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Rainfall Prediction Using Fuzzy Logic

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Abstract
This study aims to investigate the potential of a fuzzy logic to enhance rainfall prediction accuracy in Senai by considering two main parameters: temperature and wind speed. Basically, a fuzzy logic approach with Mamdani-type is used in this study. The general system's design of this approach contains linguistic variables and membership functions representing the input data and facilitating the complex weather pattern into prediction output. Thus, the study involves data collection, system implementation, and performance evaluation. The predicted rainfall is evaluated by applying the fuzzy logic to the fuzzy toolbox in MATLAB. These predictions are then compared to actual rainfall data to compute the accuracy of the system. As a result, this study shows an accuracy of 75% and an error of 25% of the fuzzy logic in predicting rainfall rate. In conclusion, this study highlights the potential of fuzzy logic in advancing rainfall prediction accuracy in Senai.
Keywords: Rainfall prediction; Fuzzy logic; Mamdani.

1. Introduction

Prediction is trendy and can be used as a source to carry out indispensable awareness for a forthcoming event [1]. Technically, prediction is the process of using available information, historical data, or models to forecast or estimate future events, outcomes, or trends. Weather forecasting is one of the most important and demanding operational responsibilities carried out by meteorological services worldwide. It is a complicated procedure that includes numerous specialized technological fields [2].

Rainfall is a stochastic process whose upcoming event depends on some precursors from other parameters, such as the sea surface temperature for monthly to seasonal time scales, the surface pressure for weekly to daily time scales and other atmospheric parameters for daily to hourly time scales [2]. Rainfall prediction is helpful in avoiding floods and saving lives and property for humans. However, the process is quite challenging as it deals with ambiguity and vague rainfall data. Therefore, fuzzy logic is the most suitable technique to deal with the problem.

Compared to fuzzy logic, traditional rainfall prediction relies more on Numerical Weather Prediction (NWP) models. NWP is the most recent weather prediction technique that is available worldwide [3]. This model uses mathematical equations to simulate the behaviour of the atmosphere, requires extensive computational resources, and is highly sensitive to the initial condition. Furthermore, NWP models often struggle with rainfall variability, particularly in regions with complex topography and diverse climatic conditions.

Meanwhile, fuzzy logic theory works well when reflecting imprecision and uncertainty in decision-making. Fuzzy set theory was first introduced by Lotfi Zadeh in 1965. This approach offers a mathematical framework for dealing with imprecision and uncertainty. With the use of actual research and expert knowledge, it is simple to integrate into conventional mathematics since fuzzy logic is also one of the core methodologies in soft computing.

There are numerous applications of soft computing based on fuzzy logic in rainfall forecasting. A fuzzy logic, for example, has been used experimentally to predict weather events such as rain, was proposed by [4]. Extending their idea, in this research, the daily rainfall measurements of the gauging station in Senai, Johor, are analyzed to predict the rainfall using fuzzy logic. The fuzzy model includes input and output defined and the Mamdani-type fuzzy logic is used in this study to compute the result.

2. Literature Review

2.1. Fuzzy Logic

Fuzzy logic have gained prominence across various fields for their ability to model uncertainty and imprecision, providing a framework for more flexible and human-like decision-making processes. In recent decades, the application of fuzzy logic and fuzzy logics has expanded significantly, with diverse applications in control systems, artificial intelligence, pattern recognition, and decision-making processes.

As mentioned by [5], fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with robust and approximate reasoning rather than brittle and exact. In contrast with crisp logic, where binary sets have two-valued logic, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1 called a membership function. Membership functions in fuzzy logic are like guides that show how much something fits into a category. These functions use numbers between 0 and 1 to describe this belongingness, where 0 means not at all in the group and 1 means totally in it. Fuzzy logic also must have consistent logical operations as the standard logical operations. The logical operations AND, OR, and NOT are the most fundamental.

Fuzzy logic is one of the practical applications forming the basis for approximating human reasoning processes. These systems consist of fuzzification, fuzzy inference engine, and defuzzification components. Fuzzification involves converting crisp input data into fuzzy sets using linguistic variables and membership functions. Fuzzy inference engine employs a set of predefined fuzzy rules to evaluate relationships between inputs and outputs based on the knowledge represented by IF-THEN rule. This is the process of reasoning and generally involves two processes which are rule evaluation and rule aggregation. Rule evaluation is to apply the fuzzy set operator (AND, OR, and NOT) to the antecedents to determine the firing strength of each rule while rule aggregation is to combine the output fuzzy sets using the firing strengths obtained in the process of rule evaluation. A fuzzy IF-THEN rule is a conditional statement can be expressed as:

IF < fuzzy proposition > **THEN** < fuzzy proposition >

or

IF x_1 is A_{i1} **and/or** x_2 is A_{i2} **and/or** … **THEN** y is B_i , $i = 1,2,3, \ldots, r$

The **IF** part is aimed at working out the membership value of input variable *x* corresponding to fuzzy set *A*. While in the consequent, the **THEN** part assigns a crisp value back to the output variable *y*. The final step is defuzzification to aggregate fuzzy outputs to derive a crisp of output. Figure 1 shows the general structure of fuzzy logic by [6].

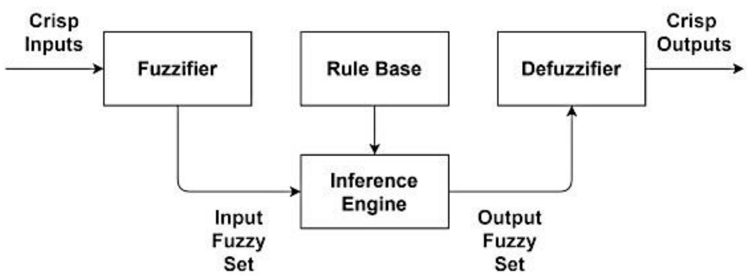


Figure 1 Fuzzy logic [6]

Fuzzy logics can be categorized based on their structures and the way they handle fuzzification, fuzzy inference engine, and defuzzification. In the case study of rainfall prediction, Mamdani FIS is the most commonly used type as this method is much more accurate than others. The versatility of fuzzy logic and fuzzy logics has found applications in many fields, including engineering, medicine, finance, and environmental science. In the domain of meteorology and, specifically rainfall prediction, the utilization of fuzzy logic has shown promise in addressing the inherent uncertainties and complexities associated with meteorological data.

2.2. Rainfall Occurrence in Malaysia

Rainfall is a meteorological phenomenon describing the amount of precipitation, typically water droplets, that falls from the atmosphere to the Earth's surface within a specific area and time frame. It is a vital component of the Earth's water cycle, essential for sustaining ecosystems, agriculture, and various human activities.

Rainfall occurs due to the condensation of water vapour in the atmosphere, forming clouds that eventually release precipitation when the droplets become large enough to fall under gravity. Factors influencing rainfall include atmospheric conditions like temperature, humidity, and air pressure, as well as geographical features such as mountains, oceans, and wind patterns.

As claimed by [7], the country as a whole does not have a uniform geographic distribution of climate change risk, as instance, the east coast of the Malaysian peninsula is more sensitive than the west. [8] emphasize that floods caused by intense rainfall have become a yearly occurrence in the states along Malaysia's east coast.

As studied by [9], the characteristics of rainfall in a few regions in peninsular Malaysia to investigate the effect of monsoon seasons on the monthly rainfall amount and proved that the analysis of rainfall events in Kota Bharu (east coast) is more intense as compared to Subang (central region) and Senai (south), especially during the northeast monsoon.

2.3. Fuzzy Logic in Predicting Rainfall

Studies exploring the application of fuzzy logic in rainfall prediction have highlighted its potential to enhance predictive accuracy. For instance, [10] developed a logic for rainfall prediction, integrating linguistic variables for meteorological parameters such as temperature, humidity, and atmospheric pressure. Their system demonstrated improved accuracy compared to traditional statistical methods.

Furthermore, fuzzy logic-based rainfall prediction models have shown adaptability to dynamic and changing environmental conditions. Studies have explored using adaptive fuzzy logic that dynamically adjusts their rules based on real-time data [11]. This adaptability enables the system to respond effectively to sudden changes in weather patterns or extreme rainfall events, enhancing the reliability of predictions.

Besides, a study by [4] applied the same approach of fuzzy logic to predict rainfall in a specific region in North-West Malaysia. They integrated meteorological data such as temperature, humidity, and atmospheric pressure as fuzzy variables and developed a fuzzy logic that demonstrated improved accuracy of up to 72% by calculating the performance indices.

In conclusion, the literature indicates that fuzzy logic offers a good framework for addressing the complexities and uncertainties in rainfall prediction. Their ability to handle imprecise data, incorporate expert knowledge, and adapt to changing conditions positions them as valuable tools in enhancing the accuracy and reliability of rainfall forecasting.

3. Methodology

3.1. Research Framework

In this study, the design process for the fuzzy model used the fuzzy logic toolbox in MATLAB based on FIS Mamdani-type. The toolbox is used to predict the rainfall rate using different input data. Below are the steps that have been performed throughout this study:

Step 1: Identify the inputs, output, linguistic variable, and its membership function.
Step 2: Fuzzification: Transforming inputs (real scalar value) into five linguistic variables (very low, low, moderate, high, and very high) in a particular fuzzy set value as shown in Table 1.

Table 1: Linguistic variable of input and output

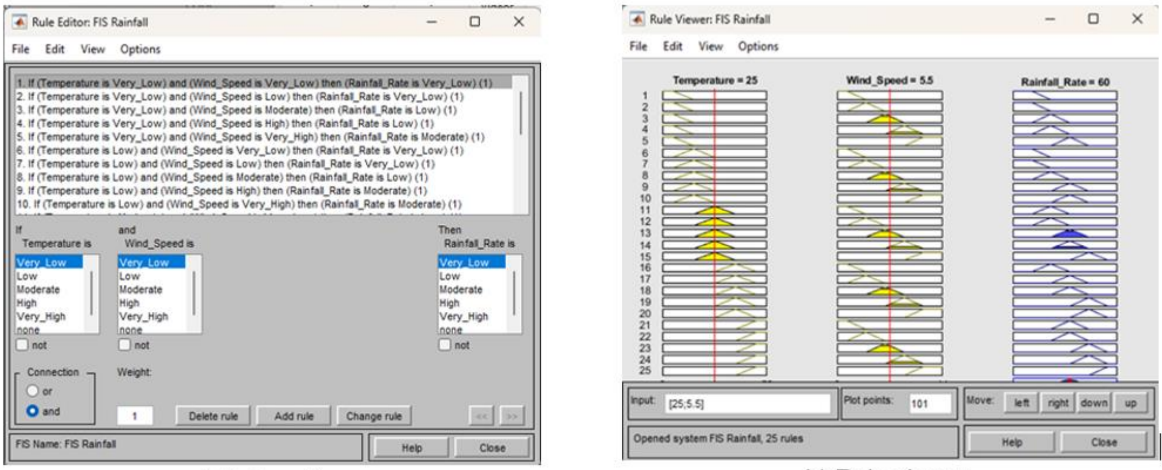
Function	Parameter	Units	Linguistic Variable
Input	Temperature	°C	Very Low
			Low
			Moderate
			High
			Very High
	Wind Speed	km/h	Very Low
			Low
			Moderate
			High
			Very High
Output	Rainfall Rate	mm	Very Low
			Low
			Moderate
			High
			Very High

Step 3: Fuzzy rules base: Construct the IF-THEN rule to predict the rainfall rate as in Table 2.

Table 2: Fuzzy IF-THEN rule for rainfall prediction [2]

IF	Temperature	AND	Wind Speed	THEN	Rainfall Rate
IF	Very Low	AND	Very Low	THEN	Very Low
IF	Very Low	AND	Low	THEN	Very Low
IF	Very Low	AND	Moderate	THEN	Low
IF	Very Low	AND	High	THEN	Low
IF	Very Low	AND	Very High	THEN	Moderate
IF	Low	AND	Very Low	THEN	Very Low
IF	Low	AND	Low	THEN	Very Low
IF	Low	AND	Moderate	THEN	Low
IF	Low	AND	High	THEN	Moderate
IF	Low	AND	Very High	THEN	Moderate
IF	Moderate	AND	Very Low	THEN	Low
IF	Moderate	AND	Low	THEN	Low
IF	Moderate	AND	Moderate	THEN	Moderate
IF	Moderate	AND	High	THEN	Moderate
IF	Moderate	AND	Very High	THEN	High
IF	High	AND	Very Low	THEN	Low
IF	High	AND	Low	THEN	Moderate
IF	High	AND	Moderate	THEN	Moderate
IF	High	AND	High	THEN	High
IF	High	AND	Very High	THEN	High
IF	Very High	AND	Very Low	THEN	Moderate
IF	Very High	AND	Low	THEN	Moderate
IF	Very High	AND	Moderate	THEN	High
IF	Very High	AND	High	THEN	High
IF	Very High	AND	Very High	THEN	Very High

Step 4: Inference engine: Predict the rainfall rate using MATLAB by inserting the input data. Figure 2 shows the interface of the inference engine in MATLAB.



a) Rule editor b) Rule viewer

Figure 2 Fuzzy inference engine

Step 5: Fuzzy aggregation: Combines the outputs of all the rules to produce a fuzzy output set.
Step 6: Defuzzification: Mapping the fuzzy numbers to real value by using the centroid defuzzification method that represents the center of gravity can be expressed as:

$$COG = \frac{\int_a^b \mu_A(x)\, xdx}{\int_a^b \mu_A(x)\, dx}.$$

4. Result and Discussion

4.1. Predicted Rainfall Rate

By using the fuzzy rule tabulated in Table 2, the prediction values of rainfall rate are computed using a fuzzy toolbox in MATLAB. Thus, Table 3 shows the comparison of the actual and prediction data at different temperatures and wind speeds.

Table 3: Comparison of the actual and predicted data of rainfall rate

Months	**Input**	**Output**				
		The amount of rainfall in a day (mm)				
	Average of temperature (°C)	Average of wind speed (km/h)	Actual	Linguistic Variable	Prediction	Linguistic variable
Jan 2020	25.8	3.7	37.0	Low	47.6	Low
Feb 2020	27.8	5.3	7.0	**Very low**	64.0	**Moderate**
Mar 2020	26.6	3.9	26.0	Low	49.2	Low
Apr 2020	27.7	3.9	48.0	Moderate	49.2	Moderate
May 2020	24.0	2.4	20.0	**Very low**	36.9	**Low**
Jun 2020	27.0	4.6	54.8	Moderate	55.2	Moderate
July 2020	27.3	6.0	82.0	High	66.5	High
Aug 2020	24.4	3.3	6.0	**Very low**	42.0	**Low**
Sept 2020	27.3	4.1	33.0	Low	50.8	Low
Oct 2020	28.2	4.5	26.0	Low	54.0	Low

Nov 2020	26.4	4.5	73.0	High	54.2	High
Dec 2020	26.0	3.1	39.2	Low	42.7	Low

4.2. Accuracy and Error

The output linguistic variables predictions that do not match the actual data are bolded in Table 3. Then, the performance of the fuzzy system can be determined by performing accuracy and error rate tests, given by the formula below [12]:

$$Accuracy = \frac{The\ number\ of\ data\ without\ bold}{Total\ number\ of\ data} \times 100\%\,,$$

$$Error = \frac{The\ number\ of\ data\ with\ bold}{Total\ number\ of\ data} \times 100\%\,.$$

The accuracy and error rate tests are computed as follows:

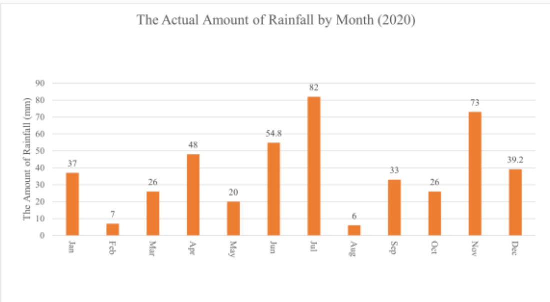
$$Accuracy = \frac{9}{12} \times 100 = 75\%\,,$$

$$Error = \frac{3}{12} \times 100\% = 25\%\,.$$

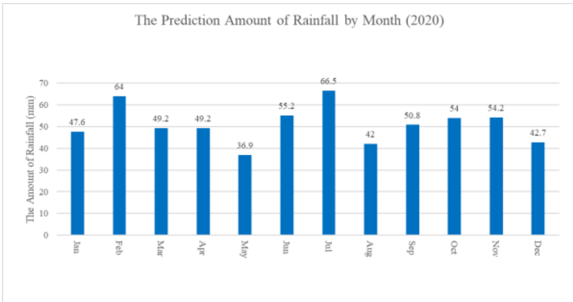
4.3. Graphical Representation of the Result

Based on Table 3, the graphs below were constructed to represent the analysis of the result. Figure 3 shows the graphical representation of the results. The first graph, (a), clearly illustrates the variability in rainfall throughout the year 2020, with notable peaks in July and November and significant lows in February and August. The second graph, (b), clearly illustrates the variability in predicted rainfall throughout the year 2020, with notable peaks in February and July and significant lows in May and August. The third graph, (c), shows the comparison between the actual and predicted rainfall rate.

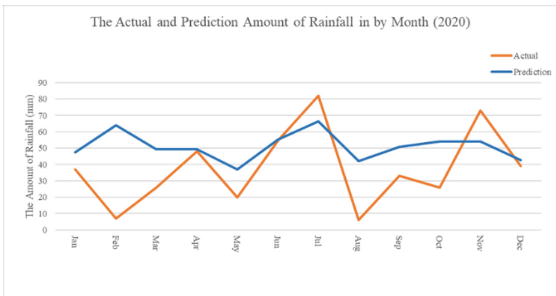
The fourth graph, (d), shows the relationship between rainfall rate and temperature. There is no clear linear correlation between temperature and rainfall rate. The last one, (e), the graph shows the relationship between rainfall rate and wind speed. Similarly, there is no clear linear correlation between wind speed and rainfall rate. The rainfall rate shows significant fluctuations across the range of wind speeds. The graph indicates that while there are notable peaks and troughs in rainfall rate at different wind speeds.



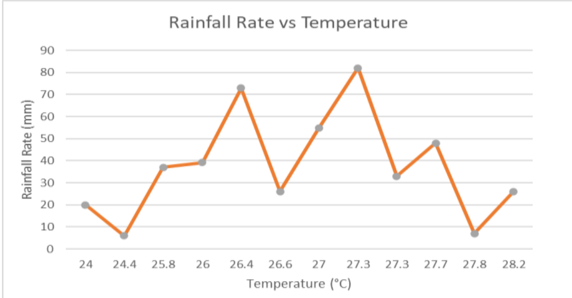
a) The graph of the actual rainfall rate in 2020



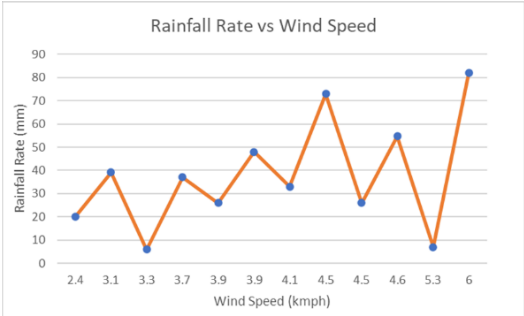
b) The graph of the predicted rainfall rate in 2020



c) The comparison between actual and predicted rainfall rate



d) The graph of actual rainfall rate versus temperature



e) The graph of actual rainfall rate versus wind speed

Figure 3: Graphical representation

Conclusion

In conclusion, this study has shown that applying fuzzy logic to the domain of rainfall prediction, with a specific focus on two key input parameters, temperature and wind speed, has yielded promising results in enhancing the accuracy of predictions. For this study, the actual weather parameters and rainfall data from the gauging station in Senai were gathered as the first step before applying the fuzzy model by [2] using a fuzzy toolbox in MATLAB. The parameters such as temperature and wind speed were considered as the inputs. The system used a Mamdani-type FIS, which is suitable for all decision-making processes that require human-like reasoning. The fuzzy-based system was tested monthly using data from 2020 to evaluate its predictive accuracy. The results showed that the system could predict rainfall rates with a high degree of accuracy, which is 75%. However, there is also an error obtained indicating that other factors, such as atmospheric pressure, humidity and dew point, significantly impact rainfall rate. The prediction model provides a reasonable approximation but does not fully capture the complexity of the actual data, highlighting the need to consider multiple variables in rainfall prediction. Therefore, for future study, all the weather parameters, which are temperature, wind speed, humidity, dew point, and atmospheric pressure need to be considered so that the result obtained will be more accurate.

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