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Weather Forecasting Using Artificial Neural Network (ANN): A Review

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Abstract

Extreme weather occurrences provide issues that necessitate the development of technology capable of accurate analysis and exact prediction in order to successfully reduce their effects. Artificial neural networks (ANNs) have appeared in the last few years as a promising weather forecasting technology because of their capacity to manage intricate and nonlinear weather factors. The use of ANNs in weather element prediction has shown considerable improvements in forecasting precision and accuracy. Factors influencing an ANN model's efficacy include input Data Type and Volume for Training, Hidden Layer Neuron Count, network architecture, Activation Functions, and training algorithms. In this paper, we will present a thorough review of the applications of Artificial Neural Networks (ANNs) in weather forecasting, specifically focusing on temperature and rainfall prediction over the past 15 years. To enhance reader comprehension, The work of numerous researchers in this topic is methodically analyzed and compared in in tabular format. The authors aim to facilitate future research decisions by offering an organized review, aiding in the determination of suitable input features, transfer functions, and training algorithms for accurate temperature and rainfall predictions.

Keywords: Artificial neural networks (ANNs); Extreme weather; temperature and rainfall predictions.

1. Introduction

Weather significantly influences human life, shaping our daily activities and decisions. The safety of individuals and property from threats like tornadoes, floods, and major storms relies heavily on accurate weather forecasting. Diverse sectors such as Business, Tourism, Sports, Agriculture, Mining, Power, Food Industry, Airport, and Naval systems are intricately linked to precise weather predictions. For instance, in agriculture, advanced weather information empowers farmers to make informed decisions for enhancing crop yields [1].
For achieving predictions there are a number of methods, ranging from naive methods to those that use more complex techniques such as artificial intelligence (AI), artificial neural networks (ANNs) being one of the most valuable and attractive methods for forecasting tasks. In prediction, ANNs, as opposed to traditional methods in meteorology, are based on self-adaptive mechanisms that learn from examples and capture functional relationships between data, even if the relationships are unknown or difficult to describe [2].

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The use of Artificial Neural Networks (ANNs) in weather prediction is gaining prominence because of their capacity to manage intricate and nonlinear weather factors. ANNs have proven large gains in predicting accuracy when employed to anticipate diverse weather aspects. The performance of an ANN model hinges on several parameters, including input Data Type and Volume for Training, Hidden Layer Neuron Count, network architecture, Activation Functions, and training algorithms.

This study offers a detailed analysis of using Artificial Neural Networks (ANNs) for weather prediction, particularly focusing on temperature and rainfall prediction. The analysis includes a comparison of ANN performance based on Root Mean Square Error (RMSE) for temperature and rainfall forecasting. The primary objectives of this study are to address key questions such as: Which optimization algorithms are deemed most effective for training neural networks? What is the optimal Hidden Layer Neuron Count for superior neural network performance? Which optimization algorithms are deemed most effective for training neural networks? What activation function is optimal for a neural network designed for weather forecasting?

The remaining sections of the paper are organized as follows: In Section 2, a review of research literature on the application of ANN in weather prediction (temperature and rainfall) is presented. Section 3 brings out an analysis of existing works. The goal of section 4 was to provide a thorough discussion and identification of the input features, hidden layer neuron count, optimization algorithm, and activation function that are utilized to predict temperature and precipitation with the least amount of error. Finally, we provide a summary and recommendations for future study directions in Section 5.

2. Related Works

Rawat and al. (2019) [2] created ANN models to estimate daily rainfall during the monsoon season in the Parbhani District of Maharashtra, India. The study used 30 years of data (1985-2014). It was discovered that the models can predict rainfall with appropriate precision.

Nastos and al. (2014) [3] employed ANN to forecast the maximum daily precipitation for the upcoming year. The data utilized in the analysis are annual maximum daily precipitation totals recorded at the National Observatory of Athens (NOA) throughout the lengthy period 1891-2009. The results of the research revealed a very excellent association ($R2 = 0.482$, $IA = 0.817$, $RMSE = 16.4$ mm, and $MBE = +5.2$ mm) between the anticipated and observed maximum daily precipitation totals one year ahead.

Hung and al. (2009) [4], used an Artificial Neural Network model to predict rainfall for Bangkok. From 1991 to 2005, historical rainfall data was gathered from 104 locations in the BMA and TMD rain gauge networks. It was discovered that the ANN model could handle the noisy and unstable data that are common in the case of meteorological data and was effective at quick calculation.

Amr and al. (2011) [5] created and applied two models in Alexandria, Egypt, to forecast rainfall. These models are the Multi-Regression MLR model and the Artificial Neural Network ANN model. The data set used in this study spans the years 1957 through 2009 and consists of daily temperature and rainfall readings. The final results indicate that, with equal RMSE values (yearly = 32.04, January = 2.83, and December = 10.04), the ANN model may be a useful tool for local rain forecasting.

Khairudin and al. (2020) [6] used five alternative machine learning models: artificial neural networks (ANN), support vector regression (SVR), decision trees (DT), random forest algorithms (RFA), and long short-term memory (LSTM). For this study, the Kuala Krai rainfall station's average weekly rainfall data were used as predictor variables. According to the model's evaluation results, the LSTM obtained the lowest values for both metrics (RMSE=8.34 and MAE=4.83).

Sulaiman and al. (2018) [7] used an artificial neural network (ANN) to estimate the monthly precipitation. Historical rainfall data from 116 rain gauge stations was gathered for this purpose during a 50-year period, from 1965 to 2015. The results show that the ANN model performed better than the ARIMA model, with a 0.01 difference in RMSE

Khalili and al. (2016) [8] employed an artificial neural network to forecast the monthly rainfall at the Iranian Mashhad synoptic station. They used monthly rainfall data for this synoptic station from 1953 to 2003.
The developed models' effectiveness is confirmed by the performance statistical analysis, which reveals that the monthly prediction model with the best tuning has a correlation coefficient (R) of 0.93, a root mean square error (RMSE) of 0.99, and a mean absolute error (MAE) of 6.02 mm.

Nguyen and al. (2021) [9] created a model for the daily and monthly rainfall forecast using artificial intelligence (AI) that is based on artificial neural networks (ANNs). The Austin KATT station's WeatherUnderground.com provided the dataset. The period of collection for the daily and monthly rainfall is from February 21, 2013, to July 31, 2017. The outcomes demonstrate that the ANN model is a good algorithm for predicting rainfall on a daily or monthly basis.

For the daily rainfall, the testing phase values are 0.8063, 0.2487, and 0.0932 for R, RMSE, and MAE, respectively. The testing portion's performance metrics for monthly rainfall are 0.8012, 0.0731, and 0.0578 for R, RMSE, and MAE, respectively.

Khan and al. (2021) [10] provided rainfall predictions for the semi-arid mountainous region of Abha, Saudi Arabia. The data was taken from the Meteorological Subdivision of Abha in the Saudi Arabian province of Aseer during the years 1978 and 2016. The study suggests that ANN and MA can predict rainfall in semi-arid mountainous regions.

MuttalebAlhashimi and al. (2014) [11] constructed rainfall estimating models using ANN, ARIMA, and MLR to forecast monthly rainfall for the Kirkuk region. The data set utilised in this study comprises monthly observations of the Kirkuk station's mean temperature, relative humidity, wind speed, and rainfall from 1970 to 2008. The ANN model with four inputs has a higher R2 (0.91) and a lower RMSE value (27.278) for the testing data set in all analyses, confirming its suitability as a forecasting tool for monthly rainfall prediction.

Dombaycı and al. (2009) [12] employed an artificial neural network (ANN) model to forecast the daily mean ambient temperatures in Denizli, southwest Turkey. Temperature readings collected over three years (2003–2005) by The Turkish State Meteorological Service were utilized as training data while values from 2006 were used as testing data to train the model. The R2 and RMSE values of this network were 0.9902 and 1.8524, respectively, indicating that the ANN method is a dependable model for ambient temperature prediction.

Fahimi Nezhad and al. (2019) [13] employed neural network techniques to predict Tehran's highest temperature. Meteorological data for this study were acquired from the Tehran Mehrabad station between 1951 and 2010. The findings indicate that a model with three neurons in the input layer, nine neurons in the hidden layer, and a hyperbolic tangent function in the hidden layer is the most appropriate structure to predict the maximum temperature in Tehran. The model's correlation coefficient, mean absolute error, and root mean square error are, respectively, 0.104, 0.997, and 0.311.

Rasel and al. (2018) [14] exhibit the effectiveness of data mining and machine learning approaches, specifically Support Vector Regression (SVR) and Artificial Neural Networks (ANN), for reliable weather prediction. The Bangladesh Meteorological Department provided a 6-year historical weather record of the temperature and rainfall in the Chittagong metropolitan, which was used for the experiment. The results of this study show that while ANN can predict temperature more accurately than SVR with an acceptable error rate deviation, SVR can predict rainfall better than ANN, producing 0.95% and 0.17% error rates in both types of datasets.

Anjali and al. (2019) [15] suggest a method for predicting temperature using three models: Multiple Linear Regression (MLR), Artificial Neural Network (ANN), and Support Vector Machine (SVM). They conduct a comparative analysis using weather data collected from Central Kerala between 2007 and 2015. Compared to ANN and SVM, MLR is a more accurate model for temperature prediction, as seen by the error metrics and the CC.

Singh and al. (2019) [16] investigated three models for weather forecasting: the Support Vector Machine (SVM), the Artificial Neural Network (ANN), and the Time Series-based Recurrent Neural Network (RNN). the data was collected from different airport weather stations in India. This dataset contains data from the previous 12 years 2006-2018. Time Series-based RNN is shown to be the most effective at predicting weather.

Madhiarasan and al. (2020) [17] provided an ANN-based model for temperature forecasting. The National Oceanic and Atmospheric Administration (USA) provided the data, which served as the ANN input variables and goal temperatures, between January 2016 and December 2018. The following performance indexes are achieved by the proposed ANN model for temperature forecasting applications, which has six inputs, one hidden layer, six hidden neurons (MRE = 7.2796e−04, R = 1, MAPE = 0.0728, MSE = 0.0059, MAE = 0.0164, RMSE = 0.077.

Finally, Azari and al. (2022) [18] examined the ability of various machine learning approaches (LR, kNN, SVM, ANN, Random Forest, and AdB) to forecast air temperature in the context of climate change research. The data was mined from the airport weather station between January 1st, 1980 and September 22nd, 2021. ANN ML approach with RMSE = 1.1694 was shown to be the most effective method for temperature prediction when dewpoint, relative humidity, wind speed, sea pressure, and precipitation were used as dependent variables.

3. Analysis

An analysis of research that used ANN to forecast temperature and rainfall is shown in Table 1. The primary objective is to analyze papers published throughout the last 14 years (2009-2023). The table is split into seven columns that contain the most pertinent details from the examined papers, including the following: Ref, Country/Study area, Prediction, Input Data, Dataset, Forecasting Model, Configuration, and Evaluation Criteria.

RMSE was the primary metric utilized in the majority of the papers to compare the algorithm's performances. To provide the reader a reference of the efficacy of each algorithm, we just put the RMSE value in the table. We excluded other metrics that were used from the table in order to maintain coherence and prevent confusion.

Table 1: Analysis of research that used ANN to forecast temperature and rainfall.

Ref	Country/ Study area	Prediction	Input Data	Dataset	Forecasting Model	Configuration	Evaluation Criteria
[2]	India, Maharashtra	Daily rainfall for monsoon season	Temperature, relative humidity, wind speed, vapor pressure, Rainfall	1985–2014	ANN	9-8-8-1, Activation Function = Hyperbolic tangent function	Best result: RMSE = 7.26
[3]	Greece, Athens	Maximum daily precipitation	Annual daily maximum precipitation	1891–2009		–	RMSE= 16.4
[4]	Thailand, Bangkok	Rainfall	Rainfall intensity, Relative humidity, wet bulb temperature, pressure, Cloudiness, Average rainfall intensity, Rainfall intensity at surrounding stations 1, 2, and 3	1991–2005		9-22-11-1, Activation Function = Hyperbolic tangent	RMSE= 0.71
[5]	Egypt, Alexandria	Rainfall on a yearly and monthly basis	Daily measurements of rainfall, maximum and minimum temperature	1957–2009		2-10-7-6-1, 2-8-5-4-1, 2-8-9-5-1, Activation Function = tan sigmoid and Log sigmoid	Yearly: RMSE= 32.04 January: RMSE= 2.83 December: RMSE= 10.04
[6]	Malaysia, Kuala Krai	Rainfall	Average weekly rainfall values	1970–2019		Two hidden layers, Activation Function = ReLu and linear function	RMSE= 9.10
[7]	Malaysia, Pahang	Heavy precipitation on a monthly basis	Monthly and past monthly rainfall data	1965–2015		12-10-10-1, Activation Function = sigmoid function	Best result: Model C RMSE= 0.06
[8]	Iran, Mashhad's	Monthly rainfall	Average rainfall, previous year's rainfall for the predicted month, and the last five bi-monthly rainfall	1953–2003		7-4-1, Activation Function = sigmoid function	Best result: M741 RMSE= 0.96
[9]	United States, Texas	Daily and monthly rainfall	Temperature, humidity, dew point, pressure, wind speed, and visibility	2013–2017		18-16-8-4-1, Algorithm = conjugate gradient, Activation Function = Hyperbolic tangent function	Daily rain (RMSE= 0.2487) Monthly rain (RMSE=0.073)
[10]	Saudi Arabia, Abha	Rainfall	Total annual rainfall	1978–2016		Algorithm = Levenberg–Marquardt	Best result: RMSE = 1.339
[11]	Iraq, Kirkuk	Rainfall	Month rainfall, average air temperature, wind speed, and relative humidity	1970–2008		4-8-1, Activation Function = sigmoid function	RMSE = 27.278
[12]	Turkey, Denizli.	Daily mean ambient temperatures	Month of the year, day of the month, average temperature of the previous day.	2003–2005		3-6-1, Algorithm = Levenberg–Marquardt, Activation Function = Hyperbolic tangent sigmoid function and purelin function	Best result: RMSE= 1.9655
[13]	Iran, Tehran	Maximum temperature	(Tmax), (Rtempt), (n), (U2), (RH mean), (T mean)	1951–2010		3-9-1, Activation Function = hyperbolic tangent	Best result: Model 4 RMSE= 0.104
[14]	Bangladesh, Chittagong	(Temperature, rainfall)	Rainfall and temperature	6-year		Maximum 3 hidden layer networks, Activation Function = Leaky ReLU	Best result: rainfall RMSE= 18.43, temperature RMSE= 3.31

[15]	India, Kerala	Temperature	Humidity, pressure, wind speed, wind direction, temperature	2007–2015	ANN	5-2-2-2-1	RMSE= 2.0100
[16]	India	Temperature	Temperature, pressure relative humidity, mean wind direction, cloud cover, horizontal visibility, and dew point temperature.	2006 -2018		–	RMSE= 3.1
[17]	United States	Temperature	Temperature, wind speed, solar irradiance, relative humidity, dew point, precipitation	2016 -2018		6-6-1, Activation Function = Hyperbolic tangent sigmoid function in the hidden and output layers.	Best result: RMSE = 0.0770
[18]	United States, Memphis	Temperature	Dewpoint, wind speed, relative humidity, sea pressure, and precipitation	1980 -2021		Algorithm = Levenberg–Marquardt	RMSE = 1.1694

4. Discussion

Extensive research has been conducted in the field of weather prediction, particularly in rainfall and temperature prediction. with significant improvements in the performance of the models. The table above displays the best-reported error values, specifically the RMSE on several models. Nevertheless, the outcomes are presented in graphs for analytical purposes.

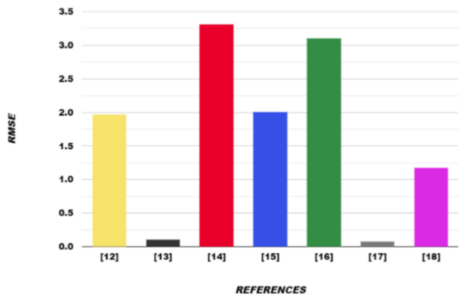

Fig 1: Comparison of ANN performance based on RMSE for temperature forecasting.

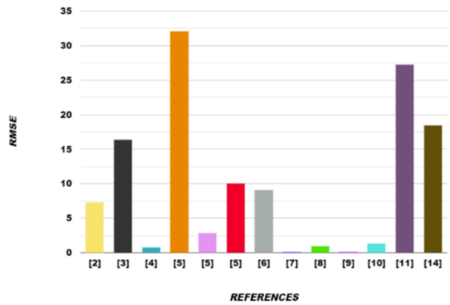

Fig 2: Comparison of ANN performance based on RMSE for rainfall forecasting.

Fig. 1 depicts the error metrics in terms of RMSE for several temperature forecasting models discussed in the literature. The models provided by Fahimi Nezhad et al. (2019) [13] and Madhiarasan, M., Tipaldi, M., & Siano, P. (2020) [17] had lower RMSE values, indicating higher temperature prediction accuracy. Fig. 2 illustrates the prediction accuracy of rainfall forecasting models based on RMSE. It can be seen that the models suggested by Hung, Nguyen Q., et al. (2009) [4], Sulaiman, J., & Wahab, S. H. (2017) [7], Khalili, Najmeh, et al. (2016) [8], Khan, Roohul Abad, et al. (2021) [10] revealed the lowest error values compared to other models, demonstrating their superior accuracy in forecasting rainfall.

Based on the evaluation results, a comparison may be drawn between the works given in the literature. Indeed, several factors influence Artificial Neural Network (ANN) performance. Key among them are input features, data format, dataset size, optimization algorithms, activation functions, and configuration parameters such as the number of hidden neurons and layers. Since there is no method for selecting the optimal number of hidden neurons and layers to avoid network underfitting and overfitting, they were primarily discovered through trial and error.

For temperature forecasting, it can be observed that temperature, Humidity, and wind speed values turn out to be the common parameters in most research. In addition, the Levenberg-Marquardt optimization technique is frequently used and outperforms others due to its high learning rate and low prediction errors. the most used combination of activation functions reported is the Hyperbolic tangent sigmoid function.

In the context of predicting rainfall, Hyperbolic Tangent or the Sigmoid Function are the most implemented functions. In addition, the Levenberg-Marquardt and the conjugate gradient are more suitable for building the rainfall forecast model with its small RMSE values.

5. Conclusion

According to the literature review, applying the Artificial Neural Network (ANN) approach for weather prediction involves four steps: selecting input variables, determining model architecture and training algorithms, selecting activation functions, and testing the model's accuracy. Additionally, the review demonstrates that the efficacy of the ANN model is dependent on a variety of factors, including the type and quantity of input data employed for training, the Hidden Layer Neuron Count, the overall network architecture, and the choice of training algorithms. In particular, determining the number of neurons in the hidden layer is crucial, and several strategies are used with the primary goal of minimizing prediction errors. It is emphasized that utilizing too many neurons in the hidden layer can lead to overfitting.

In the majority of the reviewed studies, the Levenberg–Marquardt optimization algorithm has been employed for prediction, owing to its effectiveness in predicting weather variables. Additionally, it has been demonstrated that the Hyperbolic Tangent or the Sigmoid Function are more commonly used in temperature and rainfall prediction because they provide better training performance for ANN. With these backgrounds, it shows that, ANN is a powerful tool in predicting temperature and rainfall of a specific place, provided input parameters of the model are well chosen. Moreover, in the future, we plan to employ Artificial Neural Networks (ANNs) for the prediction of rainfall and temperature, with a focus on using the best performing training algorithm and the optimal activation function.

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