Assessing the Impact of Climate Change on Yam Production using Probability Density Function in a Humid Rainforest Agroecological Region of Nigeria

By

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Abstract

This study was on the effect of some micro-climate on yam production in south-east Nigeria using a Probability Density Function. A Function was developed in such a way that it indicates the effect of climate change above 50% if the probability of having the climatic condition for yam growth is less than and or equal to 0.5, otherwise impact is below 50%. The micro climate data used in this study include forty-eight (48) years data on monthly average temperature (℃), forty (40) years data on monthly rainfall amount (mm) and forty (40) years data on monthly maximum relative humidity (%). The result showed that climate change has impacted negatively (above 50%) on rainfall for the different growth phases (March – December) of yam. The study also revealed an impact, below 50% on average air temperature and relative humidity across the growth phase. This study recommends that climate change mitigation such as irrigation-based yam production be considered against rain-fed yam production being presently practiced in humid rainforest agroecological region of Nigeria.

Keywords*; Climate-change; Probability-Indicator; Impact; Yam, Yield*

Introduction

The growing concern about climate change emphasizes the need for detailed information about the space and time of distribution of certain climatic variables. Climate change is a global phenomenon; its threat and vulnerability differ not only from one continent to another, but among sub regions, countries and even communities (Agada *et al* 2019). Between the months of July and September, 2012, about thirty states in Nigeria was affected by heavy flooding that displaced many people and destroyed properties worth millions of naira, alongside crop damage.

The climate of an area is determined by considering the climatic elements such as precipitation. Rainfall, temperature, wind relative humidity, sunshine solar radiation etc, and their variability play a significant role in the performance of agricultural production (Adejuwon, 2019). Adejuwon, (2004) in his study also stated that the main climatic drivers of crop growth and yield include temperature, sunlight, water, relative humidity. Recent studies have showed that important climatic variables for crop growth and yield are temperature, solar radiation and rainfall (Elijah *et al*. 2018). According to DFID (2004), climate change will result in northern and southern latitudes getting drier, while the tropics are expected to become wetter and hotter. Moreover, climate variability is expected to increase with increased frequency and intensity of extreme weather conditions in Africa. The implications for Sub-Saharan Africa are that the region would generally get hotter and experience more extreme weather conditions, particularly increase in air temperature and rainfall, (Bita and Great, 2013). Boko, *et al*., (2007) reported that a number of countries in Africa already face semi-arid conditions that make agriculture more challenging, and climate change will likely reduce the length of growing season as well as force large regions of marginal agriculture out of production. Projected reductions in yield in some countries could be as much as 50% in the year (2020), and crop net revenues could fall by as much as 90% by 2100, with small-scale farmers being the most affected (IPCC, 2002). Incidentally, this period falls within 2080-2099. Which Nakićenović *et al*., (2000) has predicted that, annual mean surface air temperature in Africa is expected to increase between 3 and 4°C. Crops generally require certain threshold of rainfall and air temperature during growth periods for maximum yield and when these become excess it leads to yield decline due to its impact on the activities of soil micro-organism and consequently on plant developmental processes (EMAZIYE, 2015). Rural farmers are becoming poorer because their farming system is characterized by low and declining productivity due to climate change (Oyerinde, 2010). Bello (2010) emphasized the need to monitor the effect of climatic factors on agriculture from the field. Such exercise enables us to see the reality of climate effects on agriculture.

Yam (*Dioscorea spp*) is one of the largely cultivated, climate sensitive food crop grown in Nigeria with over 600 species, out of which six are socially and economically important in terms of food (Okongor, 2019). It`s tuber is the storage organ of crop and constitutes the most significant economic part used majorly for human consumption in Nigeria. *Dioscorea rotundata* (white yam) and *D. alata* (water yam) are important staple food and sources of carbohydrate to Nigerian's diet. Yam production in Nigeria is vulnerable to the effect of climate change and variability. This has impacted on the crop growth and yield negatively (Elijah, 2019). Although Nigeria is witnessing a sporadic rise in yam production (CBN, 2008) but spatial shift in yam cropping pattern may result in mismatch of environment and yam cropping which will result in crop failure. To avoid this, there is need for an improved understanding of yam growing environment to enhance its high steady production. This is imperative because 60% of Nigerians are farmers and the study on the effect of climate change on agricultural production has received limited attention (Olah, 2019).

This work is an improvement of Agada *et al* (2019) who assumed that annual rainfall amount is evenly distributed across yam growth phases (March to December). Here we assume that the rainfall requirement for yam production is proportionally distributed across these growth phases.

2.1 Source of Data

The monthly rainfall (1972 to 2020), average air temperature (1980 – 2020) and monthly relative humidity (1980 – 2020) datasets covering 100km radius at Umudike centre were collected from National root crops Research Institute Umudike Meteorological Department.

2.1.1 Rainfall

The Specific crop (yam) used in this work has certain climate requirements for growth. The ecology of yam growth shows that yam requires an annual rainfall amount of 1035-1500mm within a growing phase of 9 months. However, in-order to obtain a mean monthly rainfall amount for this growth phase, the annual rainfall amount would be proportionally distributed across these months shown below.
Let the random variable X_{ij} represent rainfall amount, where j represents the months; j= 1,2,3, … ,12 and i represents the number of years under study; *i*=1,2,3, … , 47. Then the monthly proportion P_{ij} for the period of 47 years is given by ;

$$P_{ij} = \begin{array}{ccccc} Year & January & February & \cdots & December \\ 1 & \frac{X_{11}}{\sum_j X_{1j}} & \frac{X_{12}}{\sum_j X_{1j}} & \cdots & \frac{X_{1,12}}{\sum_j X_{1j}} \\ 2 & \frac{X_{21}}{\sum_j X_{2j}} & \frac{X_{22}}{\sum_j X_{2j}} & \cdots & \frac{X_{2,12}}{\sum_j X_{2j}} \\ & & \vdots & & \\ 47 & \frac{X_{47,1}}{\sum_j X_{47,j}} & \frac{X_{47,2}}{\sum_j X_{47,j}} & \cdots & \frac{X_{47,12}}{\sum_j X_{47,j}} \end{array}$$

However, the distribution of proportional monthly rainfall amount for this growth phase is shown below;

$$\bar{p}_{January} = \frac{1}{47}\left[\frac{X_{11}}{\sum_j X_{1j}} + \frac{X_{21}}{\sum_j X_{2j}} + \cdots + \frac{X_{47,1}}{\sum_j X_{47,j}}\right]$$

$$\bar{p}_{February} = \frac{1}{47}\left[\frac{X_{12}}{\sum_j X_{1j}} + \frac{X_{22}}{\sum_j X_{2j}} + \cdots + \frac{X_{47,2}}{\sum_j X_{47,j}}\right]$$

$$\vdots$$

$$\bar{p}_{December} = \frac{1}{47}\left[\frac{X_{1,12}}{\sum_j X_{1j}} + \frac{X_{2,12}}{\sum_j X_{2j}} + \cdots + \frac{X_{47,12}}{\sum_j X_{47,j}}\right]$$

Therefore, the mean monthly rainfall requirements for yam growth are given below as;

Monthly minimum rainfall requirement for yam growth: $(1035)\begin{pmatrix} \bar{p}_{January} \\ \bar{p}_{February} \\ \bar{p}_{March} \\ \vdots \\ \bar{p}_{December} \end{pmatrix}$

Monthly maximum rainfall requirement for yam growth: $(1500)\begin{pmatrix} \bar{p}_{January} \\ \bar{p}_{February} \\ \bar{p}_{March} \\ \vdots \\ \bar{p}_{December} \end{pmatrix}$

2.1.2 Temperature

The ecology of yam growth shows that yam requires a daily temperature amount from 25 degree Celsius to 30 degrees Celsius. Therefore, the average monthly requirement for growth is between 25 degrees Celsius to 30 degrees Celsius

2.1.3 Relative humidity

The monthly relative humidity data is presented in percentage form. The data was transformed to proportion by dividing all entries by a 100.

2.2 Distribution Fit

The following four continuous probability distribution models namely, normal, lognormal, gamma and exponential distribution were used to select the best fit probability distribution for monthly rainfall and temperature in Umudike. The discrete probability distributions considered also for best fit was the beta distribution for modeling relative humidity climate. The criteria for best fit is based on comparison of Log-likelihood (LL), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) of different distributions using maximum likelihood estimation of the parameter. When comparing different models, the centre point is in choosing the distribution with the maximum log-likelihood, minimum AIC and minimum BIC. The best distributions are subjected to goodness of fit test.

LL

$$AIC = 2k - 2ln(\hat{L}) \tag{1.1}$$

AIC = Akaike Information Criterion
k= number of estimated parameters in the model
$\hat{L}$= maximum value of the likelihood function for the model

$$BIC = k\ lin(n) - 2ln(\hat{L}) \tag{1.2}$$

BIC = Akaike Information Criterion
k = number of estimated parameters in the model
$\hat{L}$ = maximum value of the likelihood function for the model
n = number of observations

2.3 Goodness of fit test

The Anderson-Darling goodness-of-fit test was used at α (0.05) level of significance for the selection of the best fit distribution. The best fitted distribution is selected based on the maximum p-value.

The test statistic A^2 is defined as

$$A^2 = -\sum_{i=1}^{n}[(2i-1)\{lnF_X(x_i) + ln[1 - F_X(x_{n+1-i})]\}/n] - n \quad (1.3)$$

Where F_X is the cumulative distribution function of the specified distribution and x_i is the ordered data. The critical value C_α in the A-D test for a given significance level α depends on the form of the proposed theoretical distribution. The hypothesis of Anderson-Darling goodness-of-fit test is given as;

H_0 = The data follows a specified distribution.

H_1 = The data does not follow the specified distribution.

All analyses were carried out in an open source R environment version 4.0.4. The packages in R programming language used were "fitdistrplus", "goftest", "zoo", "ggplot2" and "tidyverse".

2.4 Mathematical details of the Probability Distributions

Presented below are the mathematical details of the probability models considered and tested for fitness in this work.

2.4.1 Normal Distribution

This is a continuous distribution with a bell-shaped density curve described by its mean (μ) and standard deviation (σ). If x is a continuous random variable and follows a normal distribution, then, its probability density function (p.d.f) is defined as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp^{-1/2}\left\{\left(\frac{x-\mu}{\sigma}\right)^2\right\} \quad , \ \mu = \text{mean}; \ \sigma^2 = \text{variance} \quad \sigma^2 > 0 \ ; \ -\infty < x < \infty \quad (1.4)$$

2.4.2 Lognormal Distribution

A variable x is lognormally distributed if the ln (x) is normally distributed. The general formula for the probability density function of lognormal distribution is given as;

$$f(x) = \frac{EXP^{-\left(\left(ln\left(^{(x-\theta)}/_{m}\right)\right)^2 \Big/ _{(2\sigma^2)}\right)}}{(x-\theta)\sigma\sqrt{2\pi}} \quad x > 0; m, \sigma > 0 \quad (1.5)$$

Where σ is the shape of the distribution (and is the standard deviation of the log of the distribution), θ is the location parameter and m is the scale parameter (also the median of the distribution).

2.4.3 Gamma Distribution

A continuous random variable is said to have a distribution with parameters $\alpha > 0$ and $\beta > 0$, if its probability density function (p.d.f) is given by

$$f(x;\alpha,\beta) = \frac{\beta^{\alpha}x^{\alpha-1}e^{-\alpha\beta}}{\Gamma(\alpha)} \, for \; x > 0; \; \alpha,\beta > 0 \tag{1.6}$$

$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1}e^{-x}\,dx$ where $\alpha > 0$ is the shape parameter and $\beta > 0$ is the scale parameter.

2.4.4 Exponential Distribution

A continuous variable X is said to have exponential distribution with λ>0 if its probability density function (p.d.f) is given by

$f(x;\lambda) = \lambda e^{-\lambda x} \;\; x > 0$; and 0 elsewhere. $\lambda > 0$ is the rate parameter

The mean of an exponential distribution is given as

$E(x) = \frac{1}{\lambda}$ and variance of the distribution is given as

$Var(x) = \frac{1}{\lambda^2}$

2.4.5 Beta Distribution

The general formula for the probability density function of a beta distribution is given as below

$$f(x) = \frac{(x-a)^{p-1}(b-x)^{q-1}}{B(p,q)(b-a)^{p+q-1}} \quad a \le x \le b; p,q > 0 \tag{1.7}$$

Where *p* and *q* are the shapes parameters, *a* and *b* are the lower and upper bounds

2.5 Probability Indicator Function for measuring the impact of climate change on yam growth

Let I_G represents the indictor function of growth, then the indicator function for impact of climate change on yam growth is given as;

$$I_G \Pr(yamG)_{condition} = \begin{cases} above\ 50\%,\ if\ \Pr(yamG)_{condition} \leq 0.5 \\ below\ 50\%, \Pr(yamG)_{condition}\ > 0.5 \end{cases} \tag{1.8}$$

$\Pr(yamG)_{condition}$ is the probability of yam growth condition based on the climate variables considered in this work. $I_G \Pr(yamG)_{condition}$ is a measure of Probability Indicator Function for the impact of climate change on yam growth.

3.0 DISCUSSION OF RESULTS

Table 1 presents the summary of goodness of fit for rainfall. All the months fitted the normal probability distribution with p-values greater than the level of significance (p-value> 0.05). The month of December did not fit any known probability distribution. Table 2 also presents the goodness of fit for temperature climate variable. The months of February, March, April, May, July, September, October and December fitted a normal distribution (p-value > 0.05). January, June and November fitted a lognormal distribution (p-value > 0.05) while the month of August fitted a gamma distribution (p-value >0.05). In Table 3 we have the summary of goodness of fit for relative humidity. All the months for yam production fitted a beta distribution (p-value > 0.05)

Table 1: Summary of goodness of fit test for rainfall

Months	Distribution	Parameters	Value of test statistic	P-value
Mar	Normal	mean=112.48 Sd= 70.91	An = 0.63	0.6188
Apr	Normal	mean=172.4 Sd=71.42	An = 0.81	0.4735
May	Normal	mean=269.34 Sd=82.48	An = 0.43	0.8185
Jun	Normal	mean=292.46 Sd=102.23	An = 0.59	0.6545
jul	Normal	mean=285.43 Sd=87.08	An = 0.27	0.9577
Aug	Normal	mean=310.9 Sd=107	An = 0.41	0.8391
Sep	Normal	mean=341.2 Sd=84.94	An = 0.73	0.5371
Oct	Normal	mean=257.78 Sd=93.41	An = 0.26	0.9657
Nov	Normal	mean=55.06 Sd=45.78	An = 0.86	0.4365
Dec	-	-	-	

NB: '-'means that rainfall data for the months of January and December do not fit any known distribution.

Table 2: Summary of goodness of fit test for average temperature

Months	Probability Distribution	Parameters	Test statistic (Anmax)	P-value
Mar	Normal	mean=28.1991 sd=0.9575	2.1565	0.3829
Apr	Normal	mean=27.7325 sd=0.9496	1.6889	0.5914
May	Normal	mean=26.8112 sd=1.0706	3.0107	0.1597
Jun	LogNormal	meanlog=3.2504 sdlog=0.0232	3.5698	0.087
Jul	Normal	mean=25.7331 sd=0.6363	2.5175	0.266
Aug	Gamma	shape=1634.3491 rate= 63.5114	2.4492	0.2854
Sep	Normal	mean=26.3725 sd=1.0792	1.6171	0.6276
Oct	Normal	mean=27.1873 sd=0.9822	2.3193	0.3256
Nov	LogNormal	meanlog=3.3053 sdlog=0.0301	3.4268	0.1024

Dec	Normal	mean=21.3259 sd=1.2447	1.6361	0.6178

Table 3: Summary of goodness of fit test for relative humidity

Months	Probability Distribution	Distribution Parameters	Test statistic (Anmax)	P-value
Mar	Beta	shape1 = 36.9598 shape2 = 26.7414	2.01	0.44
Apr	Beta	shape1 = 138.865 shape2 = 74.7953	2.73	0.21
May	Beta	shape1 = 138.375 shape2 = 57.8501	1.51	0.69
Jun	Beta	shape1 =138.865 shape2 = 74.7953	43.42	0
Jul	Beta	shape1 = 251.091 shape2 = 67.843	2.89	0.18
Aug	Beta	shape1 = 103.115 shape2 = 27.8228	2.45	0.29

Sep	Beta	shape1 = 124.704 shape2 = 38.4164	1.94	0.47
Oct	Beta	shape1 = 123.691 shape2 = 42.5910	1.45	0.72
Nov	Beta	shape1 = 26.5636 shape2 = 14.2780	1.97	0.46
Dec	Beta	shape1 = 28.4400 shape2 = 28.7498	0.62	1

The chance of occurrence of the rainfall condition for yam growth across the growth phases is captured in Table 4 below, for the months of February to November. The monthly conditions for yam growth recorded very low chances of occurrence (below 0.5, i.e below 50%). This implies that there are very low chances of occurrence of this rainfall condition in the months as required for yam production. We hypothesized earlier that without the effect of climate change, the study area should record and continue to record high chance of occurrence of this rainfall climatic condition for yam production (i.e above 50%). But due to the impact of climate change, chances below 50% were recorded. The indicator function for quantifying the impact of climate change on growth of Yam indicated that climate change has impacted above 50%. See Table 7 below. This result is consistent with that of Agada *et al* (2019) who observed for the months of April to October a low chance of occurrence of rainfall conditions (above 50% impact) for yam growth in Makurdi Benue state. This impact may cause a change of yield pattern of yam as collaborated by (EMAZIYE, 2015) who found a negative correlation between rainfall and yam production which implies that an increase in rainfall will cause a decrease in yam yield.

Table 4: The distribution of the chance of occurrence of the Rainfall condition for Yam growth

Months	Distribution	Parameters	Monthly conditions	Probability of Occurrence
Mar	Normal	mean=112.48 Sd=70.91	$57.62 \leq R_F \leq 83.50$	0.0133
Apr	Normal	mean=172.4 Sd=71.42	$88.31 \leq R_F \leq 127.98$	0.1475
May	Normal	mean=269.34 Sd=82.48	$137.96 \leq R_F \leq 199.94$	0.1445

Jun	Normal	mean=292.46 Sd=102.23	$149.80 \leq R_F \leq 217.11$	0.1491
Jul	Normal	mean=285.43 Sd=87.08	$146.20 \leq R_F \leq 211.89$	0.1443
Aug	Normal	mean=310.9 Sd=107	$159.25 \leq R_F \leq 230.80$	0.1489
Sep	Normal	mean=341.25 Sd=84.94	$174.80 \leq R_F \leq 253.33$	0.1253
Oct	Normal	mean=257.78 Sd=93.41	$132.04 \leq R_F \leq 191.36$	0.1494
Nov	Normal	mean=55.06 Sd=45.78	$28.20 \leq R_F \leq 40.87$	0.0996
Dec	-	-	-	

NB: '-' means that rainfall data for the months of January and December do not fit any known distribution.

The chances of occurrence of the air temperature condition for Yam production are very high (above 0.5) for all the months (March through to December). The indicator function therefore quantifies the impact of climate change to be below 50% for the air temperature. See Table 5. This agrees with the findings of Agada et al., 2019 that impact of air temperature on the growth condition for yam is below 50%. This result indicates that air temperature is still within the threshold of yam temperature requirement range. However, yam producers and scientists in the tropical region have to be cautious of Nakićenović et al., (2000) prediction of increase in annual mean surface air temperature in Africa is expected to increase between 3°C and 4°C within 2080 to 2099 and its consequent crops yield loss of 90%, especially as this period (2080 to 2099) get closer, because a combination of air temperature of this magnitude and increased precipitation might result in total crop failure.

Table 5: The distribution of temperature condition for Yam production

Months	Probability Distribution	Parameters	Temperature conditions	Probability
Mar	Normal	mean=33.47976 sd=1.085	$25 < T_{AVG} < 30$	0.9696
Apr	Normal	mean=27.7325 sd=0.9496	$25 < T_{AVG} < 30$	0.9895
May	Normal	mean=26.8112 sd=1.0706	$25 < T_{AVG} < 30$	0.9532
Jun	LogNormal	meanlog=3.2504 sdlog=0.0232	$25 < T_{AVG} < 30$	0.9134
Jul	Normal	mean=25.7331 sd=0.6363	$25 < T_{AVG} < 30$	0.8754
Aug	Gamma	shape=1634.3491 rate= 63.5114	$25 < T_{AVG} < 30$	0.8759
Sep	Normal	mean=26.3725 sd=1.0792	$25 < T_{AVG} < 30$	0.8979
Oct	Normal	mean=27.1873 sd= 0.9822	$25 < T_{AVG} < 30$	0.9849
Nov	LogNormal	meanlog=3.3053 sdlog=0.0301	$25 < T_{AVG} < 30$	0.9972
Dec	Normal	mean=21.3259 sd= 1.2447	$25 < T_{AVG} < 30$	0.0016

The chances of occurrence of relative humidity condition for yam growth appear to be very high for every other month in the growth phase except for the months of March, November and December which have low chances (below 0.5). Therefore, the indicator function shows that climate change has impacted above 50% for these months (March, November and December). See Table 6.

Table 6: Impact of climate change on rainfall, temperature and relative humidity conditions for yam growth

Months	Probability Distribution	Distribution Parameters	Monthly conditions	Probabilty
Mar	Beta	shape1 = 36.9598 shape2 = 26.7414	Pr $(0.7 < R_H < 0.91)$	0.0226
Apr	Beta	shape1 = 138.865 shape2 = 74.7953	Pr $(0.7 < R_H < 0.91)$	0.0596
May	Beta	shape1 = 138.375 shape2 = 57.8501	Pr $(0.7 < R_H < 0.91)$	0.5714
Jun	Beta	shape1 =138.865 shape2 = 74.7953	Pr $(0.7 < R_H < 0.91)$	0.9663
Jul	Beta	shape1 = 251.091 shape2 = 67.843	Pr $(0.7 < R_H < 0.91)$	0.9998
Aug	Beta	shape1 = 103.115 shape2 = 27.8228	Pr $(0.7 < R_H < 0.91)$	0.9891
Sep	Beta	shape1 = 124.704 shape2 = 38.4164	Pr $(0.7 < R_H < 0.91)$	0.9692
Oct	Beta	shape1 = 123.691 shape2 = 42.5910	Pr $(0.7 < R_H < 0.91)$	0.8997
Nov	Beta	shape1 = 26.5636 shape2 = 14.2780	Pr $(0.7 < R_H < 0.91)$	0.2596

Dec	Beta	shape1 = 28.4400 shape2 = 28.7498	Pr $(0.7 < R_H < 0.91)$	0.0007

The climatic impact of rainfall, air temperature and relative humidity are presented in Table 7. On rainfall evaluation, it is observed that climate change has impacted above 50% on monthly rainfall requirements for yam growth. The climate change impact on temperature is below 50% for the months of March through to October. This means that temperature requirement for yam growth is not affected by climate change for the months of March through to October. We also observed an above 50% impact of climate change for the month of November and December for average temperature. The same applies to relative humidity.

Table 7: The distribution of impact of climate change on Rainfall, Temperature and Relative Humidity

Month	**Rainfall impact**	**Temperature impact**	**Relativehumidity impact**
Mar	Above 50%	Below 50%	Below 50%
Apr	Above 50%	Below 50%	Below 50%
May	Above 50%	Below 50%	Below 50%
Jun	Above 50%	Below 50%	Below 50%
jul	Above 50%	Below 50%	Below 50%
Aug	Above 50%	Below 50%	Below 50%
Sep	Above 50%	Below 50%	Below 50%

Oct	Above 50%	Below 50%	Below 50%
Nov	Above 50%	Above 50%	Above 50%
Dec	-	Above 50%	Above 50%

4.0 Conclusion

The probability indicator function was developed to quantify the impact of climate change on the climatic condition for yam growth in south-east region of Nigeria. Rainfall climatic condition across the growth phase of yam production witnessed a low chance of occurrence indicating a negative impact (above 50%) of climate change on rainfall requirement for yam production.

Air temperature and relative humidity witnessed high chances of occurrence as a requirement for yam production across all growth phases, indicating that for now air temperature is still within air temperature requirement range for yam production in the study area. The implication is that south-east region of Nigeria has lost rainfall climate condition for Yam production.

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