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Temperature Prediction System in Kanyakumari District using Higher Order Stochastic Fuzzy Logic Model

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Abstract
Forecasting the weather is one of the most difficult tasks for meteorological services worldwide. Temperature is the most important weather factor affecting people and crops. Fuzzy logic has two main parts: a knowledge base and fuzzy reasoning. In this study, a Higher Order Stochastic Fuzzy Logic model was created and used to analyze temperature data from Kanyakumari. The model's steps included fuzzification, a stochastic process, and defuzzification. The predicted outputs were compared with actual temperature data to check the model's performance.
Keywords: *Prediction, Statistics Model, Meteorological Forecasting, Fuzzy Logic Model*

1. INTRODUCTION

Meteorological forecasting represents a critical and complex operational function performed by meteorological services globally. Weather data comprises atmospheric variables such as wind speed, relative humidity, surface pressure and earth skin temperature. A time series refers to a sequence of observations recorded at consistent intervals. Time series analysis encompasses techniques for extracting meaningful statistics and identifying characteristics from these data. Time series forecasting employs models to predict future values based on historical observations, facilitating the identification of patterns and the projection of future data points. Fuzzy logic provides an effective approach for addressing real-world and engineering challenges that involve imprecise or ambiguous information. Extensive research has addressed linear and nonlinear mathematical programming with fuzzy parameters, incorporating various modifications and focusing on multiple aspects.

The adoption of fuzzy set theory has increased significantly, demonstrating its applicability across diverse scientific disciplines. Fuzzy logic enables the representation of precise intervals through linguistic subsets, including terms such as low, medium, high, good, moderate, and poor. The degree of possibility and influence in fuzzy logic, resulting from ambiguous input variables, is often conceptualized as expert knowledge. This knowledge is typically conveyed through imprecise or ambiguous language rather than numerical values. Recognizing the existence and impact of vague and complex inputs, knowledge-based rules can be formulated as fuzzy statements or production rules. The present study applies these concepts to the forecasting of wheat production in India and specifically develops a fuzzy logic model to predict temperature in the Kanyakumari district.

2. LITERATURE REVIEW

Fuzzy logic was introduced in 1965 by Lotfi Zadeh through the development of fuzzy set theory. This framework allows for the representation of numerical intervals as linguistic categories, including low, medium, high, good, moderate, and poor. Recent applications of fuzzy set theory have focused on developing alternative models for rainfall prediction, particularly to address ambiguity and vagueness in meteorological data. For example, Halide and Ridd (2002) used fuzzy logic to predict local rainfall, achieving a root mean squared error of 319.0 mm, which was lower than errors from models using local rain or Niño indices. Wong et al. (2003) developed fuzzy rule bases with self-organizing maps (SOM) and backpropagation neural networks, creating a predictive rainfall model for Switzerland using spatial interpolation. Similarly, Karamouz et al. (2004) applied fuzzy rules and neural networks to forecast rainfall in western regions, observing comparable error rates between the two approaches.

Suwardi et al. (2006) implemented a neuro-fuzzy system to model wet-season tropical rainfall, reporting low root mean squared error values that indicate model reliability. Masoud et al. (2009) investigated stochastic linear programming with multi-objective functions, assuming probabilistic parameters followed a normal distribution. Bardossy et al. (1995) applied fuzzy logic to classify atmospheric circulation patterns, while Ozelkan et al. (1996) compared regression analysis and fuzzy logic for analyzing the relationship between monthly atmospheric circulation patterns and precipitation. Collectively, these studies demonstrate the effectiveness of fuzzy logic methods for modeling and predicting local rainfall data.

Fuzzy inference models achieved higher accuracy than the two multiple regression models evaluated by Brown-Brandle et al. (2003). These models also exhibited a lower error percentage relative to the linear multiple regression model developed by Hasan et al. (1995). According to Wong et al. (2003), the predictive performance of fuzzy rule-based rainfall models was comparable to that of models utilizing radial basis function networks that incorporated orographic effects. Model predictions were assessed by comparison with observed temperature data.

3. Area and Data of Study

The Kanyakumari district is located in the southernmost end of Tamil Nadu, India. The district lies between 77°15' and 77°36' east longitude and between 8°03' and 8°35' north latitude. It is bordered by Tirunelveli to the north and northeast and Kerala to the west, the Gulf of Mannar to the east, the Indian Ocean to the south, and the Arabian Sea to the west. The climate of Kanyakumari district in summer is hot from March to May. The monsoons of the district are from the month October to December and from June to September. This district is having a frequent rainfall because of northeast and southwest monsoon.

Figure 1 Kanyakumari District Map

4. RESULT AND DISCUSSION

The higher order stochastic fuzzy logic model utilizes four input variables and one output variable. The input variables include surface pressure, wind speed, temperature past two years, humidity, and earth skin temperature. The output variable is the predicted temperature. Each input variable is categorized into five linguistic terms: Very Low, Low, Normal, High, and Very High. The notations for these linguistic terms are provided in Table 1.

S.NO	Linguistic variables	Notations
1	Very Low	VL
2	Low	L
3	Normal	N
4	High	H
5	Very High	VH

Table 1: Notations of Linguistic variables

The Higher Order Stochastic Fuzzy Logic (HOSFL) model uniquely enables the integration of multiple influencing parameters, setting it apart from traditional temperature prediction approaches. By combining factors such as surface pressure, wind speed, humidity, temperature past two years, and earth skin temperature, HOSFL provides a nuanced and comprehensive estimate of temperature variation. Additionally, incorporating temperature records from the past two years further strengthens the model's predictive accuracy. The data for this analysis was sourced from the meteorological department of Kanyakumari district.

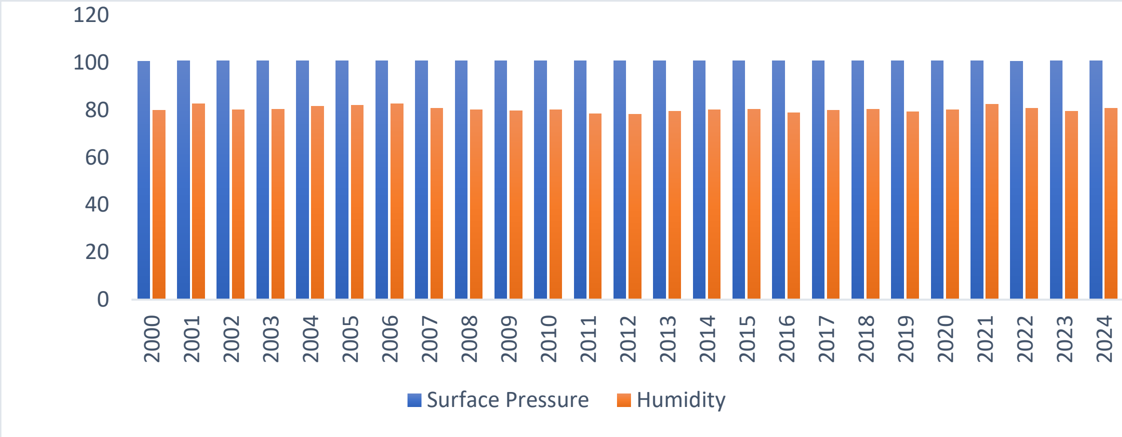

Figure 2: Year wise Surface Pressure and Relative Humidity of Kanyakumari District

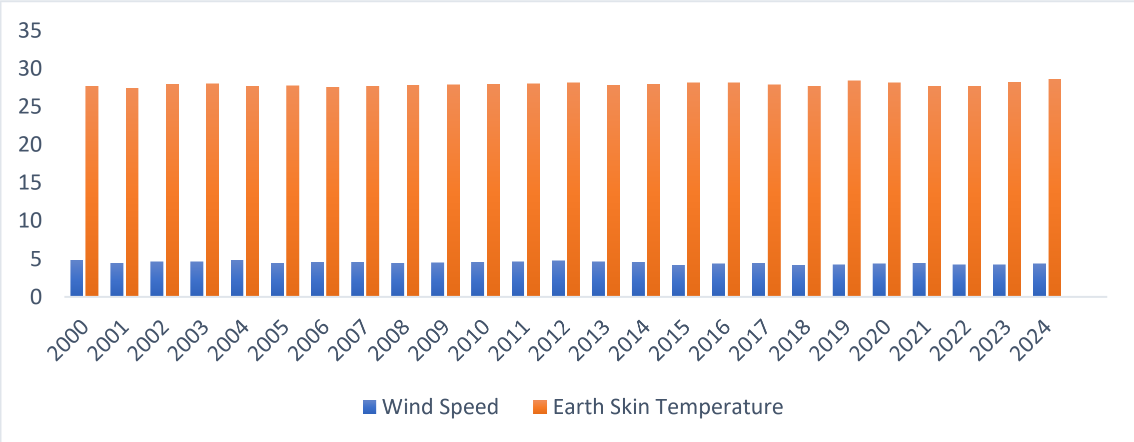

Figure 3: Year wise Wind Speed and Earth Skin Temperature of Kanyakumari District

Surface Pressure Equation:

Range of the surface pressure are from 100.65 pa to 100.88 pa, from figure 4.8. Surface Pressure takes the following membership values:

$$\mu^{SP}{}_{VL}(x) = \begin{cases} 0, & x < 100.65, x > 100.71 \\ \dfrac{x - 100.65}{100.68 - 100.65}, & 100.65 \leq x \leq 100.68 \\ \dfrac{100.71 - x}{100.71 - 100.68}, & 100.68 \leq x \leq 100.71 \end{cases}$$

$$\mu^{SP}{}_{L}(x) = \begin{cases} 0, & x < 100.69, x > 100.75 \\ \dfrac{x - 100.69}{100.72 - 100.69}, & 100.69 \leq x \leq 100.72 \\ \dfrac{100.75 - x}{100.75 - 100.72}, & 100.72 \leq x \leq 100.75 \end{cases}$$

$$\mu^{SP}{}_{N}(x) = \begin{cases} 0, & x < 100.73, x > 100.79 \\ \dfrac{x - 100.73}{100.76 - 100.73}, & 100.73 \leq x \leq 100.76 \\ \dfrac{100.79 - x}{100.79 - 100.76}, & 100.76 \leq x \leq 100.79 \end{cases}$$

$$\mu^{SP}{}_{H}(x) = \begin{cases} 0, & x < 100.78, x > 100.84 \\ \frac{x - 100.78}{100.81 - 100.78}, & 100.78 \le x \le 100.81 \\ \frac{100.84 - x}{100.88 - 100.85}, & 100.81 \le x \le 100.84 \end{cases}$$

$$\mu^{SP}{}_{VH}(x) = \begin{cases} 0, & x < 100.82, x > 100.88 \\ \frac{x - 100.82}{100.85 - 100.82}, & 100.82 \le x \le 100.85 \\ \frac{100.88 - x}{100.88 - 100.85}, & 100.85 \le x \le 100.88 \end{cases}$$

Wind Speed Equation:

The wind speed lies between the values 4.10 km/hr to 4.90 km/hr (Figure 4.9). Membership values of the wind speed are given below.

$$\mu^{WS}{}_{VL}(x) = \begin{cases} 0, & x < 4.10, x > 4.3 \\ \frac{x - 4.10}{4.2 - 4.10}, & 4.10 \le x \le 4.2 \\ \frac{4.3 - x}{4.3 - 4.2}, & 4.2 \le x \le 4.3 \end{cases}$$

$$\mu^{WS}{}_{L}(x) = \begin{cases} 0, & x < 4.25, x > 4.45 \\ \frac{x - 4.25}{4.35 - 4.25}, & 4.25 \le x \le 4.35 \\ \frac{4.45 - x}{4.45 - 4.35}, & 4.35 \le x \le 4.45 \end{cases}$$

$$\mu^{WS}{}_{N}(x) = \begin{cases} 0, & x < 4.40, x > 4.60 \\ \frac{x - 4.40}{4.50 - 4.40}, & 4.40 \le x \le 4.50 \\ \frac{4.60 - x}{4.60 - 4.50}, & 4.50 \le x \le 4.60 \end{cases}$$

$$\mu^{WS}{}_{H}(x) = \begin{cases} 0, & x < 4.55, x > 4.75 \\ \frac{x - 4.55}{4.65 - 4.55}, & 4.55 \le x \le 4.65 \\ \frac{4.75 - x}{4.75 - 4.65}, & 4.65 \le x \le 4.75 \end{cases}$$

$$\mu^{WS}{}_{VH}(x) = \begin{cases} 0, & x < 4.70, x > 4.90 \\ \frac{x - 4.70}{4.80 - 4.70}, & 4.70 \le x \le 4.80 \\ \frac{4.90 - x}{4.90 - 4.80}, & 4.80 \le x \le 4.90 \end{cases}$$

Relative Humidity Equation:

From Figure 4.8, it appears that the relative humidity ranges from 78 % to 83.2%. Relative humidity membership values are defined as follows:

$$\mu^{RH}{}_{VL}(x) = \begin{cases} 0, & x < 78, x > 79.2 \\ \frac{x - 78}{78.6 - 78}, & 78 \le x \le 78.6 \\ \frac{79.2 - x}{28.9 - 28.4}, & 78.6 \le x \le 79.2 \end{cases}$$

$$\mu^{RH}{}_{L}(x) = \begin{cases} 0, & x < 79, x > 80.2 \\ \frac{x - 79}{79.6 - 79}, & 79 \le x \le 79.6 \\ \frac{80.2 - x}{28.9 - 28.4}, & 79.6 \le x \le 80.2 \end{cases}$$

$$\mu^{RH}{}_{N}(x) = \begin{cases} 0, & x < 80, x > 82.2 \\ \dfrac{x - 80}{80.6 - 80}, & 80 \le x \le 80.6 \\ \dfrac{81.2 - x}{28.9 - 28.4}, & 80.6 \le x \le 81.2 \end{cases}$$

$$\mu^{RH}{}_{H}(x) = \begin{cases} 0, & x < 81, x > 82.2 \\ \dfrac{x - 81}{81.6 - 81}, & 81 \le x \le 81.6 \\ \dfrac{82.2 - x}{28.9 - 28.4}, & 81.6 \le x \le 82.2 \end{cases}$$

$$\mu^{RH}{}_{VH}(x) = \begin{cases} 0, & x < 82, x > 83.2 \\ \dfrac{x - 82}{82.6 - 82}, & 82 \le x \le 82.6 \\ \dfrac{83.2 - x}{28.9 - 28.4}, & 82.6 \le x \le 83.2 \end{cases}$$

Earth Skin Temperature Equation:

In Figure 4.9 EST values are respectively 27.4 °C and 28.6 °C. The membership values of EST ae shown below:

$$\mu^{EST}{}_{VL}(x) = \begin{cases} 0, & x < 27.4, x > 27.70 \\ \dfrac{x - 27.4}{27.55 - 27.4}, & 27.4 \le x \le 27.55 \\ \dfrac{27.70 - x}{28.9 - 28.4}, & 27.55 \le x \le 27.70 \end{cases}$$

$$\mu^{EST}{}_{L}(x) = \begin{cases} 0, & x < 27.6, x > 27.90 \\ \dfrac{x - 27.6}{27.75 - 27.6}, & 27.6 \le x \le 27.75 \\ \dfrac{27.90 - x}{28.9 - 28.4}, & 27.75 \le x \le 27.90 \end{cases}$$

$$\mu^{EST}{}_{N}(x) = \begin{cases} 0, & x < 27.80, x > 28.10 \\ \dfrac{x - 27.80}{27.95 - 27.80}, & 27.80 \le x \le 27.95 \\ \dfrac{28.10 - x}{28.9 - 28.4}, & 27.95 \le x \le 28.10 \end{cases}$$

$$\mu^{EST}{}_{H}(x) = \begin{cases} 0, & x < 28, x > 28.30 \\ \dfrac{x - 28}{28.15 - 28}, & 28 \le x \le 28.15 \\ \dfrac{28.30 - x}{28.9 - 28.4}, & 28.15 \le x \le 28.30 \end{cases}$$

$$\mu^{EST}{}_{VH}(x) = \begin{cases} 0, & x < 28.20, x > 28.60 \\ \dfrac{x - 28.20}{28.40 - 28.20}, & 28.20 \le x \le 28.40 \\ \dfrac{28.60 - x}{28.9 - 28.4}, & 28.40 \le x \le 28.60 \end{cases}$$

Temperature Equation of past two years:

The temperature varies between 27.45°C and 29°C. Let t-1 and t-2 be the past two years temperature. Then the membership values of temperature are defined as follows:

$$\mu^{Temp}{}_{VL}(x) = \begin{cases} 0, & x < 27.45, x > 27.85 \\ \dfrac{x - 27.45}{27.65 - 27.45}, & 27.45 \le x \le 27.65 \\ \dfrac{27.85 - x}{27.85 - 27.65}, & 27.65 \le x \le 27.85 \end{cases}$$

$$\mu^{Temp}{}_{L}(x) = \begin{cases} 0, & x < 27.75, x > 28.15 \\ \frac{x - 27.75}{27.95 - 27.75}, & 27.75 \leq x \leq 27.95 \\ \frac{28.15 - x}{28.15 - 27.95}, & 27.95 \leq x \leq 28.15 \end{cases}$$

$$\mu^{Temp}{}_{N}(x) = \begin{cases} 0, & x < 28, x > 28.40 \\ \frac{x - 28}{28.20. -28}, & 28 \leq x \leq 28.20 \\ \frac{28.40 - x}{28.40 - 28.20}, & 28.20 \leq x \leq 28.40 \end{cases}$$

$$\mu^{Temp}{}_{H}(x) = \begin{cases} 0, & x < 28.3, x > 28.7 \\ \frac{x - 28.3}{28.5 - 28.3}, & 28.3 \leq x \leq 28.5 \\ \frac{28.7 - x}{28.7 - 28.5}, & 28.5 \leq x \leq 28.7 \end{cases}$$

$$\mu^{Temp}{}_{VH}(x) = \begin{cases} 0, & x < 28.6, x > 29 \\ \frac{x - 28.6}{28.8 - 28.6}, & 28.98 \leq x \leq 28.8 \\ \frac{29 - x}{29 - 28.8}, & 28.8 \leq x \leq 29 \end{cases}$$

Temperature (t):

The output variable (temperature) can be classified into five linguistic terms which are very low, low, normal, high, very high depending on the input variables surface pressure, temperature past two years, wind speed, relative humidity and earth skin temperature. Now, we construct the temperature equations to each linguistic terms, in which T denotes the fuzzified temperature.

For very low Temperature,

$$T = \frac{x - 27.45}{0.24}, \quad 27.45 \leq x \leq 27.69$$
$$T = \frac{27.93 - x}{0.24}, \quad 27.69 \leq x \leq 27.93$$

For low Temperature,

$$T = \frac{x - 27.85}{0.24}, \quad 27.85 \leq x \leq 28.09$$
$$T = \frac{28.33 - x}{0.24}, \quad 28.09 \leq x \leq 28.33$$

For normal Temperature,

$$T = \frac{x - 28.20}{0.24}, \quad 28.20 \leq x \leq 28.44$$
$$T = \frac{28.68 - x}{0.24}, \quad 28.44 \leq x \leq 28.68$$

For high Temperature,

$$T = \frac{x - 28.55}{0.24}, \quad 28.55 \leq x \leq 28.79$$
$$T = \frac{29.03 - x}{0.24}, \quad 28.79 \leq x \leq 29.03$$

For very high Temperature,

$$T = \frac{x - 28.98}{0.24}, \quad 28.98 \leq x \leq 29.22$$
$$T = \frac{29.46 - x}{0.24}, \quad 29.22 \leq x \leq 29.46$$

The calculation of the predicted temperature for the year 2024 is illustrated below,

$$SP = 0.6667, WS = 0.8, RH = 0.1, EST = 0.2, \mu(t-1) = 0.1, \mu(t-2) = 0.95.$$

Applying the fuzzy rule,

If Surface Pressure is Normal and Wind Speed is Low and Relative Humidity is Normal and Earth Skin Temperature is Very High and Temperature (t-1) is Very High and Temperature (t-2) is Very High Then Temperature is Very High.

Firing Strength = = 0.1, Noisy Firing Strength = Firing Strength + Noise = 0.1 – 0.0045 = 0.0955.

The formula for calculating the prediction of temperature using centre of gravity is given by

$\frac{\sum_{l=1}^{k} \mu(U_l).U_l}{\sum_{l=1}^{k} \mu(U_l)}$, where U_l is the centroid of fuzzy output temperature, $\mu(U_l)$ is the noisy firing strength and k represents the number of elements in the sample.

Figure 4. represents the predicted temperature for the year 2002 to 2024.

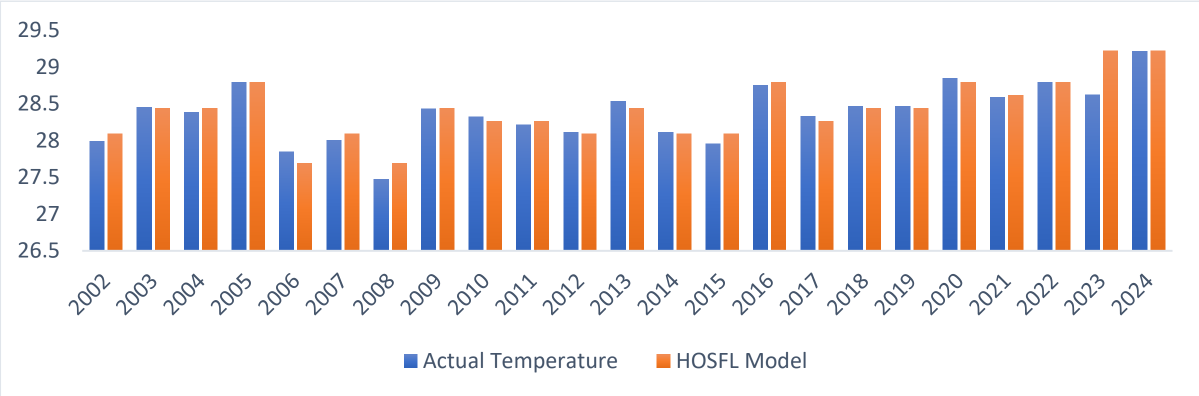

Figure 4: Predicted Temperature using HOSFL

5. CONCLUSION

In this study, an innovative Higher Order Stochastic Fuzzy Logic (HOSFL) model is developed to generate a balanced solution that accounts for simultaneous fuzziness and randomness. The proposed framework addresses the complexities of multi-objective decision-making where uncertainty stems from both stochastic variability and ambiguous parameters. This model is especially applicable to areas such as climate forecasting, manufacturing optimization, and complex decision environments that involve imprecise and uncertain data. Additionally, this framework can be extended to multi-objective geometric programming problems random variables follow different probability distributions and diverse types of fuzzy parameters are incorporated. Therefore, the HOSFL model offers a flexible, robust method that warrants further exploration for tackling various real-world challenges in science and engineering.

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