International Journal of Soft Computing and Engineering (IJSCE)
ISSN: 2231-2307, Volume-5 Issue-6, January 2016

Comparative Analysis of Rainfall Prediction Models Using Neural Network and Fuzzy Logic

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Abstract- Rainfall is a stochastic process, whose upcoming event depends on some precursors from other parameters such as temperature, surface pressure and other atmospheric parameters.Accurate information about rainfall is necessary for the use and management of water resources. Nonetheless, rainfall is one of the most complex and difficult elements in hydrology due to the tremendous range of variation over a wide range of scales both in space and time. Forecasting techniques such as Artificial Neural Network (ANN) and Fuzzy Logic (FL) have been used to study rainfall. This research work is motivated by the need to compare ANN and FL models to know which one is more efficient in predicting rainfall. The rainfall datasets used in this research work were collected from an automatic weather station in Iju, a town in Akure North Local Government Area of Ondo State for the period of four years (2007-2010). The model comparison is based on four criteria; the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), prediction error, and the prediction accuracy. The error measures are comparable for the two models. The analysis of the models accuracy, shows that, overall, the ANN model perform slightly better than the FL model in terms of PE, RMSE, MAE andaccuracy.

Keywords- Forecasting, Fuzzy Logic, Neural Networks, ,Rainfall.

I. INTRODUCTION

The propensity to discover unidentified aspects of different phenomena has occupied human being's mind from time immemorial. Rather than being a matter of questioning, forecasting is admired to be used as a basis to perform indispensable preparedness for an upcoming event. Weather forecasting is one of the most imperative and demanding operational responsibilities carried out by meteorological services all over the world. It is a complicated procedure that includes numerous specialized fields of know-how (Guhathakurata, 2006). Amongst all weather happenings, rainfall plays the most imperative role in human life. Human civilization to a great extent depends upon its frequency and amount to various scales. Rainfall is a stochastic process, whose upcoming event depends on some precursors from other parameters such as the sea surface temperature for monthly to seasonal time scales, the surface pressure for weekly to daily time scale and other atmospheric parameters for daily to hourly time scale. The latter atmospheric parameters could be temperature, relative humidity and winds. Variability of weather and climatic factors, especially those atmospheric parameters will be the major force for daily precipitation event.

Revised Version Manuscript Received on December 09, 2015.

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If variability pattern could be recognized and used for future trajectory, daily rainfall prediction is very much feasible. (Edvin and Yudha, 2008). Several stochastic models have been attempted to forecast the occurrence of rainfall, to investigate its seasonal variability and to forecast monthly/ yearly rainfall over some given geographical area. Daily precipitation occurrence has been viewed through Markov chain by (Chin, 1977). Gregory et al (1993) applied a chain-dependent stochastic model, named as Markov chain model to investigate inter annual variability of area average total precipitation. Wilks (1998) applied mixed exponential distribution to simulate precipitation amount at multiple sites exhibiting realistic spatial correlation (Agboola et al, 2013). One of the most popular data-driven techniques attributed by various authors to machine learning, data mining, soft computing etc. is an Artificial Neural Network (ANN). An ANN is an information processing system that roughly replicates the behavior of a human brain by emulating the operations and connectivity of biological neurons (Tsoukalas and Uhrig, 1997).ANN is a network consisting of an arbitrary number of very simple elements called nodes. Each node is a simple processing element that responds to the weighted inputs it receives from other nodes (Lee et al., 2004). The arrangement of the nodes is referred to as the network architecture. Fuzzy Logic (FL) was introduced in Zadeh (1965) with a view to reconciling mathematical modeling and human knowledge in the engineering sciences. Unlike the Boolean logic, Fuzzy logic can represent linguistic constructs such as "low", "medium", "high". It provides a technique to deal with imprecision and information granularity (Akinyokun, 2002).Fuzzy logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy logic's approach to control problems mimics how a person would make decisions, only much faster. Fuzzy Logic incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. Neural network and fuzzy logic have been successfully applied to a wide range of problems covering a variety of sectors. Their practical applications, especially of neural networks expanded enormously starting from mid 80s till 90s partly due to a spectacular increase in computing power (Kappen, 1996). During the last decade ANN evolved from being only a research tool into a tool that is applied to many real world problems: physical system control, various engineering problems, and statistics, medical and biological fields. Consequently they are applied more and more in chaotic time series as well. Since both neural network and fuzzy expert system are non-linear methods that map an input u (a vector of size $N\times 1$) into an output y (a vector of $M\times 1$) by the function f: u → y, estimate functions from sample data, uses basis functions (fuzzy logic has membership functions and neural networks have activation functions), then there is need to compare the two models to know which one is more efficient in predicting rainfall. In this research work, the focus is on the performance evaluation of artificial neural network model and fuzzy logic model for predicting rainfall. The performance of the models will be evaluated to know which is more efficient in predicting rainfall. The study area is Akure, the capital city of Ondo state, which is one of the states in Nigeria where the climate is influenced mainly by the rain-bearing southwest monsoon winds from the ocean and the dry northwest winds from the Sahara Desert. The climatic condition of Akure follows the pattern of south western temperatures and high humidity also characterizes the climate. There are two distinct seasons, the rainy and dry seasons. The rainy season lasts for about seven months (April to October). The rainfall is about 1524mm per year. The atmospheric temperature ranges between 28°C and 31°C and a mean annual relative humidity of about 80 per cent. The data that used in this research is collected from a weather station, which consists of many in-situ atmospheric surface parameters such as the precipitation amount, relative humidity, temperature, dew point, wind speed and surface pressure.

II. RELATED WORKS

Koizumi (1999) employed an ANN model using radar, satellite and weather-station data together with numerical products generated by the Japan Meteorological Agency (JMA) Asian Spectral Model for 1-year training data. Koizumi found that the ANN skills were better than persistence forecast (after 3 h), the linear regression forecasts, and numerical model precipitation prediction. As the ANN used only 1 year data for training, the results were limited. Manusthiparom et al. (2003) investigated the correlations between El Nin˜o Southern Oscillation indices, namely, Southern Oscillation Index (SOI), and sea surface temperature (SST), with monthly rainfall in Chiang Mai, Thailand, and found that the correlations were significant. For that reason, SOI, SST and historical rainfall were used as input data for standard back-propagation algorithm ANN to forecast rainfall one year ahead. The study suggested that it might be better to adopt various related climatic variables such as wind speed, cloudiness, surface temperature and air pressure as the additional predictors. Surajit (2001)endeavors to develop an Artificial Neural Network (ANN) model to forecast average rainfall during summer-monsoon in India. Indian economy is standing on Indian summer monsoon. So prediction of Indian summer monsoon is a challenging topic to Indian atmospheric scientists. This paper develops ANN model step-by-step to predict the average rainfall over India during summer- monsoon. The proposed ANN model is a three layered ANN with Back propagation learning. Present contribution deviates from the study of Guhathakurta (2006) in the sense that instead of choosing a particular state, the authors implement Back propagation ANN to forecast the average summer-monsoon rainfall over the whole country. The applicability of the model is limited to monthly rainfall data. Agboola*et al.* (2012) developed an Artificial Neural Network Model for rainfall forecasting in South-Western Nigeria. The performance evaluation of the model was done by calculating Prediction Error, Root Mean Square Error; Mean Absolute Error, and Prediction Accuracy to know how efficient the model was. As the PE, RMSE, MAE values on data were comparatively less, the ANN prediction model is reliable and efficient and can be used for rainfall prediction. Fujibe (1989) classified the pattern of precipitation at Honshu with fuzzy C-means method. Galambosi*et al.* (1999) investigated the effect of ENSO and macro circulation patterns on precipitation at Arizona using Fuzzy Logic. Vivekanandan*et al.* (1999) developed and implemented a fuzzy logic algorithm for hydrometeor particle identification that is simple and efficient enough to run in real time for operational use. Bardossy*et al.* (1995) implemented fuzzy logic in classifying atmospheric circulation patterns. Özelkan*et al.* (1996) compared the performance of regression analysis and fuzzy logic in studying the relationship between monthly atmospheric circulation patterns and precipitation. Pesti*et al.* (1996) implemented fuzzy logic in drought assessment. Baum *et al.* (1997) developed cloud classification model using fuzzy logic. Halide and Ridd (2002) used fuzzy logic to rainfall prediction. The fuzzy logic technique is used to model and predict local rainfall data. The RMSE between data and model output is found to be 319.0 mm which is smaller than that by using either the local rain or the Niño 3.4 alone of 349.2 and 1557.3 mm, respectively. Hansen (2003) applied fuzzy k-nn weather prediction system to improve the technique of persistence climatology by past and present weather cases. Shao (2000) established fuzzy membership functions, based on cloud amount, cloud type, wind speed and relative humidity, to compose a fuzzy function of weather categorization for thermal mapping. Wong *et al.* (2003) constructed fuzzy rule bases with the aid of SOM and back propagation neural networks and then with the help of the rule base developed predictive model for rainfall over Switzerland using spatial interpolation. Karamouz*et al.* (2004)used model based on fuzzy rules and neural network**s** using large-scale climatic signals to predict rainfall in the western Iran (the basins of Karoon, Karkheh and the western border). Their results showed that except for the southwest region, where both models had similar errors of above 35%, in the northwest and the western regions, the error of the fuzzy model was 8.4%; that is, 13% lower than that of neural network. Agboola et al 2013 developed a fuzzy logic based rainfall prediction model for South Western Nigeria. The model predicted outputs were compared with the actual rainfall data. Simulation results reveal that predicted results are in good agreement with measured data. Prediction Error, Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and the Prediction Accuracy were calculated, and on the basis of the results obtained, it can be suggested that fuzzy methodology is efficiently capable of handling scattered data. The developed fuzzy rule-based model shows flexibility and ability in modeling an ill-defined relationship between input and output variables. The fuzzy logic approach has also been applied to sedimenttransport (Tayfur et al. 2003); precipitation (Maskey et al. 2004); reservoir operation (Tilmant et al.2002); and storm water infiltration (Hong et al. 2002).

III. MODEL COMPARISON

In this paper, a comparative analysis of the Artificial Neural Network (ANN) model presented in Agboola et al. (2012) and Fuzzy Logic (FL) model presented in Agboola et al. (2013) will be carried out. The model comparison will be carried out using the following criteria:

(a) Prediction Error $(PE) = \frac{\langle |y_{predicted} - y_{actual}| \rangle}{\langle y_{actual} \rangle}$ (1.0)

The predictive model is identified as a good one if the PE is sufficiently small i.e. close to 0.

(b) RRoot Mean Square Error (RMSE) is a good measure of prediction accuracy. It is frequently used to measure the differences between values predicted by a model and the values actually observed from the thing being modeled. These individual differences are also called residuals.

$$RMSE = \sqrt{\frac{\sum_j^N (y_j - \hat{y}_j)^2}{N}} \quad (2.0)$$

where y_j are observed values, $\hat{y}_j$ are predicted values for rainfall and N is the number of observation.

(c) Mean Absolute Error (MAE): the smaller the MAE, the better the model fit.

$$MAE = \frac{|y_j - \hat{y}_j|}{N} \quad (3.0)$$

where y_j are observed values, $\hat{y}_j$ are predicted values for rainfall and N is the number of observation.

(d) $PredictionAccuracy = 100 - RMSE$ (4.0)

Table I: Actual Values versus Predicted Values

Rainfall condition	ANN		FUZZY LOGIC	
	Actual	Predicted	Actual	Predicted
Very low RF	8162	8111	8162	8093
Low RF	29	27	29	22
Medium RF	9	8	9	5
High RF	1	0	1	0
Very High RF	3	3	3	2

The error measures are comparable for the two models as presented in Table 1, ANN had the minimum MSE=521.4 mm/h, RMSE=22.83 mm/h,MAE=11 mm/h and maximum PE=0.006704 respectively. The analysis of the model accuracy, shows that, overall, the neural network models perform slightly better than the fuzzy logic model in terms of PE,MSE, RMSE, MAE and accuracy. Also as seen in Table 2, the ANN and FL models satisfactorily predicted rainfall. Overall, higher values of the observed data were better predicted by the ANN model. Overall, both approaches may be used within the framework of a real time forecasting system, though with different levels of reliability.

IV. ESULTS DISCUSSION

This research addresses the problem of comparing two data driven approaches (the artificial neural network approach and the fuzzy logic approach) in terms of accuracy and reliability within the framework of a rainfall forecasting system. Table II, presents the rainfall condition and the results of the ANN and FL predicted value from the actual value

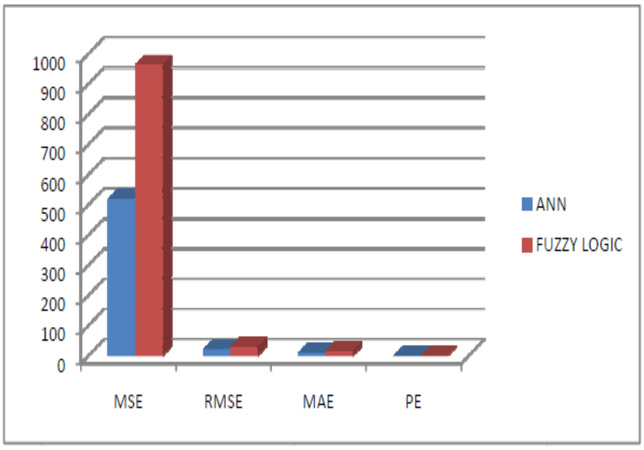

Fig. 1: ANN calculated error measures versus FL calculated error measures

Table II: Actual Values versus Predicted Values

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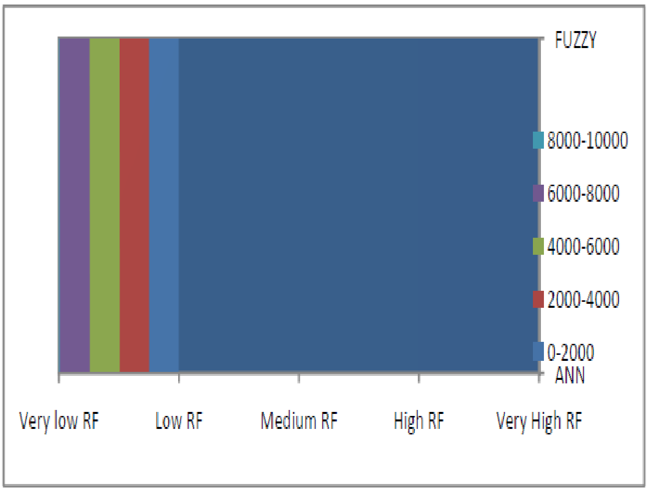

Fig. 2: Neural Network predicted values versus Fuzzy Logic predicted values

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

V. CONCLUSION

This research has contributed to knowledge by establishing the best model for predicting rainfall accurately in the South-western Nigeria.In this work, Neural Network and Fuzzy Logic models were developed for rainfall prediction. The performance analysis of the two models is done using mean square error, root mean square error; mean absolute percentage error, and prediction accuracy. The prediction accuracy of neural network is 77.17% and that of the fuzzy logic is 68.92%. The results show that the neural network model is better than the fuzzy logic model.

VI. FUTURE WORK

It is therefore recommended that the ANN and FL techniques could be improved upon by combining it with another method i.e., genetic algorithm for its optimization purpose. Focus should be placed on:

(a) The similarities between the three technologies through the common keyword of nonlinear relationship in a multi-dimensional space.

(b) How to use these technologies at a practical or programming level.

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