Assessing the impact of climate change on crop water requirements in Nigeria

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Abstract: Climate change is a phenomenon most of the world is recently coming to terms with, but unfortunately, the African region is yet to fully understand and prepare for its effects. This study highlights the impact these changes experienced in the Nigerian climate system will have onCrop water requirements (CWR)for optimal productivity.Data were obtained from five global climate modelsnamely CCCMA, MIROC, ICHEC, NOAA and NCC. These data were sourced in Representative Concentration Pathway 8.5 (RCP8.5) for the 36 states including the Federal Capital Territory (FCT). The data length varies from 1985 – 2100 for historical, present and future periods. Penman Monteith evapotranspiration (ET_o) calculator was used to determine CWR.Trend analysis was carried out on the rainfall, temperature data, and the CWR. This analysis showed a projected slight increase in rainfall and significant increments in temperature varying in the range of 131.18 mm to 135.3mm and 27.2^{o}C to 29.1^{o}C for rainfall and temperature respectively.Results also showed that CWR will increase in future and it correlated strongly with temperature and weakly with rainfall. This result implies that temperature affects CWR more withit driving up the water use of cassava, rice and soybean, thereby leading to increase in yield if adequate water is available as well as coupled with proper management practices. The study has concluded that CWR will increase as the years go by and is higher in states with higher latitudes; it is therefore recommended that farmers' crop production activities should be adapted to maximize available water efficiently.

Keywords: crop water requirement, climate change, Nigeria, rainfall, temperature, representative concentration pathways

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1 Introduction

Crop water requirement (CWR) is the quantity of water needed by a crop during its growing season. It is also usually referred to as the cropevapotranspiration, and it is commonly estimated through the use of cropcoefficients defined for each crop development stage – initial, development,midseason and late season – and the reference evapotranspiration, (Allen et al., 1998; Lazar, 2011).

In recent times, the effect of climate change on crop growth and development, agricultural water resources, and production in many parts of the world has been highlighted through extensive documentation (Ochieng et al., 2016), with numerous uncertainties making novel adaptations difficult (Tao et al., 2009).

Climate change is expected to alter rainfall and temperature regimes worldwide, Nigeria inclusive (Ogunrayi et al., 2016). It will also impact crop water use efficiency and yield despitethe drought resistant

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characteristics of certain crops,rainfall unpredictability among temperature rise might lead to decrease in yield (Tubiello et al., 2007). The adverse reactions of crops to extreme climatic conditions can also be more severe than mean climatic variations (IPCC, 2007; Morton, 2007; Ajewole and Iyanda, 2010).

Stott et al. (2011),Trenberth et al. (2007),Trenberth (2012), and Min et al. (2011), posited that global warming, significantly increases in minimum and maximum temperatures will occur in the 2000s with Ly, et al.(2013)supporting this scenario focusing on West Africa. Also, increased temperatures will influence and increase evapotranspiration which will, in turn, affect water availability for crops (Holmén, 2003).

Studies have established that climate change and variability will majorly affect livelihoods and socio-economic activities of people across various sectors, especially in West Africa (Ly et al., 2013), with the region experiencing an observed trend of increasing minimum and maximum temperatures at a quicker rate (Sarr, 2011).

An FAO (2008) report stated that Africa has contributed the least to climate change but is likely to suffer the most. Paeth and Thamm (2007) examined the impact of climate change on crop water use in a region in Cameroun, with their findings have profound implications for agriculture and food security. Studies have also shown that the effects of these climatic variations might not be harmful. In some regions of the United States and Canada; increased crop yields are predicted due to rising CO_2 levels and at times length of the season (Paustian et al., 2000; Cabas et al., 2010). According to Durand(2006), the impact of climate change on crop water use to achieve the same level of production as before may be less than expected, as the shortening of the production cycle leads to a decrease in water use over time.

Rotich and Mulungu (2017) assessed the adaptation and impact of climate change on CWR and found that CWR will increase by 3.8% in the 2020s and 7.1% in the 2050s. Chowdhury et al. (2016) predicted an increase in CWR for crop production. This is the current state of the subject matter in West Africa, including Nigeria.

Nonetheless, the warming trend on a global scale has been studied comprehensively in different regions, primarily through the works by IPCC (New et al., 2001; Giorgi 2002). With insufficient data on temperature trends among other climatic variables usually experienced in Sub-Saharan Africa, New et al. (2006) showed that the climate is significantly warming in the region (Malhi and Wright, 2004). The warming trend in the West African region might lead to a rise in demand for water for crop use (Moyo et al., 2015; Shimeles et al., 2018).

Rain-fed agriculture is the mainstay of most African farmers in agricultural production for food and livelihood; they are vulnerable to climate change, and climatic data show that the continent is experiencing decreasing and increasing trends in rainfall and temperature, respectively (IPCC, 2007). Also, Sultan and Gaetani (2016) confirmed that the climate scenario in West Africa is rapidly changing, with much warming.

Numerous studies have shown that rainfall depth has been declining across the Western Africa sub-region, specifically Nigeria (Lazar, 2011; Oguntunde et al., 2011; Ly et al., 2013; Ogungbenro and Morakinyo, 2014; Gizaw and Gan, 2017; Oloruntade et al., 2018). Other studies also established that there had been evidence of warming due to an increase in temperature (Lazar, 2011; Oguntunde et al., 2012; Gizaw and Gan, 2017; Akinbile et al., 2020; Olubanjo, 2019). Furthermore, an increase in temperature, evapotranspiration, variable rainfall patterns and interactions of other meteorological parameters may have adverse effects on CWR (Chowdhury et al., 2016).To better manage available resources and agricultural productions, it is crucial to understand CWR and the possible effects of climate change in the future. Therefore, this study aims to consider the impact of climate change, especially precipitation and temperature, on the water requirements of crops in Nigeria and assess the probable effects on the future yield of Cassava, Rice and soybeans in Nigeria.

2 Materials and method

2.1 Description of the study area

Nigeria is the area of study, and the region lies within latitudes 4°N – 14°N and Longitudes 2°E – 15°E. (Figure 1)

The country's southern region is characterized by a coastline spanning from the southwestern to the southeastern part of the country, with the largest delta in Africa, the Niger delta. It has a tropical rainforest climate having an annual rainfall of between 60 – 80 inches (1524 – 2032mm), with the most southern region of the forest zone having salty water swamp popularly referred to as the mangrove swamp forest due to the presence of a large amount of mangrove in the area. Further north is the freshwater swamp and the rain forest. The relief of this region is typified by its hilly nature, having rugged highlands in the west extending to the Benue Mountains in the east.

North of the tropical forest region of Nigeria is the Savannah Zone depicting the starting point of Northern Nigeria, characterized by an annual rainfall of between 20 – 60 inches (508 – 1524mm). The savannah can be categorized into three; the Guinea savannah has tall grasses and trees with a little moist climate. Further north is the Sudan Savannah, a region of shorter grasses and more scattered, drought-resistant trees such as the baobab, tamarind, and acacia. In the furthest north of the country, the third category is the Sahel savannah which has a near-desert climate with annual rainfall usually below 20 inches. The relief of the northern region of Nigeria is that of lowland with a relatively level topography spanning the Lake Chad basin to the Sokoto lowlands.

Nigeria is a tropical country having two significant seasons: dry and wet. November toMarch, usually referred to as the dry season, is characterized by low humidity and high temperatures (42ºC in the northern part of the country) due to warm North East trade winds from the Sahara Desert. April to October, the wet season isdominated by high humidity and low temperatures (<30ºC), especially during the daytime. The location ofNigeria in West Africa is quite peculiar, giving the country a wide variation inthe climate from the coast to the Sahel region in the north (Ogunrinde et al., 2019).

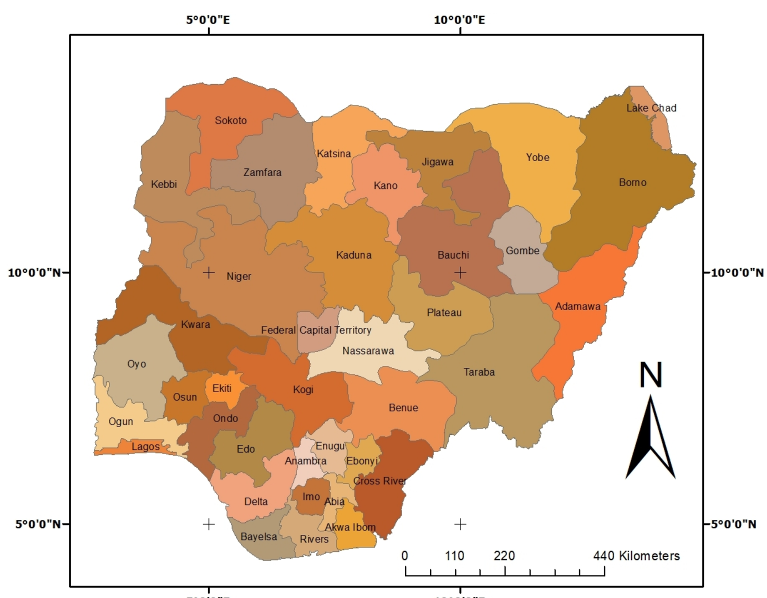


Figure 1 Map of Nigeria

2.2 Data source

Climatic data for this research were statistically downscaled at the weather station level. Climatic data for this research was in two datasets. One dataset was used to represent the present-day climate. The second was climate modelled data (statistically downscaled at the weather station level), usually called global climate models(GCM). The observation dataset was the 0.5° × 0.5° resolution monthly precipitation, minimum and maximum temperature gridded dataset from January through December for 1985 to 2100 collected from the Climate Research Unit, University of East Anglia (Harris et al., 2014). The GCMs, based on the RCP 8.5 scenario as described by the IPCC (2013), were used. RCP6 and RCP8.5 show a relatively constant trend for the carbon factor (heavy reliance on fossil fuels). Still, they are very different in terms of the development of energy intensity, high for RCP8.5 and intermediate for RCP6. They are detailed below;

Table 1 List of statistically downscaled and bias-corrected GCMs used in the study

Modelling group	IPCC Model ID	Resolution
Japan Agency for Marine-Earth Science and Technology	MIROC	$1.4^0 \times 1.4^0$
Norwegian Climate Centre	NCC	$2.5^0 \times 1.9^0$
National Oceanic and Atmospheric Administration (USA)	NOAA	$2.5^0 \times 2.0^0$
Irish Centre for High-End Computing (Europe)	ICHEC	$1.25^0 \times 1.25^0$
Canadian Centre for Climate Modelling and Analysis	CCCMA	$2.8^0 \times 2.8^0$

The data used in the analysis represented three time periods which cut through 1985 - 2100: i) past/present (2000), (average values of simulations for the period 1980 - 2010), ii) intermediate (2050) (average values of simulations for the period 2020-2050) and, future (2100) (average values of simulations for the period 2070-2100).

In carrying out this study, Climatic data were obtained from Global Climatic models and downscaled using scenarios referred to as representative concentration pathways (RCPs).In the Fifth Assessment Report of IPCC, the scientific community has defined a set of four new scenarios, denoted RCPs. Their approximate total radiative forcing identifies them in the year 2100 relative to 1750: 2.6 Wm^{-2}for RCP2.6, 4.5 Wm^{-2}for RCP4.5, 6.0 Wm^{-2}for RCP6.0, and 8.5 W m^{-2} for RCP8.5. Each RCP provides spatially resolved data sets of land-use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2100. RCPs are based on integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models (IPCC, 2013).

These RCPs complements and, for some purposes, are meant to replace earlier scenario-based projections of atmospheric composition, such as those from the Special Report on Emissions Scenarios. The four RCPs are based on multi-gas emission scenarios selected from the published literature. The RCPs are named according to the radiative forcing target level for 2100. The four-set RCPs are considered to be representative of the literature. They included one mitigation scenario leading to a very low forcing level (RCP2.6), two medium stabilization scenarios (RCP4.5/RCP6) and one very high baseline emission scenario (RCP8.5) (Meinshausen et al., 2011). Meteorological data required for climate change studies are usually obtained based on these postulations. The four RCPs together span the range of the year 2100 radiative forcing values found in the open literature, i.e. from 2.6 to 8.5W m^{-2}. The RCPs are the product of an innovative collaboration between integrated assessment modellers, climate modellers, terrestrial ecosystem modellers and emission inventory experts (Van-Vuuren et al., 2011).

2.3 Methods

2.3.1 Estimation and projection of crop water requirement/evapotranspiration

CWR is the amount of water required to compensate for evapotranspiration loss from a cropped field. It is the quantity of water consumed by a crop during its growing season. It corresponds to crop evapotranspiration (ET_c). It is usually determined through the use of crop coefficients defined for each crop development stage – initial, development, midseason and late season – and the reference evapotranspiration (ET_o), through the following equation (Allen et al., 1998; Jensen and Allen, 2016; Altalib et al., 2021):

$$ET_c = K_c \times ET_o \quad (1)$$

Where, Kc is crop coefficient, ET_o is reference evapotranspiration(mmday^{-1}), and ET_C(mmday^{-1})represents the water used by a crop for growth and cooling purposes (mmday^{-1})). This water is extracted from the soil root zone by the root system and is therefore not available as stored water in the soil.

The knowledge of this parameter is of paramount importance in food production, especially in all-year-round crop cultivation. It assists in designing irrigation systems and scheduling irrigation to compensate for inadequate available soil water during periods when there are shortfalls in the year.

Estimation of reference evapotranspiration (ETo) was done using the ETo calculator (Raes, 2012). The reference evapotranspiration is accessed in the ETo calculator software from meteorological data. It employs the FAO Penman-Monteith equation (Allen et al., 1998; Ilesanmi et al., 2012; Ilesanmi et al., 2014). This equation was used to project future CWR across Nigeria, making use of projected climatic data for the future based on the models described in Table 1.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where, ET_o is the reference evapotranspiration (mm day^{-1}), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G is the soil heat flux density (MJ m^{-2} day^{-1}), T is the mean daily air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), e_s - e_a is the saturation vapour pressure deficit (kPa), Δ is the slope vapour pressure curve (kPa °C^{-1}), and γ is the psychrometric constant (kPa °C^{-1}).

The program can handle daily, ten-day and monthly climatic data.

The Estimation of the CWR followed the procedure described in the ET_o Calculator Reference Manual (Version 3.2, 2012)

The parameter K_c varies on thecrop type and the crop's growing stage (e.g., initialphase, crop development, midseason and late season). On the other hand, ETo depends on climatic data (e.g., temperature, wind speed, sunshine hours and humidity). The K_c for Cassava, Rice and Soybean are 0.66, 1.05 and 0.83, respectively.

2.3.2 CWR percentage change

The percentage change of projected CWR for Nigeria was calculated using the expression below;

$$\Delta = \frac{\beta_o - \beta_n}{\beta_o} x100 \quad (3)$$

Where Δ is the percentage change, β_o (mmday^{-1})is the CWR for the first year of the projection, and β_n(mmday^{-1}) is the CWR of the final forecast.

2.3.3 Temporal/ data analysis

The non-parametric Mann – Kendall test was applied to detect the trend and significance of the water requirement of the crops. The trends will be analyzed on an annual and location (state by state) basis. Sen's non-parametric test is applied using a linear model to detect the magnitude of the trend in percentage. This magnitude is the degree of either increase or decrease of the water requirement over the period considered for this study. The procedures followed were outlined by Salmi et al. (2002). The temporal trend was carried out using an excel template, MAKESENS, the combination of both the Mann-Kendall test for trend and Sen's slope estimates. The Mann-Kendall test statistic S, according to Salmi et al. (2002), is given by

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\operatorname{sgn}(x_j-x_k) \quad (4)$$

Where,n is the length of the time series $x_i, \ldots, x_n$, and *sgn(.)* is a sign function, x_j and x_k are values in years j and k, respectively. The expected value of S equals zero for series without trend, and the variance is computed as:

$$\sigma^2(S)=\frac{1}{18}\left[n(n-1)(2n+5)-\sum_{p=1}^{q}t_p(t_p-1)(2t_p+5)\right] \quad (5)$$

Where q is the number of tied groups and t_p is the number of data values in the p_{th} group. The test statistic Z is then given as:

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{\sigma^2(S)}} & if \quad S>0\\ 0 & if \quad S=0\\ \dfrac{S+1}{\sqrt{\sigma^2(S)}} & if \quad S<0\end{cases} \quad (6)$$

As a non-parametric test, no assumptions about the underlying distribution of the data are very significant. The Z statistic was then used to test the null hypothesis, H_o that the data are randomly ordered in time, against the alternative hypothesis, H_1, where there is an increasing or decreasing monotonic trend. *A* positive (negative) value of Z indicates an upward (downward) monotone trend. H_o will be rejected at a particular level of significance if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. Hobbins et al. (2001) noted that the Mann-Kendall test is non-dimensional and does not quantify the scale or the magnitude of the trend but the direction of the trend. To estimate the true slope of an existing trend, Sen's non-parametric method will be used (Salmi et al., 2002, Oguntunde et al., 2006).

3 Results and discussions

3.1 Trend of rainfall and temperature

The trend of rainfall and temperature between 1985 and 2100 for each state across Nigeria was analyzed. This analysis showed that both climatic variables are increasing in the country. Average rainfall for Nigeria in 1985 was 131.18mm, and it is projected to increase to 135.3mm by 2100 (3.1% increase) while average temperature increased from 27.2°C in 1985 to 29.1°C in 2100 (7% increase).The observed rainfall and temperature experienced increments. The observed rainfall and temperature experienced increments. Temperature increments were statistically significant across the 36 states and the FCT while rainfall increments were also statistically significant across the states and the FCT except in Anambra, Delta, Ebonyi, Ekiti, Kaduna, Kwara, Ogun, Ondo, Osun, Oyo and Taraba states. These were insignificant because Oyo and Kwara states had very slight rainfall decrease while the other states where the changes were insignificant had virtually an unchanged rainfall pattern.Table 2 Temporal trend of rainfall and temperature in Nigeria (1985 - 2100).

3.2 Changes in CWR

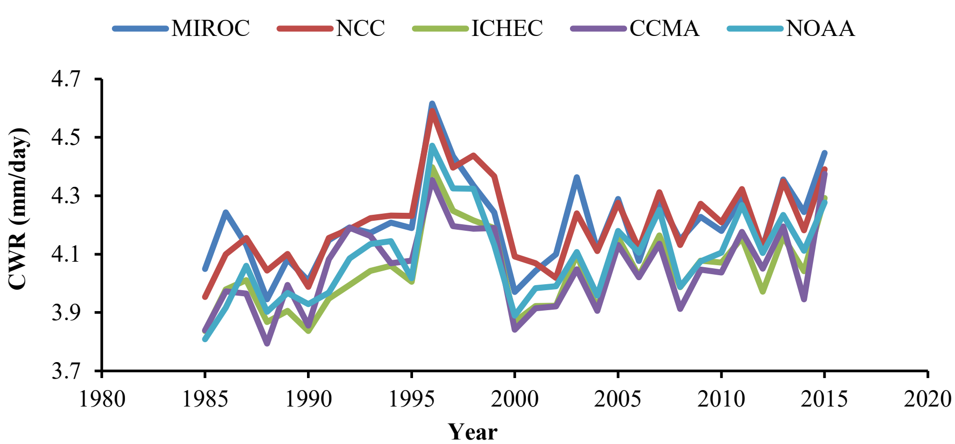
The average annual CWR for model CCCMA ranged from 3.84mmday^{-1} to 4.35mmday^{-1} for years 1985 – 2015, 3.90mmday^{-1} to 4.77mmday^{-1} for years 2020 – 2050 and 4.37mmday^{-1} to 4.83mmday^{-1} for years 2070 – 2100. Model ICHEC produced CWR values that ranged from 3.84mmday^{-1} to 4.40 mmday^{-1} , 3.98mmday^{-1} to 4.56mmday^{-1} and 4.17mmday^{-1} to 4.86mmday^{-1} for years 1985 – 2015, 2020 – 2050 and 2070 – 2100 respectively. Climate model MIROC estimated CWR values that ranged from 4.05mmday^{-1} to 4.62mmday^{-1} in 1985 – 2015, 4.10mmday^{-1} to 4.70mmday^{-1} in 2020 – 2050 and 4.29mmday^{-1} to 5.01mmday^{-1} in 2070 – 2100. In the case of NOAA, estimated CWR had values of 3.81mmday^{-1} to 4.47mmday^{-1}for 1985 – 2015, 4.00mmday^{-1} to 4.67mmday^{-1} for 2020 – 2050 and 4.29mmday^{-1} to 4.98mmday^{-1} for year 2070 – 2100. Finally, NCC had CWR values of 3.95mmday^{-1} to

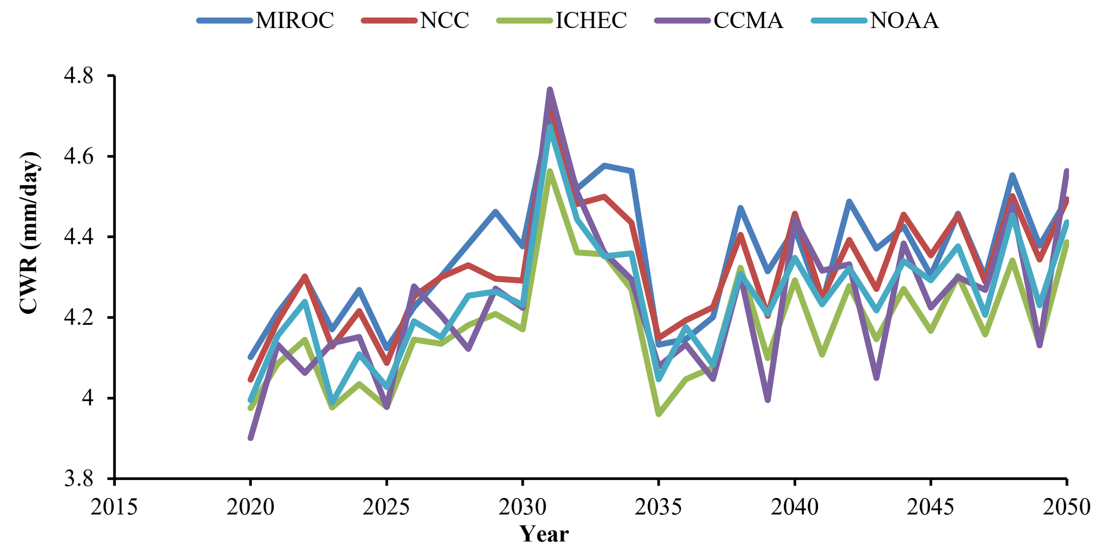
4.59mmday^{-1}, 4.05mmday^{-1} to 4.73mmday^{-1} and 4.23mmday^{-1} to 5.00mmday^{-1} for the years 1985 – 2015, 2020 – 2050 and 2070 – 2100 respectively.

Table 2 Temporal trend of rainfall and temperature in Nigeria (1985 - 2100)

States	Rainfall		Temperature	
	% Change	Sig	% Change	
AbiaState	2.54	*	10.08	***
Adamawa State	2.82	**	10.10	***
AkwaIbom State	6.33	***	10.44	***
Anambra State	1.59		10.25	***
Bauchi State	3.65	***	9.17	***
Bayelsa State	4.94	***	10.40	***
Benue State	1.93	+	10.02	***
BornoState	2.82	**	9.71	***
Cross River State	6.17	***	10.44	***
Delta State	1.31		10.27	***
Ebonyi State	1.02		10.30	***
Edo State	2.66	**	10.34	***
Ekiti State	0.35		10.36	***
Enugu State	1.97	*	10.28	***
FCT	4.03	***	10.48	***
Gombe State	3.22	**	10.07	***
Imo State	3.43	***	10.30	***
Kaduna State	1.41		10.18	***
Kano State	2.70	**	9.88	***
Katsina State	3.22	**	9.67	***
Kebbi State	3.35	***	10.00	***
Kogi State	2.61	**	10.25	***
KwaraState	-1.43		10.30	***
Lagos State	2.37	*	10.30	***
Nasarawa State	4.01	***	10.41	***
Niger State	2.95	**	10.29	***
Ogun State	0.73		10.25	***
Ondo State	0.00		10.35	***
Osun State	0.00		10.30	***
Oyo State	-0.32		10.31	***
Plateau State	3.52	***	10.29	***
Rivers State	5.82	***	10.34	***
Sokoto State	2.82	**	9.82	***
Taraba State	0.92		10.14	***
YobeState	2.19	*	9.83	***
Zamfara State	2.53	*	10.10	***
National	3.89	***	10.39	***

Note: *** significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1





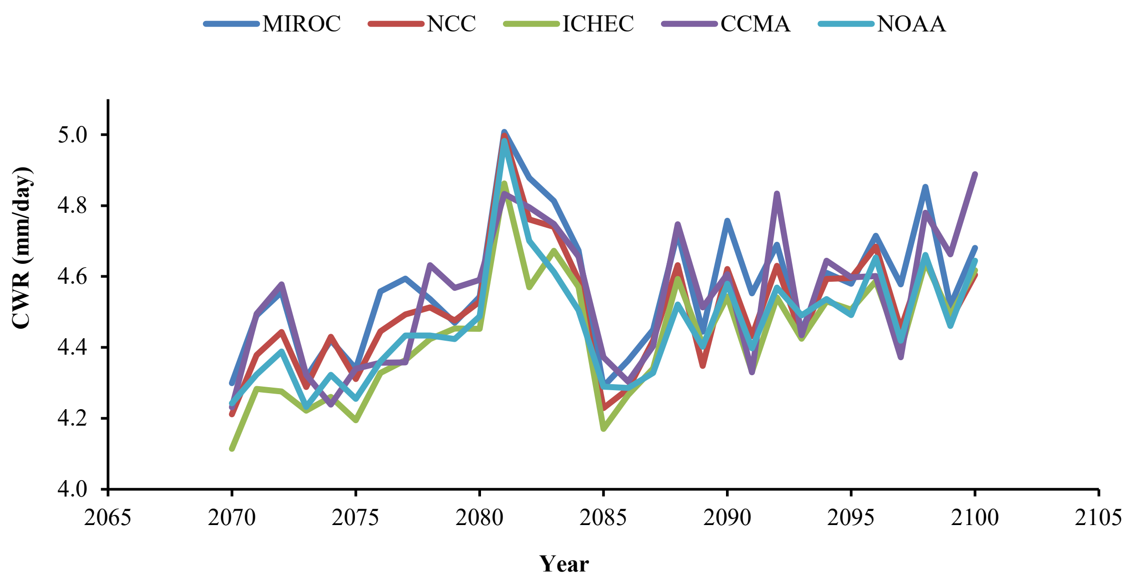
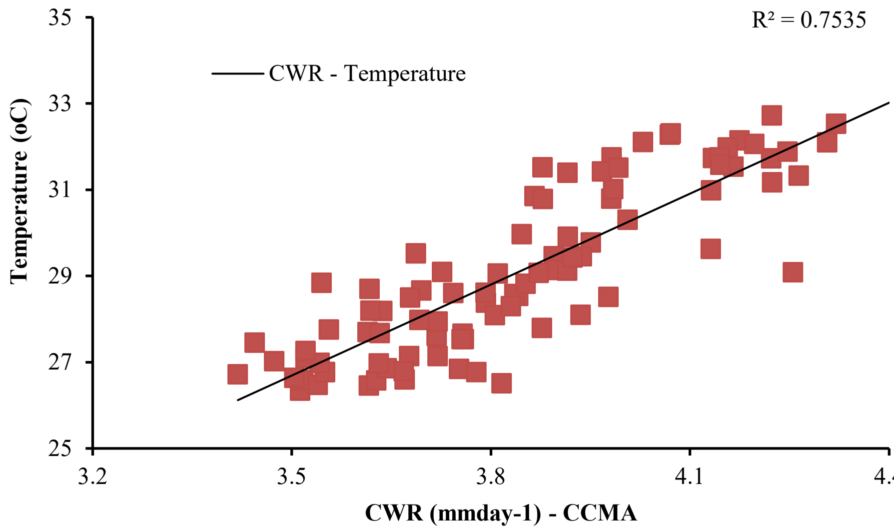


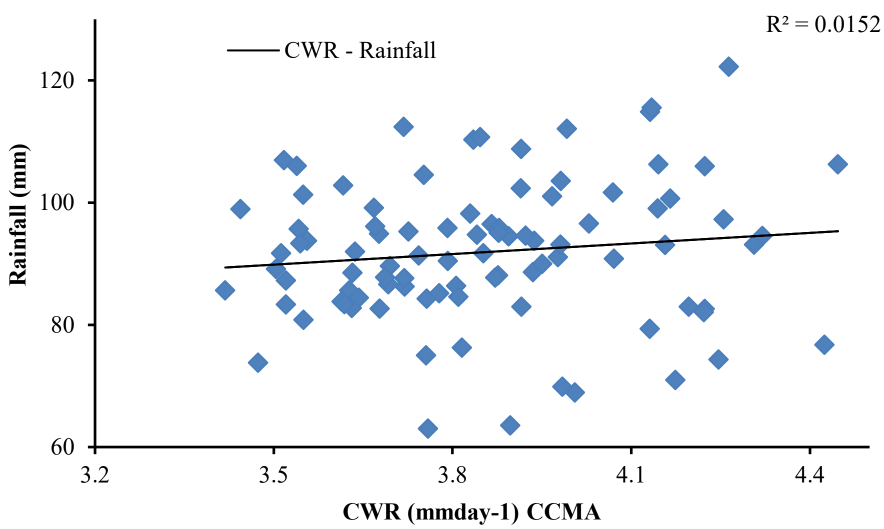
Figure 2Average CWR for Nigeria between 1985 – 2015; 2020 – 2050 and 2070 – 2100

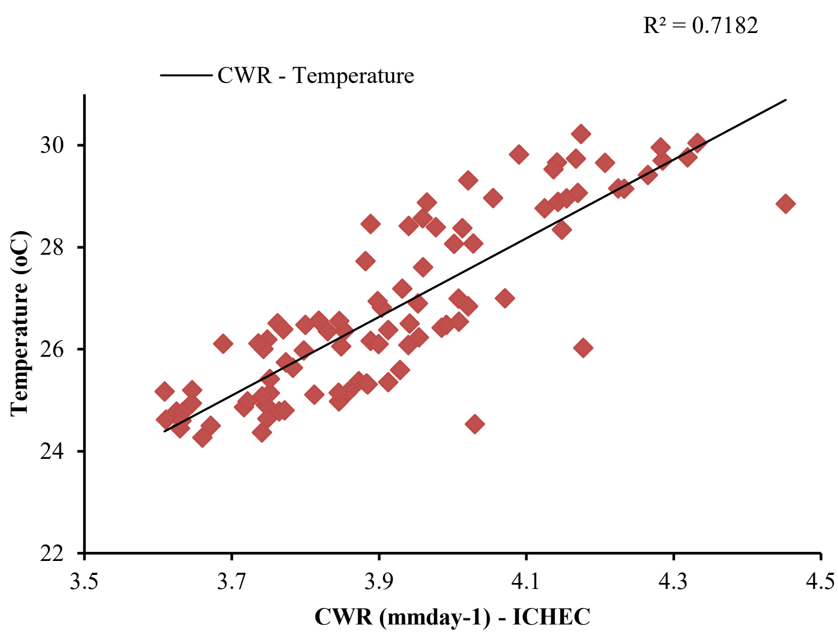
The above agree that the temperature value increases as the CWR increases with rainfall declining. Several studies have produced a similar school of thought. Researchers concluded that the rise in CWR majorly happened due to the observed increase in temperature, while the effect of rainfall changes on CWR was minimal (Chowdhuryet al., 2016; Olubanjo, 2019). However, according to Supitet al (2010), there are projections of declining water requirement of the annual crops in various European regions. This decline can be attributed to a shorter growing period not considered in carrying out this study.

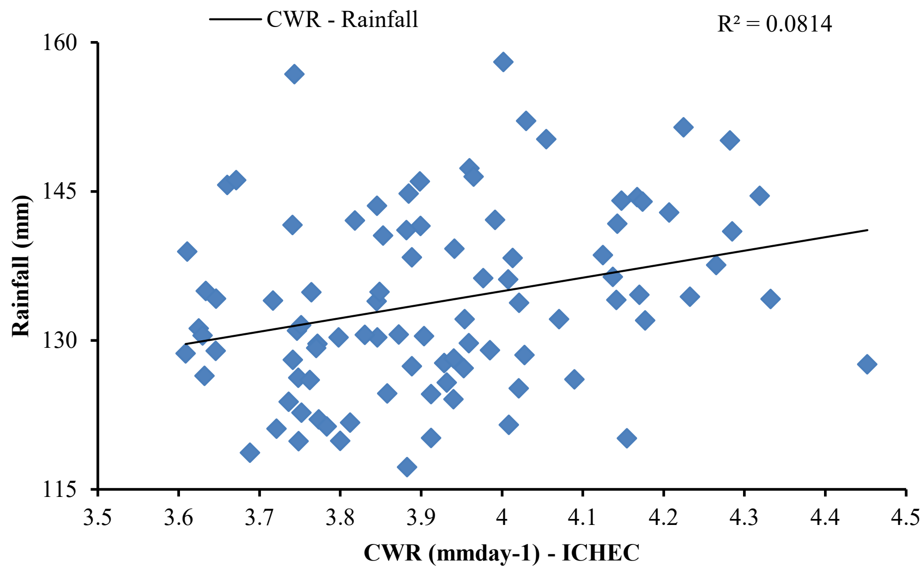
Table 3Correlation (*R*) between CWR, temperature and rainfall

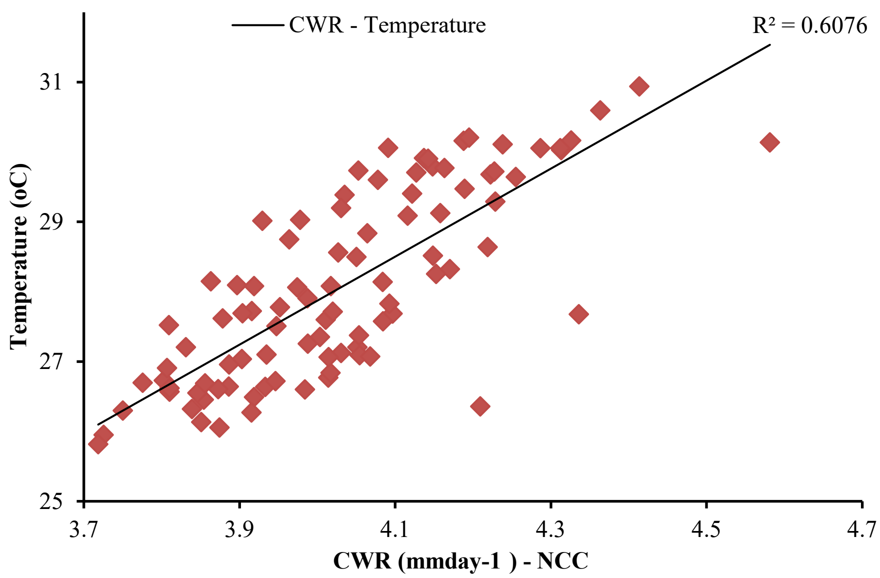
	MODELS				
	CCCMA	ICHEC	MIROC	NOAA	NCC
Temperature (R)	0.87	0.85	0.82	0.84	0.78
Rainfall (R)	0.12	0.29	0.28	-0.02	0.15

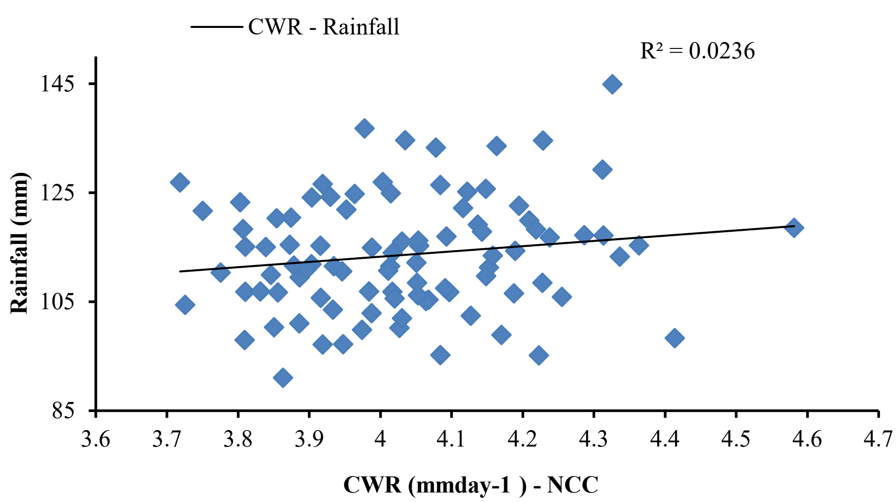

R² = 0.7535
CWR - Temperature
Temperature (oC)
35
33
31
29
27
25
3.2
3.5
3.8
4.1
4.4
CWR (mmday-1) - CCMA

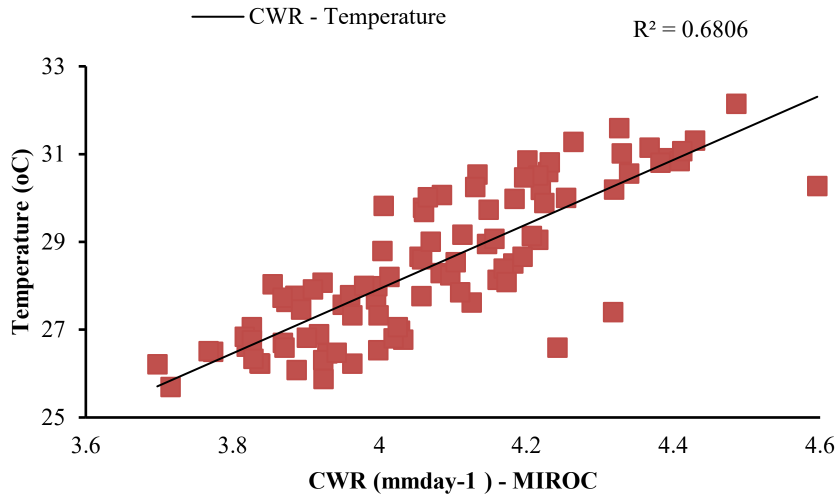

R² = 0.0152
CWR - Rainfall
Rainfall (mm)
120
100
80
60
3.2
3.5
3.8
4.1
4.4
CWR (mmday-1) CCMA

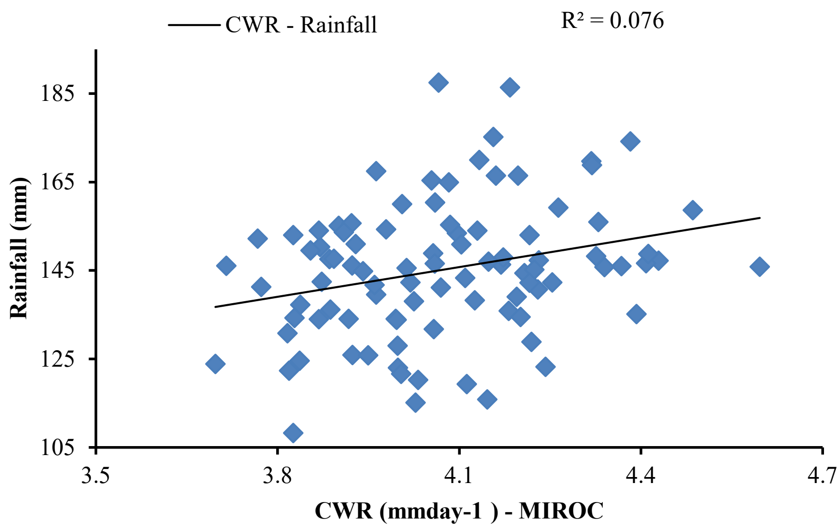

R² = 0.7182
CWR - Temperature
Temperature (oC)
30
28
26
24
22
3.5
3.7
3.9
4.1
4.3
4.5
CWR (mmday-1) - ICHEC

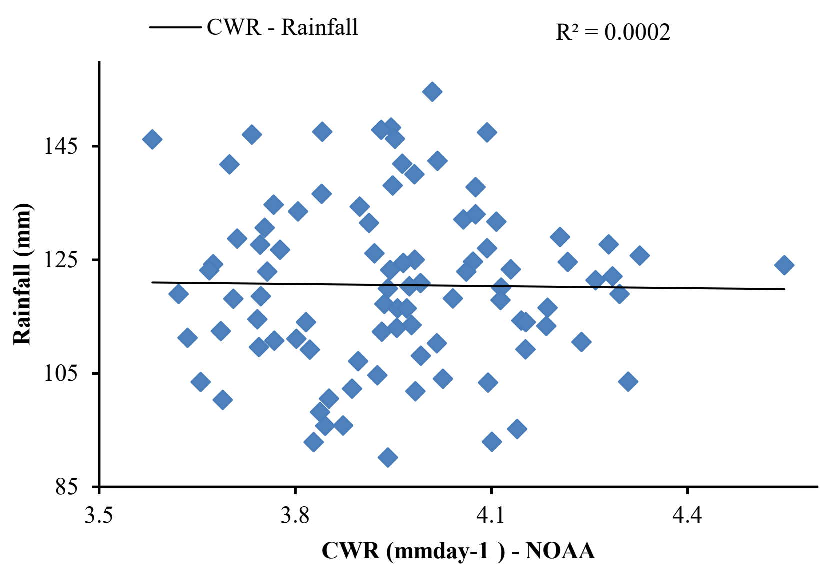

CWR - Rainfall
R² = 0.0814
Rainfall (mm)
160
145
130
115
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
CWR (mmday-1) - ICHEC


CWR - Temperature
R² = 0.6076
Temperature (oC)
31
29
27
25
3.7
3.9
4.1
4.3
4.5
4.7
CWR (mmday-1) - NCC


CWR - Rainfall
R² = 0.0236
Rainfall (mm)
145
125
105
85
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
4.5
4.6
4.7
CWR (mmday-1) - NCC


CWR - Temperature
R² = 0.6806
Temperature (oC)
33
31
29
27
25
3.6
3.8
4
4.2
4.4
4.6
CWR (mmday-1) - MIROC


CWR - Rainfall
R² = 0.076
Rainfall (mm)
185
165
145
125
105
3.5
3.8
4.1
4.4
4.7
CWR (mmday-1) - MIROC


CWR - Rainfall
R² = 0.0002
Rainfall (mm)
145
125
105
85
3.5
3.8
4.1
4.4
CWR (mmday-1) - NOAA

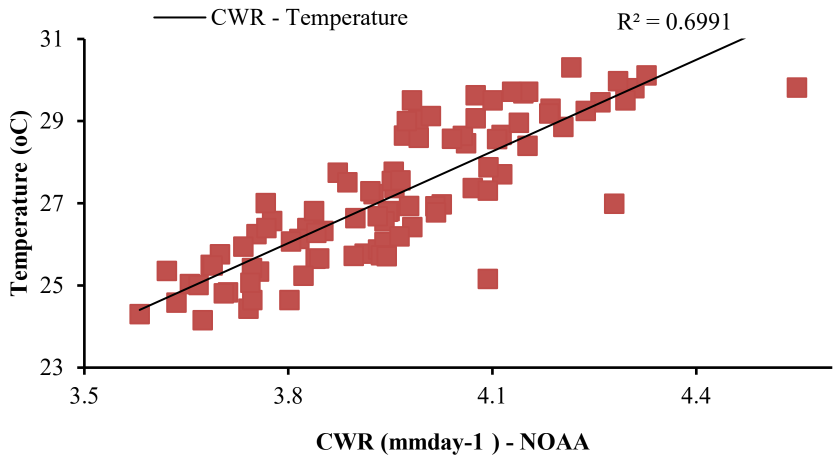


Figure 3 The correlation (R) between CWR, temperature and rainfall for five (5) GCMs

Table 4 Average daily crop water requirements (mmday^{-1}) for 1985-2100 in Nigeria(CCCMA)

States	Latitude	Average CWR	% change	Sig
Osun State	7.77	3.40	6.79	***
Rivers State	4.78	3.42	7.19	***
Ondo State	7.25	3.42	6.99	***
Ekiti State	7.46	3.42	7.96	***
Cross River State	4.95	3.43	8.29	***
Bayelsa State	4.92	3.45	7.79	***
Delta State	6.2	3.45	7.88	***
AkwaIbom State	5.03	3.47	7.44	***
Anambra State	6.21	3.50	6.35	***
Enugu State	6.44	3.52	8.19	***
Lagos State	6.45	3.52	6.63	***
AbiaState	5.53	3.53	6.32	***
Imo State	5.48	3.54	6.76	***
Ebonyi State	6.32	3.56	8.18	***
Edo State	6.34	3.61	6.55	***
Oyo State	7.39	3.61	7.18	***
Ogun State	7.15	3.66	6.89	***
Kwara State	8.50	4.39	6.76	***
Kogi State	7.80	4.43	6.79	***
Kano State	11.99	4.67	8.39	***
Jigawa State	11.76	4.7	8.12	***
Katsina State	12.99	4.76	6.57	***
Borno State	11.85	4.9	8.25	***
Bauchi State	10.31	4.96	7.66	***
Kaduna State	10.52	4.97	8.35	***
Plateau State	9.92	4.98	6.90	***
Kebbi State	12.45	5.13	7.01	***
Gombe State	10.29	5.14	8.25	***
Adamawa State	9.2	5.24	6.79	***
FCT	9.06	5.28	8.32	***
Benue State	7.74	5.35	7.02	***
Zamfara State	12.16	5.35	6.93	***
Nasarawa State	8.53	5.38	7.17	***
Taraba State	8.88	5.42	6.95	***
Niger State	9.61	5.44	6.74	***
Yobe State	11.75	5.47	7.19	***
Sokoto State	13.06	5.55	6.99	***

Note: *** significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1

The estimated average dailyCWR for each state are shown in Tables 4 - 8 below. The estimated values across the 36 states and the Federal Capital Territory of Nigeria posited that there will be increment every year between 1985 – 2100 in the quantity of water required by Cassava, Rice and Soybean to grow effectively in Nigeria.

In CCCMA, the minimum CWR was 3.4 $mmday^{-1}$ in Osun and maximum of 5.55 $mmday^{-1}$ in Sokoto for 1985 to 2100; for NOAA, the minimum was 3.29 $mmday^{-1}$ in Rivers while the maximum was 5.15 $mmday^{-1}$ in Sokoto; for NCC, the minimum was 3.34 $mmday^{-1}$ in Rivers while the maximum was 5.41 $mmday^{-1}$ in Sokoto. The minimum CWR estimate for ICHEC was 3.24 $mmday^{-1}$ in Rivers while the maximum was 5.34 $mmday^{-1}$ in Adamawa and for MIROC, minimum was also 3.34 $mmday^{-1}$ in Rivers while the maximum was 5.56 $mmday^{-1}$ in Adamawa. The above values were for the periods between 1985 – 2100 and were all statistically significant.

Table 5 Average daily crop water requirements ($mmday^{-1}$) for 1985-2100 in Nigeria (ICHEC)

States	Latitude	Average CWR	% change	Sig
Rivers State	4.78	3.24	6.31	***
Bayelsa State	4.92	3.28	6.32	***
Cross River State	4.95	3.30	6.69	***
AkwaIbom State	5.03	3.30	6.19	***
Ekiti State	7.46	3.32	8.61	***
Osun State	7.77	3.32	8.62	***
Delta State	6.20	3.33	6.36	***
Ondo State	7.25	3.33	6.95	***
Imo State	5.48	3.35	8.59	***
Lagos State	6.45	3.35	6.10	***
Abia	5.53	3.38	8.64	***
Anambra State	6.21	3.39	8.66	***
Oyo State	7.39	3.41	8.60	***
Ebonyi State	6.32	3.42	8.56	***
Edo State	6.34	3.42	8.52	***
Ogun State	7.15	3.46	8.56	***
Kwara State	8.50	4.36	8.69	***
Enugu State	6.44	4.38	8.57	***
Kogi State	7.80	4.41	8.78	***
Plateau State	9.92	4.70	8.49	***
Kaduna State	10.52	4.96	6.75	***
FCT	9.06	5.00	6.55	***
Zamfara State	12.16	5.09	6.79	***
Kano State	11.99	5.10	6.95	***
Taraba State	8.88	5.11	6.74	***
Jigawa State	11.76	5.11	6.93	***
Bauchi State	10.31	5.12	6.87	***
Nasarawa State	8.53	5.14	6.55	***
Katsina State	12.99	5.15	6.85	***
Benue State	7.74	5.19	6.49	***
Niger State	9.61	5.21	6.53	***
Yobe State	11.75	5.21	6.89	***
Gombe State	10.29	5.23	6.77	***
Sokoto State	13.06	5.28	6.77	***
Borno State	11.85	5.29	6.89	***
Kebbi State	12.45	5.32	6.64	***
Adamawa	9.02	5.34	6.73	***

Note: *** significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1

Arranged in ascending order of latitudes

Table 6Average daily crop water requirements (mmday^{-1}) for 1985-2100 in Nigeria (MIROC)

States	Latitude	Average CWR	% change	Sig
Rivers State	4.78	3.34	6.00	***
Bayelsa State	4.92	3.37	6.02	***
Cross River State	4.95	3.39	6.24	***
AkwaIbom State	5.03	3.39	5.84	***
Ondo State	7.25	3.43	7.76	***
Ekiti State	7.46	3.43	7.82	***
Osun State	7.77	3.43	7.76	***
Delta State	6.20	3.44	5.90	***
Imo State	5.48	3.45	7.84	***
Lagos State	6.45	3.46	5.68	***
Abia	5.53	3.48	7.76	***
Enugu State	6.44	3.49	7.72	***
Anambra State	6.21	3.50	7.77	***
Oyo State	7.39	3.51	7.64	***
Edo State	6.34	3.52	7.76	***
Ebonyi State	6.32	3.53	7.58	***
Ogun State	7.15	3.55	7.72	***
Kwara State	8.50	4.48	7.74	***
Kogi State	7.80	4.54	7.77	***
Plateau State	9.92	4.88	6.57	***
Kaduna State	10.52	5.14	6.29	***
FCT	9.06	5.16	6.30	***
Taraba State	8.88	5.29	6.12	***
Nasarawa State	8.53	5.30	6.24	***
Zamfara State	12.16	5.30	6.25	***
Kano State	11.99	5.33	6.36	***
Bauchi State	10.31	5.34	6.20	***
Jigawa State	11.76	5.34	6.33	***
Benue State	7.74	5.37	6.05	***
Niger State	9.61	5.38	6.21	***
Katsina State	12.99	5.39	6.24	***
Gombe State	10.29	5.43	6.16	***
Yobe State	11.75	5.44	6.11	***
Sokoto State	13.06	5.50	6.10	***
Borno State	11.85	5.52	6.20	***
Kebbi State	12.45	5.53	6.13	***
Adamawa	9.20	5.56	6.07	***

Note: *** significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1

Arranged in ascending order of latitudes

Table 7 Average daily crop water requirements (mmday^{-1}) for 1985-2100 in Nigeria (NOAA)

States	Latitude	Average CWR	% change	Sig
Rivers State	4.78	3.29	5.80	***
Bayelsa State	4.92	3.33	5.91	***
Cross River State	4.95	3.34	6.14	***
AkwaIbom State	5.03	3.35	5.53	***
Imo State	5.48	3.41	8.56	***
Abia	5.53	3.42	8.49	***
Delta State	6.20	3.37	5.83	***
Anambra State	6.21	3.43	8.51	***
Ebonyi State	6.32	3.46	8.39	***
Edo State	6.34	3.46	8.47	***
Enugu State	6.44	3.42	8.45	***
Lagos State	6.45	3.37	5.59	***
Ogun State	7.15	3.49	8.33	***
Ondo State	7.25	3.36	8.53	***
Oyo State	7.39	3.45	8.31	***
Ekiti State	7.46	3.36	8.57	***
Benue State	7.74	5.25	6.51	***
Osun State	7.77	3.36	8.55	***
Kogi State	7.80	4.45	8.75	***
Kwara State	8.50	4.40	8.70	***
Nasarawa State	8.53	5.22	6.49	***
Taraba State	8.88	5.15	6.59	***
FCT	9.06	5.08	6.39	***
Adamawa	9.20	5.39	6.85	***
Niger State	9.61	5.30	6.45	***
Plateau State	9.92	4.75	6.94	***
Gombe State	10.29	5.27	6.68	***
Bauchi State	10.31	5.17	7.06	***
Kaduna State	10.52	5.01	6.55	***
Job State	11.75	5.24	6.93	***
Jigawa State	11.76	5.14	7.22	***
Borno State	11.85	5.30	7.09	***
Kano State	11.99	5.13	7.21	***
Zamfara State	12.16	5.13	6.81	***
Kebbi State	12.45	5.36	6.66	***
Katsina State	12.99	5.19	6.91	***
Sokoto State	13.06	5.15	6.82	***

Note: *** significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1

Arranged in ascending order of latitudes

Table 8 Average daily crop water requirements (mmday^{-1}) for 1985-2100 in Nigeria (NCC)

States	Latitude	Average CWR	% change	Sig
Rivers State	4.78	3.34	4.99	***
Bayelsa State	4.92	3.37	5.01	***
Cross River State	4.95	3.39	5.34	***
AkwaIbom State	5.03	3.40	4.65	***
Imo State	5.48	3.46	7.32	***
Abia	5.53	3.46	7.04	***
Delta State	6.20	3.43	5.01	***
Anambra State	6.21	3.49	7.44	***
Ebonyi State	6.32	3.53	7.24	***
Edo State	6.34	3.52	7.17	***
Enugu State	6.44	3.49	7.36	***
Lagos State	6.45	3.45	4.62	***
Ogun State	7.15	3.56	7.14	***
Ondo State	7.25	3.42	7.38	***
Oyo State	7.39	3.52	7.09	***
Ekiti State	7.46	3.42	7.46	***
Benue State	7.74	5.35	5.65	***
Osun State	7.77	3.42	7.34	***
Kogi State	7.80	4.52	7.58	***
Kwara State	8.50	4.46	7.40	***
Nasarawa State	8.53	5.30	5.57	***
Taraba State	8.88	5.26	5.71	***
FCT	9.06	5.16	5.59	***
Adamawa	9.20	5.50	5.82	***
Niger State	9.61	5.37	5.50	***
Plateau State	9.92	4.84	5.97	***
Gombe State	10.29	5.38	5.71	***
Bauchi State	10.31	5.27	5.80	***
Kaduna State	10.52	5.10	5.65	***
Job State	11.75	5.34	5.73	***
Jigawa State	11.76	5.24	6.07	***
Borno State	11.85	5.42	5.81	***
Kano State	11.99	5.23	6.00	***
Zamfara State	12.16	5.22	5.65	***
Kebbi State	12.45	5.46	5.58	***
Katsina State	12.99	5.28	5.63	***
Sokoto State	13.06	5.41	5.61	***

Note: *** significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1

Arranged in ascending order of latitudes

3.2 Temporal trend of water requirements of crops in Nigeria

Table 9 shows the temporal trend of CWR with different GCMs. The CWR increases in the present, intermediate and future for CCCMA. Similar results were found for NOAA, ICHEC, NCC and MIROC

(Table 9).

Table 9 Trend of crop water requirement in Nigeria under RCP85

	MODELS									
	CCCMA CWR ($mmday^{-1}$)		ICHEC CWR ($mmday^{-1}$)		MIROC CWR ($mmday^{-1}$)		NOAA CWR ($mmday^{-1}$)		NCC CWR ($mmday^{-1}$)	
PERIOD	% change	Sig	% change	Sig	% change	Sig	% change	Sig	% change	Sig
1985 – 2015	1.50		2.48	*	2.21	*	2.75	**	2.41	*
2020 – 2050	2.31	*	2.58	**	2.41	*	2.82	**	2.75	**
2070 – 2100	2.75	**	3.20	**	2.07	*	3.20	**	2.48	*

Note: *** significant at 0.001, **significant at 0.01, * significant at 0.05, + significant at 0.1

3.3 Discussion of results

3.3.1 Assessing the trend of rainfall and temperature

The temperature trend has been predicted to increase in the 21st century (IPCC, 2001). The outcomes above point towards global warming, widely reported in several studies and reports. Observers have noticed these changes, and this research serves as scientific evidence of such observations.

3.3.2 Variability of CWR in the present, intermediate and future

Each period considered showed an increase in both minimum and maximum CWR values in all climatic scenarios implemented for this study (Figure 2).

Climate change increases CWR. The findings agree with existing studies (Rotich and Mulungu, 2017; Chowdhury et al., 2016). By implication, more water or irrigation regimes will be required to supplement any noticeable water shortage that can be brought about by low rainfall.

To further investigate the climatic parameter that might be responsible for the upward tick in the CWR in Nigeria, the values of estimated CWR using data from the five (5) GCMs was correlated against temperature and rainfall data from the same GCMs. It was observed that temperature values correlated strongly with CWR estimates while rainfall values correlated weakly with estimated CWR in the five (5) climate models (Table 3), it therefore can be inferred from the observed correlation outcome that temperature as a climatic variable has the most impact on the changes that were established in CWR. For CCCMA, Temperature had an R-value of 0.87 while rainfall had 0.12; in the ICHEC model, the temperature had R = 0.85 and rainfall had R = 0.29. Furthermore, analyzing the values using the MIROC model, the correlation values for temperature and rainfall are 0.82 and 0.28, respectively, NOAA had 0.84 and -0.02 for temperature and rainfall in that order with climate model NCC resulted in temperature having R of 0.78 and rainfall returning R of 0.15 (Figure 3).

From the above Tables 4 - 8, it can be seen that the CWR in each state or station was projected to increase between 1985 – 2100 by the five (5) GCMs. The increase is attributed to the confirmed growing trend of temperature and decreasing precipitation across the country.

Observing outcomes from each state, it can also be deduced that there appeared to increase in CWR as the latitude increases.As the latitude of each state increases, the CWR also increases. The finding agrees with existing studies (Liu et al., 2008; Yusufet al., 2017).These reports help to corroborate the instances of increased temperature and decrease in rainfall as we travel northwards from Nigeria's coastal areas; the higher the latitude, the farther north we travel. The rise in CWR also corresponds to the temperature trend, which is expected to continue in the twenty-first century (IPCC, 2001). This implies that rainfall amounts in the region are expected to decline (Oguntunde et al., 2011; Ewonaet al., 2014; Olubanjo, 2019), increasing water demand. The implication of the preceding is that farmers in Nigeria will need to make a cultural shift from rainfed agriculture to more robust and beneficial irrigation agriculture.

3.3.3 Temporal trend of CWR in Nigeria

CCCMA projected a 1.50% (not significant) increase in CWR between 1985 and 2015, historical period, 2.31% ($p<0.05$) increase between 2020 – 2050, intermediate period and a further increase of 2.75% ($p<0.01$) from 2070 to 2100, future period. In the scenario when ICHEC was applied, a 2.48% ($p<0.05$) increase was projected between 1985 and 2015, an increase of 2.58% ($p<0.01$) for the period between 2020 and 2050, with the period from 2070 – 2100 predicting a 3.20% ($p<0.01$) increase. MIROC projected that CWR will experience a 2.21% ($p<0.05$) increase from 1985 -to 2015, another increase of 2.41% ($p<0.05$) between 2020 and 2050 and a further 2.07% ($p<0.05$) increase from 2070 -2100. In using GCM NOAA, the output predicted a 2.75% ($p<0.01$) increase in CWR from 1985 – 2015, a positive trend with an increase of 2.82% ($p<0.01$) from 2020 – 2050 and a final increment of 3.20% ($p<0.01$) from 2070 – 2100. The fifth GCM, NCC, also predicted an increase in CWR, as earlier stated. The increase are 2.41% ($p<0.05$) from 1985 – 2015, 2.75% ($p<0.01$) from 2020 – 2050 and 2.48% ($p<0.05$) from 2070 -2100.

4 Conclusion

The impact of climate change was assessed on CWR of cassava, rice and soybean across Nigeria. The study established that the CWR of these crops will increase in the intermediate and future periods relative to present observations. The increased CWR values will range between 3.24 mm day^{-1} to 5.55mmday^{-1} over these periods, with these changes translating into increments of 2.82% in the intermediate and 3.2% in the future. This increase was majorly influenced by the rising temperatures across the study area, prompting an increase in demand of water from these crops. It was observed that the temperature across the region is on the increase while the rainfall portrayed a very slight increase. It can be concluded that the country is experiencing a warming climate as the years go by. The CWR trend was also established which predicted that the values would rise over time, increasing air temperature. Crop yield and performance are more sensitive to rainfall and water availability than temperature; therefore, it is recommended that crop production periods be shifted to months with more precipitation. This implies the changing of planting dates of crops to help mitigate any negative impact that can arise if available or culturally accepted planting dates are maintained.

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