USING ARTIFICIAL NEURAL NETWORKS TO FORECAST RAINFALL OVER GUINEA ECOLOGICAL ZONE, NIGERIA

Audu, E.B.,[1] Musa, S.D.,[2] Yahaya, T.I.,[3] Emigilati, M.A.[3] and Yisa, C.L.[4]

[1]Government Secondary School, Abuja@30, Pegi, Federal Capital Territory, Nigeria
[2]Departmnt of Geography and Environmental Planning, Kogi State University, Anyigba, Nigeria
[3]Department of Geography, Federal University of Technology, Minna, Niger State, Nigeria
[4]Department of Geography, Niger State College of Education, Minna, Nigeria
Correspondence author: audu_ebamaiyi@yahoo.com (+234-803-585-6619).

Abstract

Rainfall forecast is very crucial in view of the fact that Nigeria is not left out in the global rainfall variation and climate change occurrence. This research used the artificial neural networks to forecast rainfall for 2019 over the Guinea Ecological Zone, Nigeria (GEZN) and comparing its results with the Nigerian Meteorological Agency (NiMet) Seasonal rainfall Prediction (SRP) for the same region in the corresponding year. Daily rainfall data which spanned through 1981 to 2015 and obtained from NiMet, Oshodi, Lagos; were used. The NiMet rainfall forecast with its margin of error were obtained from 2019 SRP by NiMet. The data were trained using artificial neural networks (ANNs). The test dataset was used to evaluate the performance of the networks by computing the Root Mean Square Errors (RMSEs). Fuzzy logics were also used for the neural networks training. The neural networks outputs were probability of density of rainfall, regression and margin of error. Margin of errors were also calculated for the data collection points. Results were shown in figures. According to the results from ANNs were able to forecast rainfall over the study area. Onset and cessation of rains are April and October, while August has the highest mean rainfall. Both NiMet and ANN forecasts showed near accurate annual rainfall over Abuja, Ibi, Kaduna, Lokoja and Makurdi while discrepancies were observed over Ilorin, Minna, Lafia and Jos. It was then recommended that rainfall review should be carried out at the end of 2019 to evaluate the performance of the ANNs so as to ascertain its suitability for future use.
Keywords: Rainfall, rainfall forecast, rainfall variability, models, artificial neural networks.

Introduction

Rainfall is very important in Nigeria not only because it is a weather variable, but also because of its role in agriculture, ecology and hydrology including the hydrological cycle. It is also a major determinant of crop germination, growth, maturation and yield. According to the Nigerian Meteorological Agency (NiMet) (2017), the 2017 rainfall season favoured the agricultural sector particularly in crop production as it was characterized by normal rainfall pattern in most parts of the country and above normal over places like Jos, Lafia, Nguru, Ilorin, Kaduna, Yelwa, Enugu, Calabar and Lagos. In hydrology, heavy/frequent/prolonged rainfall leads to floods, especially flash floods; landslides and erosion. According to NiMet (2018), in Nigeria; there were levee failures in 2012 and 2018 because water levels in major dams were observed to be above normal due to heavy rainfall occurrence recorded in August and September in some northern states leading to flash floods which greatly impacted catchment areas and aquifers.

The derived rainfall parameters which require forecast include onset, cessation, duration, wet spells, dry spells, drought, frequency, intensity and total amount. According to NiMet (2019), annual rainfall amount is the total amount of rainfall observed and recorded in the year under reference. Rainfall forecast could be for a very short term, short term, medium term and long term. This forecast is for a long term because it covers a year.

Rainfall forecast is done using different methods. However, in recent times; the use of Numerical Weather Prediction (NWP) and other numerical models are very common because they have high accuracy and reliability. Nigeria adopted the use of Consortium for Small Scale Modelling (COSMO) since 2012 in collaboration with German Meteorological Office (DWD) and has proven its ability to forecast deep convection successfully; that performed quite well for many heavy convection events including the explicit simulation of deep convention during 2017 rainy season (NiMet, 2017). According to NiMet (2017), NWP consists of numerical models that stimulate dynamical, radiation and thermo-dynamical atmospherical physics and further processes on the earth boundary layer as well as on a large variety of different observation data which are focused into a coherent state of the atmosphere by data assimilation techniques.

Agogbuo *et al* (2017) evaluated selected NWP models for a case of widespread rainfall over Central and Southern Nigeria on 21st March, 2015 using data from ECMWF, UKmet, NCEP

Global Forecast System (GFS) and Weather Research and Forecast (WRF) model. The rainfall forecasts were compared with observed rainfall at station and gridded observation points using the Method of Objective-based Diagnostic Evaluation (MODE), Grid statistics and point statistics. Results showed that ECMWF, UKMet and GFS underestimated the rainfall amount when compared to the WRF regional models.

Capacci *et al* (2004) conducted a research on the probability of precipitation estimation using SEVIRI-LIKE data and artificial neural networks. The ANNs techniques were adopted to establish an indirect procedure to estimate Probability of Precipitation (PoP). Result shows that a new SEVIRI-based scheme could provide better estimation of precipitation.

As good as these models are in terms of categorical rainfall forecast, the ANNs were not used to forecast rainfall in year 2019 over the GEZN hence this research which aimed at forecasting annual rainfall over the GEZN and comparing its result with the NiMet forecast for 2019.

Study area

The Guinea Ecological Zone, Nigeria (GEZN) is the study area. It is located between longitudes 4^{o}–10^{o}E and latitudes 6^{o}–$11^{o}30^{1}$N. It shares boundaries with the Sudano–Sahelian Zone, Nigeria (SSZN) to the north and the forest vegetation zone, Nigeria (FVZN) to the south (Figure 1).

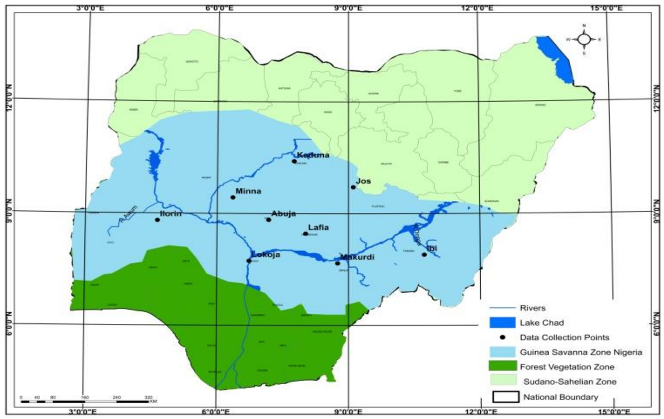


Figure 1. The Study Area

Source: National Space Research and Development Agency (NASRDA) (2019).

The GSZN has two (2) distinct seasons which are rainy and dry. The onset of rain is April while its cessation is October. Dry season period is November to March, while the harmattan is experienced between November and February (Malik, 2004 cited in Musa *et al*., 2012). There is inter-annual variation in rainfall over the area (Ibrahim *et al*, 2018). Total annual rainfall is over 1220 mm in most years (Abdulkadir, 2007; Yusuf, 2012, FUT Minna, 2014). The highest mean monthly rainfall occurs in August (Obateru, 2017; NiMet, 2018). Mean annual temperature is about 31°C except for Jos Plateau where it is lower (MS, 2013 cited in Musa *et al*, 2013). In dry season, relative humidity is about 30%, while during the rainy season, it is about 70% (Audu, 2001; Audu, 2012). The two (2) predominant air masses that influence the weather and climate of the area are the Tropical Maritime Air mass (mT) also called the South–West (SW) trade wind which is moisture laden and the Tropical Continental (cT) air mass. (Iwena, 2000).

The study area consists of gently undulating plain, hills, ridges and plateaux whose heights are between 300m-1500m (Ola, 2001 cited in Obateru, 2017; Gonap *et al*, 2018). There are numerous rivers in the area such as Rivers Niger, Benue, Katsina Ala, Kaduna, Gurara, Awum, Donga and Usuma (Audu, 2019). These rivers and the associated features such as flood plains and islets are of great economic importance such as fishing, irrigation farming especially in the dry season, hydroelectric power generation, industrial uses and tourism. However, these potentials are grossly under harnessed. Two (2) prominent man–made lakes found in the area are Kainji Lake on River Niger and Shiroro Lake on River Kaduna. Few dams within the study area include the Kainji and Jebba Dams located on River Niger, Shiroro Dam located on River Kaduna as well as the Jabi and Lower Usuma Dams in Abuja–FCT (Iwena, 2000). The vegetation is guinea in nature with pockets of gallery forest around water courses (Bello, 2007). The geology of the study area is mainly Precambrian basement and sedimentary rocks (Ayuba *et al*, 2013). The major occupations are farming, hunting, little lumbering and little mining.

Materials and methods

Secondary data were used for this research. These data included the daily rainfall and annual rainfall forecast (mm) by Nimet (2019) for Makurdi, Lokoja, Ibi, Ilorin, Lafia, Abuja, Minna, Jos and Kaduna. The period covered in the data is from 1st January, 1981 to 31st December, 2015 (35 years). The data points are evenly distributed across the study area. The secondary data were sourced from the Nigerian Meteorological Agency, Oshodi, Lagos.

Artificial neural networks (ANNs) were used to train the daily rainfall data on time series (using year and day of year as inputs). The data were arranged in four columns such as day of year sum of rainfall, day of year index of rainfall, day of year daily rainfall and actual annual rainfall, . Fifty networks were simulated varying the number of hidden neurons from 1–50. Before the training, the daily rainfall data were split into three in this manner: Training=70%; Validation=15% and Testing=15%. The test dataset was used to evaluate the performance of the networks by computing Root Mean Square Errors (RMSEs). Fuzzy logics were also used for the neural networks training. The neural networks outputs were densities of rainfall. Rainfall amount for a day was obtained using the following equation:

$$\frac{probability\ density\ for\ the\ day\ (PDD)}{sum\ of\ probability\ densities\ for\ the\ year\ (SPDDY)}\ x\ \frac{Rainfall\ cummulative\ for\ the\ year\ (mm)}{1} \quad 1$$

Where: *PDD* = an index for indicating rainfall amount for the day,

RCY= rainfall cumulative (total annual rainfall) in mm for the year; and

SPDDY= sum of probability densities for all the days in the year

The RMSE was determined using the following equation:

$$RMSE=\sqrt{\sum \frac{(x-f)^2}{n}} \quad 2$$

Where:$x\ = observed\ rainfall\ in\ mm,$ f= rainfall forecast from the network, n=15% of data point (in days) used for testing.

$$H_{vm}=\tanh(iwm * ivm + B_1) \quad 3$$

tanh is the hyperbolic tangent of trigonometric function. Input weight matrix (iwm) is a parameter of the network which is obtained after the network training. Input variable matrix (ivm) contains the inputs for the neural networks.

$$O_{vm}=B_2 + L_{wm} * H_{vm} \quad 4$$

Both $B_1$and B_2 (called bias vectors) are parameters of the network that are obtained after the training. They are constant vectors. Layer weight matrix (L_{wm}) is also a parameter of the network which is obtained after the training. It is a constant matrix.

Eqns 3 and 4 are respectively functions of the neural networks representing the transfer functions from the in input to the hidden layer and from the hidden layer to the output layer.

$$FL = A - R = B \qquad 5$$

Where: $A \ and \ B$ are fuzzy sets, R is a fuzzy relation and $A - R$ stands for the composition of A with R.

To determine the expression for the linear regression, the following equation was used:

$$y = mx + c \qquad 6$$

Where: y =which is the output (predicted annual rainfall in mm),$m \ is \ slope \ of \ the \ line$

$x = O_{vm}$ (observed annual rainfall in mm), c is the *intercep*t of the line ($m \ and \ c$ are constants in the equation).

The neural network diagram is shown in Figure 2.

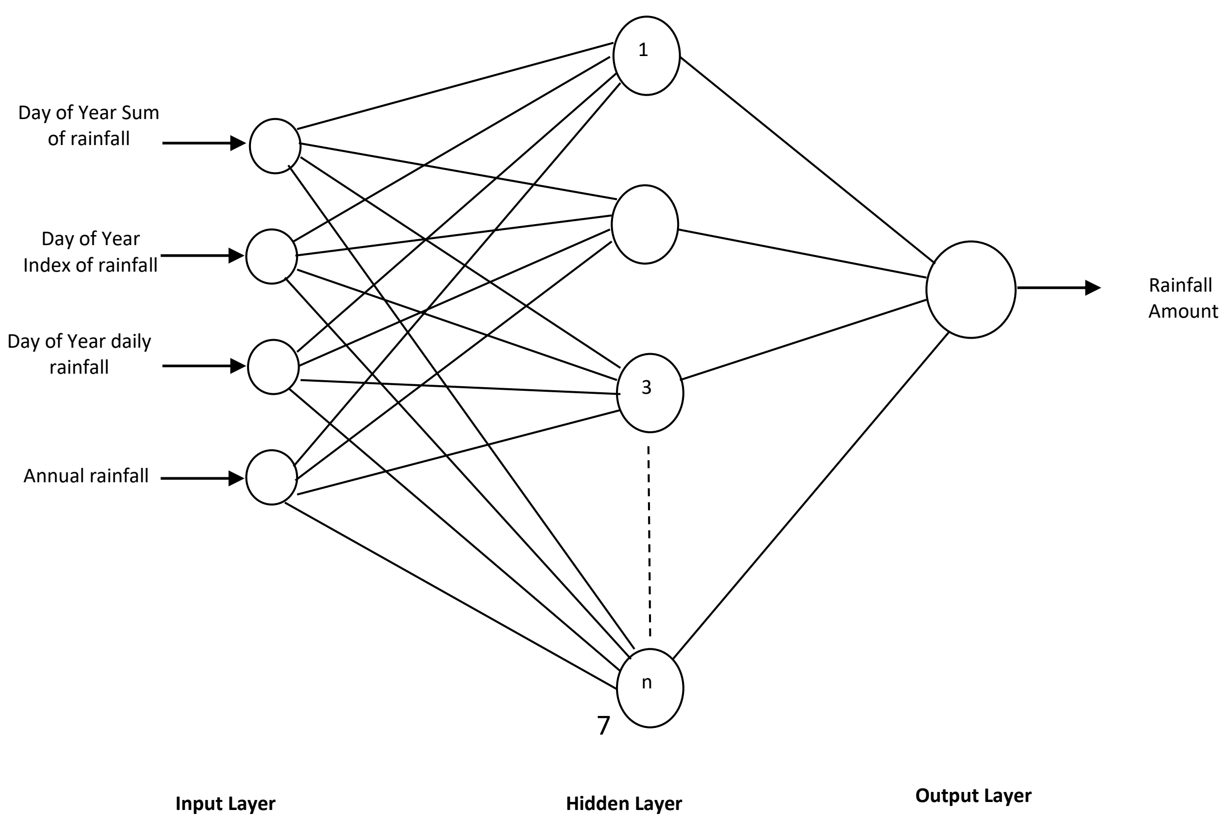


Figure 1: Neural Networks diagram

Source: Authors' computation, 2019

To take care of the errors in the total annual rainfall forecast by ANNs, margin of errors (MEs) were calculated for all the data collection points. A margin of error is the range of values below and above the sample statistic in a confidence interval. MEs were calculated using the following equation:

$$ME = z_{\frac{\alpha}{2}} x \ \sigma \qquad 7$$

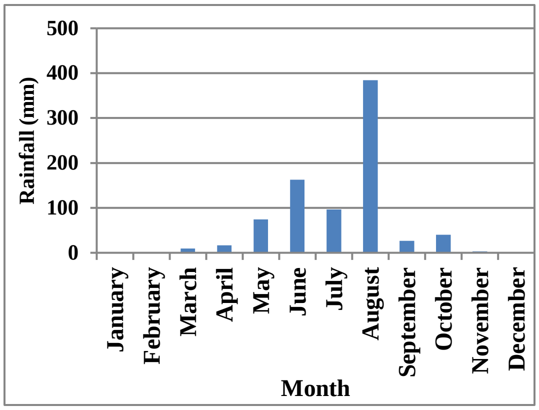
Where: ME = margin of error,

$Z\frac{\alpha}{2}$ = critical value which is 1.96 based on the 95 % level of confidence for this study,

$\sigma =$ standard deviation

Results and discussion

Figures 3-12 show the total monthly rainfall forecast by ANNs over the study area. Ilorin and Makurdi are expected to experience rainfall in January and February. In March, all the stations are expected to experience rainfall except Kaduna and Lafia. All the stations are expected to have rains in April-October except Jos where rain is not expected in October. Abuja, Ilorin and Makurdi are expected to have rains in November, while rains are expected over Ibi and Ilorin in December. In the study area, April-October marks the rainy season (Audu, 2012; Obateru, 2017).



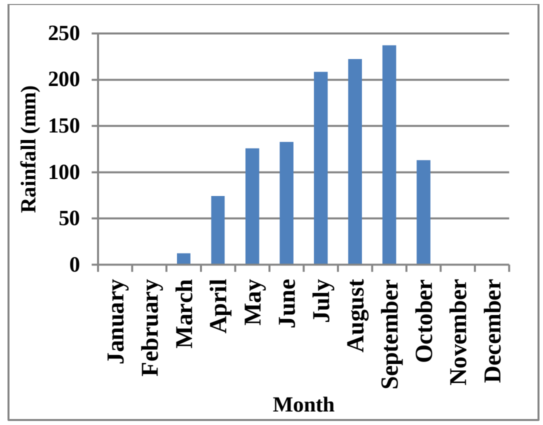
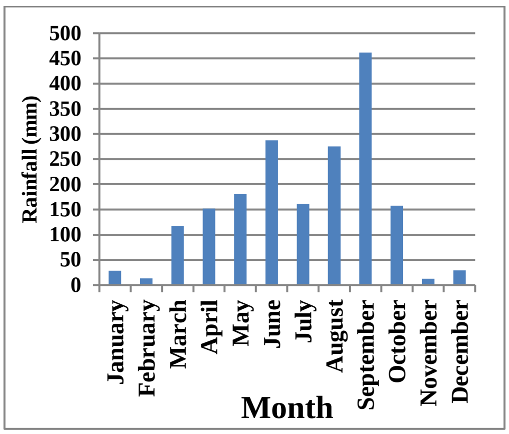


Fig.3: Monthly rainfall forecast by ANNs over Abuja in 2019
Source: Authors' computation, 2019

Fig.4: Total monthly rainfall forecast by ANNs over Ibi in 2019
Source: Authors' computation, 2019



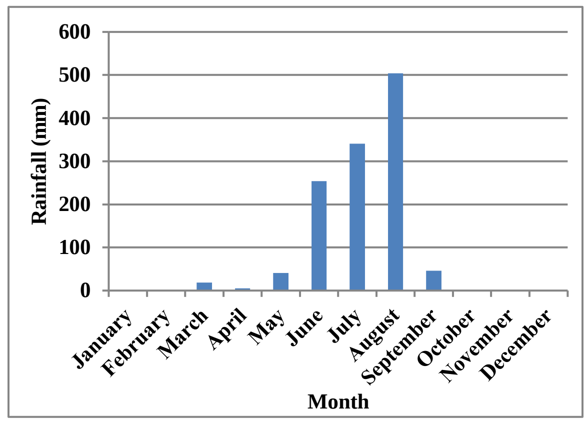
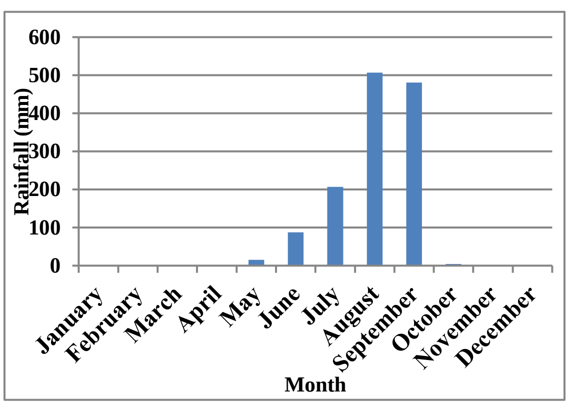


Fig.5: Total monthly rainfall forecast by ANNs over Ilorin in 2019
Source: Authors' computation, 2019

Fig.6: Total monthly rainfall forecast by ANNs over Jos in 2019
Source: Authors' computation, 2019



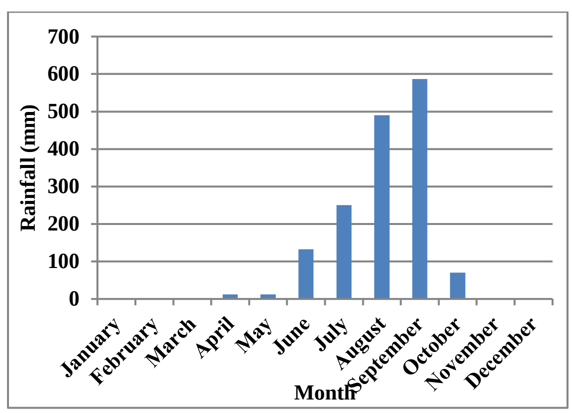


Fig.7: Total monthly rainfall forecast by ANNs over Kaduna in 2019
Source: Authors' computation, 2019

Fig.8: Total monthly rainfall forecast by ANNs over Lafia in 2019
Source: Authors' computation, 2019

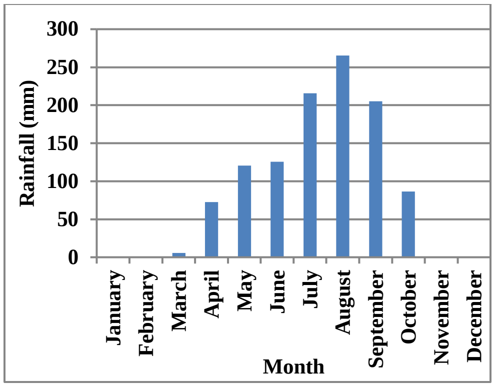


Fig.9: Total monthly rainfall forecast by ANNs over Lokoja in 2019
Source: Authors' computation, 2019

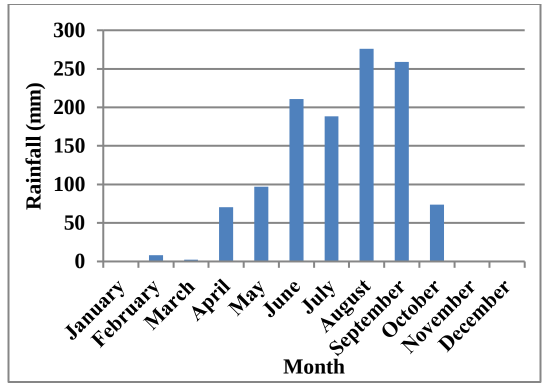


Fig.10: Total monthly rainfall forecast by ANNs over Makurdi in 2019
Source: Authors' computation, 2019

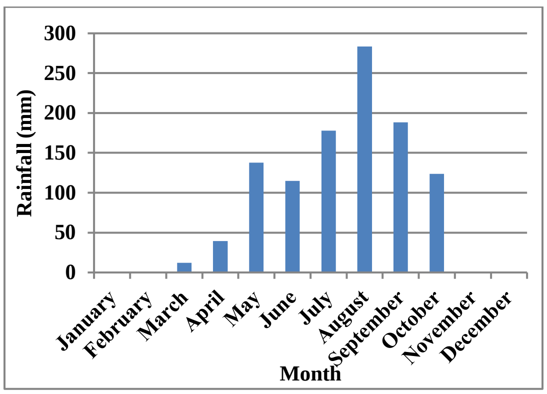


Fig.11: Total monthly rainfall forecast by ANNs over Minna in 2019
Source: Authors' computation, 2019

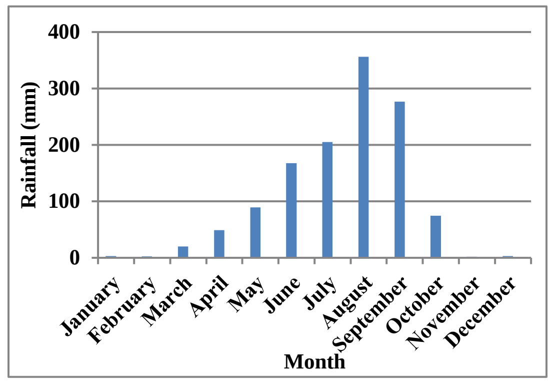


Fig.12: Mean monthly rainfall forecast by ANNs over GEZN IN 2019
Source: Authors' computation, 2019

In Abuja, highest rainfall is expected in August (fig. 3). Obateru (2017) opined that highest mean monthly rainfall over Abuja occurs in August. There is also a sign of double maxima rainfall in June and August. In fig.4, Ibi is expected to have high values of monthly rainfall which is over 50 mm between April-October with the highest in September. According to fig.5, Ilorin is expected to have rainfall throughout the year with March-October having monthly rainfall of over 100 mm. there is double maxima rainfall over the station with September having the highest rainfall. A delayed onset of rain was observed over Jos and Kaduna (figures 6 & 7). May is the onset, while September is the cessation with August having the highest rainfall. Figure 8 depicts that Lafia will experience onset of rain in June and cessation will be in October, while the highest rainfall is in September. Over Lokoja and Makurdi (figures 9 & 10), April is the onset of rain, October is the cessation while August has the highest. Makurdi shows a sign of double maxima rainfall with a reduction of rain in July. In Minna (figure 11), onset of rainfall is in May, cessation is in October, while highest rainfall is in August. According to figure 12, April is the onset of rain over the GEZN, October is the cessation while the highest rainfall is in August with single maximum.

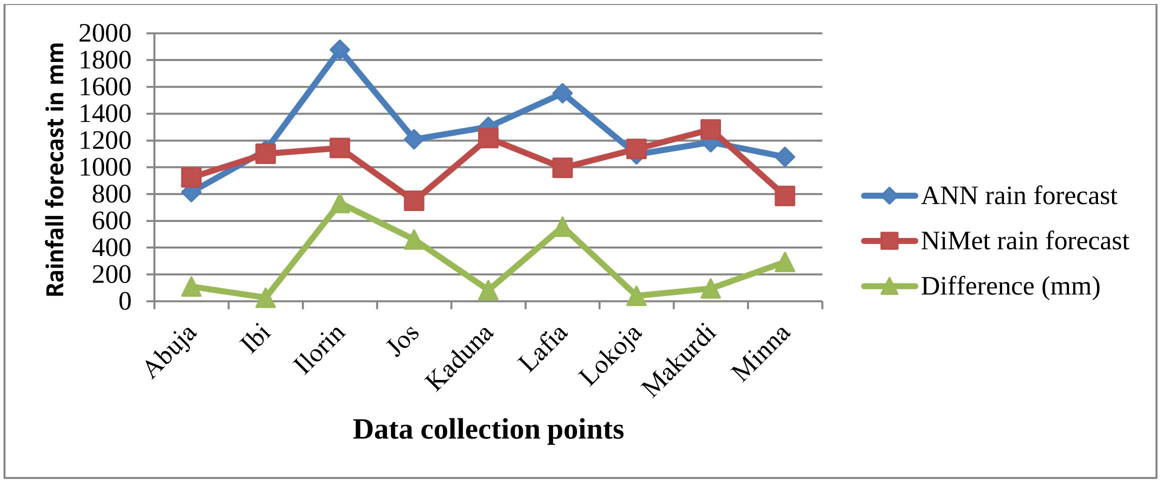


Fig. 13: Rain forecasts by ANNs and NiMet for 2019
Sources: 1. NiMet (2019) 2. Authors' computation, 2019

According to figure 13, NiMet annual total rainfall for the data collection points shows below normal rainfall over all the points for the year 2019 except for Kaduna and Makurdi where normal rainfall is expected. The artificial neural network (ANNs) forecasts show below normal rainfall over Jos, Kaduna and Makurdi, while above normal rainfall forecast was made over Ilorin and Lafia. Results from NiMet forecast also shows a decline in total annual rainfall over the stations except Kaduna and Makurdi, while ANN forecasts show downward trend in annual rainfall over Abuja. In a research conducted by Audu *et al* (2019), it was discovered that Abuja and Ibi are experiencing downward trend in total annual rainfall in recent time.

According to Audu (2019), no forecast is 100% accurate; hence the need for margin of error (ME) to be calculated for every forecast. The margin of error for this study is shown in fig. 14.

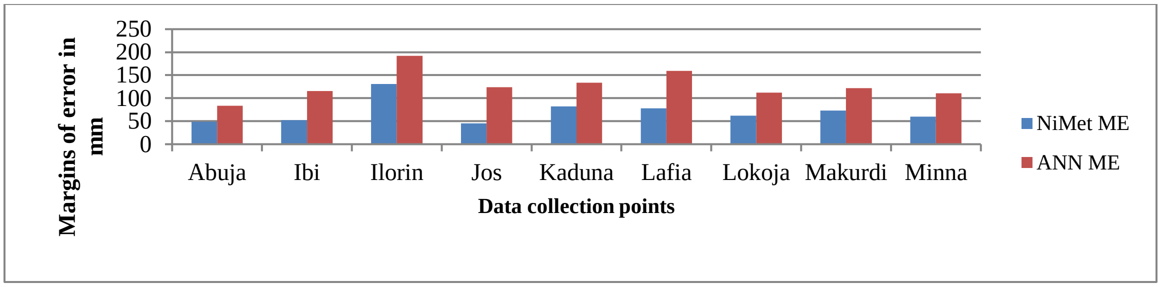


Fig. 14: Margin of error over the data collection points in GEZN.
Source: Authors' computation, 2019

According to figure 14, all the data collection points have NiMet ME that is above 50 mm except for Abuja and Jos, while the ANNs ME is higher than 50 mm in all data collection points. In ANNs ME, Abuja has the least, while Ilorin has the highest. The mean NiMet ME is 70.2 mm, while ANN ME is 128 mm. Generally; the ANNs MEs are higher than NiMet ME.

Conclusion and recommendation

The artificial neural network (ANNs) was able to forecast rainfall over the GEZN for the year 2019. According to the forecast, there were significant rains in March, but the onset of rain is April, while its cessation is October. The ANNs mean annual rainfall over the study area is August. The ANNs forecast performed well when compared with the NiMet's forecast except for Ilorin, Minna, Jos and Lafia. It is therefore recommended that a rainfall review should be carried out at the end of 2019 to evaluate the performance of the ANN so as to ascertain its suitability for forecast in the future.

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