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PREDICTION OF RAINFALL EVENT IN COASTAL REGION WITH FUKYAMMA AND FUZZY EXPERT SYSTEM

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Abstract

Climate is one of the most important factors in agricultural production and livelihoods of the coastal zone of Tamil Nadu, India. In this study, nearly 10 years (2010-2020) of historical rainfall and temperature data from six weather stations located in the coastal zone were analyzed to assess their key characteristics influencing crop growth and yield. The results revealed that the rainfall in the coastal zone varied both spatially and seasonally. The total annual rainfall generally increased from the west to east and from north to south, resulting in rainfall difference up to 1000 mm year-1. In addition to spatial variations, the rainfall varied seasonally, with the wettest 25% of days during the wet season contributing to more than 70% of the annual total precipitation. The rainfall behavior was more varied, although it exhibited a general increase in the recent decade. The above inferences are taken into considerations for the proposed method. The proposed method involves the fuzzy logic for prediction of weather event after rainfall in the coastal region. For risk assessment, sub models have been designed for environmental, business and personal safety. The sub models have been coordinated with the fuzzy logic and the entire system acts as a closed loop, where the sub models responses according to the weather event predicted.

1. Introduction

In the 1960s, Lotfi Zadeh of the University of California at Berkeley proposed the concept of fuzzy logic for the first time. Zadeh was working on a computer programme that could understand natural language. While coastal

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Tamil Nadu receives about 60% of its annual rainfall, interior Tamil Nadu receives about 40-50% of annual rainfall during NEM season. During NEM season, Tamil Nadu generally receives rainfall due to the formation of trough of low, cyclonic circulation, easterly waves, low pressure area, depression and cyclonic storm over Bay of Bengal. (Balachendran et al. 2006). The special issue on agriculture in the coastal zone of Tamil Nadu, India is the major criteria of the work. Tirunelveli, Ramanathapuram, Thanjavur, Kanyakumari, and Tuticorin are some of the coastal regions have been taken and focuses on soil, water, and crop management in order to enhance agricultural output. One of the main goals of the paper is to come up with techniques for predicting weather events after rainfall for the purpose of crop protection and production. Too much rain around sowing might cause water logging and seedling failure; on the other hand, mild rain at sowing or other times throughout the dry season is helpful for crop growth and yield realization. The data collecting for coastal regions begins in 2010 and continues through 2020. With an elevation of 47 meters, Tirunelveli is located between 780 7' 30" E – 770 35' 30" E longitude and 8o 27'30" *S* - 8 0 2' 30" *S* latitude (Ramarajan et al.) With a height of 2 meters, Ramanathapuram is located at 9.3639° N longitude and 78.8395° E latitude. With an elevation of 88 meters, Thanjavur is located at 10.7870° N longitude and 79.1378° E latitude. Kanyakumari is located at 8.0883° N longitude and 77.5385° latitude, at a height of 30 meters. With an elevation of 4 meters, Tuticorin is located at 8.9063° N longitude and 78.1348° E latitude. The climate of Thanjavur can be termed as a fairly healthy one like other coastal areas. November to February is the pleasant months in a year with climate full of warm days and cool nights. From March onwards, the climate rather becomes sultry and the mercury shoot-up and reaches its peak by the end of May and June depending upon the onset of summer rain (Priya et al. 2018). Rainfall in Kanyakumari is due to the influence of both southwest and northwest monsoons. More amount of rainfall is coming from southwest monsoon. Annual rainfall over the district varies from 826 to 1456 mm. South-eastern part of Kanyakumari receives low rainfall (Raj et al.). The various theoretical experiments detailed elsewhere on this subject are susceptible to the vagaries of the weather, but they may not provide a representative picture of crop development and yield expectations. The goal of this research is to better understand temperature and rainfall changes and increase the value of experimental trials by determining if recent weather patterns in the coastal region may promote or inhibit crop development and production. A clear understanding of weather data would improve farmers in not just updating the crop calendar, but also in boosting crop yields, reducing crop failures, and preparing for irregular weather patterns and natural catastrophes brought on by global warming and climate change. The considerable unpredictability of rainfall, along with variances in the times and locations investigated, may explain the variations in the reported rainfall patterns. Whereas the studies mentioned above provide a reasonable picture of climate trends across Tamil Nadu, India as a whole, and to some extent the coastal region in particular, they largely ignore some of the climate characteristics that are critical for increasing cropping intensity in the coastal zone.

2. Data

Current weather reports of Tamil Nadu, India have been used for a period of 10 years (2010-2020). In the present study, Rainfall, temperature, wind speed, wind direction, cloud have been taken as the basic parameters.

2.1 Extreme Rainfall Events. The precipitation is comparatively higher between March and September, with average slopes of approximately 53 mm per day-1at Kanyakumari, Ramanathapuram, and 11 mm day-1 for the other stations. The total annual precipitation can reach up to 2000 mm at Tirunelveli in the west and 3000 mm at Kanyakumari in the eastern costal region. The annual rainfall differed in different five-year periods, with the period 2011-2017 being the driest at all stations, with a reduction of about 20% compared to other three periods.

The reduction is attributed to reductions of extreme rainfall events during that period. An average of 28% reduction in annual maximum 5-day precipitation was found in the south of the coastal zone (Tuticorin, Tirunelveli and Kanyakumari) between 2010 and 2017, which again indicates the reductions of extreme rainfall events in the recent years. The most significant events were observed at Kanyakumari, which recorded maximum precipitation more than 450 mm in 5 consecutive days. At Tirunelveli, maximum precipitation up to 400 mm was recorded in 5 days. The extreme events occurred at the other stations were from 250 to 300 mm. At a return period of 5 years, one-day maximum precipitation was generally larger than

150 mm. Extreme one-day precipitation reaches approximately 230 mm day-1 in the west and 350 mm day-1 in the east at a return period of 100 years.

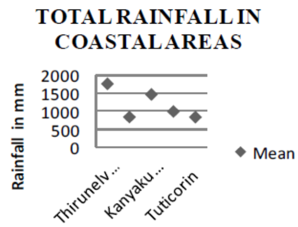
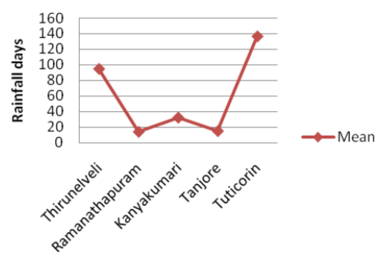


Table 3. The average value of the weather parameters.

Place	Rainfall	Cloud	Temperature	Humidity	Wind speed	Wind direction
Thanjavur	17.4	48.6	28	209	14.9	NE
Ramanatha puram	12.3	42.6	28	199	25.2	SW
Thirunveli	21.1	32.3	26	189	17.3	NW
Kanyakum ari	88.1	13.3	29	200	25.8	SW
Tuticorn	21.6	27.6	27	207	24.4	W



2.2 Rainfall Events During The Rabi Season. Depending on the seasonal distribution, quantity and timing, rainfall either contributes beneficially to agricultural production through reduced demand of irrigation and increased yield, or negatively increasing the risks of crop water logging. Based on the long-term rainfall records, it is evident that some sudden heavy rainfalls have occasionally taken place during the rabi season in the recent years, which might have negative effects on crop production. The 10-day accumulated precipitation was generally less than 50 mm in December, but could reach approximately 100 mm in January and February. Occurrences of sudden heavy rainfall increased in the early January during the decade 2010-2020, compared to the previous decade. In addition to quantity and timing of sudden rainfalls, it was also found that despite being the driest location, Tirunelveli may receive some of the heaviest sudden rainfall during the rabi season, such as 30 mm in the mid December and early January, 75 mm in the late January, 90 mm in the late February.

3. Methodology

Rainfall Event is generally confined with Flood, Heavy Flow, swathe of paddy field, Sunny (i.e. not rainy). Therefore, surface parameters have been considered in this study. Details of the FES including fuzzy sets, membership functions, fuzzy rule base are as follows:

3.1 Fukuyama Cluster Validity Indexing. Cluster Validity Indices Cluster validity indices are mathematical functions which are used to evaluate the quality of clustering of a clustering algorithm. popular validity index was proposed by Fukuyama and Sugeno by exploiting cohesion and separation. Here the first term is a compactness measure and the second term is a degree of separation between each cluster and the mean (V) of cluster centroids.

The Fukuyama and Sugeno (FS) minimization index is defined as

$$v_{fs}(u, f, x) = \sum_{i=1}^{C} \sum_{i=1}^{N} u_{ij}^{m} \| x_j - v_i \|^2 - \sum_{i=1}^{C} \sum_{i=1}^{N} u_{ij}^{m} \| v_j - \bar{v} \|^2$$

u_{ij}^{m} is the membership value of data x_k of class c_i

$$\bar{\bar{v}} = \frac{1}{c} \sum_{i=1}^{n} v_i$$

Where, x_j is the j^{th} data point v_i are cluster prototype (cluster center) c are number of cluster $\bar{v}$ is the grand mean of all data x_j Min $\{v_{fs}(u, f, x)\}$ is an optimal cluster numbers.

3.2 Fuzzy Expert Systems. Fuzzy Expert Systems (FES) are popular computing frameworks based on the concept of fuzzy set theory. Their success is mainly due to their closeness to human perception and reasoning, as well as their intuitive handling and simplicity, which are important factors for acceptance and usability of the systems Nauck et al. (1999). Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping provides a basis from which decisions can be made. The process of fuzzy inference involves formulating Membership Functions, Logical Operations, and IF-THEN rules. Because of its multidisciplinary nature, FIS are associated with a number of names, such as fuzzyrule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and fuzzy systems. There are two types of FIS that can be implemented in Fuzzy Logic: Mamdani-type and Sugeno-type. These two types of inference systems vary somewhat in the way outputs are determined, Mamdani et al. (1974) and Takagi-Sugeno (TS), Jang et al. (1997).

Fuzzy rule-based model (i.e. FIS), proposed in this paper is Mamdani-type inference. The major difference between Mamdani and Sugeno is the construction of the rule consequent. In the Mamdani, the consequents are linguistic (fuzzy sets) resulting in a transparent model, whereas the Sugeno employs linear combinations of the inputs allowing for approximation. The Mamdani FIS has many attractive features. First, it is suitable for engineering systems because its inputs and outputs are real valued variables. Second, it provides a natural framework to incorporate fuzzy IF-THEN rules from human experts. Third, there is much freedom in the choices of fuzzifier, fuzzy inference engine, and defuzzifier, so that we may obtain the most suitable fuzzy logic system for a particular problem

3.2.1 Fuzzy Sets and Membership Functions. The basic idea of fuzzy sets is easy to grasp. Hence an object with membership degree 1 absolutely belongs to the set and those with 0 membership values again absolutely do not belong to the set but objects with intermediate membership degrees belong to the same set partially. The greater is the membership degree the more the object belongs to the set. The parameters that are depicted, as fuzzy sets in this paper are District (DI), Rainfall (RF), Temperature (TE), Humidity (HU), wind speed (WS), Wind Direction (WD) And Cloud Status (CS). The basic structure of the fuzzy sets, which has been used in this study, is shown in Table 1. In Table 1, RF (°C /hour) is characterized by three categories, whether the atmosphere Rainfall is Low, Moderate and High. The WD have been classified into NW, W, SW, NE. Similarly, others have been defined. These fuzzy sets have been created from the qualitative study of Rainfall Event and quantitatively defined by membership functions. These functions contain a specified domain of the value of the system input and have been shown in Figure 2 in the form of singleton.

Table 1.

Parammeter	District	Rainfall (mm)	Temperature (◦C)	Humidity	Wind Speed (mph)	Wind Direction	Cloud Status (okta)
1	Tirunelveli	Low	Low	Low	Low	NW	Scattered
2	Ramanathapuram	Moderate	Moderate	Moderate	Moderate	W	Partily cloudy
3	Thanjavur	High	High	High	High	SW	Partly Sunny
4	Kanyakumari					NE	Overcast Cloud
5	Tuticorin						

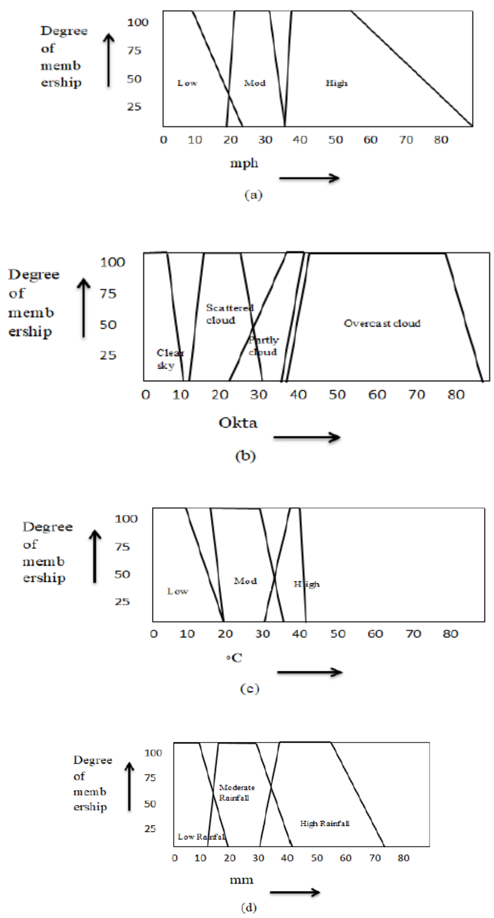


Figure 2. The above results (a), (b), (c) and (d) are the simulations of the

membership functions obtained for the parameters wind speed (mph), cloud status (Okta), temperature (◦C) and rainfall (mm) respectively.

3.2.2 Fuzzy Rule Base. The rule base is a set of rules of the If-Then form. The If portion of a rule refers to the degree of membership in one of the fuzzy sets. The Then portion refers to the consequence, or the associated system output fuzzy set. Let *a*, *b*, *c*, *d* and e be sets of antecedents where *a*, *b*, *c*, *d*, and *e* are different fuzzy sets, whereas *X* be sets of consequences. The rules are applied in this manner: If (ai and bi and ci and di and ei) Then (X_j)

(1)

where in equation (1), 'i' is the variable, which belongs to that fuzzy set, and '*j*' is the maximum possible consequences in terms of very low, low, medium, high and very high probability of fog. The total number of rules is the product of the number of fuzzy sets in the system. In other words, the number of rules equals all possible permutations of categorized system inputs. From Table 1, Five sets are associated with the DI, three with the RF, three with the TE, three with the HU, three with WS, four with WD and three with the CS. The total number of rules that completely define the set then is $5 \times 3 \times 3 \times 3 \times 4 \times 4 = 6480$. These rules are defined in such a way that if six parameters are RF, TE, WS, WD and CS with high, low, high, low, now and Scattered respectively then there will be a very high probability of Flood formation. In a similar way, other rules have been defined. These rules are shown in tabular form in Table 2. The prediction of Rainfall Event is based on the degree of the membership of the inputs from the evaluation of a set of predefined rules. The strength of a rule is derived from the corresponding degrees of membership of the inputs. Since an input can be a member of multiple fuzzy sets, then another set of rules involving these sets can be applied. The higher degrees of membership result in corresponding rules, which have more strength in the final computational process. In particular, to be able to deploy fuzzy logic in a rule-based system, one needs to be able to handle the operators 'AND' and 'OR' and carry out inferencing on the rules. Therefore, we need to be able to perform the intersection and union of two fuzzy sets. To calculate the intersection of a pair of fuzzy sets there are a family of functions, triangular norms or *T*-norms, that meet certain requirements such as monotonicity, commutativity and associativity and the intersection of a fuzzy set.

Table 2.

Rule no.	District	Rainfall	Temperature	Humidity	Wind Speed	Wind Direction	Cloud Status	Rainfall Event
75	Thirunelveli	High	Low	High	Low	NW	Scattered	Flood
654	Kanya kumari	High	Low	High	Moderate	W	Partly Cloud	Heavy Flow
1789	Ramanatha puram	High	Low	High	Low	NW	Partly Sunny	Flood
4009	Thanjavur	Low	Low	High	Low	NW	Overcast Cloud	swathe of paddy field
5087	Tuticorin	Moderate	Low	Moderate	Low	NW	Scattered	Flood

3.3 MAMDANI-FIS. Mamdani introduced the fuzzification/inference/ defuzzification scheme and used an inference strategy that is generally mentioned as the max-min method. This inference type is a way of linking input linguistic variables to output ones in accordance with the generalized modules, using only the MIN and MAX functions (as T-norm and S-norm (or T-conorm) respectively). It allows achieving approximate reasoning (or interpolative inference). The main feature of such a type of FIS is that both the antecedents and the consequents of the rules are expressed as linguistic constraints. A fuzzy set A in X is defined as a set of ordered pairs.

$$A = \{(x, \mu_A(x)) \mid x \in X\} \tag{1}$$

where $\mu_A(x)$ is called the membership function (MF) for the fuzzy set A. The MF maps each element of X to a membership grade (or membership value) between zero and one.

The intersection of two fuzzy sets A and B is specified in general by a function.

$$T : [0, 1]^{*}[0, 1] \to [0, 1],$$

which aggregates two membership grades as follows:

$$\mu A_1 B(x) = T(\mu A(x), \mu B(x)) = \mu A(x) \delta \mu B(x) \tag{2}$$

where is a binary operator for the function T. These classes of fuzzy intersection operators are usually referred to as T-norm operators. Like T norm intersection, the fuzzy union operator is specified in general by a function

$$S : [0, 1]^{*}[0, 1] \to [0, 1],$$

which aggregates two membership grades in the following fashion:

$$\mu_{AUB}(x) = S(\mu_A(x), \mu_B(x)) = \mu_A(x) K \mu_B(x) \tag{3}$$

where K is the binary operator for the function S. This class of fuzzy union operators is often referred to as T-conorm (or S-norm) operators. When a crisp output is required, the resulting fuzzy set has been defuzzified by means of several strategies such as centroid, mean of maximum, linear, bisector of area defuzzifier, among which the yagers defuzzification gave best results and defined as:

4. Results and Discussion

However, the success of this technique mainly depends on the accurate estimates of the input variables and skill in tuning FES. Careful construction of the membership functions as well as the rule base is necessary. Though the technique is developed for probability of occurrence of Rainfall Event, the forecast can be updated during the subsequent observation hours. The iterative process of designing the rule base, choosing a defuzzification algorithm, and testing the system performance was repeated several times with different shapes of fuzzy membership function.

4.1 Performance of FES for Rainfall Event. There are several different methods that can be used to forecast. The method a forecaster chooses depends upon the experience of the forecaster, the amount of information available to the forecaster, the level of difficulty that the forecast situation presents, and the degree of accuracy or confidence needed in the forecast. We have tested our FES model with the developed dataset using persistence method of estimating input values. Four categorizations of the predictions derived from the constructed model are used to calculate the accuracy, precision, and recall values. "Events anticipated in exact, "Events anticipated in imprecise, "Events anticipated incorrect," and" Events anticipated correct" are the four categories.

Accuracy can be calculated as,

$$\text{accuray} = \frac{[\text{events anticapted in exact} + \text{events anticapted correct}]}{[\text{events anticapted in exact} + \text{events anticapted in imprecise} + \text{events anticapted incorrect}]} = 89\%$$

Precision can be calculated as,

$$\text{precision} = \frac{[\text{events anticapted in exact}]}{[\text{events anticapted in imprecise}]} = 94\%$$

Recall value can be calculated as,

$$\text{Reecall Value} = \frac{[\text{events anticapted correct}]}{[\text{events anticapted correct} + \text{events anticapted incorrect}]} = 83\%$$

Thus, the accuracy, precision and the recall value can be calculated as 89%, 94% and 83%. Overall, both annual maximum precipitation and daily temperature generally increased over the years in the coastal zone, associated with longer durations of consecutive wet period. It was found that precipitation exhibits spatial and seasonal variations in the coastal zone.

5. Conclusion

Fuzzy Expert systems can be applied in a vast number of meteorological application areas. An important advantage of the fuzzy expert system is that the knowledge is expressed in the form of easy to-understand linguistic rules. If we have large amount of data, the fuzzy expert system can be taught with other adaptation techniques. Data collecting and acquisition are initial and one of the most critical parts of expert systems computations. Automated data collecting systems must be available rather than using human manual inputs. Local data collection is very important if we want to make very precise forecasting. This paper addresses the issue of fuzzy rule-based modeling from available data. The goal is achieved by modifying the rule antecedents to produce a flexible and interpretable output space. The present study indicates a solution for predicting the probability of the formation of Rainfall Event by formulating the problem within a fuzzy framework. The Temperature and the Humidity spread have been the most important parameters for the Rainfall Event.

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