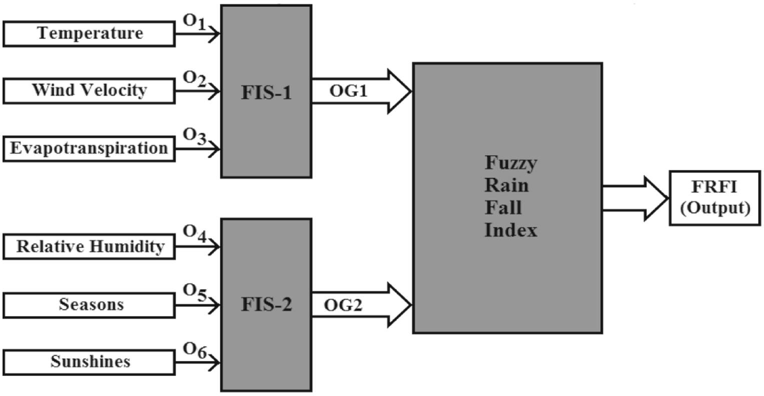

Fig. 2. Structure of fuzzy model for prediction of rainfall

Eq. 1, where a < b < c. and season can be done by Pi membership function. The following steps involve fuzzy rules base; Fuzzy information can be represented in the form of a rule base which consists of a set of rule. The fuzzy rule base contains premises Ai, K in the form of fuzzy sets with membership function with μAi K and a consequence Bi in the fuzzy format set. The most straightforward rules are formulated using AND only [8]. The membership function for all the variables used in this study is shown in Fig. 3

$$Triangular\ FunctionT(x) = \begin{cases} 0 & x < 0 \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & c < x \end{cases} \quad (1)$$

The rule base contains a linguistic statement in the form of IF-THEN rules associated with antecedents and consequents connected by AND Operator. In conventional antecedent and consequent forms such as Rule1: if x is P, then Y is Q, Where P, and Q represents fuzzy proportions (sets). The rule base for each FIS can be written separately, FIS 1 carries 27 possible rules, and FIS2 has 36 possible rules, whereas FRFI carries nine rules, a total 72 rules carried out for this model. It cannot show all rules; thus, some implementation rules were mentioned in Table 3 for understanding purposes. Fuzzy inference and Defuzzification: the fuzzy model ended with fuzzy inference and defuzzification. It is mandatory to select suitable aggregation and defuzzification of the output to get the crisp output, fuzzification means transforming the real value into fuzzy values, whereas defuzzification implies the process of transforming fuzzy output into real values. A familiar and useful defuzzification technique is the centre of gravity (COG) method for determining the model's production, which is computed as follows.

$$z = \frac{\int \mu_i(x).x.dx}{\mu_i(x).dx} \quad (2)$$

Table 2. Input and output with associated with fuzzy index

Variable	Linguistic values	Fuzzy Intervals
Temperature	Low Moderate High	0° - 15° 5° - 25° 15°-30°
Wind velocity	Low Moderate High	0–10 5–30 25–50
Evapotranspiration	Low Moderate High	0–3 2–6 4–10
Relative humidity	Low Moderate High	10–40 30–60 50–100
Season	Winter Summer South west monsoon North east monsoon	0–3 2–6 5–9 8–12
Sunshine	Low Moderate High	0–4 3–7 6–10
FRFI	Very Low Low Normal High Very High	0–25 0–50 25–75 50–100 75–100

2.3 Mamdani Fuzzy Model

Figure 4 shows Membership function design for Input and output variable. The Mamdani fuzzy model converts the resulting fuzzy outputs from the fuzzy inference engine to a number. In this study, we used Mamdani fuzzy-based model for computation of the final output membership function, in which three crisp inputs are given, and three If-Then rules are assigned. Crisp outputs are obtained by the defuzzification method. Various methods are available such as bisector of area (BOA), Centre of gravity (COG), Left most maximum (LM), and Right most maximum (RM). These BOA, LM, RM, can be used for particular problems. In the COG Methods, the crisp value is obtained under the center of gravity of the combined output fuzzy subset. The COG Method is generally used for defuzzification process.

Table 3. Some implemented rules

	If	**is**	**And**	**is**	**And**	**is**	**Then FIS output**
	Mean. Avg. Temp.	Moderate	Avg. W.V.	Moderate	EVT.	Moderate	High
	Mean. Avg. Temp.	High	Avg. W.V.	High	EVT.	High	Very Hig
	Mean. Avg. Temp.	Low	Avg. W.V.	Low	EVT.	Low	Very Low
FIS1	Mean. Avg. Temp.	Moderate	Avg. W.V.	High	EVT.	High	High
	Mean. Avg. Temp.	Low	Avg. W.V.	Low	EVT.	Moderate	Very Lo
	Mean. Avg. Temp	High	Avg. W.V.	Moderate	EVT.	High	High

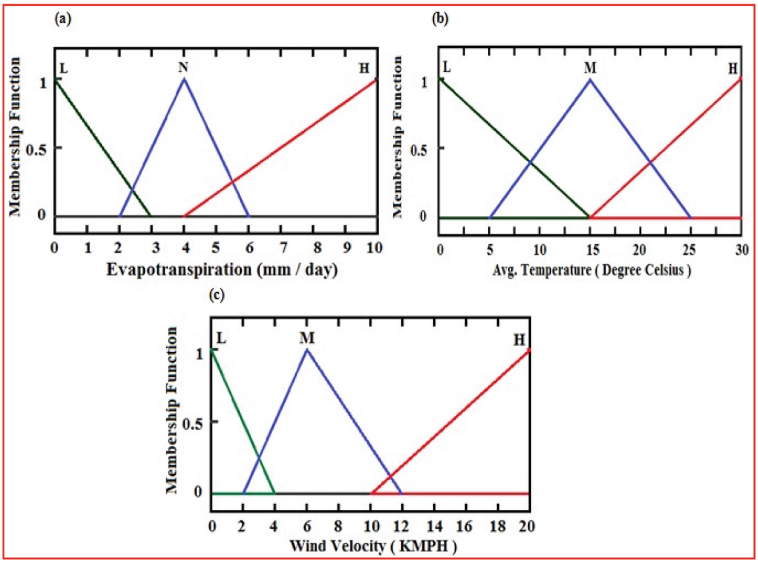

Fig. 3. Membership functions for input and output variables (a) Temperature (b) Wind speed

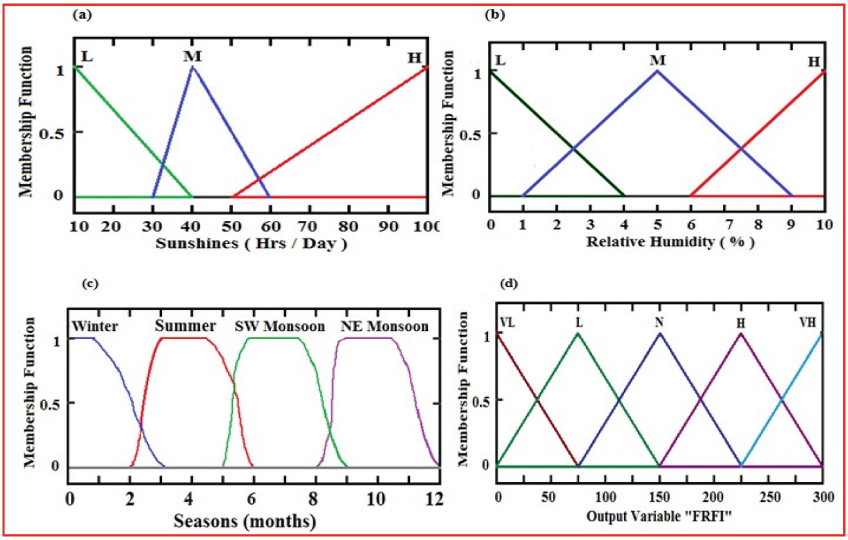

Fig. 4. Membership functions for input and output variables (a) Seasons (b) Relativity (c) Sunshine (d) FRFI (Output)

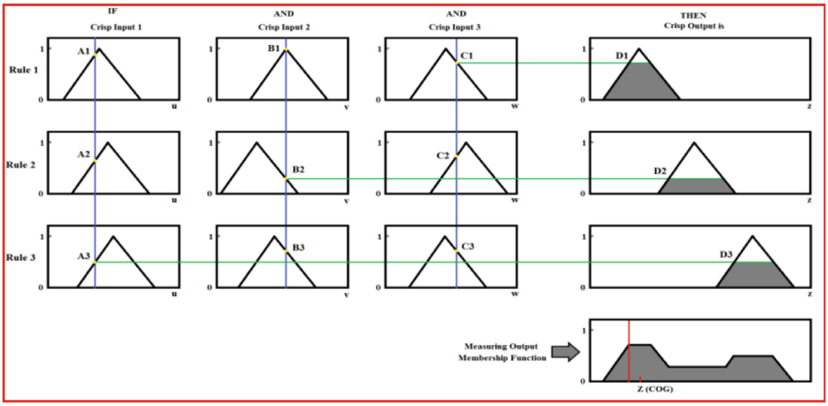

Fig. 5. Mamdani fuzzy model

3 Results and Discussion

The fuzzy rule base system for predicting the rainfall (FIS1), as shown in Fig. 6, this system carries 27 possible If-Then rules; the probable output of the FIS1 is 168 when the average values of variables temperature, Wind speed, and Evapotranspiration are 15∘C, 10 KMPH and 5 mm respectively, to see variation among the variables FIS1 results can be analyzed through 3D-Plot like a surface plot which is shown in Fig. 7 a-c, it can be inferred that either wind speed or Evapotranspiration increase the FIS1 also increase.

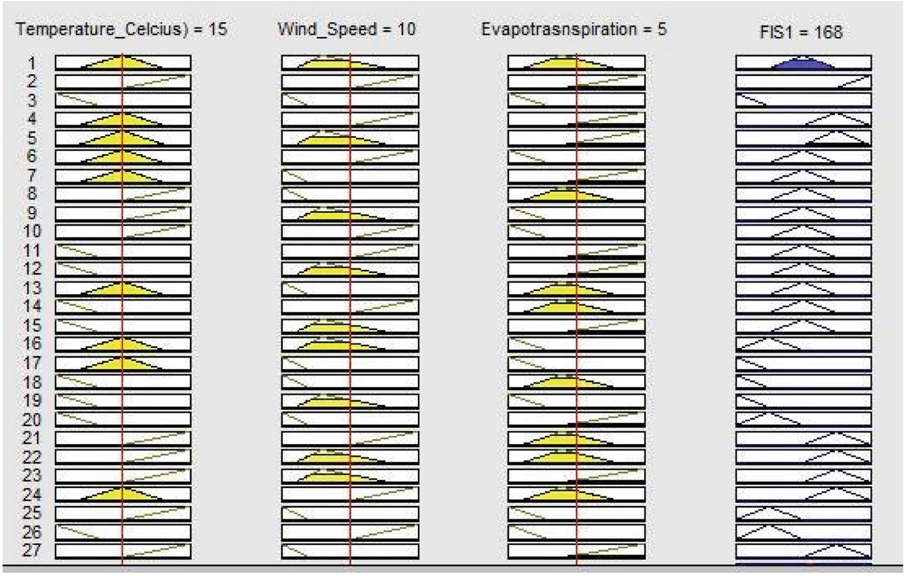

Fig. 6. Fuzzy rule base system for FIS1

The most important observation from Fig. 6-a is that FIS1 rapidly increases with increment in Evapotranspiration; it is specified that FIS 1 increases only after reaching Evapotranspiration is 2.5 mm/day. Similarly, Fig. 7-b shows that either Wind speed increases or Temperature increases, FIS 1 has increased, and in connection to that model, FIS1 with other variables can be illustrated. The FIS2 Rule-based model, as shown in Fig. 8, this system carries 36 possible If- Then rules; the probable value of the FIS2 system is 150 when the average value of relative humidity, Season, and Sunshine is 55%, 6 and 5 h/day, respectively. The FIS2 results can be investigated through a surface plot that is 3D-Plot which is shown in Fig. 9 a-c; it can be understood that The FIS2 increase only when the season is reached southwest monsoon or northeast monsoon and sun shines increases rapidly with the season period is either North West monsoon or southeast monsoon, FIS2 also increases. Similarly, other variables' relationship with FIS is illustrated. The Final model for FRFI with nine rules, as shown in Fig. 10, it shows that the possible output is 150 when the average values of both FIS1 AND FIS are 150 and the results of this system can be analyzed through the surface plot as shown in Fig. 11. It shows good results that either FIS1 or FIS2 Increases, and FRFI also increases in scale. Therefore the high value of FRFI indicates that higher possibility of rainfall. The summary of the results is given in Table 4 and (Fig. 12).

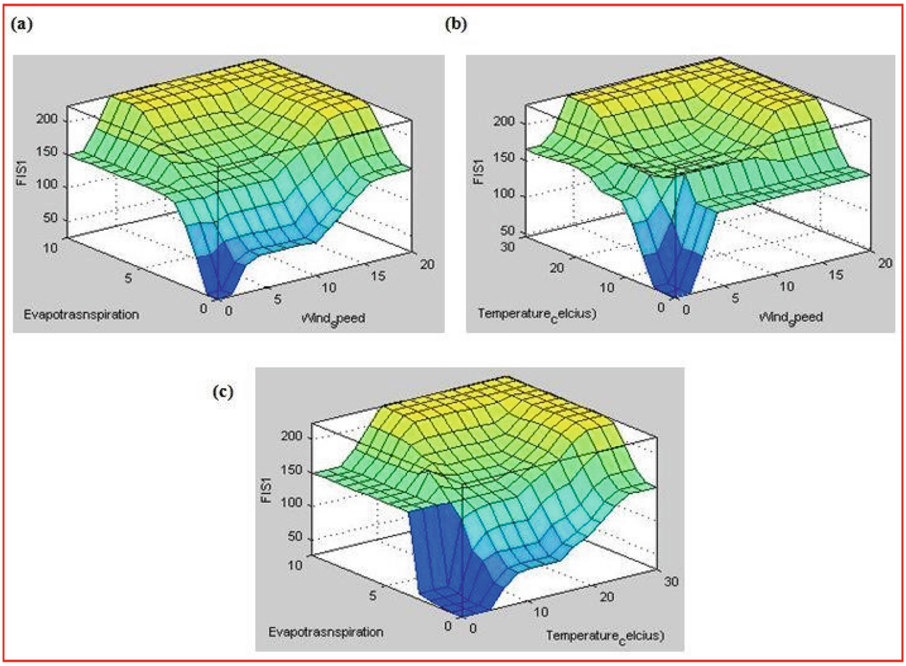

Fig. 7. Surface plot 3-D (a) Evapotranspiration Vs. Wind speed (b) Windspeed vs Temperature (c) Evapotranspiration Vs Temperature.

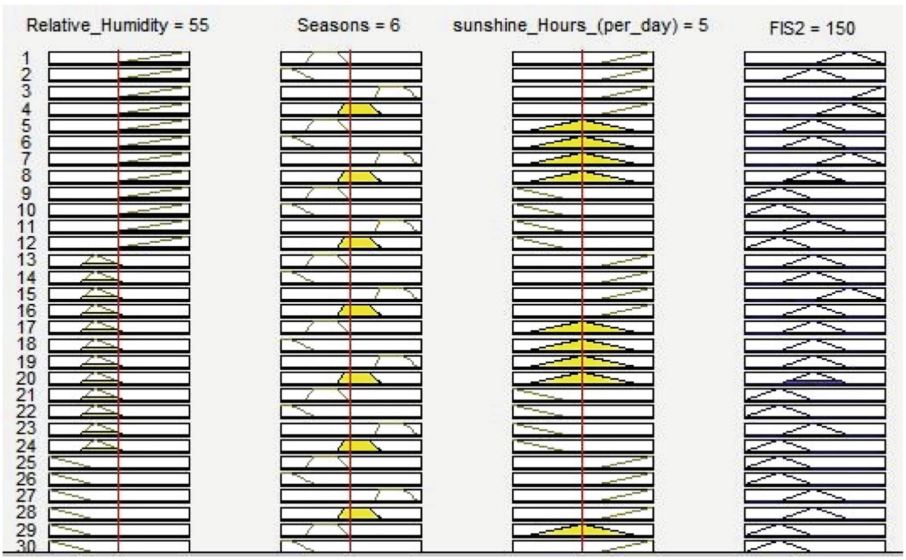

Fig. 8. FIS2 Rule base System

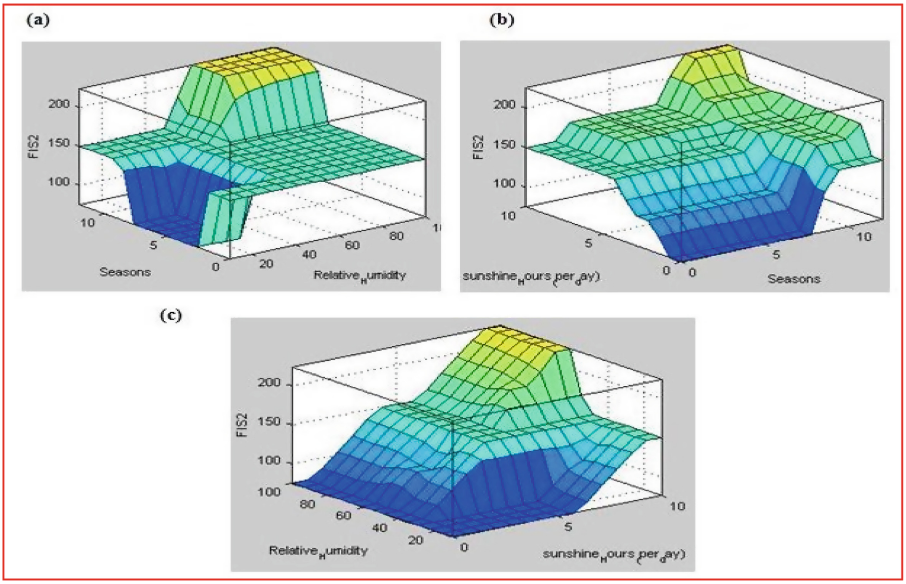

Fig. 9. Surface plot 3-D (a) Evapotranspiration Vs. Wind speed (b) Windspeed Vs. Temperature (c) Evapotranspiration Vs. Temperature

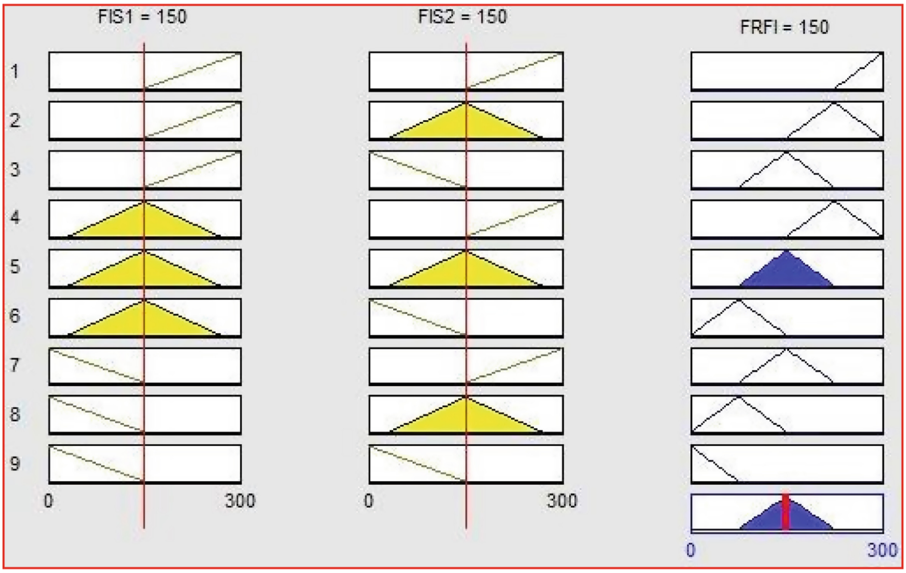

Fig. 10. FRFI Rule base System

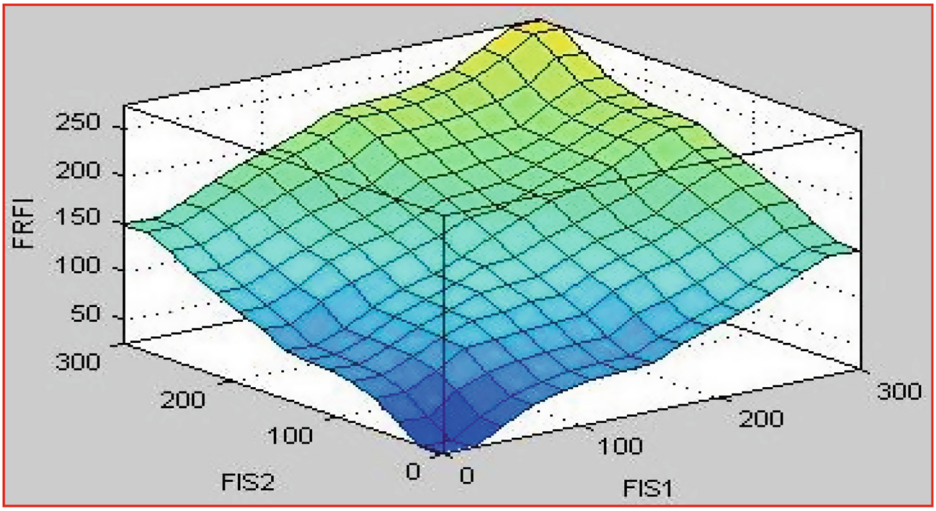

Fig. 11. Surface Plot - 3 D Plot FIS1 Vs. FIS2

Table 4. Summary of Results

Period of 2010	Observed Rainfall	Predicted Rainfall
4.03.2019	149	150
30.04.2019	149	150
29.05.2019	148.8	150
30.06.2019	149.0	150
31.07.2019	9.20	10
31.08.2019	223.5	225
28.09.2019	149	150
25.10.2019	224	225
23.11.2019	229.4	300
31.12.2019	98.20	98.5

Validation of fuzzy results can be validated through a regression plot as shown in fig; it reflects that the coefficient of determination is (R2) as 0.725. Hence, the proposed fuzzy model predicts rainfall with reasonable accuracy.

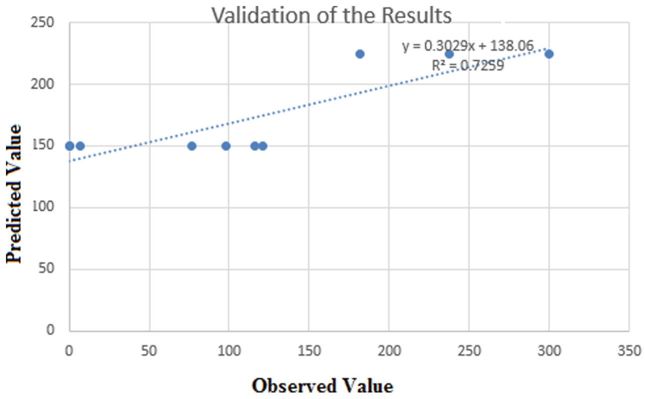

Fig. 12. Regressions plot between Observed and predicted value

4 Conclusion

In this article, we have designed Mamdani based Fuzzy model for rainfall prediction of rainfall, the proposed model has six linguistic variables, FIS1 consists of Temperature (degree Celsius), Wind velocity (KMPH), and Evapotranspiration (mm/day), whereas Relative humidity (%), Season, Sunshines (hrs/day) belongs to FIS2, each model has three triangular membership functions except season variable, which has four bi membership functions. The output model has four memberships function like Very high, High, Normal, Low and Very Low. The model can be processed through natural language such as IF-THEN Rules. Totally 72 rules have been implemented, and the result of the model can be analyzed via surface plot and behavior among variables also observed. Finally, the predicted fuzziness value was compared with the observed value using a regression plot and observed that coefficient determination was 0.7225. Thus, We concluded that the proposed fuzzy model would predict rainfall with a reasonable accuracy.

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