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ARTIFICIAL INTELLIGENCE (AI) MODEL: ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS) FOR DIAGNOSIS OF COVID-19 INFLUENZA

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Abstract. The COVID-19 influenza became a curse on the world. It has been around for two years, so no one needs to make a big introduction of it. It has became a significant challenge around the world. Owing to this, we made dynamic networks using an amalgamating of fuzzy logic and neural networks for the prediction of sufferers of COVID-19. These hybrid networks serve for the assessment of the COVID-19 victims and usefully serve for the assessment of the medical resources needed for future victims. This manuscript proposed Sugeno Adaptive Neuro-Fuzzy Inference System (SANFIS) prediction model for COVID-19 prediction in Andhra Pradesh, India. We gathered data on positive COVID-19 sufferers in Andhra Pradesh for this purpose. The data can be separated into three categories: training set, testing set and checking set. We have utilized Root Mean Square Deviation (RMSD) for prediction precision. If the prediction model has a lower RMSD value, it is regarded as the best forecast. In this study, we concluded that the 3 Triangular MFns for each input were excellent with the extreme precision for all of the districts based on our expertise. In the end, we deployed seven SANFIS replicas in Andhra Pradesh, but we discovered that SANFIS6 and SANFIS7 provided excellent COVID-19 prediction results. These findings will assist the government, healthcare agencies, and medical organizations in planning for future COVID-19 victims' medical requirements. These sorts of Sugeno Adaptive Neuro-Fuzzy Inference System (SANFIS) prediction models based on Artificial Intelligence (AI) will be beneficial in overcoming the COVID-19.

Keywords: COVID-19, Sugeno adaptive neuro-fuzzy inference system (SANFIS), neural networks (NN), root mean square deviation (RMSD), membership function, artificial intelligence (AI)

1 INTRODUCTION

The COVID-19 was found for the first time in Wuhan, China, at the end of 2019 December [1]. The World Health Organization (WHO) revealed on March 11, 2020 that the new coronavirus (COVID-19) might be recognized as a pandemic. After then, the virus triggered a global catastrophe that endangered not only public health and well-being, but also the global financial system [2]. COVID-19 is illness by the disease SARS-CoV2, which stands for "Severe Acute Respiratory Syndrome Coronavirus2" and is transmitted from person to person [3]. Since then, it has outspread throughout the world and it has been a plague on the world. So far, the virus has infected more than 212 milion people worldwide, and it persists to afflict people in this manner. All the countries are affected by COVID-19, but India is also one of the most affected countries all over the world. The countries most adversely affected by COVID-19 include the United States, India, Brazil, the United Kingdom, and Russia, among many others. The worldwide capital markets and international transportation are crumbling as a result of the COVID-19 outburst. COVID-19 has been recorded in over 4 million people in the United States, with over 600 000 human deaths. In India, the number of reported cases has exceeded 3.33 million, with 440 000 victims deceased owing to COVID-19. In Brazil, the United Kingdom, and Russia, respectively, 2 million instances were exceeded, 500 000 patients died, 7.3 milion cases were reported, and more than 100 000 perished, 7.1 milion cases were registered, and 190 000 sufferers died [4].

In this study, we researched Andhra Pradesh, India to control the perilous situation of pervasive COVID-19 prediction. In India, Andhra Pradesh is one of the most affected states due to the outbreak, the number of reported cases has exceeded 2 milion, more than 1.9 milion sufferers fully recovered and roughly 13 thousand people passed away [5]. Since this pandemic came, people have been following precautionary rules like wearing masks, using sanitizer, and maintaining social distance. Lockdowns have been implemented in a number of states in India. Most states lag behind economically in all sectors like industry, agriculture, etc. The education system was primarily impacted as a consequence of COVID-19. Many students have faced numerous challenges as a result of the educational system's breakdown. Vaccination campaigns were carried out throughout India. During the first wave of COVID-19, the daily positive cases have ensued fewer than 10 000, but in the second wave, it peaked over 20 000 each day since the information was missing and human dissemination was not understood and neglected. With the second phase of the influenza, people lost their lives owing to respiratory troubles because of a scarcity of oxygen sources. The second wave of COVID-19 wreaked havoc on Andhra Pradesh. In Andhra Pradesh, where all of these precautionary rules are being implemented, the impact of COVID-19 is not diminishing. Keeping all of this in mind, many researchers have been conducting research on COVID-19 prediction throughout the world.

1.1 Related Work

Niazkar and Niazkar [6] utilized artificial neural networks to predict the COVID-19. Ly [2] deployed an adaptive neuro-fuzzy inference system for defeating COVID-19 through a prediction. Neural networks with prey predator algorithms for COVID-19 prediction have been implemented by Hamadneh et al. [7]. Deep learning and Holt-Trend algorithms have been devised as a result of high COVID-19 infections in Saudi Arabia, Italy, and Spain by Aldhyani et al. [8]. COVID-19 in the US caused excessive fatality rate. Behnood et al. [9] utilized the Adaptive Neuro-Fuzzy Inference System (ANFIS) model and Virus Optimization Algorithm (VOA) to reduce the risk of fatality. In order to anticipate daily positive cases, deaths, and recovery cases, Bodapati et al. [10] employed Long Short Term Memory (LSTM) networks. The Adaptive Neuro-Fuzzy Inference System was built by Deif et al. [11] to predict the COVID-19 using blood test results. Iwendi et al. [12] were exploring on COVID-19 patients using an Adaptive Neuro-Fuzzy Inference Model to forecast COVID-19. To combat the issue of congestion in railway stations, Alawad et al. [13] used ANFIS networks. ANFIS nets have been used by Al Ali et al. [14] to detect COVID-19 positive patients.

1.2 Motivation and Contribution

According to our expertise in neural networks and fuzzy logic, these are confined for diagnosing COVID-19 positive patients. To control this perilous situation in Andhra Pradesh, the Sugeno Adaptive Neuro-Fuzzy Inference System (SANFIS) network was considered which is the union of fuzzy logic and neural networks. By investigating multiple membership functions on SANFIS models which include Triangular MFns, Trapezoidal MFns, Generalized Bell MFns, Gaussian MFns, Sigmoidal MFns, and Pi MFns it was concluded that the triangular membership function obtained better predictions to compare with others in terms of forecasting the future victims of COVID-19 with more accuracy. The best results were obtained by increasing the number of membership functions for each input, what tends to consume more time, so three MFns were more effective to predict the positive cases with less time and high precision. The recommended method is designed by using three triangular membership functions for each input and a linear membership function for the output, which makes it simpler to assess the positive cases of the infection. These seven predicting models anticipate positive individuals and are valuable for medical care; many people lost their professions as a result of the crisis, therefore these predictions will assist them in returning to work, will be helpful to make farmers re-farm, assisting in the revitalization of a sagging economy, and these predictions are quite beneficial in returning to the usual circumstances. The recommended model is not restricted to COVID-19 predictions and it can also be used to diagnose various epidemics, forecast time series data, handle non-linear complicated problems, and it is also useful for forecasting stock markets, oil prices, electricity consumption, agricultural production, and so on.

2 DATA AGGREGATION PROCESS

We have accumulated everyday COVID-19 positive sufferers from 13 Andhra Pradesh districts. From January to February 2021 (data gathered over 60 days), COVID-19 positive sufferers were gathered from the source of the Department of Health, Medical, and Family Welfare of the Government of Andhra Pradesh. Data pertained to COVID-19 positive patients were later partitioned into a training set (60 % data), testing set (20 % data), and checking set (20 % data) for specific forecasting. Due to the significant discrepancy in confirmed cases, all districts were considered in Andhra Pradesh to anticipate COVID-19. Upon analyzing all districts in Andhra Pradesh, a massive number of positive cases ensued in Chittoor, Guntur, Visakhapatnam, East Godavari, and West Godavari.

2.1 Explanation of Data

MS-Excel was used to interpret the gathered data, since it enables a wide range of options for interpreting and conducting analytical techniques. The results of this analysis, as well as the data intervals utilized in all districts, are listed in Table 1.

Districts	**Data Period in the Year 2021**	**Total Number of Positive Cases**
Anantapur	01 January to 01 March	421
Chittoor	01 January to 01 March	1 348
East Godavari	01 January to 01 March	762
Guntur	01 January to 01 March	976
Kadapa	01 January to 01 March	391
Krishna	01 January to 01 March	1 135
Kurnool	01 January to 01 March	325
Nellore	01 January to 01 March	389
Prakasam	01 January to 01 March	186
Srikakulam	01 January to 01 March	270
Vishakapatnam	01 January to 01 March	861
Vizianagaram	01 January to 01 March	142
West Godavari	01 January to 01 March	484

Table 1. COVID-19 positive cases in Andhra Pradesh, from January 1 to March 1, 2021

COVID-19 has afflicted all districts, according to the data, but Chittoor, Krishna, Guntur, Visakhapatnam, and East Godavari are the most hardly hit.

3 MATERIALS AND METHODS

3.1 Preliminaries

Adaptive Networks. Adaptive networks are also considered as neural networks, a modern strategy to enhance the accuracy of pattern recognition and predictions. The network frame comprises inputs and outputs that have a customized parameter for their functionality. All interconnections between the nodes are direct connections.

Fuzzy Inference System. Fuzzy Inference System (FIS) is the most recognizable architecture based on the fuzzy rules and logic. It is the ideal architecture for the time-series prediction, recognition of patterns and data categorization. The primary architecture includes three layers: defining membership, determining fuzzy rules, and defuzzification.

3.2 Development of SANFIS Architecture

Sugeno Adaptive Neuro-Fuzzy Inference System (SANFIS) is an integration of Adaptive Networks with Fuzzy Inference. It is a supervised learning technique that may be used to implement fuzzy inference systems in adaptive networks [9]. This approach is an extension of the TSK fuzzy system; it employs If-Then fuzzy rules to establish the information between the system's input and output variables [9]. Each fuzzy rule has two parts: a predecessor and consequences, the former of which is stated as fuzzy inputs and the latter as a concatenation of crisp input variables. Moreover, using AND logistic operator, the fuzzy inputs in the predecessor section of a rule are aggregated with each other [9]. The ANFIS framework encompasses both the Sugeno and Tsukamoto fuzzy models [15]. RBFNNs (Radial Basis Function Neural Networks) are a form of artificial neural network used to solve function assessment problems; they are functionally related to the Sugeno Fuzzy Model's ANFIS architecture [15].

Fuzzification Layer, Fuzzy Rule Layer, Normalization Layer, Defuzzification Layer, and Output Membership Layer are the 5 stages that make up the SANFIS framework [11]. The following is an overview of the SANFIS framework with two membership functions utilized:

Stage 1. That is what it signifies in the initial stage. For obtaining fuzzified values, the Fuzzification layer consists of all adaptive nodes with membership functions:

$$O_{l_1,j} = f_{A_j}(x), \quad \text{for } j = 1, 2. \tag{1}$$

The membership function implemented in the Fuzzification layer is $f_{A_j}(x)$ in this stage. There are several sorts of membership functions accessible, but when compared to other membership functions, the Generalized Bell membership function produces the finest outcomes.

Stage 2. This stage's nodes are labeled as Π. At this point, the findings are equivalent to the total of all input signals. T-norm operators such as fuzzy AND can be used to assess this product:

$$O_{l_2,j} = W_{l_2,j} = f_{A_j}(x) * f_{B_j}(y), \quad \text{for } j = 1, 2. \tag{2}$$

Stage 3. This stage's nodes are labeled as N. The output is calculated in this layer using the proportion of the j^{th} output in Stage 2 to the sum of all outputs in Stage 2:

$$O_{l_3,j} = \bar{W_{l_3,j}} = \frac{W_{l_2,j}}{\sum_{j=1}^{2} W_{l_2,j}}, \quad j = 1, 2. \tag{3}$$

The outputs at this stage are normalized values.

Stage 4. Nodes are adaptive nodes having a node function at this stage:

$$O_{l_4,j} = \bar{W_{l_3,j}} * f_j = \bar{W_{l_3,j}}(p_j x + q_j y + r_j). \tag{4}$$

Here, $\bar{W_{l_3,j}}$ normalized output and $\{p_j, q_j, r_j\}$ is the parameter in this stage.

Stage 5. This stage contains only one node which represents the predicted output labeled as $\sum$ and assesses the predicted output as the summing of all input signals.

$$\text{Predicted Output} = O_{l_5,1} = \sum_j \bar{W_{l_3,j}} * f_j. \tag{5}$$

All gathered COVID-19 data is sent from the SANFIS architecture at each of these stages. This architecture is particularly efficient for more precisely assessing the COVID-19.

3.3 Flow Diagram of SANFIS Architecture

The SANFIS architecture can be depicted as a flow diagram in Figure 1.

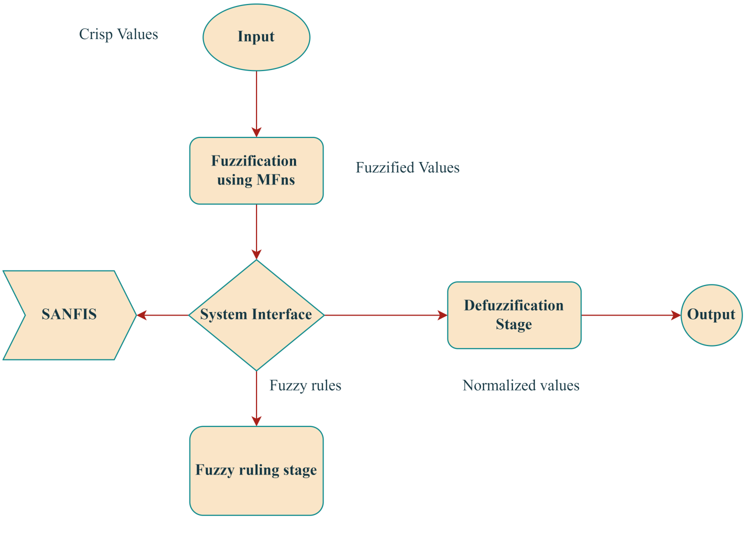


Figure 1. Structural outline of SANFIS architecture

4 EXPERIMENTAL SIMULATIONS AND VALIDATIONS

The proposed method in this study was developed using the COVID-19 positive infections as inputs and outputs in Matrix Laboratory (MAT Lab). To examine the widespread of COVID-19, we used the existing technology Neuro-Fuzzy designer in MATLAB R2020b software. The suggested approach was initiated by employing the grid partition technique and a SANFIS design with a triangle membership function. To model the technique, data can be considered as training, testing, and checking sets. Testing set is considered to test the capability of trained SANFIS model and checking set is employed to analyse the over fitting of the model during training procedure. Based on our expertise with MFns selection, the fuzzy inference system (FIS) was developed by employing three membership functions for each input and a linear MFn for the output as well as fuzzy rules were shown in Figure 2, in order to provide more exact forecasts within a short duration. Furthermore, while analyzing linear and constant MFns for output layer, linear MFn was demonstrated to achieve superior results with less inaccuracy than constant MFn. Finally, in order to alleviate the RMSD error, the backpropagation technique was employed to optimise the randomly chosen parameters throughout the training phase. The vector representation of inputs X and their respective outputs $\bar{X}$ used in the proposed technique is shown below.

$$X = \begin{bmatrix} x_1 & x_2 & x_3 & \dots & x_{n-1} \\ x_2 & x_3 & x_4 & \dots & x_n \\ x_3 & x_4 & x_5 & \dots & x_{n+1} \\ x_4 & x_5 & x_6 & \dots & x_{n+2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix}, \tag{6}$$

$$\bar{X} = \begin{bmatrix} x_n \\ x_{n+1} \\ x_{n+2} \\ x_{n+3} \\ \vdots \\ \vdots \end{bmatrix}. \tag{7}$$

4.1 MFns Employed in Our SANFIS Model

In the existing MAT Lab Neuro-Fuzzy Designer, various types of membership functions are accessible. After exploring through all membership functions like Gaussian, Bell, Sigmoidal, etc., Triangular MFns were used as the membership function for input variables in the proposed research work; a schematic illustration of triangular MFns is exhibited in Figure 3.

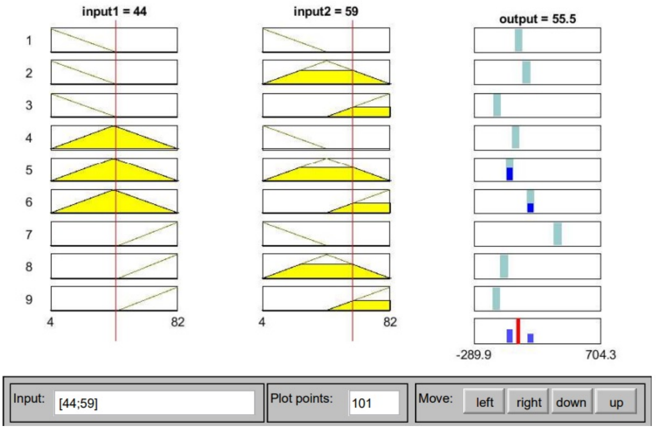


Figure 2. Fuzzy rules applied for initial SANFIS model

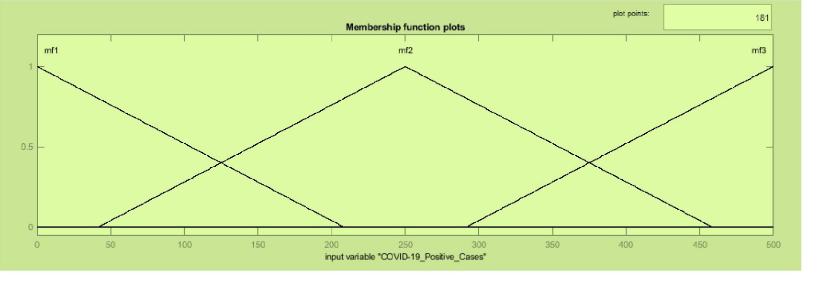


Figure 3. Triangular MFns used for input variables

The ANFIS MAT Lab toolbox contained constant and linear MFns for output prediction. Linear MFn was used in this study to obtain an accurate performance. The following is a pictorial representation of linear MFns in Figure 4.

4.2 SANFIS Design

The Sugeno Adaptive Neuro-Fuzzy Inference System (SANFIS) framework for two inputs and one output with three membership functions utilized is shown in Figure 5.

After performing the five stages, we computed the Root Mean Squared Deviation (RMSD) error for the finest prediction of COVID-19. The formula for Root Mean Squared Deviation (RMSD) is as follows:

$$RMSD = \sqrt{\frac{\sum_{j=1}^{N}(AO_j - PO_j)^2}{N}}. \tag{8}$$

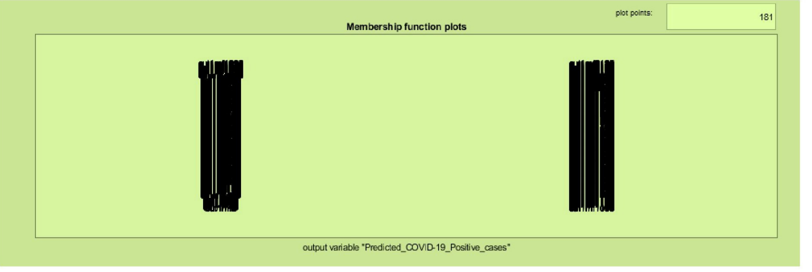


Figure 4. Linear MFns used for output variables

Here,

- AO_j: j^{th} actual output,
- PO_j: j^{th} predicted output, and
- N: Total number of data.

Following the end of the forward phase, we included a backpropagation technique

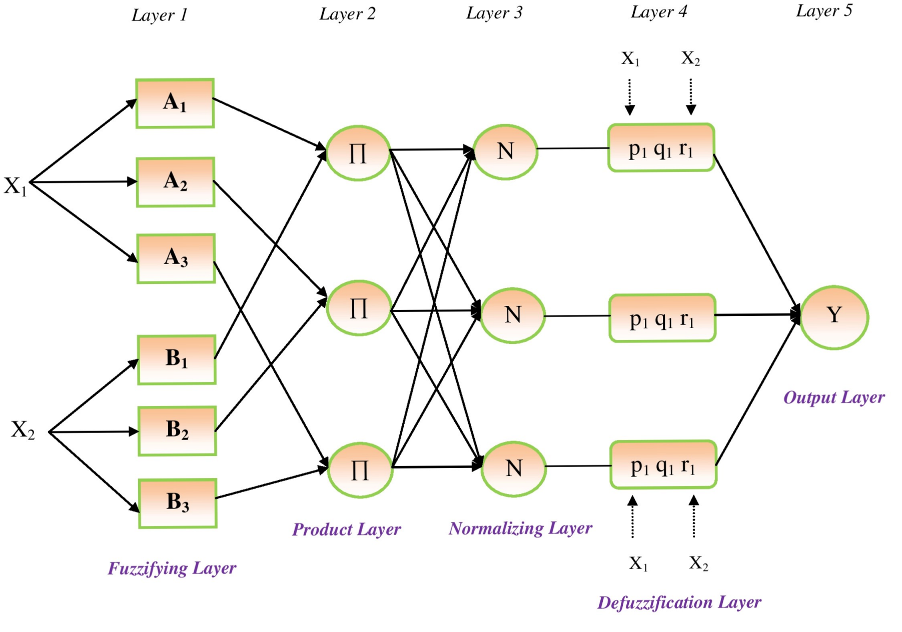


Figure 5. Sugeno Adaptive Neuro-Fuzzy Inference System (SANFIS) architecture with three MFns for each input

to update the parameters in first stage in order to reduce the error. We employed triangular, generalized bell and Gaussian membership functions in this research. These are represented as

$$\text{triangle}(x; a, b, c) = \begin{cases} 0, & x \leq a, \\ \frac{x-a}{b-a}, & a \leq x \leq b, \\ \frac{c-x}{c-b}, & b \leq x \leq c, \\ 0, c \leq x, \end{cases} \tag{9}$$

$$\text{bell}(x; p, q, r) = \frac{1}{1 + \mid \frac{x-r}{p} \mid^{2q}}, \tag{10}$$

$$\text{gaussian}(x; r, q) = e^{\frac{-1}{2}(\frac{x-r}{q})^2}. \tag{11}$$

We used triangular, generalized bell, and Gaussian membership functions in 7 SANFIS replicas on the Chittoor district and found differences in training and testing RMSD values. These variances are illustrated in Table 2.

SANFIS	**RMSD Values When Using 2 MFns**					
Models	**Triangular MFns**		**Generalized Bell MFns**		**Gaussian MFns**	
	Training	Testing	Training	Testing	Training	Testing
SANFIS1	17.4	7.7547	17.1654	7.821	17.151	8.065
SANFIS2	14.4901	6.7263	13.0743	7.2227	13.3915	7.2973
SANFIS3	11.913	6.4736	11.0923	6.4328	11.636	6.461
SANFIS4	11.903	6.8189	11.1222	6.6779	11.6221	6.6489
SANFIS5	9.6515	7.206	9.234	7.4221	9.5539	7.2502
SANFIS6	9.9407	7.3417	9.6533	7.8224	9.8727	7.5419
SANFIS7	9.5396	5.6064	8.8552	5.9987	9.401	5.8827

Table 2. Variations in RMSD values in 7 SANFIS models on Chittoor district employed 2 MFns for each input

While contrasted to other membership functions, Triangular MFns demonstrated the finest outcomes in training and testing for most of the SANFIS models, according to Tables 2 and 3. As a consequence, we also have achieved the best checking error. Based on these results, we found that the triangular MFns is the optimum for anticipating the COVID-19 in our research, based on Tables 2 and 3.

5 RESULTS AND DISCUSSIONS

New hybrid SANFIS networks have been analyzed in this section. Fuzzification, Fuzzy Rule, Normalization, Defuzzification, and Output Membership Phases are the five consecutive phases which constitute these SANFIS networks [16]. SANFIS

SANFIS Models	**RMSD Values When Using 3 MFns**					
	Triangular MFns		**Generalized Bell MFns**		**Gaussian MFns**	
	Training	Testing	Training	Testing	Training	Testing
SANFIS1	16.785	9.2197	17.0804	8.7741	16.8878	9.2249
SANFIS2	9.9421	6.8787	10.4577	6.5191	9.8102	6.6463
SANFIS3	10.5291	6.5962	11.1376	6.3149	11.0507	6.512
SANFIS4	4.5341	12.0321	3.6174	12.0167	8.5948	8.2507
SANFIS5	3.8839	10.9247	2.9537	10.8203	3.7182	11.2321
SANFIS6	4.3958	7.2271	3.4907	7.1246	4.234	7.1654
SANFIS7	3.2564	5.7353	1.4662	8.0989	3.5486	6.0508

Table 3. Variations in RMSD values in 7 SANFIS models on Chittoor district employed 3 MFns for each input

networks have outperformed the rest of the neural networks in machine learning approaches. To ensure the efficiency of SANFIS for COVID-19 forecasting, we implemented 7 SANFIS replicas with a grid partitioned fuzzy inference system and a backpropagation optimization technique to produce the best results with arbitrary precision. We have explored various types of membership functions such as Triangular MFns, Trapezoidal MFns, Generalized Bell MFns, Gaussian MFns, Sigmoidal MFns, and Pi MFns. Out of these MFns, the Triangular membership function achieved a better prediction than others in training set, testing set, and checking set according to our analyses. To attain superior forecasting, we applied three triangular MFns for each input and linear MFns for the output. After employing the three triangular MFns, we achieved the predictions; Figures 6, 7 and 8 show the graphical depiction of training forecasting, whereas Figure 9 shows the graphical representation of testing forecasting, and Table 4 shows the training, testing, and checking errors.

The COVID-19 foreboding in Anantapur district by implementing SANFIS models: In the Anantapur district of Andhra Pradesh, the SANFIS networks accomplished a lot in assessing COVID-19 confirmed cases versus the predicted cases during the training stage of SANFIS networks. Figure 6 illustrates the prediction of COVID-19 confirmed cases versus the predicted cases during the training process of SANFIS networks, and it is clearly seen that the networks predicted the COVID-19 with a good reliability. While examining 7 SANFIS networks, we found that the 6^{th} SANFIS network, out of seven networks, yielded better results for the Anantapur district than the other networks, with training error 2.1352, testing error 2.626, and checking error 3.6665, as shown in Table 4. Other SANFIS networks such as SANFIS4, SANFIS5, and SANFIS7 also produced accurate results with minor flaws. As a result, when the second wave of the COVID-19 is detected in the training set, the SANFIS networks stated above are suggested for predicting confirmed sufferers.

The COVID-19 foreboding in Chittoor district by implementing SANFIS models: COVID-19 has impacted the Chittoor district the most in Andhra

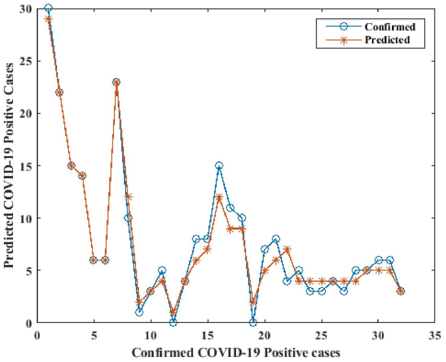
Pradesh. Chittoor district, in particular, requires the SANFIS networks to assess the COVID-19. In the Chittoor district, seven proposed models were used, and seven of them were successful in forecasting the COVID-19. Improving the disease forecasting in the Chittoor district becomes easier with the use of SANFIS networks. The 7th SANFIS network garnered the most reliable data in our investigation, with training, testing, and checking errors of 3.2564, 5.7353, and 12.5129, respectively, in Table 4. However, in the SANFIS 7th model, the training, testing errors are minimal, and the checking errors are wide. SANFIS7 has outperformed other network models in terms of training, testing, and checking error detection. Figure 6 depicts predicted cases that are quite analogous to confirmed cases. In Andhra Pradesh, Chittoor, these SANFIS networks proved to be beneficial in combating the future impact of COVID-19.

The COVID-19 foreboding in East Godavari district by implementing SANFIS models: When checking Table 1, we can see that there were 762 COVID-19 positive cases in the East Godavari district from 1st January to 1st March. In this district, our SANFIS networks performed much better in detecting the COVID-19. Table 4 shows that the SANFIS7 network performed well in terms of reliability and precision in estimating positive cases, with RMSD values of 3.6691, 2.83, and 3.7951 for training, testing, and checking errors, respectively. In comparison to the SANFIS7 networking model, the SANFIS6, SANFIS5 models generated superior outcomes with random errors and less accurateness.

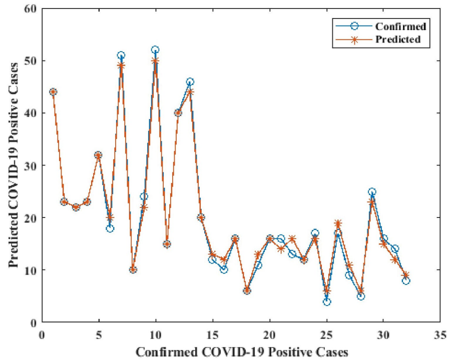
Districts	**Best SANFIS Network**	**Training Error**	**Testing Error**	**Checking Error**
Anantapur	SANFIS6	2.1352	2.6262	3.6665
Chittoor	SANFIS7	3.2564	5.7353	12.5129
East Godavari	SANFIS7	3.6691	2.83	3.7951
Guntur	SANFIS5	4.9721	3.7318	4.5623
Kadapa	SANFIS5	1.8625	3.6475	3.573
Krishna	SANFIS7	0.2190	3.3555	6.5466
Kurnool	SANFIS6	3.0375	2.4621	2.6902
Nellore	SANFIS6	1.2752	2.4867	2.9576
Prakasam	SANFIS2	2.6523	3.0172	1.0176
Srikakulam	SANFIS6	0.3464	2.2442	3.7416
Visakhapatnam	SANFIS6	2.1915	6.5861	4.9225
Vizianagaram	SANFIS5	1.3982	0.8211	1.7587
West Godavari	SANFIS7	5.0397	4.5386	2.2322

Table 4. Training, testing, and checking errors of each district's finest SANFIS networks

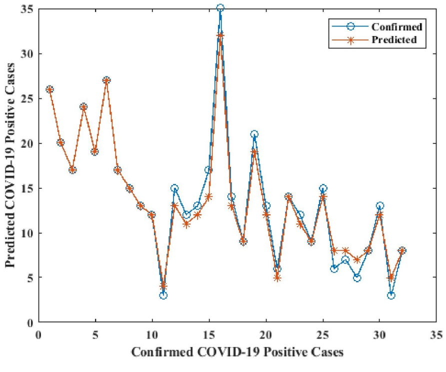
The COVID-19 foreboding in Guntur district by implementing SANFIS models: The SANFIS5 network is most needed for predicting COVID-19 in



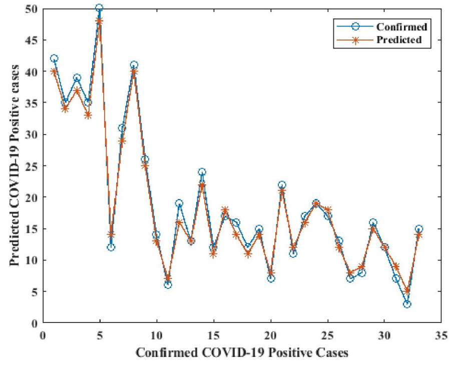
a) SANFIS6 model performance in Anantapur district



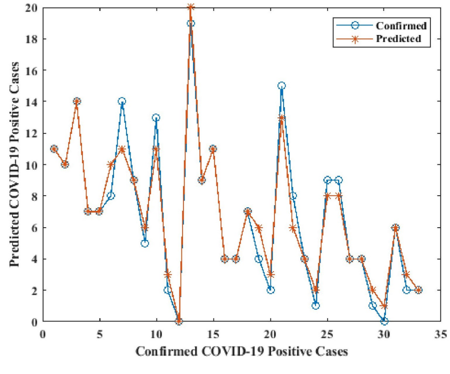
b) SANFIS7 model performance in Chittoor district



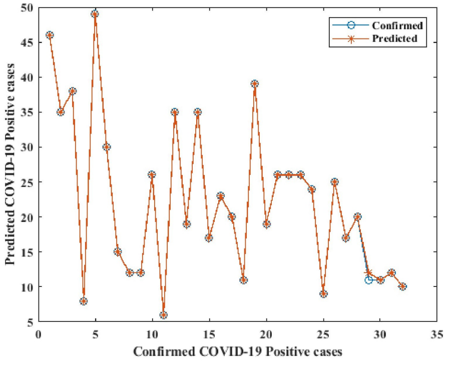
c) SANFIS7 model performance in East Godavari district



d) SANFIS5 model performance in Guntur district

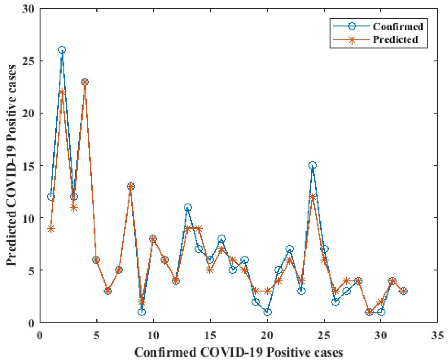


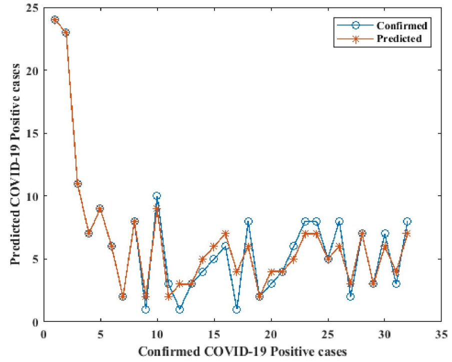
e) SANFIS5 model performance in Kadapa district



f) SANFIS7 model performance in Krishna district

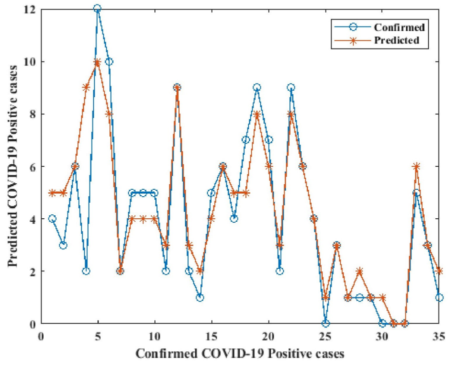
Figure 6. Graphical depiction of the best models observed vs. forecasted COVID-19 cases for Anantapur, Chittoor, East Godavari, Guntur, Kadapa, and Krishna districts during training process

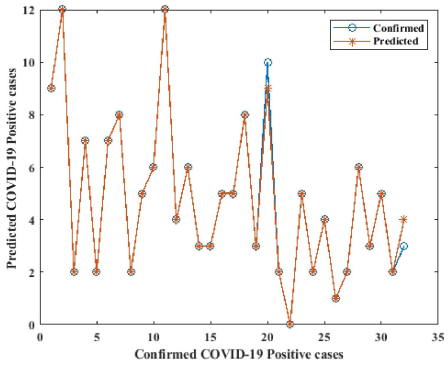




a) SANFIS6 model performance in Kurnool district

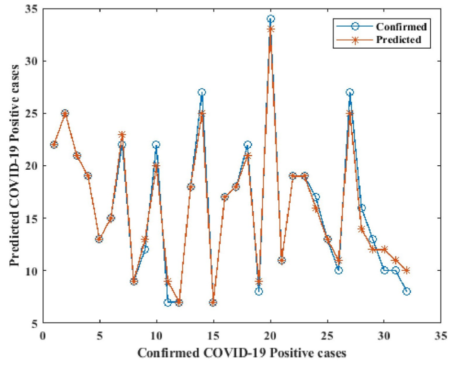
b) SANFIS6 model performance in Nellore district

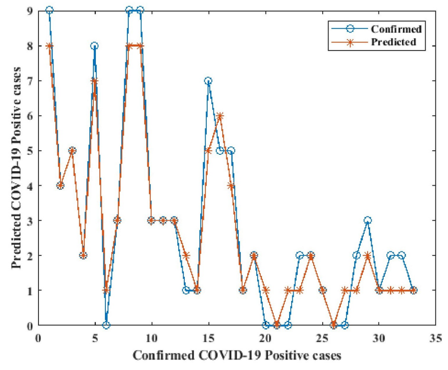




c) SANFIS2 model performance in Prakasam district

d) SANFIS6 model performance in Srikakulam district

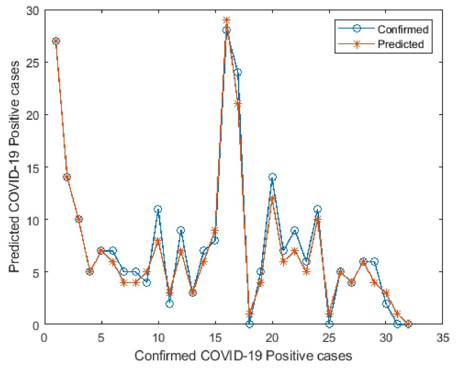




e) SANFIS6 model performance in Visakhapatnam district

f) SANFIS5 model performance in Vizianagaram district

Figure 7. Graphical depiction of the best models observed vs. forecasted COVID-19 cases for Kurnool, Nellore, Prakasam, Srikakulam, Visakapatnam, and Vizianagaram districts during training process



a) SANFIS7 model performance in West Godavari district

Figure 8. Graphical depiction of the best model observed vs. forecasted COVID-19 cases for WestGodavari district during training process

Guntur district because all other districts performed with less accuracy, only the SANFIS5 network provided better prediction with RMSD values for training, testing, and checking as 4.9721, 3.7318, and 4.5623, respectively. Figures 6 and 9, 4th and 3rd figures depict training and testing plots of Guntur district, respectively.

The COVID-19 foreboding in Kadapa district by implementing SANFIS models: In Andhra Pradesh, Kadapa is one of the districts that were frequently affected by COVID-19. Table 4 presents that the training, testing, and checking errors were 1.8625, 3.6475, and 3.573, respectively, and that these values were garnered by Kadapa district's best network, SANFIS5. With training, testing, and checking errors of 2.9285, 3.3045, and 3.2424, respectively, the SANFIS4 had acceptable performance in predicting the COVID-19.

The COVID-19 foreboding in Krishna district by implementing SANFIS models: Between the first of January and the first of March in Andhra Pradesh, Krishna district had the second highest number of positive cases of COVID-19. In the Krishna district, all 7 SANFIS models were shown to be more suitable for evaluating COVID-19. Figure 6 shows how the 7th SANFIS network proved to be better in the Krishna region. The SANFIS7 network excelled other six different networks in predicting the positive cases with pinpoint precision, is clearly visible in Figure 6, with training, testing, and checking errors of 0.2190, 3.3555, and 6.5466, respectively, as shown in Table 4. Furthermore, the SANFIS7 network performed effectively in anticipating COVID-19 in the test dataset, as shown in 4th graph in Figure 9.

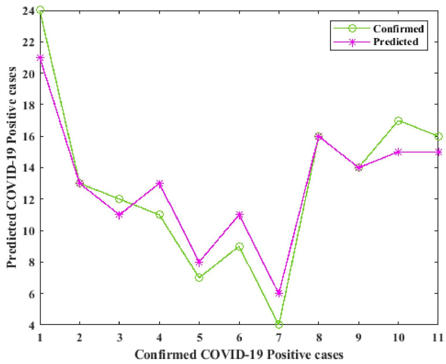
The COVID-19 foreboding in Kurnool district by implementing SANFIS models: According to the Table 1, we have clearly identified that how Kurnool district was less affected by COVID-19, by seeing of transpired a total number of confirmed cases from 1st January to 1st March as 312. We determined that the 6th SANFIS network is the strongest at anticipating the COVID-19 after studying 7 SANFIS networks. The training, testing, and checking errors for the best model SANFIS6 were 3.0375, 2.4621, and 2.6902, respectively, as shown in Table 4.

The COVID-19 foreboding in Nellore district by implementing SANFIS models: Nellore was the first district in the state of Andhra Pradesh to be hit by the pandemic COVID-19, and it has since seen an upswing in COVID-19 positive cases. The SANFIS networks are extremely effective in reducing COVID-19 infection in Nellore by anticipating COVID-19 infections. As a consequence, 7 SANFIS hybrid models have successfully predicted positive cases. Table 4 provided the significant forecasting models for every district. The SANFIS6 model is considered to be the best tool for estimating COVID-19 cases in Nellore, with training, testing, and checking RMSD values of 1.2752, 2.4867, and 2.9576, respectively. COVID-19 training predictions in Nellore are demonstrated in Figure 7.

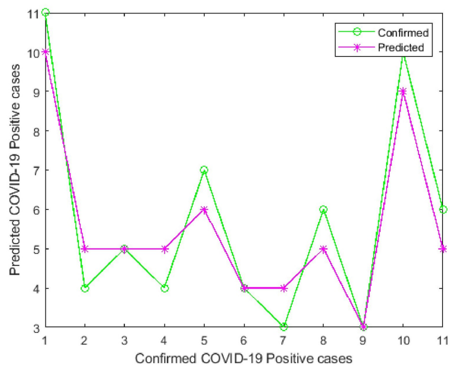
The COVID-19 foreboding in Prakasam district by implementing SANFIS models: COVID-19 influences all districts in Andhra Pradesh, but Prakasam district was the second least affected district. Table 1 indicates the number of cases that occurred in each Andhra Pradesh district; according to Table 1, the Prakasam district had 186 cases. The COVID-19 was anticipated exceptionally well using SANFIS networks. Seven SANFIS models were used, and the second model, with RMSD values of 2.6523, 3.0172, and 1.0176, provided quite accurate results for training, testing, and checking, respectively, as shown in Table 4.

The COVID-19 foreboding in Srikakulam district by implementing SANFIS models: From 1st January to 1st March, number of COVID-19 positive cases occurred in Srikakulam district is 270. The SANFIS6 model has the greatest performance among the different SANFIS networks employed in forecasting the COVID-19 in Srikakulam district, as shown in Table 4, with a graphical depiction of the SANFIS6 model's training set provided in Figure 7. As a consequence, the training, testing, and checking errors for the SANFIS6 network were 0.3464, 2.2442, and 3.7416, respectively, as shown in Table 4.

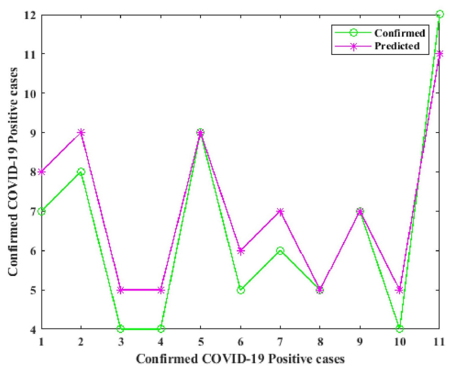
The COVID-19 foreboding in Visakhapatnam district by implementing SANFIS models: COVID-19 appears to be most widely spread in Visakhapatnam, which is one of Andhra Pradesh's most populous districts. Figure 7 shows that the SANFIS6 model produced better results for predicting COVID-19 with high precision, and Table 4 reveals that the training, testing, and checking errors of the SANFIS6 network are 2.1915, 6.5861, and 4.9225, respectively. The 5th and 7th SANFIS networks, according to our observations, likewise produced improved outcomes with minor flaws.



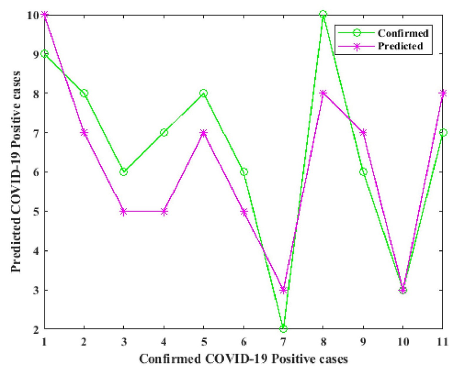
a) Execution of SANFIS7 Network in Chittoor district



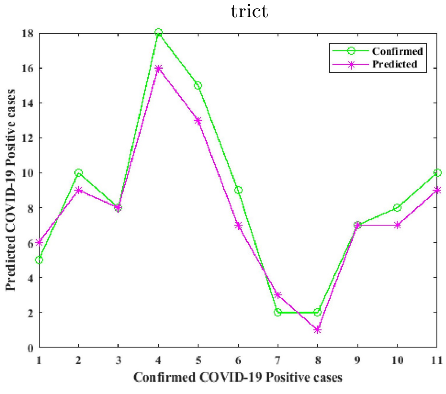
b) Execution of SANFIS7 Network in East Godavari district



c) Execution of SANFIS5 Network in Guntur district



d) Execution of SANFIS7 Network in Krishna district



e) Execution of SANFIS6 Network in Visakhapatnam district

Figure 9. Anticipated outcomes of testing datasets from Andhra Pradesh's most severely impacted districts

The COVID-19 foreboding in Vizianagaram district by implementing SANFIS models: COVID-19 has had the slightest effect on Vizianagaram, the smallest district in Andhra Pradesh. The Department of Health, Medical, and Family Welfare of the Government of Andhra Pradesh recorded 142 positive cases in Vizianagaram between January 1 and March 1, 2021, in COVID-19 data. The graphical depiction of proven cases vs. anticipated cases of the best SANFIS network is shown in Figure 7. Table 4 shows that the SANFIS5 model was the best replica for the Vizianagaram district of Andhra Pradesh, with RMSD values of 1.3982, 0.8211, and 1.7587, respectively, for training, testing, and checking.

The COVID-19 foreboding in West Godavari district by implementing SANFIS models: Figure 8 depicts the performance of the best SANFIS network in forecasting daily positive cases in West Godavari. In this location, seven SANFIS networks were used, and the seventh SANFIS network performed well in forecasting daily positive cases, with training, testing, and checking errors of 5.0397, 4.5386, and 2.2322, respectively, as shown in Table 4. The SANFIS4 and SANFIS5 networks also performed accurately with minor errors of our investigation.

In Andhra Pradesh, India, 7 SANFIS network models were investigated. We concluded that the 6^{th} and 7^{th} SANFIS networks are exceptionally well-proposed for all of Andhra Pradesh's districts. Furthermore, acquired results were compared with COVID-19 predictions using artificial neural networks in Table 5 and the initial surface illusion projected by the SANFIS networks for these two best models are in Figure 10 and Figure 11.

Prediction	**5^{th} model**			**6^{th} model**			**7^{th} model**		
Model	RMSD	MAE	MAPE	RMSD	MAE	MAPE	RMSD	MAE	MAPE
Artificial Neural Networks	5.5530	3.4012	2.9156	5.0812	2.9478	2.8812	4.2109	2.9011	2.6654
ANN-Prey predator algorithm	4.8314	3.0091	2.9543	4.3478	2.9178	2.7056	4.1140	2.6664	2.1819
ANN-Holt trend method	3.836	2.787	2.2212	3.4470	2.2589	2.1019	3.1139	2.2113	1.9056
LSTM networks	3.545	2.9980	2.21	2.7639	2.1245	2.0101	2.1730	1.9980	1.5623
SANFIS models	**1.3982**	**0.9515**	**0.7032**	**1.2752**	**0.9155**	**0.2024**	**0.21902**	**0.0979**	**0.0062**

Table 5. Comparative study of ANN vs. SANFIS models

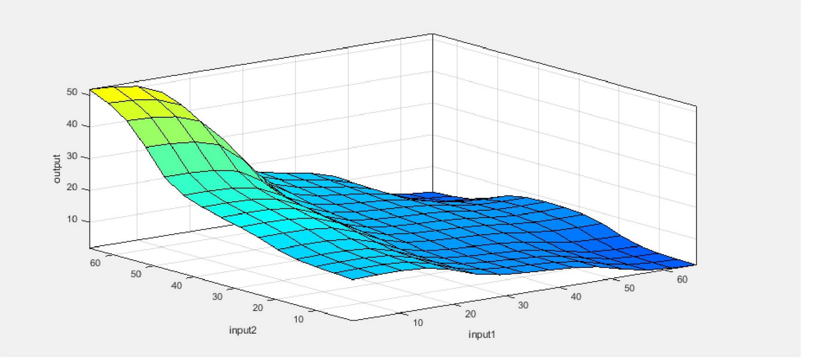


Figure 10. The inceptive SANFIS6 network's surface view for two inputs and one output

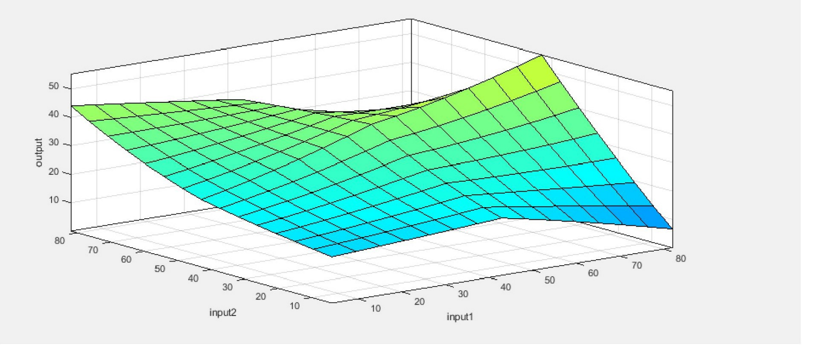


Figure 11. The inceptive SANFIS7 network's surface view for two inputs and one output

6 CONCLUSION

COVID-19 is the most significant public health issue that has emerged in 2019, and it has been quickly infecting people all around the world as a consequence of human dissemination. This pandemic had tremendous impact on not just the local economy, but also the worldwide economy affecting various sectors such as the industry, agriculture, and automotive industry, as well as national and international stock markets. However, the COVID-19 had a tremendous impact on the educational sector. As a consequence, the number of confirmed and fatal cases is rising. We applied Sugeno Adaptive Neuro-Fuzzy Inference System (SANFIS) networks to forecast the COVID-19 as part of this. We implemented seven SANFIS network models to manage this dangerous situation. Various types of membership functions were used during this process, and after observing all of the networking models with varying number of membership functions, we used the three triangular membership functions for each input and the linear membership function for the output variable to predict the positive cases. Figures 6, 7, 8 and 9 exhibit high-accuracy training and testing predictions for all districts of Andhra Pradesh, whereas Figures 10 and 11 show surface plots (3D plots) for the trained FIS tool for evaluating the inputs that have a major influence on the anticipated output. The recommended method outperforms different AI models, as shown in Table 5 with RMSD values. In the next future, these Sugeno models will be beneficial in the fight against COVID-19. Governments, public health managers, and medical organizations can utilize these findings to plan medical resources for future victims.

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