Appraisal of global rainfall forecasting models on heavy rainfall days over the Guinea Savanna Zone, Nigeria

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Abstract

Numerical models are vital tools in forecasting rainfall globally. In most cases, these models underperform. This has formed the basis for this research which was aimed at the appraisal of global rainfall forecasting numerical models on heavy rainfall days over the Guinea Savanna Zone, Nigeria (GSZN) which served as the study area. Nine (9) meteorological stations were chosen from the study area for the purpose of data collection due to their long history of data. These stations included Makurdi, Lokoja, Ibi, Ilorin, Lafia, Abuja, Minna, Jos and Kaduna. Secondary data were used for the study. These included the observed daily rainfall data obtained from the Nigerian Meteorological Agency (Nimet), Oshodi, Lagos and rainfall forecasts obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) as well as the United Kingdom Met Office (UKMet). Data were presented in figures as well as tables and analysed using the probability of detection (POD), root mean square error (RMSE), mean absolute error (MAE) and rainfall intensities. The results indicated that both global numerical models appraised performed well in categorical rain forecasting over the study area, but under-estimated the total rainfall on the nine (9) events appraised. It was therefore suggested among others that both models be dynamically downscaled to take into consideration local peculiarities over Nigerian domain and local numerical model such as *the artificial neural network (ANN) be developed to forecast various degrees of rainfall intensities.*

Key words: Rainfall, heavy rainfall, numerical models, COSMO, observed rainfall

Introduction

Rainfall remains the most important weather variable in Nigeria because the most important occupation in Nigeria which is agriculture is majorly rain-fed. Other sectors of the socio-economic activities in Nigeria such as hydrology/water resources, inland water transport, hydro electric power generation as well as domestic water supply are heavily dependent on rainfall both directly and indirectly. Similarly, rainfall is highly variable than other weather parametres. Hulme *et al* (2005) cited in Lawal *et al* (2012) observed that rainfall exhibits notable spatial and temporal variability over Nigeria. It is therefore inevitable to embark on rainfall forecast. Heavy rainfall is one of the derived rainfall parameters in Nigeria. According to Audu *et al* (2018), heavy rainfall is that total amount of rainfall which is ≥ 50 mm within 24 hours (1 day). This amount of rainfall can occur in any month of the year within the study area. However, it is mostly concentrated within the peak of the wet season that is, August over the study area (Audu *et al*, 2019).

Commenting on the need for the use of numerical models in weather forecast, Anthes (1984) cited in Ajayi *et al* (2010) argued that; if human can modify climate and weather inadvertently, they should be able to intentionally modify weather most especially rainfall in a constructive way. Ajayi *et al* (2010) used the ICTP Regional Climate Model ($RegCM^3$) to analyse the impact of land-cover changes on rainfall in West Africa. The study of Agboluaje and Dangana (2014) utilized the SARIMA and ARIMA models for the seasonal modeling and forecasting of rainfall in Badeggi-Bida Area of Niger State, Nigeria. The study carried out by Akinsanola *et al* (2014) on the diagnostic evaluation of precipitation over West Africa using three of the Coordinated Regional Climate Downloading Experiment (CORDEX) Africa simulations, used three (3) of the Regional Climate Model (RCM). The Nigerian Meteorological Agency (NiMet), adopted the use of Consortium for Small Scale Modelling (COSMO) which is a non-hydrostatic, high resolution, limited area atmospheric prediction model in 2012 in collaboration with the German Meteorological Office (DWD) (NiMet, 2018a) in weather forecast. It is a regional numerical weather prediction system with additional components such as data assimilation and interpolation of boundary conditions from driving model. As good as these models are in the area of performance, they are limited because they are not global in nature.

There are several global numerical models used for rainfall forecast. Some of these models include European Centre for Medium-Range Weather Forecasts (ECMWF), United Kingdom Met Office (UKMet), Action de Recherche Petite Echelle Grande (ARPEGE) (Asaniyan, 2006), Meteo-France (Ibrahim, 2006) and Global Forecasting System (GFS). This study aimed at the appraisal of the most commonly used global rainfall forecasting numerical models on heavy rainfall days over the Guinea Savanna Zone, Nigeria which are the ECMWF and UKMet models.

Study area

The study area is the Guinea Savanna Zone, Nigeria (GSZN) which lies between longitudes 4º–10ºE and latitudes 6º–11º30¹N (Figure 1). The Sudano–Sahelian Zone, Nigeria (SSZN) bordered it to the north, while the forest vegetation zone, Nigeria (FVZN) bordered it to the south.

There are two (2) seasons in the area namely, wet and dry. Wet season is experienced between April and October, while dry season is experienced between October and April (Mohammed, 2010). The total annual rainfall ranges between 697.10 mm–2456.9 mm (Audu *et al*, 2018). Mean annual temperature is between 28.03ºC-31ºC (MS, 2013) cited in (Musa *et al*, 2013). August has the highest mean monthly rainfall (NiMet, 2018). The Tropical Maritime Air mass (mT) also called the South–West (SW) trade wind which is described as moisture laden and brings rainfall across the area and the Tropical Continental (cT) air mass also called the North–East (NE) trade (harmattan) wind which blows in the dry season between November and February are the two (2) major air masses that affect the area (Iwena, 2000; Malik, 2004 cited in Musa *et al*., 2012). The wind speed is about 10km/hr (MMS, 2013) cited in (Musa *et al*, 2013).

The study area consists of gently undulating plain with some hills, ridges and plateaux whose heights are between 300m-900m (Ola, 2001) cited in (Obateru, 2017). It also consists of part of the western upland as well as the Niger–Benue Trough (Falola *et al*, 2015). The highest elevation is about 1500m. There are numerous rivers in the area such as Rivers Niger, Benue, Katsina Ala, Kaduna, Gurara, Awum, Donga and Usuma. The confluence of Rivers Niger and Benue is found at Lokoja (Audu, 2001). There are two (2) main artificial or man–made lakes such as the Kainji Lake on River Niger and Shiroro Lake on River Kaduna in the region and few dams such as Kainji Dam and Jebba Dam located on River Niger, Shiroro Dam located on River Kaduna (all in Niger State) as well as the Jabi and Lower Usuma Dams in Abuja–FCT (Iwena, 2000).

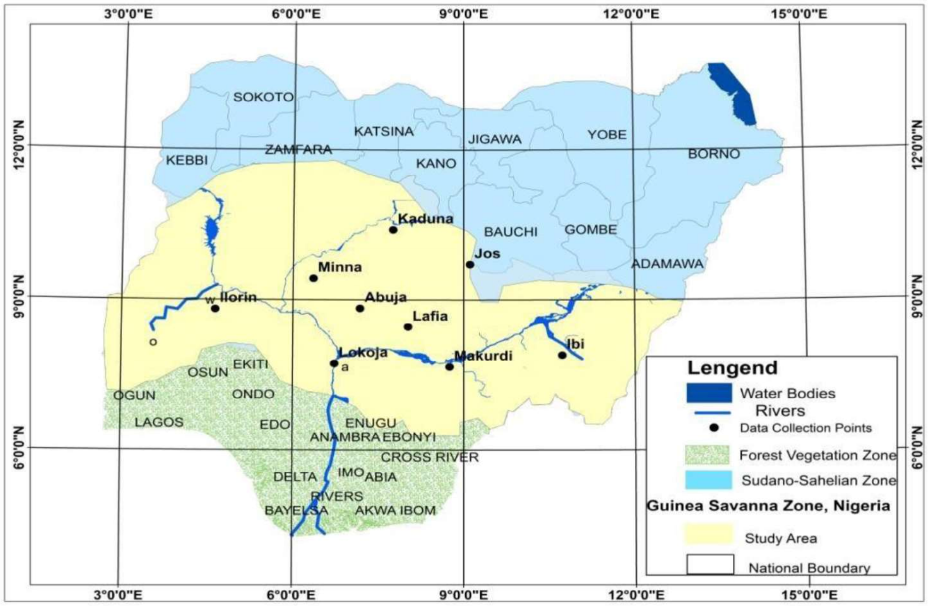


Figure 1: The Study Area

Source: National Space Research and Development Agency (NSRDA), Abuja (2019)

The zone is the largest vegetation belt in Nigeria, the Guinea Savanna with the presence of gallery forests mainly along Rivers Niger and Benue (Bello, 2007). The geology of the study area is predominantly Precambrian basement as well as various sedimentary rocks (Ayuba *et al,* 2013; MMS, 2013 cited in Musa *et al*, 2013; Dan–Hassan *et al*, 2015). The major land uses in the study area include settlement, construction, farming, trading, small scale manufacturing and tourism (Odekunle *et al*, 2007; Shehu, 2014; Gonap *et al*, 2018).

Materials and methods

Secondary data on daily rainfall (in mm) were obtained from Nigerian Meteorological Agency (NiMet), Oshodi, Lagos, and rainfall forecasts from two (2) most popular global numerical models obtained from European Centre for Medium-Range Weather Forecasts (ECMWF) and United Kingdom Met Office (UKMet) were used for this study. The data were from 2007 to 2015 and covered nine (9) data collection points namely, Makurdi, Lokoja, Ibi, Ilorin, Lafia, Abuja, Minna, Jos and Kaduna. Heavy rainfall data were extracted from daily rainfall using micro soft excel in which all cells containing the considered data were selected. Conditional formatting was chosen in a manner that cells rules were highlighted and greater than was clicked. The available text box with desired threshold value of ≥ 50 mm was then clicked and all dates with rainfall value ≥ 50 mm appeared. Tigge data were retrieved online from ECMWF and UKMet using python script and Grid Analysis and Display System (GRADS).

Probability of detection (POD) (Gaili *et al*, 2016) was used to determine the fraction of observed "yes" events which were correctly forecasted. It was determined using the equation:

$$POD = \frac{Hits}{Hits+misses} \quad 1$$

Where: Hits is the number of rainfall forecast that matches with observed rainfall, while misses is the number of rainfall forecasts that did not match with the observed rainfall. Hits range between 0 1. 1 means perfect score for the events.

The magnitude of forecast errors was determined using root mean square error (RMSE). It measures average error, weighted according to the square of the error. It ranges from 0 to ∞. 0 means perfect score. It puts greater influence on large errors than smaller errors. It was calculated after Gaili *et al* (2016) as thus:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2} \quad 2$$

The magnitude absolute error (MAE) was used to determine the average of the forecast error. It was calculated after Gaili *et al* (2016) as follows:

$$MAE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}/F_i - O_i/} \quad 3$$

From equations 2 and 3, F_i means the forecast values, O_i means the observed values, N means the number of events and perfect score=0

Rainfall varies in intensity over time and space. Rainfall intensity (RI) is described as the ratio of total amount of rain (rain depth) falling during a particular period to the duration of the period. It is shown in depth units/unit time usually as mm per hour (mm/hr). It is measured as the height of the water layer covering the ground in a period of time. Rainfall forecasts from the two (2) global numerical models and the observed rainfall were also compared with rainfall intensities. Table 1 shows the rainfall intensities.

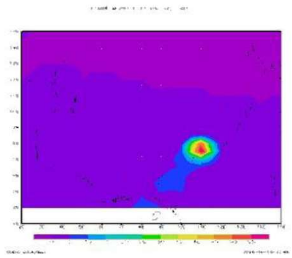
Table 1: Rainfall intensities

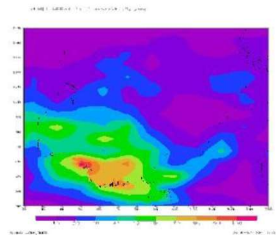
Descriptive Term Used	Rainfall Amount (mm/day)
No rain	0.0
Very light	0.1–2.4
Light rain	2.5–7.5
Moderate rain	7.6–35.5
Rather heavy	35.6–64.4
Exceptionally heavy rain	When the amount is a value near about the heaviest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm (120 mm)
Heavy rain	64.5–124.4
Very heavy rain	124.5–244.4
Extremely heavy rain	> 244.5

Source: Meera and Priyanca (2015)

Results and Discussion

The relationship between model forecasts and observed rainfall is the model performance which could be accurate, near accurate or inaccurate. Figures 2 to 19 show the results on the model forecasts by ECMWF and UKMET for nine (9) events under appraisal. Both models were able to capture the rain forecast over the study area.





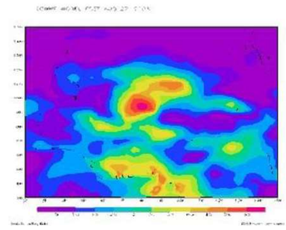
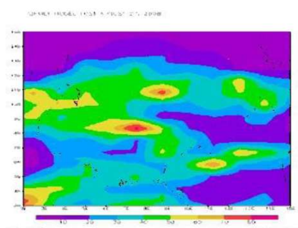
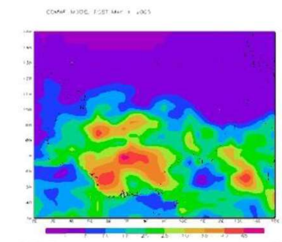


Fig. 2: ECMWF forecast, 16th Aug, 2007 **Fig. 3:** UKMet forecast, 16th August, 2007 **Fig. 4:** ECMWF forecast, 27th August, 2008

Source: Authors' computation, 2018 **Source:** Authors' computation, 2018 **Source:** Authors' computation, 2018





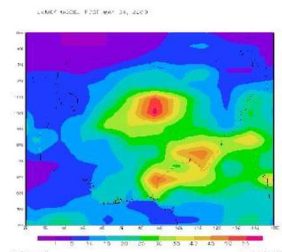
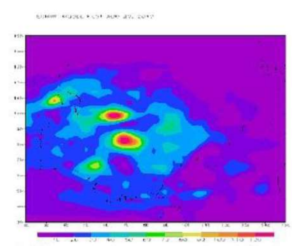
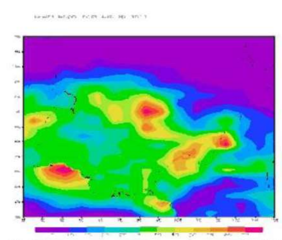
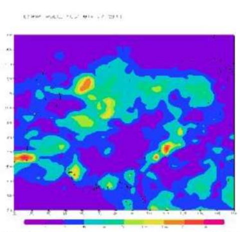


Fig. 5: UKMet forecast, 27th Aug. 2008 **Fig. 6:** ECMWF forecast, 4th May, 2009 **Fig. 7:** UKMet forecast, 4th May, 2009

Source: Authors' computation, 2018 **Source:** Authors' computation, 2018 **Source:** Authors' computation, 2018







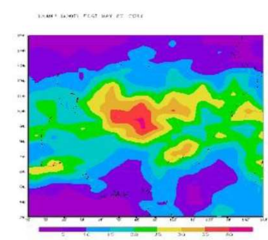


Fig. 8: ECMWF forecast, 20th Aug, 2010 **Fig. 9:** UKMet forecast, 20th Aug, 2010 **Fig. 10:** ECMWF forecast, 27th May, 2011 **Fig. 11:** UKMet forecast, 27th May, 2011

Source: Authors' computation, 2018 **Source:** Authors' computation, 2018 **Source:** Authors' computation, 2018 **Source:** Authors' computation, 2018

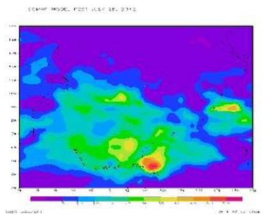
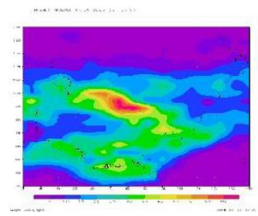
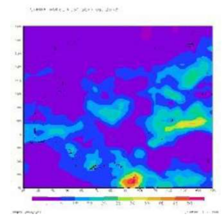
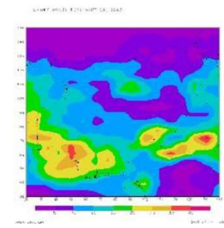





Fig. 12: ECMWF forecast on 26th July, 2012 *Fig. 13: UKMet forecast on 26th July, 2012* *Fig. 14: ECMWF forecast on 9th Sep, 2013* *Fig. 15: UKMet forecast on 9th Sep, 2013*

Source: Authors' computation, 2018 **Source:** Authors' computation, 2018 **Source:** Authors' computation, 2018 **Source:** Authors' computation, 2018

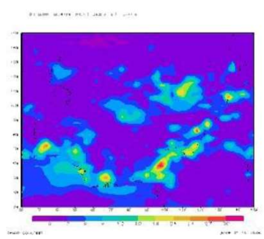
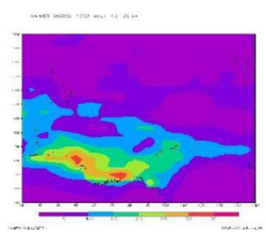
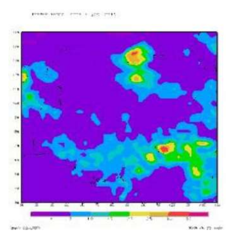
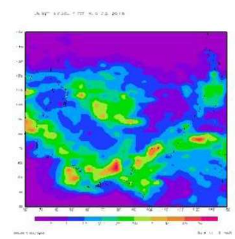





Fig. 16: ECMWF forecast on 13th Jul, 2014 *Fig. 17: UKMet forecast on 13th Jul, 2014* *Fig. 18: ECMWF forecast on 20th Aug, 2015* *Fig. 19: ECMWF forecast on 20th Aug 2015* ***Source:*** *Authors' computation, 2018* ***Source:*** *Authors' computation, 2018* ***Source:*** *Authors' computation, 2018* ***Source:*** *Authors' computation, 2018*

Both the ECMWF and UKMet numerical models performed very well in the area of categorical rainfall forecast since the observed "yes" events were equal to forecast "yes" events (figs. 19 and 20). The UKMet model values are higher than the ECMWF model values. However, the two (2) models underestimated all the nine (9) events under investigation (fig. 20). Heavy rainfall was not forecast by the two (2) global models.

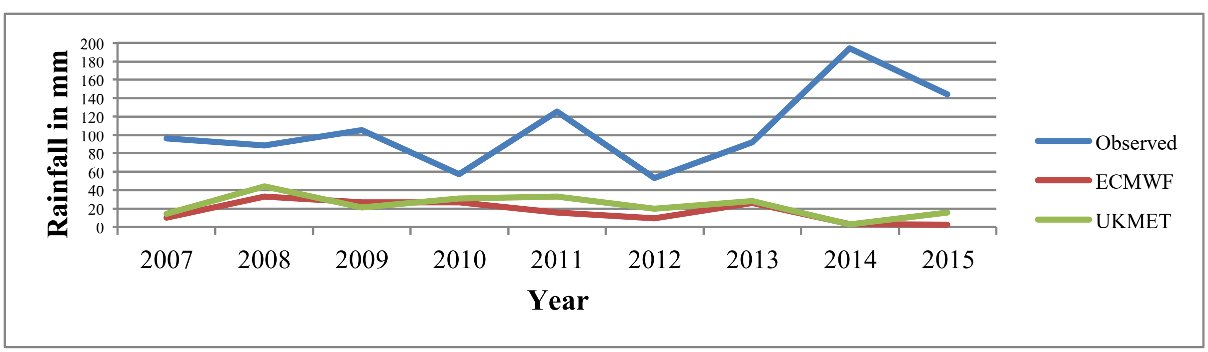


Figure 20: ECMWF and UKMet forecasts and observed rainfall on heavy rainfall days, 2007-2015 over the study area

Sources: Nigerian Meteorological Agency, Oshodi, Lagos (2018b) and ECMWF (2018)

Figure 20 shows the differences between ECMWF and UKMet forecasts and observed rainfall on heavy rainfall days, 2007-2015 over the study area. The observed rainfalls were higher than the forecasts by both numerical models appraised which means that the models were unable to forecast heavy rainfall over the area. Reasons for the inability of the two (2) numerical models to forecast heavy rainfall over the study area could be that they are not producing high vertical motion at the top of the boundary layer, some parametization schemes such as cloud microphysics and convection used in the models may not work well over the Nigerian domain; and that they did not consider the local peculiarities over the Nigeria's domain owing to the parametization schemes used.

Results on probability of detection (POD) for both ECMWF and UKMet are one (1) each which implies perfect score. The Root Mean Square Error (RMSE) of the ECMWF rainfall forecast is 101.43, while that of the UKMet is 96.33. This implies that the error magnitude of the ECMWF rainfall forecast was greater than the UKMet. The result on mean absolute error (MAE) for ECMWF forecast is 89.22, while that of UKMet is 83.03. This implies that, there exist large variations between the numerical models rain forecasts and the observed rainfall. However, the MAE of UKMet is lower than that of the ECMWF because the rainfall model forecasted values by UKMet are higher than the ECMWF which implies that, although these two (2) models forecasted rainfall over the study area; UKMet model performed better in Quantitative Rainfall Forecast (QRF).

Results on rainfall forecasts by ECMWF and UKMet numerical models as well as the observed rainfall were further compared with rainfall intensities as shown in tables 2-10. The observed rainfall is the actual rainfall recorded over a particular location. This is the rainfall value that is used for planning in the areas of agriculture, water resources, construction, drainage, erosion, landslide and flood management.

Table 2: Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 16th August, 2007 over the study area.

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)**
1.	No rain	0.0	-	- -	

2.	Very light rain	0.1-2.4	-	-	-
3.	Light rain	2.5-7.5	-	-	- 4.
	Moderate rain	7.6-35.5	10	14	-
5.	Rather heavy rain	35.6-64.4	-	-	-
6.	Exceptionally heavy rain	120 +	-	-	- 7.
	Heavy rain	64.5-124.4	-	-	96
8.	Very heavy rain	124.5-244.4	-	-	-
9.	Extreme heavy rain	>244.5	-	-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

According to table 2, the ECMWF and UKMet numerical models were able to forecast rainfall over the study area on 16th August, 2007. Both models forecasted moderate rainfall intensity, while the observed rainfall intensity was heavy rainfall. Both models therefore underestimated the rainfall intensity for the day over the study area.

Table 3: *Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 27th August, 2008 over the study area.*

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)**
1.	No rain	0.0	-	-	-

-

2.	Very light rain	0.1-2.4	-	-	-
3.	Light rain	2.5-7.5	-	-	-
4.	Moderate rain	7.6-35.5	33	-	-
5.	Rather heavy rain	35.6-64.4	-	44	-
6.	Exceptionally heavy rain	120 +	-	-	-
7.	Heavy rain	64.5-124.4	-	-	88.7
8.	Very heavy rain	124.5-244.4	-	-	-
9.	Extreme heavy rain	>244.5	-	-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

ECMWF rainfall forecast, UKMet model rainfall forecast and observed rainfall over the study area on 27th August, 2008 and rainfall intensities are presented in table 3. The ECMWF model forecasted moderate rain while UKMet model forecast indicated rather heavy rain. Meanwhile, while the observed rainfall was heavy rainfall intensity. The two (2) models performed fairly well, but underestimated rainfall intensity for the day.

Table 4: Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 4th May, 2009 over the study area.

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)**
1	No rain	0.0	-	-	-
2	Very light rain	0.1-2.4	-	-	-

3	Light rain	2.5-7.5	-	-	-
4.	Moderate rain	7.6-35.5	30	25	-
5.	Rather heavy rain	35.6-64.4		-	-
6.	Exceptionally heavy rain	120 +	-	-	- 7.
	Heavy rain	64.5-124.4	-	-	105.4
8.	Very heavy rain	124.5-244.4	-	-	-
9.	Extreme heavy rain	>244.5	-	-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

Table 4 shows the results on ECMWF and UKMet model forecasts as well as the observed rainfall on 9th September, 2009 in relation to intensities of rainfall. Both models forecasted moderate rainfall intensities, while the observed rain was heavy rainfall intensity. The two (2) models performed poorly due in the area of heavy rainfall forecast over the study area.

Table 5: Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 20th August, 2010 over the study area

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)**
1.	No rain	0.0	-	-	- 2. Very light
rain	0.1-2.4	-	-	-	

-

3. Light rain	2.5-7.5	-	-	- 4.
Moderate rain	7.6-35.5	27	31	-
5. Rather heavy rain	35.6-64.4	-	-	57
6. Exceptionally heavy rain	120 +	-	-	- 7.
Heavy rain	64.5-124.4	-	-	- 8.
Very heavy rain	124.5-244.4	-	-	-
9. Extreme heavy rain	>244.5	-	-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

The results on ECMWF and UKMet models forecasts as well as the observed rainfall on 20th August, 2010 are shown in table 5. Both models forecasted moderate rainfall intensity, while the observed rainfall intensity was rather heavy. The two (2) models forecasts were near-accurate.

Table 6: Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 27th May, 2011 over the study area.

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)**
1	No rain	0.0	-	-	-
2	Very light rain	0.1-2.4	-	-	- 3 Light
	rain	2.5-7.5	-	-	-

4. Moderate rain	7.6-35.5	16	33	- 5.
Rather heavy rain	35.6-64.4	-	-	- 6.
Exceptionally heavy rain	120 +	-	-	125.6
7. Heavy rain	64.5-124.4	-	-	- 8.
Very heavy rain	124.5-244.4	-	-	-
9. Extreme heavy rain	>244.5		-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) ***** NiMet (2018b)**

Table 6 presents the comparism between ECMWF model rain forecast, UKMet model rain forecast and observed rainfall in relation to rainfall intensities on 27th May, 2011. Both numerical models forecasted moderate rain intensity, while the observed rainfall intensity was exceptionally heavy. The performance of the two (2) models is therefore poor even though they were able to forecast rainfall intensities.

Table 7: Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 26th July, 2012 over the study area.

S/N Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)**
1. No rain	0.0	-	-	- 2. Very
light rain	0.1-2.4	-	-	-

			-		
3.	Light rain	2.5-7.5	-	-	- 4.
	Moderate rain	7.6-35.5	9.5	20	- 5.
	Rather heavy rain	35.6-64.4	-	-	53.1
6.	Exceptionally heavy rain	120 +	-	-	-
7.	Heavy rain	64.5-124.4	-	-	-
8.	Very heavy rain	124.5-244.4	-	-	-
9.	Extreme heavy rain	>244.5	-	-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

Table 7 presents the results on model forecasts, ECMWF and UKMet as well as the observed rainfall in relation to rainfall intensities on 26th July, 2012. Both models forecasted moderate rain intensity, while the observed rainfall intensity is rather heavy rain. The two (2) models under-estimated rainfall intensity.

Table 8: *Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 9th September, 2013 over the Guinea Savanna Zone, Nigeria (GSZN).*

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)**
1.	No rain	0.0	-	-	-
2.	Very light rain	0.1-2.4	-	-	-

3.	Light rain	2.5-7.5	-	-	-
4	Moderate rain	7.6-35.5	26	28	-
5.	Rather heavy rain	35.6-64.4	-	-	-
6.	Exceptionally heavy rain	120 +	-	-	-
7.	Heavy rain	64.5-124.4	-	-	92.1
8.	Very heavy rain	124.5-244.4	-	-	-
9.	Extreme heavy rain	>244.5		-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

Table 8 presents the results on model rain forecasts for ECMWF and UKMet, observed rainfall and rainfall intensities on 9th September, 2013. Both models forecasted moderate rain intensity while heavy rainfall intensity was observed.

Table 9: Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 13th July, 2014 over the Guinea Savanna Zone, Nigeria (GSZN).

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)***
1.	No rain	0.0	-	-	-
2.	Very light rain	0.1-2.4	-	-	-
3.	Light rain	2.5-7.5	3.1	2.8	-
4.	Moderate rain	7.6-35.5	-	-	-

5.	Rather heavy rain	35.6-64.4	- -	-	- 6.
	Exceptionally heavy rain	120 +	-	-	194.3
7.	Heavy rain	64.5-124.4	-	-	- 8.
	Very heavy rain	124.5-244.4	-	-	-
9.	Extreme heavy rain	>244.5	-	-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

Table 9 presents the results on model forecasts for both ECMWF and UKMet, observed rainfall and rainfall intensities on 13th July, 2014. Both models forecasted light rain intensity, while the observed rainfall indicated exceptionally heavy rain. Therefore, both models underestimated rainfall intensity for that day over the study area.

Table 10: Comparism between ECMWF and UKMet models rainfall forecasts, observed rainfall and rainfall intensities on 20th August, 2015 over the study area.

S/N	Descriptive terms Used*	Rainfall amount (mm/day)	ECMWF forecast**	UKMet forecast**	Observed heavy rainfall (mm)***
1.	No rain	0.0	-	-	-
2.	Very light rain	0.1-2.4	-	-	-
3.	Light rain	2.5-7.5	2.5	-	-
4.	Moderate rain	7.6-35.5	-	16	-
5.	Rather heavy rain	35.6-64.4	-	-	-
6.	Exceptionally heavy rain	120 +	-	-	144.6
7.	Heavy rain	64.5-124.4	-	-	-
8.	Very heavy rain	124.5-244.4	-	-	-
9.	Extreme heavy rain	>244.5	-	-	-

Sources: *Adapted from Meera and Priyanca (2015) **ECMWF (2018) *** NiMet (2018b)

Table 10 shows the results on model forecasts- ECMWF and UKMMet; actual rainfall as well as rainfall intensities on 20th August, 2015. ECMWF model forecasted light rain intensity; UKMet model forecasted moderate rain intensity; while the observed rain was exceptionally heavy rain intensity. Generally, rainfall intensities forecasted by both models over the study area were under-estimated.

Conclusion and recommendations

The two (2) numerical models appraised performed well in the area of categorical rainfall forecast on the nine (9) events investigated. Out of the nine (9) events appraised, the models performed well by forecasting moderate rain on 16th August, 2007; 4th May, 2009; 20th August, 2010; 27th May, 2011; 26th July, 2012 and 9th September, 2013. The models also performed well by forecasting light rain intensity on 13th July, 2014. On the contrary, the models did not forecast same rain intensities on 27th August, 2008 and 20th August, 2015. On a whole, both numerical models under performed in the area of heavy rainfall forecast. Due to this inadequacies, the Nigerian Meteorological Agency (NiMet) which is the most authoritative agency saddled with the responsibility of weather forecast in Nigeria has adopted the use of a regional model called Consortium for small scale modeling (COSMO) alongside other global numerical models. It is hereby recommended that NiMet should work on both numerical models by dynamically downscaling them in such a way that local peculiarities over the Nigerian domain are considered in the physics and dynamics of the models. This will also create room for possible tuning of the model to get the best configuration and set up during heavy rainfall effects. Further, the use of artificial neural network (ANN) is advocated to forecast all the degrees of rainfall intensities especially heavy rain over Nigeria in view of the fact that heavy rainfall has been causing colossal loss to both lives and property annually in Nigeria.

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