CrossMark

Assessment of projected agro-climatic indices over Awun river basin, Nigeria for the late twenty-first century

Talardia Gbangou[1,2] • Mouhamadou Bamba Sylla[3] • Onemayin David Jimoh[4] •
Appollonia Aimiosino Okhimamhe[1]

Abstract

This paper examines changes in rainfall effectiveness indices of the Awun basin in Nigeria during the late twenty-first century for agricultural applications with outputs from high-resolution regional climate model (RCM) simulations. The RCM simulations are driven by two global climate models for a reference period (1985–2004) and a future period (2080–2099) and for RCP4.5 (a scenario with some mitigation) and RCP8.5 (a business as usual scenario) forcings. Simulations are provided for the control (1985–2004) and scenario (2080–2099) periods. Observations from synoptic station are used for bias-correction. Three indices being local onset date, seasonality index (SI), and hydrologic ratio (HR) are analyzed. Onset and HR are tested with two evapotranspiration (ET_p) models. Farmers' perceptions are also collected to validate trends of rainfall indices for the present-day climate. We found that onset dates do not depend much on the ET_p models used, and farmers' perceptions are consistent with predicted rainfall patterns. Present-day climate trend shows an early onset. However, onset is projected to be late in future and the delay will be magnified under the business as usual scenario. Indeed, average onset date is found on the 5th May for present-day while in the future, a delay about 4 and 8 weeks is projected under RCP4.5 and RCP8.5 scenarios respectively. SI is between 0.80 and 0.99, and HR is less than 0.75 for all scenarios, meaning respectively that (i) the rainy season will get shorter and (ii) the area will get drier in the future compared to the present-day. Local stakeholders are forewarned to prepare for potential response strategies. A continuous provision of forecast-based rainfall indices to support farmer's decision making is also recommended.

✉ Talardia Gbangou
talardia.gbangou@wur.nl

Back Affiliation

1 Introduction

Rain-fed agriculture is the main mode of agronomic production undertaken by smallholder farmers from developing countries and other economically deprived societies (Wani et al. 2009). In the Guinea-Savannah zone of West Africa, rainy-season farming is a major source of income for the rural population (Cooper et al. 2008; Müller et al. 2013). Climate change projections suggest an increase of sub-seasonal variability of the frequency and intensity of rain events across the Guinea-Savannah (Morris et al. 2009, Sylla et al. 2016a, Salack et al. 2016); this variability could in turn affect agricultural production through reduction of water availability (Iglesias et al. 2007).

In this article, we analyze the agriculturally relevant climate metrics across the Awun river basin in Nigeria. This basin is located in Guinea-Savannah part of West Africa (Fig. 1) where many farmers are facing challenges related to rainfall variability as they are mainly involved in rain-fed agriculture. Within this region, high inter-annual variability of onset and cessation of the rainy season leads to a lack of skillful predictability using traditional knowledge (Efe 2009) and challenges in determining the optimal crop selection and planting date each year (Mugalavai et al. 2008). Generally, yields may suffer significantly with either a late onset or early cessation of the growing season and a high frequency of damaging dry spells within the growing season (Mugalavai et al. 2008; Garcia-Carreras et al. 2015). The ability to accurately estimate the actual start of the season therefore is vital for farmers (Mugalavai et al. 2008).

Several studies have tried to assess local rainfall indicators for agriculture in Nigeria focusing on present-day climate (Odekunle et al. 2007; Marteau et al. 2009; Sawa and Adebayo 2011; Ufoegbune et al. 2012). However, in the context of climate change, emphasis need to be made towards future climate as well. This can bring insights on future climate conditions and help for short- and long-term planning in agriculture.

Previous studies on rainy season characteristics which include future climate simulations over West Africa are often done using regional technics and large-scale observational products (Mariotti et al. 2014; Klutse et al. 2016; Diallo et al. 2016) instead of local methods and data. However, regional methods are not always consistent with local methods which are calibrated locally and represent better the experience on the local scale (Fitzpatrick et al. 2015). For example, Fitzpatrick et al. (2015) identified an existing disharmony between the regional and local onset date estimation over West Africa. Moreover, these studies on projected rainfall characteristics have, often, used satellite or re-analysis data as observations to validate models' simulations instead of local station data. This is another concern for characterizing local scale rainfall as large scale products have limitations. For instance, when comparing satellite-gauged merged observations products, Sylla et al. (2013) identified significant differences among them. Important discrepancies were also found between gauge-based observations and satellite products by Nikulin et al. (2012) and Diallo et al. (2013). Therefore, rigorous validation of climate model runs using high quality observations remains a challenge for regional (West Africa) estimation of rainfall characteristics (Diallo et al. 2016).

Understanding farmers' perceptions on changes of agro-climatic indices has been less studied but plays a key role for anticipating the impacts of climate change (Simelton et al. 2013; Codjoe et al. 2014). It can help explore the nature of meteorological evidence of the perceived changes for better adaptive planning in future climate.

The current study attempts to fill these gaps by evaluating not only present climate but also future trend of three rainfall characteristics called onset dates, the seasonality index (SI) or spread of rainy season, and the hydrologic ration (HR) or degree of dryness of an area. To

achieve that, future climate simulations are chosen carefully and corrected with local station observations instead of satellite products. The unique approach in the current study relays particularly on the use of (i) local gauge-based observations to correct model simulations, (ii) farmers' perceptions to validate present climate rainfall characteristics, and (iii) comparatives evapotranspiration models to strengthen the generalization of results.

The study area is Awun river basin, Kwara State, Nigeria. The entire basin is located between latitudes 8° 00′ and 9° 00′ North and longitudes 4° 30′ and 4° 90′ East (Fig. 1). The watershed has an area of 954 km². Awun basin falls, mainly, within the agro-ecological zone C
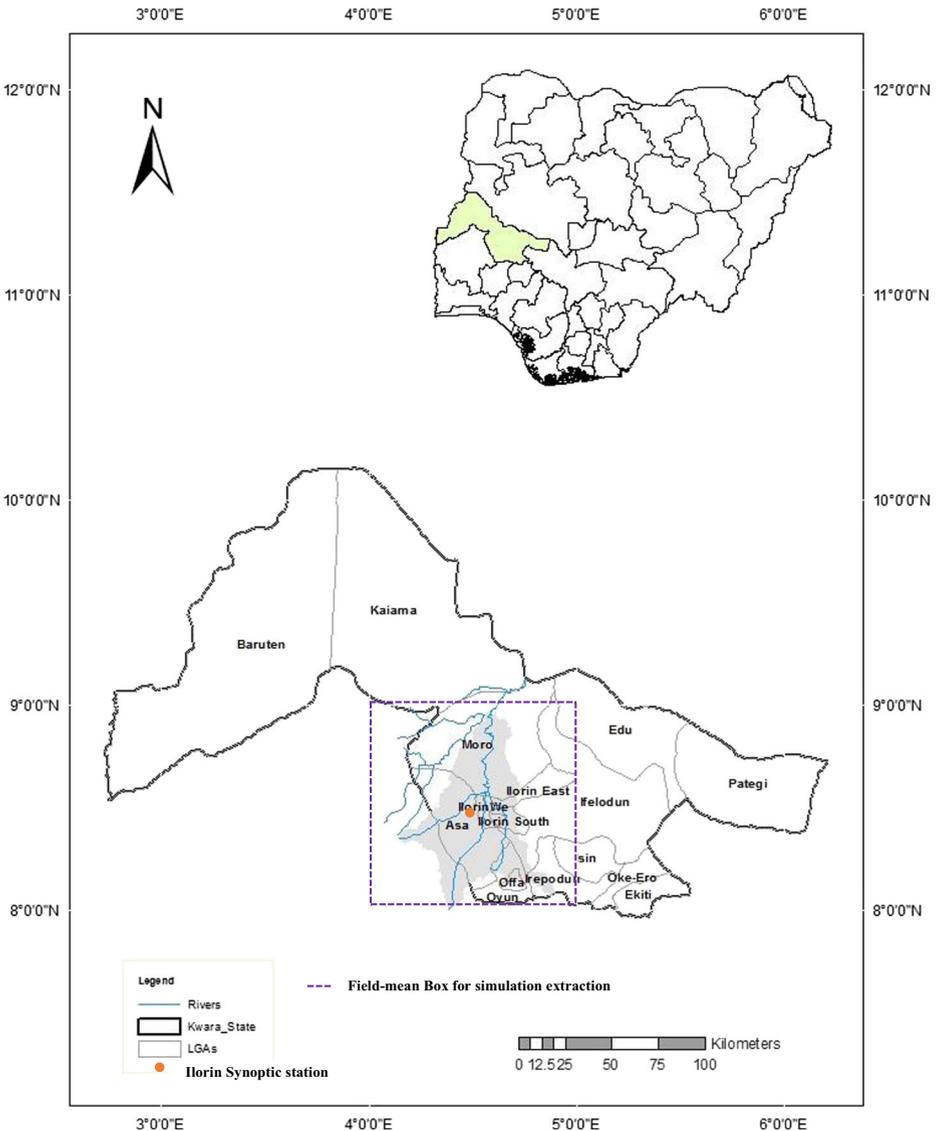
Fig. 1 Map of Kwara State showing Awun basin in gray. The position of Ilorin synoptic station and the box used for simulations extraction are represented

of Kwara State. Zone C encompasses five local government areas namely: Moro, Ilorin West, Ilorin East, Ilorin South, and Asa. The southern part of the Basin is located in Oyo state. Annual rainfall in the basin varies from 1000 to 1500 mm. The average temperatures are 27.5 °C (wet season) and 33.5 °C (dry season). The water of the basin runs into Niger River channel. The cultivated land area within the basin is about 296 km^2 (Sule and Alabi 2013).

2 Data

2.1 Regional climate model description and experiment

The regional climate model simulations used in the current study have been validated and used in previous studies exploring projected changes in extreme events and shift in climate zones over West Africa (Sylla et al. 2015; Sylla et al. 2016a). In this article, we used the latest version regional climate model of the International Centre for Theoretical Physics (RegCM4; Giorgi et al. 2012) simulated at 0.25° × 0.25° horizontal resolution. The planetary boundary layer scheme and the convective scheme are from Holtslag et al. (1990) and Emanuel (1991) respectively. The resolvable scale precipitation was treated with the subgrid explicit moisture scheme (Pal et al. 2000). The ocean flux scheme was taken from Zeng et al. (1998), while land/atmosphere interactions were described using the Community Land Model version CLM3.5 (Oleson et al. 2008). RegCM4 simulations were run for 20 years (1985–2004) for the reference period and 20 years (2080–2099) for future scenarios at 25-km horizontal grid spacing over the domain selected by Browne and Sylla (2012) (i.e. 5S/25N and 25W/25E) and considered as optimal for regional climate modeling domain for West Africa. The two global climate models (GCMs) namely MPI-ESM-MR (Max-Planck Institute Earth System Model-Medium Resolution; ~1.9° × 1.9° horizontal resolution; (Giorgetta 2012a, b, c)) and GFDL-ESM-2M (Geophysical Fluid Dynamics Laboratory Earth System Model version 2M; ~2.5° × 2.0° horizontal resolution; (Dunne et al. 2012, 2013)) were used to provide initial and boundary conditions. The resulting simulations are respectively referred hereafter MPI_RegCM4 and GFDL_RegCM4 in the results sections. The model time step is 6 hourly with boundary conditions and sea surface temperature taken from the driving GCMs. The choice of GCMs was justified by their relatively good performances over Africa (Elguindi et al. 2014). For future scenarios, the new storylines of the Intergovernmental Panel on Climate Change Fifth Assessment Report (Moss et al. 2008) called "Representative Concentration Pathways" (RCPs) were used for each GCM-driven runs. The medium, or some mitigation, scenario (RCP4.5) and the extreme or business as usual scenario (RCP8.5) were used for the future 2080–2099 period.

2.2 Observations and RegCM4 simulations data

The RegCM4 simulations were extracted considering the field mean over a box[1] (Fig. 1) that contains Awun basin in order to get a point-simulated data representative of the whole basin. In the meantime, Ilorin International Airport synoptic station data (8.44° N, 4.49° E; Fig. 1) was used as observations. Ilorin station is the only reliable station located inside the basin and is assumed to be representative of Awun basin. Rainfall recorded by that station is considered to

---

[1] The box is selected such that it covers the entire Awun basin and a field mean was computed

be spatially homogenous over selected cultivated lands given its location in the middle of zone C (Matthew et al. 2017). Simulations include the reference period with daily rainfall (P), relative humidity (RH), and minimum and maximum temperatures (T_{min} and T_{max}) for the period 1985–2004 and for MPI and GFDL-driven runs. The future climate also includes the same variables for the period 2080–2099 and for the two forcing scenarios (RCP4.5 and RCP8.5). Synoptic station-based observations for similar variables were purchased at the Nigerian Meteorological Agency, Abuja for the period 1985–2014. Observations for a period of 20 years (1985–2004) were used to correct the model simulations and those for the period 1995–2014 were used to characterize present climate.

2.3 Bias correction of regional climate model (RegCM4) simulations

Most climate models exhibit systematic errors (biases) in their outputs (Themeßl et al. 2012).[2] Model biases can be caused by, among other factors, limited horizontal and vertical spatial resolution. This is because the spatial resolution is related to the parameterized convection schemes mentioned earlier. Bias correction methods are used to overcome these errors. The linear scaling described first in Newton et al. (2012) was applied to bias-correct the simulated P, T_{min} and T_{max}, and RH. The advantage of this technique is its ability to correct means values (Teutschbein and Seibert 2012). Gauged-based observations and model runs for the period 1985–2004 were analyzed to compute scaling factors which were subsequently used to correct future model runs. The methodology is described in the Appendix.

3 Methods

3.1 Onset of the growing season

The onset definition first presented by Benoit (1977) and widely used by many studies in Nigeria (Ati et al. 2002; Edoga 2007; Laux et al. 2008; Mugalavai et al. 2008) was adopted in determining onset of the growing season. Benoit (1977) defined the onset date for northern Nigeria as the date when accumulated daily rainfall exceeded 50% of accumulated potential evapotranspiration (ET_p), i.e., $\sum (P - 0.5 \times ET_p) > 0$ for the remainder of the season, provided that no dry spell longer than 5 days occurs immediately after that date. This onset definition was chosen instead of many others (Olaniran 1984; Stern et al. 1981; Marteau et al. 2009; Sivakumar 1988) because it includes potential evapotranspiration rather than based on rainfall only. Benoit (1977) onset definition seeks to ensure that the rain compensates water losses by evapotranspiration throughout the growing season. After the onset, the soil will keep enough moisture and protect crops from any plausible long dry spells which may occur during the growing season. ET_p was calculated using two models namely Blaney Morin Nigeria (BMN) (Duru 1984) and Hargreaves and Samani (HS) (Hargreaves 1994) to ensure that onset dates computed do not depend on the limitations of a particular ET_p model. These models were chosen instead of the recommended Penman-Monteith equation (Allen et al. 1998) for their reliability in calculating ET_p in Nigeria when there are limited climatic variables. Each model

---

[2] The RegCM4 model assessment is described in the supplementary material (Appendices 2 and 3) prior to bias correction. Relative biases for P and RH; and absolute biases for T_{min} and T_{max} of raw simulations against observations were assessed.

requires only three climatic variables to calculate ET_p (Ilesanmi et al. 2014). According to BMN model, daily potential evapotranspiration can be calculated as in Eq. 1:

$$ET_p = r_f(0.45T_{mean} + 8)(520 - RH^{1.31})/100 \tag{1}$$

Hargreaves (1994) formula is defined in Eq. 2 as

$$ET_p = 0.0135\,KRS.Ra.\sqrt{T_{max} - T_{min}}\cdot(T_{mean} + 17.8) \tag{2}$$

In these equations: ET_p (mm/day) is the daily potential evapotranspiration; r_f is the ratio of monthly radiation to annual radiation; RH (%) is the daily relative humidity. T_{mean} (°C), T_{min} (°C) and T_{max} (°C) are the daily mean, minimum, and maximum temperatures respectively. Ra (mm/day) is the extra-terrestrial radiation. KRS is the radiation adjustment coefficient. Hargreaves (1994) recommended using KRS = 0.16 or "interior" regions and KRS = 0.19 for coastal regions. Interior regions (case of Awun basin) indicate inland areas far from the coasts.

3.2 Seasonality index (SI)

SI was computed for the present and future climate. It measures the spread and steadiness of the rainfall during rainy season. Walsh and Lawler (1981) have categorized SI in several classes described in Table 1. The table shows the ranges of SI with corresponding rainfall regimes and was used to identify rainfall regimes or characteristics within Awun basin. Walsh and Lawler (1981) mathematically expressed seasonality index SI following Eq. 3.

$$SI = \frac{\sum_{n=1}^{12}|\overline{X}_n - R/12|}{R} \tag{3}$$

3.3 In this equation: R (mm/year) is the mean annual rainfall and $\overline{X}_n$ (mm/month) is the mean rainfall of monHydrologic ratio (HR)

HR is the degree of wetness or dryness of a place. It is defined as the ratio of mean annual rainfall to ET_p (Adefolalu 1988; Sawa and Adebayo 2011). The value indicates soil moisture deficiency or surplus. It is an accurate method of estimating water availability considered as soil moisture and thus appropriate drought indicator. The index helps in agricultural decision making as it provides information on the best areas for a particular crop to thrive and give high yield. Considering land ownership constraints, HR can actually aid farmers to choose, in the

Table 1 Seasonality index (SI) classes and rainfall regimes (Walsh and Lawler 1981)

Rainfall regimes	SI classes
Very equable	≤0.19
Equable but with definite wetter season	0.20–0.39
Rather seasonal with a shorter drier season	0.40–0.59
Seasonal	0.60–0.79
Markedly seasonal with a long drier season	0.80–0.99
Most rain in 3 months or less	1.00–1.19
Extreme, almost all rain in 1–2 months	≥1.20

Table 2 Hydrological ratio and ecological zones (Adefolalu 1988)

Ecological zones in Nigeria	HR classes
Areas located in forest belt south of latitude 7° N	≥ 0.75
Area located in the wooded savanna middle belt (7°–10° N)	0.40–0.75
Area located in the steppe-type vegetation of the Sahel (further north of 10° N)	≤ 0.40

area where they are allowed to grow, the crop types that will sustainably and successfully grow. The lower the value derived, the drier the wet season. According to Adefolalu (1988), when HR = 1, then optimum crop yield exists. Table 2 shows the HR values with corresponding ecological zones in Nigeria.

3.4 Farmers' perceptions

A stratified random sample of 100 local farmers who grow locally common crops (maize, sorghum, yam, and cassava) within the Awun river basin was chosen to study their perceptions on present climate rainfall characteristics. Farmers, across communities, were asked about their perceptions on the trends of onset/cessation, the length of the growing season (LGS), and the frequency of dry spells over the past 20 years. The survey concerned local farmers who had, at least, 20 years' experience in farming. This corresponds to the period 1995–2014 that is also used to calculate present-day agro-climatic indices over the basin.

The current study did not integrate how farmers and scientists agreed on the definitions of the different agro-climatic indices. It investigated whether farmers' perception on indices trends has a scientific or meteorological evidence only. Further data collection is required to investigate the understanding and connection between local/indigenous knowledge and scientific knowledge on these indices.
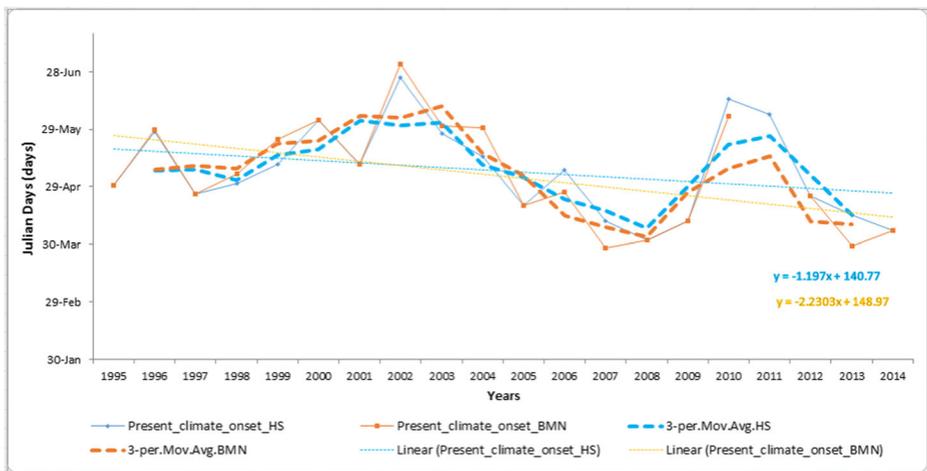
Fig. 2 Trend of present climate (1995–2014) onset dates using both HS and BMN ETp models. The square dot lines indicate the 3-year centered moving average to smooth the year to year variability

Table 3 Trend significance test using Mann-Kendall test for the present and future scenarios. Positive and negative tau values indicate the increasing and decreasing trends respectively

	Present climate		MPI_RegCM4 (RCP4.5)		MPI_RegCM4 (RCP8.5)		GFDL_RegCM4 (RCP4.5)		GFDL_RegCM4 (RCP8.5)		Ensemble_mean (RCP4.5)		Ensemble_mean (RCP8.5)	
	Tau	p value	Tau	p value	Tau	p value	Tau	p value	Tau	p value	Tau	p value	Tau	p value
HS	− 0.233	0.1625	+ 0.242	0.1442	+ 0.239	0.1527	− 0.121	0.4751	+ 0.221	0.1834	+ 0.137	0.4173	+ 0.337	0.0409**
BMN	− 0.295	0.0743*	+ 0.242	0.1442	+ 0.322	0.0514*	− 0.1	0.5590	+ 0.174	0.2989	+ 0.216	0.19413	+ 0.311	0.0597*

*Significant trend at $p < 0.10$; **Significant trend at $p < 0.05$

3.5 Statistical analyses

Statistical significance tests were performed for the trend and change in mean onset dates over the present and future scenarios. The Mannkendall test analysis of linear trend significance was carried out. This method has been used in many studies across the globe (Partal and Kahya 2006; Obot et al. 2010; Manzanas et al. 2014). Welch t test, often called unequal variance t test, was used to test the change in mean onset dates.

4 Results and discussions

4.1 Present-day onset, cessation, and growing season length

As discussed in Section 3.1, two comparative HS and BMN ET_p schemes are used to help calculate monsoon onset dates. Figure 2 presents the observed trend of onset dates for the present climate 1995–2014. Onset dates vary from 1 year to another. The best fit lines are negative ($y = -1.197 \times + 140.77$) and ($y = -2.2303 \times + 148.97$) for HS and BMN respectively implying Julian days. This is also confirmed by the negative tau values (i.e., -0.233 and -0.295 for HS and BMN respectively) of the significance test (Table 3). This indicates a decreasing Julian days and implies a progressive early start of rainfall for the present period over Awun basin. However, p values of 0.1625 and 0.0743 were found for HS and BMN respectively implying that only the present-day onset date trend under BMN model is significant at 90% confidence level. Mean onset dates based on Benoit (1977) definition are presented in Fig. 4 for the present climate (1995–2014). The start of the growing season begins

a Perception of Onset evolution over the last 20 years   b Perception of Cessation evolution over the last 20 years

c Perception of LGS evolution over the last 20 years   d Perception of Dry Spells Frequency over the last 20 years
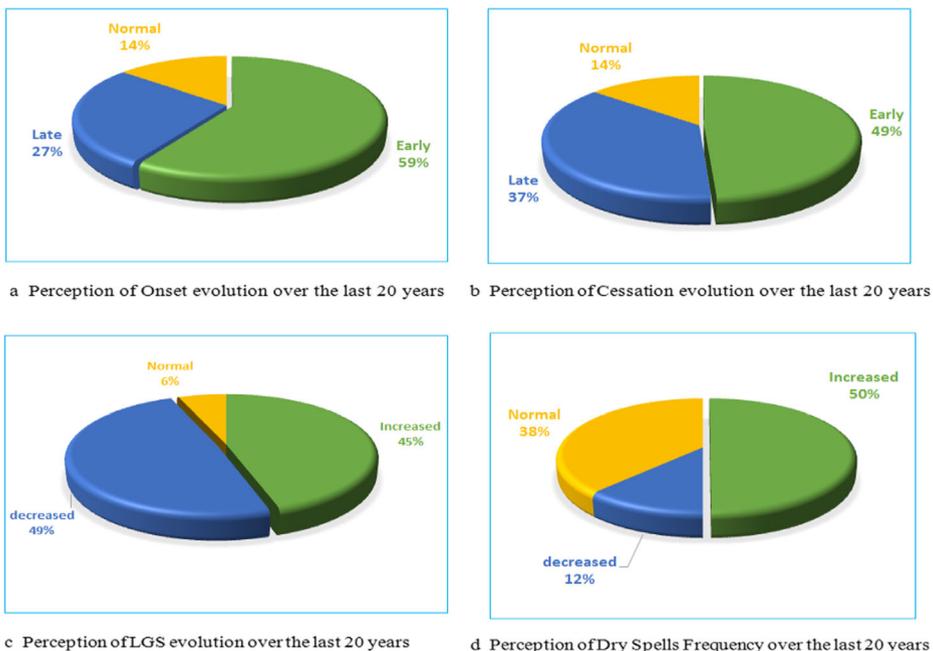
Fig. 3 Farmers' perceptions on rainfall patterns over the last 20 years

in 6th May and 5th May using HS and BMN models respectively for the present climate. The estimations are close to those obtained by Olaniran and Sumner (1989) using the same onset definition. However, onset dates show some differences with previous values that were obtained in Kwara State using only rainfall-based models (Olanrewaju 2012). This is because local onset dates are known to differ depending on the definition chosen and dataset used (Fitzpatrick et al. 2015).

Farmers' perceptions on rainfall characteristic findings are given in Fig. 3, and each characteristic is categorized as (i) normal, (ii) early, and (iii) late for onset and cessation. The length of the growing season (LGS) and the frequency of dry spells are categorized as (i) normal, (ii) increased, and (iii) decreased. According to Fig. 3a, b, the majority of farmers have noticed that onset (59% responses) and cessation (49% responses) start early over the last 20 years. Following Fig. 3c, the largest responses (49% responses) agreed on the decrease of the LGS over this period. Figure 3d also indicates that the largest share of farmers (49% responses) think that the frequency of dry spells is likely to increase in the area. Therefore, farmers' perceptions on the onset date trends are consistent with scientific findings as presented in Fig. 2 for the last 20 years. The modeled onset trends in the present climate (1995–2014) is therefore supported by local farmers' knowledge as being early.

4.2 Projected onset dates

The projected future change in mean onset date is presented in Fig. 4 alongside with current present-day values. Under RCP4.5 scenario, mean onset dates are 2nd June and 13th June for MPI and GFDL-driven runs respectively when using HS model. With the same scenario, the
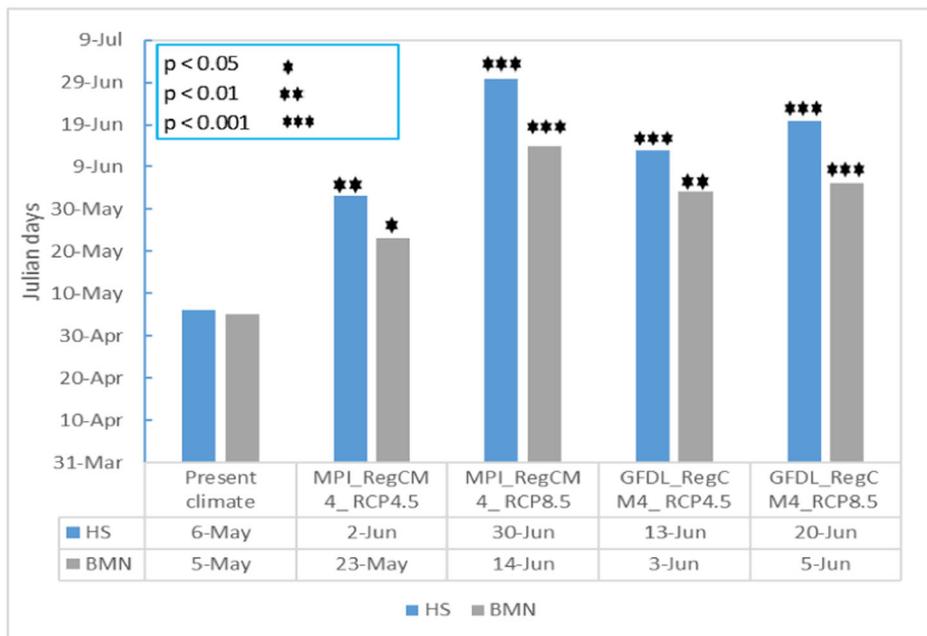
Fig. 4 Mean onset dates calculated for the present climate (1995–2014) and future scenarios (2080–2099) using HS and BMN ETp models. Asterisks indicate significance test of changes in mean onset dates from present to future scenarios
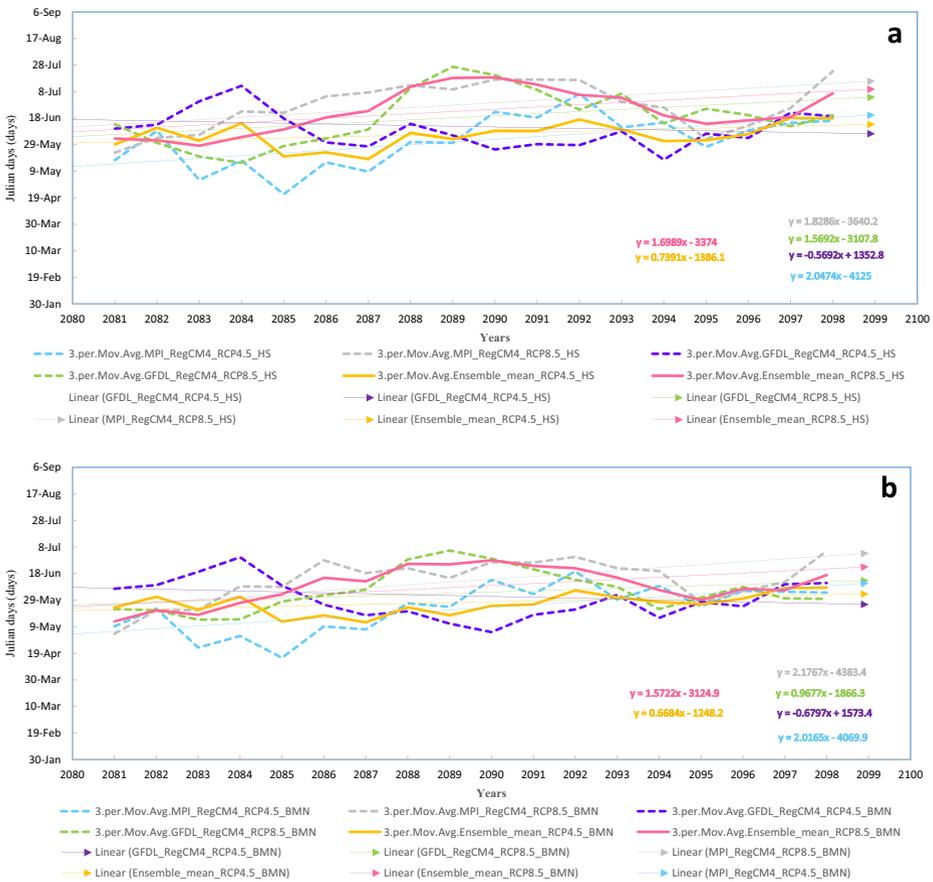
Fig. 5 Trend of future climate scenarios (2080–2099) onset dates using HS (**a**) and BMN (**b**) ETp models. MPI_RegCM4_RCP4.5, GFDL_RegCM4_RCP4.5, MPI_RegCM4_RCP8.5, and GFDL_RegCM4_RCP4.5 refer, respectively, to the scenario with some mitigation (RCP4.5) driven by MPI, the scenario with some mitigation (RCP4.5) driven by GFDL, the business as usual scenario (RCP8.5) driven by MPI, and the business as usual scenario (RCP8.5) driven by GFDL. The ensemble mean for each scenario is also presented. The 3-year centered moving averaging is presented for each scenario

onset dates are 23rd May and 3nd June for MPI and GFDL-driven runs respectively when using BMN model. This corresponds to 4 weeks delay roughly in onset dates for the scenario with some mitigation (i.e., RCP4.5). For RCP8.5, the projected mean onset dates are 30th June and 20th June for MPI and GFDL-driven runs respectively using HS model, while with BMN model, the mean onset dates expected to be 14th June and 5th June for MPI and GFDL-driven runs respectively. This corresponds to about 8 weeks delay in onset dates under the business as usual scenario. Also, changes in mean onset dates between present-day and all future scenarios are significant at $p < 0.05$ (Fig.4). Thus, onset dates will occur within a range of 4 to 8 weeks later than currently experienced. The expected delay of onset dates in comparison to present climate is therefore clear. These results, based on high-resolution regional climate simulations, confirm the findings of Woodley (2011) who also projected a late onset in this part of Nigeria under the optimistic (B1) and extreme (A2) scenarios at the end of the twenty-first ccentury.
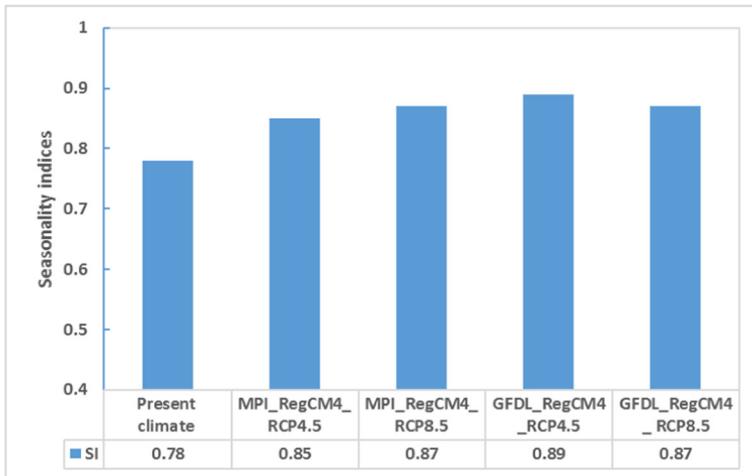
Fig. 6 Mean seasonality indices (SI) for present-day and future climate

The projected trend of onset dates is shown in Fig. 5a, b for the future climate (2080–2099) using two ET_p models. Onset dates fluctuate from 1 year to another as in present-day climate. The best fit lines show a small positive (the equations are shown on Fig. 5a and b) for all scenarios, independently of the ET_p models used, with the exception of GFDL_RegCM4_RCP4.5 which shows a negative slope. The same positive and negative patterns are also confirmed with tau-values of the significance test (Table 3). Therefore, we interpret that Julian days are likely to increase in the future with the exception of GFDL_RegCM4_RCP4.5. The increase is further confirmed with the ensemble means (i.e., Ensemble_mean_RCP4.5 and Ensemble_mean_RCP8.5) presented in Fig. 5. However, only the trend of Ensemble_mean_RCP8.5 scenario is significantly increasing at 95 and 90% under
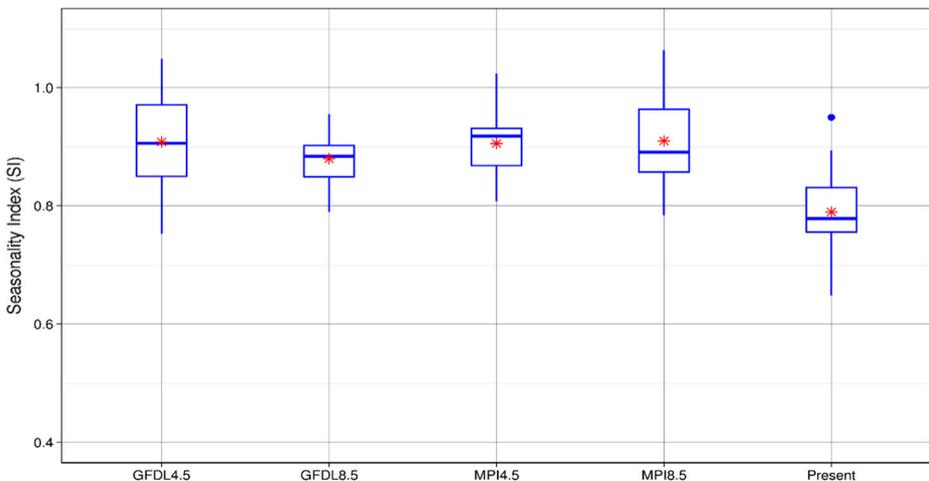
Fig. 7 Interquartile range of seasonality indices (SI) for present-day and future climate. MPI4.5, GFDL4.5, MPI8.5, and GFDL4.5 refer, respectively, to the scenario with some mitigation (RCP4.5) driven by MPI, the scenario with some mitigation (RCP4.5) driven by GFDL, the business as usual scenario (RCP8.5) driven by MPI, and the business as usual scenario (RCP8.5) driven by GFDL
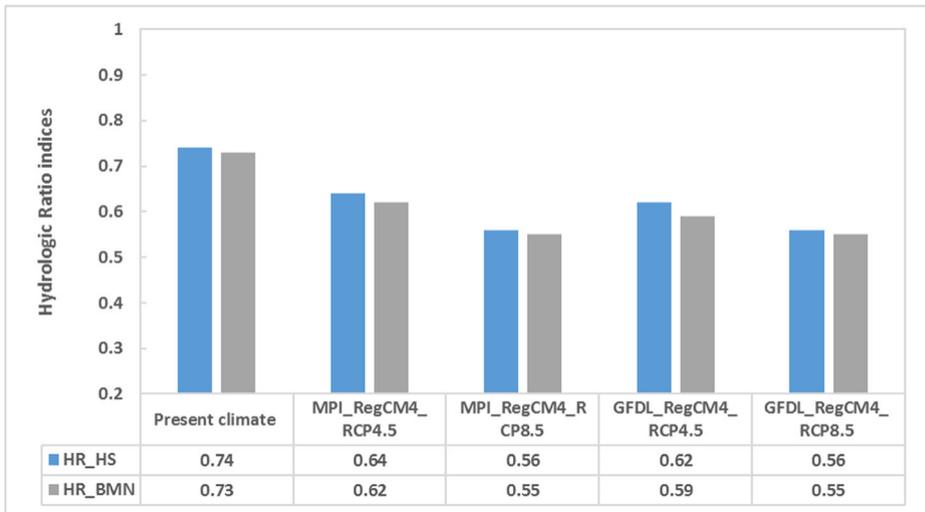
Fig. 8 Mean hydrologic ratio (HR) for present-day and future climate using HS and BMN ETp models

the HS and BMN models respectively (Table 3). This increase implies a likely progressive late start of the growing season for both future scenarios in Awun basin. We conclude that onset progressively starts earlier in recent times but will start late towards the end of the twenty-first century in Awun basin, especially, under the business as usual scenario.

There are some possible explanations of the future changes in onset dates. One of the reasons is related to changes in temperature. There is a strong evidence regarding the projected increase of temperature over West African unlike precipitation which is more uncertain and
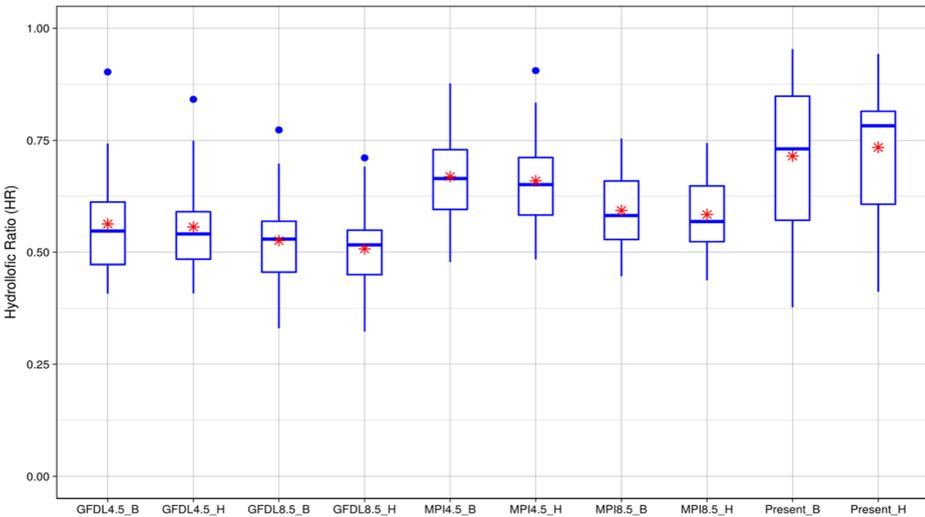
Fig. 9 Interquartile range of hydrologic ratio (HR) for present-day and future climate using HS and BMN ETp models. MPI4.5, GFDL4.5, MPI8.5, and GFDL4.5 refer, respectively, to the scenario with some mitigation (RCP4.5) driven by MPI, the scenario with some mitigation (RCP4.5) driven by GFDL, the business as usual scenario (RCP8.5) driven by MPI, and the business as usual scenario (RCP8.5) driven by GFDL. _H and _B indicate HS and BMN respectively

does not show a drastic change in the future (Rowell 2012; Orlowsky and Seneviratne 2012; Barros et al. 2014; Sylla et al. 2016b). Thus, future changes in onset dates found are expected to be largely driven by temperature changes since Benoit onset date definition has the advantage of taking into account evapotranspiration in future scenarios.

4.3 Seasonality index and hydrologic ratio for present and future climate

The results of SI analysis are summarized in Fig. 6. Under the present-day climate, the SI is 0.78, which is classified as seasonal (around 6 months of wet season) according to Walsh and Lawler (1981) (Table 1). This classification is logical since the Awun basin is located within the Wooded Savanah climatic zone (Adefolalu 1988). In the future and for the RCP4.5, the SI values are 0.85 and 0.89 for MPI and GFDL-driven runs respectively. Under the business as usual scenarios, the values are 0.87 for both MPI and GFDL-driven runs respectively. These values of SI range between 0.80 and 0.99. According to Walsh and Lawler (1981), that range corresponds to a "markedly seasonal with long drier season." The interannual variability of SI presented on Fig. 7 using boxplots confirms the increasing SI values from the present to future scenarios. For instance, the interquartile range and central value (e.g., median and mean) of SI for future scenarios are greater than present-day climate. Therefore, all future scenarios of rainfall regimes will shift from seasonal type of 6 months wet season to a shorter wet season type.

As for the HR or degree of dryness, the average HR in the region is 0.74 and 0.73 for the present climate using HS and BMN ET_p models respectively (Fig. 8). This result confirms that Awun basin is located in the wooded savannah zone but close to the rainforest area as categorized by Adefolalu (1988) (Table 2). The future scenarios project an important shift of this degree of dryness. For instance, under the RCP4.5, the degree of dryness is 0.62 and 0.59 for the MPI and GFDL respectively using BMN model while, under the RCP8.5, the hydrologic ratios are 0.55 for both MPI and GFDL-driven runs. Also, the interannual variability of HR, presented on Fig. 9 using boxplot for the two ET_p models, confirms the decreasing from the present to future scenarios. Central tendency values (i.e., median and mean) of HR for future scenarios are less than those of the present-day climate. It is thus likely that HR will decrease in the future, and the decrease will be accentuated under the business as usual scenario. Since the lower the ratio the more the region is drier (Adefolalu 1988), our findings imply that Awun basin will get drier than it is today. The findings confirm that climate trend of Kwara State is towards more aridity (Olanrewaju 2012; Sylla et al. 2016a, b).

5 Conclusions

In this analysis, we assess changes in mean and trends of onset dates, SI and HR at the end of the twenty-first century over the Awun basin using outputs from high-resolution regional climate model simulations considering a scenario with some mitigation (i.e., RCP4.5) and a business as usual world (i.e., RCP8.5). It is found that onset of the growing season will be late compared to present-day for both scenarios in Awun basin, but the delay will be severe in the RCP8.5 scenario. The delay is projected to range from 4 to 8 weeks in the future. In addition, the rainy season will get shorter for the RCP4.5 but much shorter for the business as usual scenarios. Finally, Awun basin will get drier than it is today under both scenarios. These results highlight the importance of social, agricultural, and genetic developments to make the farmers of Awun basic resilient to climate risks. Although the study used projections from a single

climate model driven by two global climate models instead of ensemble projections encompassing several regional climate models to facilitate the uncertainty assessment, the results can still be considered to some extent with regard to forewarning and decision-making support in agriculture.

At local level and for present climate, crops sowing should be encouraged in May when the start of the growing season is set. Kwara State agricultural extensions should provide farmers with more precise early warning predictions, for instance, seasonal forecasts whose skills have increased recently over West Africa (Ingram et al. 2002). In the future, there is a need for an integrated planning between governmental agricultural agencies and local farmers to prepare for the forthcoming shortening of the rainy season and increase of the dryness. This planning can include provision of water information services, based on climate forecasts and projections, to support agriculture. In this way, farmers can take better decisions about specific crop types to use, planting and harvesting dates, fertilizer applications, and water allocation optimization for irrigation. More research is also needed to integrate scientific and local knowledge systems to produce useful and usable predictions (culturally accepted) for farmers. More broadly, Nigerian government and governments from other countries together with private sector partnership should encourage practices (agricultural, industrial, and domestic practices) which will not increase greenhouse gasses emission up to the level of RCP8.5: clean and environment-friendly technologies for both supplied energy and consumption could be used.

References

Adefolalu D (1988) Precipitation trends, evapotranspiration and the ecological zones of Nigeria. Theor Appl Climatol 39:81–89

Allen RG, Pereira LS, Raes D, Smith M 1998 Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56 FAO, Rome 300: D05109

Ati O, Stigter C, Oladipo E (2002) A comparison of methods to determine the onset of the growing season in northern Nigeria. Int J Climatol 22:731–742

Barros V, Field C, Dokke D, Mastrandrea M, Mach K, Bilir TE, Chatterjee M, Ebi K, Estrada Y, Genova R 2014 Climate change 2014: impacts, adaptation, and vulnerability-part B: regional aspects-contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change

Benoit P (1977) The start of the growing season in northern Nigeria. Agric Meteorol 18:91–99

Browne NA, Sylla MB (2012) Regional climate model sensitivity to domain size for the simulation of the West African summer monsoon rainfall. Int J Geophys Article ID 625831. https://doi.org/10.1155/2012/625831

Codjoe SNA, Owusu G, Burkett V (2014) Perception, experience, and indigenous knowledge of climate and variability: the case of Accra, a sub-Saharan African city. Reg Environ Chang 14:369–383

Cooper P, Dimes J, Rao K, Shapiro B, Shiferaw B, Twomlow S (2008) Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: an essential first step in adapting to future climate change? Agric Ecosyst Environ 126:24–35

Diallo I, Giorgi F, Deme A, Tall M, Mariotti L, Gaye AT 2016 Projected changes of summer monsoon extremes and hydroclimatic regimes over West Africa for the twenty-first century. Clim Dyn 1–24

Diallo I, Sylla MB, Gaye AT, Camara M (2013) Comparaison du climat et de la variabilité interannuelle de la pluie simulée au Sahel par les modèles climatiques régionaux. Sécheresse 24:96–106

Dunne JP, John JG, Adcroft AJ, Griffies SM, Hallberg RW, Shevliakova E, Stouffer RJ, Cooke W, Dunne KA, Harrison MJ (2012) GFDL's ESM2 global coupled climate–carbon earth system models. Part I: physical formulation and baseline simulation characteristics. J Clim 25:6646–6665

Dunne JP, John JG, Shevliakova E, Stouffer RJ, Krasting JP, Malyshev S, Milly P, Sentman LT, Adcroft AJ, Cooke W (2013) GFDL's ESM2 global coupled climate–carbon earth system models. Part II: carbon system formulation and baseline simulation characteristics. J Clim 26:2247–2267

Duru JO (1984) Blaney-Morin-Nigeria evapotranspiration model. J Hydrol 70:71–83

Edoga RN (2007) Determination of length of growing season in Samaru using different potential evapotranspiration models. AU JT 11:28–35

Efe S (2009) Climate Change and Food Security in African: Delta State Nigeria Experience. Anyadike RNC, Madu LA, and Ajaero, Eds, Conference Proceeding on Climate Change and the Nigerian Environment, Nsukka, 29 June-2 July 2009, 105–126.

Elguindi N, Giorgi F, Turuncoglu U (2014) Assessment of CMIP5 global model simulations over the subset of CORDEX domains used in the phase I CREMA. Clim Chang 125:7–21

Emanuel KA (1991) A scheme for representing cumulus convection in large-scale models. J Atmos Sci 48:2313–2329

Fitzpatrick RG, Bain C, Knippertz P, Marsham JH, Parker DJ (2015) The West African monsoon onset: a concise comparison of definitions. J Clim 28:8673–8694

Garcia-Carreras L, Challinor AJ, Parkes B, Birch C, Nicklin K, Parker D (2015) The impact of parameterized convection on the simulation of crop processes. J Appl Meteorol Climatol 54:1283–1296

Giorgetta M et al. (2012a) CMIP5 simulations of the Max Planck Institute for Meteorology (MPI-M) based on the MPI-ESM-MR model: the historical experiment, served by ESGF. DKRZ World Data Center for Climate. Accessed 13 May 2014

Giorgetta M et al. (2012b) CMIP5 simulations of the Max Planck Institute for Meteorology (MPI-M) based on the MPI-ESMMR model: the rcp45 experiment, served by ESGF. DKRZ World Data Center for Climate. Accessed 13 May 2014

Giorgetta M et al. (2012c) CMIP5 simulations of the Max Planck Institute for Meteorology (MPI-M) based on the MPI-ESMMR model: the rcp85 experiment, served by ESGF. DKRZ World Data Center for Climate. Accessed 13 May 2014

Giorgi F, Coppola E, Solmon F, Mariotti L, Sylla M, Bi X, Elguindi N, Diro G, Nair V, Giuliani G (2012) RegCM4: model description and preliminary tests over multiple CORDEX domains. Clim Res 52:7–29

Hargreaves G 1994 Simplified coefficients for estimating monthly solar radiation in North America and Europe. Dept Paper

Holtslag A, De Bruijn E, Pan H (1990) A high resolution air mass transformation model for short-range weather forecasting. Mon Weather Rev 118:1561–1575

Iglesias A, Avis K, Benzie M, Fisher P, Harley M, Hodgson N, Horrocks L, Moneo M, Webb J (2007) Adaptation to climate change in the agricultural sector, report to European Commission Directorate–general for agriculture and rural development, AEA Energy & Environment and Universidad de Politécnica de Madrid. AGRI-2006-G4-05, ED05334

Ilesanmi OA, Oguntunde PG, Olufayo AA (2014) Evaluation of four ETo models for IITA stations in Ibadan. Onne and Kano, Nigeria

Ingram K, Roncoli M, Kirshen P (2002) Opportunities and constraints for farmers of west Africa to use seasonal precipitation forecasts with Burkina Faso as a case study. Agric Syst 74:331–349

Klutse NAB, Sylla MB, Diallo I, Sarr A, Dosio A, Diedhiou A, Kamga A, Lamptey B, Ali A, Gbobaniyi EO (2016) Daily characteristics of West African summer monsoon precipitation in CORDEX simulations. Theor Appl Climatol 123:369–386

Laux P, Kunstmann H, Bárdossy A (2008) Predicting the regional onset of the rainy season in West Africa. Int J Climatol 28:329–342

Manzanas R, Amekudzi L, Preko K, Herrera S, Gutiérrez J (2014) Precipitation variability and trends in Ghana: an intercomparison of observational and reanalysis products. Clim Chang 124:805–819

Mariotti L, Diallo I, Coppola E, Giorgi F (2014) Seasonal and intraseasonal changes of African monsoon climates in 21st century CORDEX projections. Clim Chang 125:53–80

Marteau R, Moron V, Philippon N (2009) Spatial coherence of monsoon onset over Western and Central Sahel (1950-2000). J Clim 22:1313–1324

Matthew OJ, Imasogie OG, Ayoola MA, Abiye OE, Sunmonu A (2017) Assessment of prediction schemes for estimating rainfall onset over different climatic Zones in West Africa. J Geog Env E Sci Int 9:1–15

Morris ML, Binswanger-Mikhize HP, Byerlee D (2009) Awakening Africa's sleeping giant: prospects for commercial agriculture in the Guinea Savannah zone and beyond. World Bank Publications

Moss R, Babiker W, Brinkman S, Calvo E, Carter T, Edmonds J, Elgizouli I, Emori S, Erda L, Hibbard K (2008) Towards new scenarios for the analysis of emissions: climate change, Impacts and response strategies. Intergovernmental Panel on Climate Change Secretariat (IPCC)

Mugalavai EM, Kipkorir EC, Raes D, Rao MS (2008) Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agric For Meteorol 148:1123–1135

Müller M, Sanfo S, Laube W (2013). Impact of Changing Seasonal Rainfall Patterns on Rainy-Season Crop Production in the Guinea Savannah of West Africa. Annual Meeting, August 4-6, 2013, Washington, DC, 2013. Appl Econ Perspect Policy

Newton G, Dadson S, Lafon T, Prudhomme C (2012) Scoping study for precipitation downscaling and bias-correction

Nikulin G, Jones C, Giorgi F, Asrar G, Büchner M, Cerezo-Mota R, Christensen OB, Déqué M, Fernandez J, Hänsler A (2012) Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. J Clim 25:6057–6078

Obot N, Chendo M, Udo S, Ewona I (2010) Evaluation of rainfall trends in Nigeria for 30 years (1978-2007). Int J Phys Sci 5:2217–2222

Odekunle T, Orinmoogunje I, Ayanlade A (2007) Application of GIS to assess rainfall variability impacts on crop yield in Guinean savanna part of Nigeria. Afr J Biotechnol 6(18): 2100–2113

Olaniran O (1984) The start and end of the growing season in the Niger River basin development authority area of Nigeria. Malays J Trop Geogr (9): 49–58.

Olaniran O, Sumner G (1989) A study of climatic variability in Nigeria based on the onset, retreat, and length of the rainy season. Int J Climatol 9:253–269

Olanrewaju R (2012) Effect of Climate on Yam Production in Kwara State, Nigeria. Environmental Issues, Department of Geography and Environmental Management, University of Ilorin, Ilorin 3

Oleson K, Niu GY, Yang ZL, Lawrence D, Thornton P, Lawrence P, Stöckli R, Dickinson R, Bonan G, Levis S (2008) Improvements to the community land model and their impact on the hydrological cycle. J Geophys Res Biogeosci 113

Orlowsky B, Seneviratne SI (2012) Global changes in extreme events: regional and seasonal dimension. Clim Chang 110:669–696

Pal JS, Small EE, Eltahir EA (2000) Simulation of regional-scale water and energy budgets: representation of subgrid cloud and precipitation processes within RegCM. J Geophys Res Atmos 105:29579–29594

Partal T, Kahya E (2006) Trend analysis in Turkish precipitation data. Hydrol Process 20:2011–2026

Rowell DP (2012) Sources of uncertainty in future changes in local precipitation. Clim Dyn 39:1929–1950

Salack S, Klein C, Giannini A, Sarr B, Worou ON, Belko N, Bliefernicht J, Kunstman H (2016) Global warming induced hybrid rainy seasons in the Sahel. Environ Res Lett 11:104008

Sawa B, Adebayo A. 2011. The impact of climate change on precipitation effectiveness indices in Northern Nigeria

Simelton E, Quinn CH, Batisani N, Dougill AJ, Dyer JC, Fraser ED, Mkwambisi D, Sallu S, Stringer LC (2013) Is rainfall really changing? Farmers' perceptions, meteorological data, and policy implications. Clim Dev 5: 123–138

Sivakumar M (1988) Predicting rainy season potential from the onset of rains in southern Sahelian and Sudanian climatic zones of West Africa. Agric For Meteorol 42:295–305

Stern R, Dennett M, Garbutt D (1981) The start of the rains in West Africa. J Climatol 1:59–68

Sule B, Alabi S (2013) Application of synthetic unit hydrograph methods to construct storm hydrographs. Int J Water Res Environ Eng 5:639–647

Sylla MB, Elguindi N, Giorgi F, Wisser D (2016a) Projected robust shift of climate zones over West Africa in response to anthropogenic climate change for the late 21st century. Clim Chang 134:241–253

Sylla M, Giorgi F, Coppola E, Mariotti L (2013) Uncertainties in daily rainfall over Africa: assessment of gridded observation products and evaluation of a regional climate model simulation. Int J Climatol 33:1805–1817

Sylla MB, Giorgi F, Pal JS, Gibba P, Kebe I, Nikiema M (2015) Projected changes in the annual cycle of high-intensity precipitation events over West Africa for the late twenty-first century. J Clim 28:6475–6488

Sylla MB, Nikiema PM, Gibba P, Kebe I, Klutse NAB (2016b) Climate change over West Africa: Recent trends and future projections. Adaptation to climate change and variability in rural West Africa. Springer, p 25–40

Teutschbein C, Seibert J (2012) Bias correction of regional climate model simulations for hydrological climate-change impact studies: review and evaluation of different methods. J Hydrol 456:12–29

Themeßl MJ, Gobiet A, Heinrich G (2012) Empirical-statistical downscaling and error correction of regional climate models and its impact on the climate change signal. Clim Chang 112:449–468

Ufoegbune G, Bello N, Dada O, Eruola A, Makinde A, Amori A (2012) Estimating water availability for agriculture in Abeokuta, South Western Nigeria GJSFR-D: Agriculture and Veterinary 12

Walsh R, Lawler D (1981) Rainfall seasonality: description, spatial patterns and change through time. Weather 36:201–208
Wani SP, Rockström J, Oweis TY (2009) Rainfed agriculture: unlocking the potential. n. 7: CABI
Woodley E (2011). Building Nigeria's Response to Climate Change: Pilot Projects for Community-Based Adaptation in Nigeria. Experiences of Climate Change Adaptation in Africa: Springer, p. 297–315.
Zeng X, Zhao M, Dickinson RE (1998) Intercomparison of bulk aerodynamic algorithms for the computation of sea surface fluxes using TOGA COARE and TAO data. J Clim 11:2628–2644

Affiliations

Talardia Gbangou [1,2] · Mouhamadou Bamba Sylla [3] · Onemayin David Jimoh [4] · Appollonia Aimiosino Okhimamhe [1]

[1]   West African Centre Service on Climate Change and Adapted Land Use, Federal University of Technology, Minna, Nigeria

[2]   Water System and Global Change Group, Wageningen University of Research, Wageningen, Netherlands

[3]   West African Centre Service on Climate Change and Adapted Land Use, Competence Centre, Ouagadougou, Burkina Faso

[4]   Department of Civil Engineering, Federal University of Technology, Minna, Nigeria