PROBABILITY INDICATOR FUNCTIONS FOR ASSESSING THE IMPACT OF CLIMATE CHANGE ON THE GROWTH AND STORAGE OF CROPS IN MAKURDI, NIGERIA.

by

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Abstract

Physical evidence as well as study results based on analysis of data on climatic variables, have been used to ascertain that climate change constitute recent threats to crop production and humanity in general. Quantifying the impact of climate change most especially on the growth and storage of crops has remained a challenge. This work is a bold step towards overcoming this challenge as it seeks to assess the impact of climate change on crop growth and storage in Makurdi Metropolis, Benue State, Nigeria. Thirty seven (37) years data on daily rainfall amount (mm), maximum air temperature (^oC) and maximum relative humidity (%) for Makurdi Metropolis was used in the study. The selected crops for the study include; Yam, Rice and Pearl millet. Two Probability Indicator Functions were developed. The first, for quantifying the impact of climate change on the climatic condition for crop growth and the second for quantifying its impact on the climatic condition for crop storage, using the data on the aforementioned climatic variables. The underlying assumption is that, without the effect of climate change, there should be a 100% chance of having the climatic conditions for crop growth and storage. The Probability Indicator Functions were developed in such a way that they indicate the effect of climate change above or below 50% in accordance to whether the probability of having the climatic condition for crop growth or storage is less than or equal to 0.5 or greater than 0.5. A major conclusion of the study is that if climate change is not checked, Makurdi, Nigeria, will lose its climate for the growth and storage of Yam, Rice and Pearl Millet in the long run. This means that climate change has impacted negatively on the growth and storage of the aforementioned crops. The study recommends that; the Probability Indicator Functions should be applied to other crops grown in the area to further assess the impact of climate change on their growth and storage.

1.0 INTRODUCTION

The growing concern about climate change emphasizes the need for detailed information about the space and time of distribution of certain climatic variables. Although 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. Between the months of July and September, 2012, about thirty states in Nigeria had been affected by heavy flooding that has displaced many people and destroyed properties worth millions of naira, alongside crop damage. For which the causes of the flooding which could be natural and or manmade have not yet been established. Climate change has been established by a good number of authors to have adverse effects on crop production. Some of these works include that of Efe (2009) and Agada *et al*. (2016) who affirm that climate is the most important factor that influences agricultural production.

There are many factors that affect and influence crop growth and storage including soil, relief, climate, pests and diseases, among others. According to Ayoade (2004), agriculture largely depends on climate to function, hence, precipitation, solar radiation, wind, temperature, relative humidity and other climatic variables affect and solely determine the global distribution of crops and livestock as well as their productivity (yields). The concept of climate and agriculture has been extensively discussed. For example, Lema (1978), Oguntoyinbo (1986), Ayoade (2004) and Cicek and Turkogu (2005), have all confirmed that climatic variables are closely interrelated in their influence on crops. In fact in Nigeria, variations and changes in climatic variables can have significant impacts on agricultural production, forcing farmers to adopt new practices in response to altered conditions (Bryant, 1997).

It is therefore known that climate is one of the major elements that influence agricultural productivity; however, the extent of these is not mostly shown, a gap this study seeks to fill. Several studies on crop-climate relations have also been reported in different parts of Nigeria; Akintola ,1983, Showemimo , 2002, Tyubee, 2006 and Adamgbe 2012. The results of these studies indicate that climate effects vary among crops and regions in Nigeria Consequently, in a large country like Nigeria with different climatic regions, studies of crop-climate relations are important towards government's programs on revitalizing the agricultural sector of the economy.

An increase in the intensity of rainfall may be a potential serious risk of an increased flood frequency and severity for most regions of the world (Gordon, Whetton, Pittock, Fowler and Haylock, 1992, Fowler and Henessy, 1995). High daily rainfall may be potentially destructive to agriculture in sensitive areas that are prone to flood. This situation could compound the problem of food shortages and lead to unprecedented food price increase. Rainfall stands as one of the most unpredictable event even with updated climatic models. The extent of uncertainty varies from model to model depending on the physical phenomenon of atmospheric conditions and the complexity associated with its mathematical modeling. Statistical models contribute a great deal to reducing this uncertainty, a major reason why it is adopted in this study. This is because, analysis of these climatic variables strongly depend on distribution patterns. To gain an insight into the nature of climatic variability within the climate system, it is necessary to study its components in a systematic way. Previous studies have shown that among all the climatic elements, rainfall is the most variable element in Nigeria, both temporally and spatially and such variations can have significant impacts on economic activity (Kowal and Kanabe, 1972, Kowal and Kassam, 1978, Adefolalu, 1986). Thus in this study, emphasis is placed on rainfall, maximum air temperature and relative humidity which were analyzed in terms of changes in the statistical distribution of the respective climatic condition. It has been observed over time that the Natural Systems in general are changing and becoming more complex and unpredictable due to certain climatic factors, such that even pre-existing developed laws are no longer able to completely explain the natural hydrological phenomena. Rainfall, air temperature and relative humidity are some of the climatic variables that influence and affect plant growth and storage. These factors form the principal input to all agronomic models and some scientific models. The future probability of occurrence of rainfall and other factors if accurately assessed can be used for crop planting planning, crops and climate management decisions, and the risk due to weather uncertainty can be reduced (Priyaranjan, 2012).

The work of Agada, Imande and Ahmedu (2018), is a work in this direction specifically for Makurdi, Nigeria. The authors developed two (2) Functional Statistical Indicators of climate change for Makurdi Metropolis using data on three climatic variables namely; rainfall, air temperature and relative humidity. They concluded that climate change is fast setting into Makurdi with the evidence of the climate becoming warmer and drier.

Furthermore, the authors discussed the implication of their result to crop production in the area using existing literature as supportive evidence. They did not statistically assess or quantify the impact of climate change on the growth and storage of crops in the area, but only discussed the implication of their result to crop production based on literature as earlier mentioned.

This work is an extension of the work of Agada *et al*., (2018), to the assessment or quantification of climate change impact specifically on the chance of occurrence of the climatic conditions for the growth and storage of crops in Makurdi, Nigeria.

We assume in this work that without the effect of climate change, the area should continue to record very high chances (possibly with probability 1) of occurrence of the climatic conditions for growth and storage of crops. Otherwise, very low chances should be recorded. This work proceeds to develop Two (2) Probability Indicator Functions, one for assessing the impact of climate change on the climatic conditions for crop growth in respect of each climatic variable (rainfall, air temperature and relative humidity). And the other for assessing the impact of climate change on the climatic conditions for crop storage in respect of the aforementioned variable. The rest of the paper is organized as follows; methodology, result and discussion, conclusion and recommendation.

2.0 Methodology

2.1 Source and Nature of Data

The secondary data employed in this work is sourced from the Nigerian Meteorological Agency Headquarters, Tactical Air command, Makurdi-Airport Benue state. The data is a climatic data on rainfall amount (mm), maximum air temperature (^{0}c) and relative humidity (%), for Makurdi metropolis for a period of 37 years (1980-2016).

2.2 Data Transformation

The Specific crops used in this work have certain climate requirements for growth and storage. The climatic condition for yam growth shows that yam requires an annual rainfall amount of 1035-1500mm within a growing phase of 7-9 months. However, in-order to obtain a mean monthly rainfall amount for this growth phases, the annual rainfall amount would be evenly distributed across these growth phases as shown below;

Let the random variable X represent rainfall amount, then the annual climatic condition for yam in millimeters would be;

$$1035 \leq X \leq 1500 \qquad (1)$$

for the respective growth phases of 7,8 and 9 months, we would have mean monthly rainfall amount of;

$$\frac{1035}{7} \leq \overline{X} \leq \frac{1500}{7} \qquad (2)$$

$$\frac{1035}{8} \leq \overline{X} \leq \frac{1500}{8} \qquad (3)$$

$$\frac{1035}{9} \leq \overline{X} \leq \frac{1500}{9} \qquad (4)$$

For Pearl Millet with a single growth phase of 3 months and an annual rainfall amount of 350-500mm, we would have a mean monthly rainfall amount of;

$$\frac{350}{3} \leq \overline{X} \leq \frac{500}{3} \qquad (5)$$

where $\overline{X}$ is the mean monthly rainfall amount.

This transformation is not required for rice, since its climatic condition for rainfall is presented monthly in literature. Furthermore, data transformation would not be required for crop storage in respect of temperature and relative humidity for the same reason.

2.3 Distribution Fit

The following probability distributions fit the data for each climatic variable used in this work. This include the exponential distribution (for rainfall amount in the month of March), the gamma distribution (for rainfall amount in the months of April - October). For temperature, we have the normal distribution for the months of January - December and finally for that of relative humidity, we have the gamma distribution for the months of January, February, March and November.

2.3.1 Fitting Distribution using the Anderson-Darling test statistic

In this work, the Anderson-Darling test statistic would be employed in fitting the aforementioned probability distributions into the data for each climatic variable. It is used to test if a sample of data comes from a population with a specific distribution. Anderson makes use of the specific distribution in calculating critical values.

The Anderson-Darling test statistic is defined as;

$$A^2 = -N - 1/N \sum_{i=1}^{N}(2i-1)\left[\ln F(x_i) + \ln\left(1 - F(x_{N-i+1})\right)\right] \qquad (6)$$

where N= Sample size, F= cumulative distribution of the specified distribution and x_i = the ordered data. The critical values are dependent on the specific distribution that is been tested.

Anderson-Darling test is a goodness-of-fit test and its hypothesis is given as;

H_0: The data follows a specified distribution.

H_1: The data does not follow the specified distribution.

The critical values are obtained for the specific distribution at a given $\propto$ level of significance. The test is a one-sided test and the hypothesis that the distribution has a specific form is rejected if the test statistic A is greater than the critical value. The MINITAB statistical software (version 17) was used to implement this test.

2.4 Mathematical details of the Probability Distributions

Presented below are the mathematical details of the probability models that are employed for this work.

2.4.1 Exponential Distribution

A continuous random variable x is said to follow an exponential distribution with parameter $\lambda > 0$,if its probability density function (p.d.f) is given by;

$$f(x) = \begin{cases} \lambda e^{-\lambda x} \\ 0 \end{cases}, x > 0 \qquad (7)$$

The cumulative probability density function (CDF) for $x > 0$ is given by;

$$F(X) = P(X \leq x) = \int_0^x f(x)dx \qquad (8)$$

The mean for an exponential distribution is given by;

$E[X] = \frac{1}{\lambda}$ and Variance $\frac{1}{\lambda^2}$.

2.4.2 Gamma Distribution

In this study, we employed the gamma distribution for the analysis of rainfall amount to

obtain the probabilities of rainfall occurrence and that of relative humidity.
A continuous random variable X is said to have a distribution with parameters α>0 and λ>0, if its probability density function (p.d.f) is given by;

$$f(x) = \frac{(x/\beta)^{\alpha-1} e^{-x/\beta}\ )}{\beta\Gamma(\alpha)} \qquad (9)$$

$$\Gamma(\alpha) = \int_0^\infty e^{-t} t^{\alpha-1} \partial t \qquad (10)$$

where α > 0 is the shape parameter and β > 0 is the scale parameter.

2.4.3 Normal Distribution

This distribution has a bell-shaped density curve described by its mean (μ) and standard deviation (σ). It is a stable distribution and the most common type of distribution.
A continuous random variable x is said to follow a normal distribution if the probability density function (p.d.f) is defined as:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left\{-1/2\left(\frac{x-\mu}{\sigma}\right)^2\right\} \qquad (11)$$

$$f(x) = \left(\frac{e^{-x^2/2}}{\sigma\sqrt{2\pi}}\right) \qquad (12)$$

For $-\infty < x < \infty$, $-\infty < \mu < \infty$, and $0<\sigma<\infty$

The mean of x = μ and the variance of x =σ^2,then we say X$\sim N(\mu, \sigma^2)$.
The case where μ=0 and σ=1, it is called a standard normal distribution and this is given by equation (12) above.

2.5 Chance of occurrence of Climatic Conditions

The chance of occurrence of the climate conditions for growth and storage of each crop would be computed using the probability distributions.
For yam, the chance of occurrence of the mean monthly rainfall amount for each of the growth phase is given by;

$$P\left(\frac{1035}{7} \le \overline{X} \le \frac{1500}{7}\right) \qquad (13)$$

$$P\left(\frac{1035}{8} \le \overline{X} \le \frac{1500}{8}\right) \qquad (14)$$

$$P\left(\frac{1035}{9} \le \overline{X} \le \frac{1500}{9}\right) \qquad (15)$$

where $\overline{X}$ is the mean monthly rainfall amount.
Using the probability density function f(x) for the fitted rainfall distribution, the chance of occurrence in the equations (13, 14 and 15) above can be computed using;

$$P\ (x_1 \le X \le x_2) = \int_{x_1}^{x_2} f(x)\partial x \qquad (16)$$

The equation (16) would also be used to compute the chance of occurrence for Pearl Millet using its climatic condition, $\frac{350}{3} \le \overline{X} \le \frac{500}{3}$ for mean monthly rainfall amount.

Similarly, the chance of occurrence of the climatic condition in respect to mean monthly air temperature for growth and storage of each crop would be computed using their respective condition and equation (16). These chances are stated as follows;

For yam growth and storage, we have;

P ($25°C \leq T \leq 30°C$) and P ($12°C \leq T \leq 16°C$) respectively.

For the growth and storage of pearl millet, we have;

P ($23°C \leq T \leq 30°C$) and P ($20°C \leq T \leq 25°C$) respectively.

And for rice growth and storage, we have;

P ($27°C \leq T \leq 35°C$) and P ($20°C \leq T \leq 28°C$) respectively

where T represents mean monthly air temperature.

The chance of occurrence of the climatic condition in respect to the mean monthly relative humidity (RH) for storage of each crop would be computed using equation (16) and their respective climatic conditions. They are;

P ($70\% \leq R_H \leq 91\%$), P ($86\% \leq R_H \leq 91\%$) and P ($60\% \leq R_H \leq 80\%$) respectively for yam, pearl millet and rice.

Where R_H represents the mean monthly relative humidity.

The chance of occurrence of the climatic conditions for each crop was computed using R-software (version 3.2.3), while the Microsoft Excel package was used for graphical illustrations.

2.6 Probability Indicator Functions

Two probability indicator functions are presented in this section. The function is for measuring the impact of climate change on the climatic condition for crop growth and the other for measuring its impact on the climatic condition for crop storage.

2.6.1 Probability Indicator Function for measuring the impact of climate change on crop growth

$$I_G[P(C_G)] = \begin{cases} 50\% \; and \; above, & if \; P(C_G) \leq 0.5 \\ Below \; 50\%, & if \; P(C_G) > 0.5 \end{cases}$$

Where $C_G =$ the climatic condition for crop growth in respect of the climatic parameter in question (i.e, rainfall, air temperature and relative humidity),

$P(C_G) =$ the chance of occurrence of the climatic condition for crop growth and,

$I_G[P(C_G)] =$ the Probability Indicator Function for measuring the impact of climate change on crop growth.

2.6.2 Probability Indicator Function for measuring the impact of climate change on crop storage

$$I_S[P(C_S)] = \begin{cases} 50\% \; and \; above, & if \; P(C_S) \leq 0.5 \\ Below \; 50\%, & if \; P(C_S) > 0.5 \end{cases}$$

Where $C_S =$ the climatic condition for crop storage in respect of the climatic parameter in question (i.e, rainfall, air temperature and relative humidity),

$P(C_S) =$ the chance of occurrence of the climatic condition for crop storage in respect of the climatic parameter in question and,

$I_S[P(C_S)] =$ the Probability Indicator Function for measuring the impact of climate change on crop storage.

3.0 RESULT AND DISCUSSION

3.1 Discussion on the Distribution Fit

The distribution fit to data on monthly rainfall, air temperature and relative humidity were done using Anderson Darling test statistic on the Minitab Statistical platform. For the monthly rainfall amount, the months of January, February, November and December do not fit any known distribution. The month of March fit the exponential distribution, while the months of April to October fit the Gamma distribution ($p > 0.01$). See table 1 for details of the distribution fit. For the monthly temperature data, the months of July and August do not fit any known distribution while the rest month of the year fit the gamma distribution ($p > 0.01$) See table 2 for details. The monthly data on relative humidity only fit the January, February, March and November data ($p > 0.01$). See table 3 for distributional details.

Table 1: Summary of goodness of fit test for rainfall

Months	Distribution	Parameters	Value of Test Statistic	P-Value
Jan	-	-	-	-
Feb	-	-	-	-
March	Exponential	Mean=28.40 Lamda=0.0352	AD=1.095	0.087
April	Gamma	$\propto$=2.071 β=27.18	AD=0.0420	0.0250
May	Gamma	$\propto$=5.082 β=27.18	AD = 0.688	0.079
June	Gamma	$\propto$=3.415 β=47.80	AD = 0.524	0.205
July	Gamma	$\propto$=5.369 β=34.89	AD = 0.433	0.250
August	Gamma	$\propto$=7.553 β=30.92	AD = 287	0.250
September	Gamma	$\propto$=2.328 β=232.2	AD= 0.605	0.112
October	Gamma	$\propto$=2.342 β=50.51	AD = 1.105	0.010
November	-	-	-	-
December	-	-	-	-

NB: '-' means that rainfall data for the months of January, February, November and December do not fit any known distribution. $\alpha = 0.01$

Table 2: Summary of goodness of fit test for temperature

Months	Distribution	Parameters	Value of Test Statistic	P-Value
Jan	Normal	Mean = 27.02 SD = 1.146	AD = 0.407	0.333
Feb	Normal	Mean = 29.77 SD = 1.218	AD = 0.192	0.890
March	Normal	Mean = 31.40 SD = 0.7024	AD = 0.424	0.303
April	Normal	Mean = 30.47	AD = 0.286	0.606

		SD = 1.065		
May	Normal	Mean = 28.52 SD = 0.9043	AD = 396	0.354
June	Normal	Mean = 27.14 SD = 0.5049	AD = 588	0.119
July	-	-	-	-
August	-	-	-	-
September	Normal	Mean = 26.58 SD = 0.3861	AD = 0.456	0.252
October	Normal	Mean = 27.33 SD = 0.3861	AD = 0352	0.449
November	Normal	Mean = 27.39 SD = 0.8682	AD = 0.441	0.275
December	Normal	Mean = 25.96 SD = 0.8440	AD = 0.248	0.732

NB: '-' means that temperature data for the months of July and August do not fit any known distribution. $\alpha = 0.01$

Table 3: Summary of goodness of fit test for Relative Humidity

Months	Distribution	Parameters	Value of Test Statistic	P-Value
Jan	Gamma	∝=13.19 β=2.871	AD = 0.218	0.250
Feb	Gamma	∝=11.46 β=2.871	AD = 0.401	0.250
March	Gamma	∝=22.82 β=2.229	AD = 0.434	0.250
April	-	-	-	-
May	-	-	-	-
June	-	-	-	-
July	-	-	-	-
August	-	-	-	-
September	-	-	-	-
October	-	-	-	-
November	Gamma	∝=52.09 β=1.168	AD = 0.709	0.068
December	-	-	-	-

NB: '-' means that relative humidity data for the months of April to October and December do not fit any known distribution. $\alpha = 0.01$

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

Growth months	Dist.	Parameters	$P\left(\frac{1035}{7} \leq R_F \leq \frac{1500}{7}\right)$	$P\left(\frac{1035}{8} \leq R_F \leq \frac{1500}{8}\right)$	$P\left(\frac{1035}{9} \leq R_F \leq \frac{1500}{9}\right)$
April	Gamma	∝=2.071 β=39.62	0.09103688	0.1198228	0.14449394

May	Gamma	$\propto$=5.082 β=27.18	0.2680059	0.3066674	0.3189300
June	Gamma	$\propto$=3.415 β= 47.80	0.2581084	0.2611298	0.2516965
July	Gamma	$\propto$=5.369 β=34.89	0.3259500	0.3034477	0.2672015
August	Gamma	$\propto$=7.553 β=30.92	0.3071628	0.2350098	0.1724625
Sept	Gamma	$\propto$=2.328 β=232.2	0.07898193	0.06384716	0.05238879
Oct	Gamma	$\propto$=2.342 β=50.51	0.1725036	0.1955560	0.2089935

3.2 Discussion on the formulation of the Probability Indicator Functions

As earlier mentioned, two probability indicator functions were formulated. One, for quantifying the impact of climate change on the climatic condition for crop growth and the other, for quantifying its impact on the climatic condition for crop storage. See sections 2.7.1 and 2.7.2.

It is important to mention that climate change has been assessed by previous works in the city of Makurdi using Anomaly. Anomaly is the deviation of a climatic parameter (observation) from the mean (ground mean) value. This deviation can be positive (positive anomaly) or negative (negative anomaly).The works include those of Agada *et al.*, (2016), Agada *et al.*, (2017), in Makurdi Nigeria.

A critical look at these works shows that the effect of climate change has been assessed to have placed the value of the climatic parameter above or below the mean value. This assessment informed the researchers in developing the probability indicator functions in such a way that they indicate the effect of climate change above or below 50%. This is in accordance to whether the probability of having the climatic condition for crop growth or storage is less than or equal to 0.5 or greater than 0.5. The mean value of the climatic parameter adopted by previous work in assessing the impact of climate change, correspond to the 0.5 (50%) chance of occurrence of the climatic condition for crop growth or storage adopted in this work.

However, it must be ascertained that there is an evidence of climate change impact before its quantification or assessment. Agada et al. (2018) successfully ascertained that climate change has set into Makurdi metropolis with the evidence of the climate becoming warmer and drier. This informed the aim of this work; an extension of the work of Agada et al.(2018), to include the quantification and assessment of the impact of climate change, on the growth and storage of some crops produced in the area.

3.3 Discussion on the chance of occurrence of the climatic condition for crop growth and storage as well as the impact of climate change.

For Yam, the chance of occurrence of the rainfall condition for growth, for the 7, 8 and 9 months growth phases is captured in table 4 below, for the months of April to October. Observe on this table the low chances of occurrence. In fact all the chances are below 0.5 (i.e 50%), showing that there are no high chances of occurrence of this climatic condition in each month. 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 growth (i.e 50% and above). 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 16 below.

Table 16 : The distribution of the impact of climate change on the Rainfall condition for Yam across growth phases

Growth months	Impact of climate Change for the seven months growth phase	Impact of climate Change for the eight months growth phase	Impact of climate Change for the nine months growth phase
April	Above 50%	Above 50%	Above 50%
May	Above 50%	Above 50%	Above 50%
June	Above 50%	Above 50%	Above 50%
July	Above 50%	Above 50%	Above 50%
August	Above 50%	Above 50%	Above 50%
Sept	Above 50%	Above 50%	Above 50%
Oct	Above 50%	Above 50%	Above 50%

The chance of occurrence of the air temperature condition for Yam growth are very high (above 0.5) for the months of May, June, September and October but below 0.5 in the month of April. The indicator function therefore quantify the impact of climate change to be below 50% in the months of May, June, September and October but above 50% in the month of April. See table 5.

Table 5: The distribution of the chance of occurrence of the Temperature condition for Yam growth

Growth months	Distribution	Parameters	$P(25^{o}C \leq T \leq 30^{o}C)$	Impact of climate change
April	Normal	Mean = 30.47 SD = 1.065	0.3294925	Above 50%
May	Normal	Mean = 28.52 SD = 0.9043	0.949096	Below 50 %
June	Normal	Mean = 27.14	0.9999096	Below 50 %
July	-	-	-	-
Aug	-	-	-	-
Sept	Normal	Mean = 26.58 SD = 0.3861	0.9999786	Below 50 %
Oct	Normal	Mean = 27.33 SD = 5344	0.9999932	Below 50 %
December		-	-	-

NB: '-' means that air temperature data for the months of July and August do not fit any known distribution.

Though in most of the growth months, there is a below 50% impact of climate change on the climatic condition for crop growth in respect of air temperature, and an above 50% impact of climate change in respect of rainfall in all the growth months, Yam growth will still be affected by climate change since the climatic condition for rainfall is affected. This is because; the crop will not thrive with low rainfall. See table 6.

Table 6: The distribution of the chance of occurrence of the Temperature condition for Yam storage

Storage	Distribution	Parameters	$P(12^{o}c \leq T \leq 16^{o}c)$	Impact of climate change

Months				
Nov	Normal	Mean = 27.39 SD = 0.8682	$1.279834e^{-39}$	Above 50%
Dec	Normal	Mean = 25.96 SD = 0.8440	$1.929697\ e^{-32}$	Above 50%
Jan	Normal	Mean = 27.02 SD = 1.218	$3.420195\ e^{-22}$	Above 50%
Feb	Normal	Mean = 29.77 SD = 1.218	$6.198214\ e^{-30}$	Above 50%
March	Normal	Mean = 31.40 SD = 0.7024	$7.530115\ e^{-107}$	Above 50%

For Yam storage, the chance for air temperature condition are all very low (below 50%) showing that climate change impacted above 50% in the storage months (November, December, January, February and March). The relative humidity condition for Yam storage, reveal a similar situation. There is a below 0.5 chance of occurrence across the storage months indicating above 50% impact of climate change. See table 7 below. This translates into the fact that if climate change is not checked, the city of Makurdi, Nigeria will lose storage conditions for Yam resulting into post harvest loses.

Table 7: The distribution of the chance of occurrence of the Relative Humidity condition for Yam storage

Storage months	**Distribution**	**Parameters**	**P (70%$\leq R_H \leq$ 91%)**	**Impact of climate change**
November	Gamma	$\propto$=52.09 β=1.168	0.1224362	Above 50%
December	-	-	-	-
January	Gamma	$\propto$=13.19 β=2.871	0.004337759	Above 50%
February	Gamma	$\propto$=11.46 β=3.532	0.01288292	Above 50%
March	Gamma	$\propto$=22.52 β=2.229	0.3853417	Above 50%
December	-	-	-	-

NB: '-' means that relative humidity data for the month of December did not fit any known distribution.

For Rice growth, table 8 shows that the climatic condition in respect of rainfall has a below 0.5 chance of occurrence across the growth months. This means that climate change has impacted above 50% across these months. The climatic condition for Rice growth in respect of air temperature, reveal a below 0.5 chance of occurrence in the months of June, October and November and an above 50% chance of occurrence in the month of September. This means that climate change has impacted above 50% in the months of June, October and November but impacted below 50% in the month of September. See table 9.

Table 8: The distribution of the chance of occurrence of the Rainfall condition for Rice growth and the impact of climate change

Growth months	Distribution	Parameters	P ($100 \leq R_F \leq 200$)	Impact of climate change
June	Gamma	∝=3.415 β=47.80	0.4565796	Above 50%
July	Gamma	∝=5.369 β=34.89	0.4949854	Above 50%
August	Gamma	∝=7.553 β=34.89	0.3572965	Above 50%
September	Gamma	∝=2.328 β=232.2	0.1047787	Above 50%
October	Gamma	∝=2.342 β=50.51	0.3732523	Above 50%
November	-	-	-	
December		-	-	- -

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

Table 9: The distribution of the chance of occurrence of the Temperature condition for Rice growth

	Distribution	Parameters	P($27^0c \leq T \leq 32^0c$)	Impact of climate change
June	Normal	Mean = 27.14 SD = 0.5049	0.6092185	Below 50%
July	-	-	-	-
August	-	-	-	-
September	Normal	Mean = 26.58 SD = 0.3861	0.1383415	Above 50%
October	Normal	Mean = 27.33 SD = 0.5344	0.7315524	Below 50%
November	Normal	Mean = 27.39 SD = 0.8682	0.6733581	Below 50%
December	-	-	-	-

NB: '-' means that temperature data for the months of July- August, November and December do not fit any known distribution.

From this analysis, one will deduce that Makurdi climatic condition in respect of rainfall will not support Rice growth in each of the growth month. Also, it will not support growth in respect of temperature in the month of September but will support it in the months of June, October and November because of the below 50% impact of climate change. The requirement of rainfall for Rice growth is as important as the air temperature requirement. Hence it can be inferred that, the city will eventually lost its climatic requirement for Rice growth if climate change is not checked.

For Rice storage, the climatic conditions in respect of air temperature and relative humidity reveal a far below 0.5 chance of occurrence in the storage months considered. This translates into above 50% impact of climate change in these months. See tables 10 and 11 below. It becomes certain that farmers should prepare for post harvest loses if climate change is not checked.

Table 10: The distribution of the chance of occurrence of the Temperature condition for Rice storage and the impact of climate change

Storage months	Distribution	Parameters	P (10^0F $\leq$ T $\leq$ 15^0 F)	Impact of climate change
December	Normal	Mean = 25.96 SD = 0.8440	7.366284 e $^{-39}$	Above 50%
January	Normal	Mean = 27.02 SD = 1.146	4.87019 e $^{-26}$	Above 50%
February	Normal	Mean = 29.77 SD = 1.218	3.825326 e $^{-34}$	Above 50%
March	Normal	Mean = 31.40 SD = 0.7024	7.133628 e $^{-12v}$	Above 50%
April	Normal	Mean = 30.47 SD = 1.0653	3.139619 e $^{-42}$	Above 50%
May	Normal	Mean = 28.52 SD = 0.9043	7.695544 e $^{-51}$	Above 50%
June	Normal	Mean = 27.14 SD = 0.5049	4.780671 e $^{-128}$	Above 50%

Table 11: The distribution of the chance of occurrence of the Relative Humidity condition for Rice storage and the impact of climate change

Storage months	Distribution	Parameters	P (60% $\leq R_H \leq$ 80%)	Impact of climate change
December	-	-	-	-
January	Gamma	∝=13.19 β=2.871	0.02811169	Above 50%
February	Gamma	∝=11.46 β=3.532	0.06056914	Above 50%
March	Gamma	∝=22.82 β=2.229	0.1813409	Above 50%
April	-	-	-	-
May	-	-	-	-
June	-	-	-	-

NB: '-' means that relative humidity data for the months of April – June and December do not fit any known distribution.

For the growth of Pearl Millet in the area, table 12 below shows a below 0.5 chance of occurrence of the climatic condition in respect of rainfall in the growth months. This means that climate change impacted above 50%. In table 13, the result shows that the climatic condition in respect of air temperature also have below 0.5 chance of occurrence in the month of June. No result for other growth months (July and August) since no known distribution fit the temperature data for these months to the best of our knowledge). It can be inferred that climate change impacted above 50% in respect of air temperature. This result when combined with that of rainfall as discussed above shows that Pearl Millet will not continue to thrive in Makurdi if climate change is not checked.

Table 12: The distribution of the chance of occurrence of the Rainfall condition for the growth of Pearl Millet and the impact of climate change

Growth months	Distribution	Parameters	P ($\frac{350}{3} \leq R_F \leq \frac{500}{3}$)	Impact of climate change
June	Gamma	∝=3.415 β=2.47.80	0.2430478	Above 50%
July	Gamma	∝=5.369 β=34.89	0.259507	Above 50%
August	Gamma	∝=7.553 β=30.92	0.168938	Above 50%

Table 13: The distribution of the chance of occurrence of the Temperature condition for the growth of Pearl Millet and the impact of climate change

Growth months	Distribution	Parameters	P ($23^0c \leq T \leq 30^0c$)	Impact of climate change
June	Normal	Mean = 27.14 SD = 0.5049	1.00	Below 50%
July	-	-	-	-
Aug	-	-	-	-

NB: '-' means that air temperature data for the months of July and August do not fit any known distribution.

For the storage of Pearl Millet, the situation is similar with that of Rice. The climatic conditions in respect of air temperature and relative humidity reveal a far below 0.5 chance of occurrence in the storage months considered. This translates into far above 50% impact of climate change in these months. See tables 14 and 15 below.

Table 14: The distribution of the chance of occurrence of the Temperature condition for the storage of Pearl Millet and the impact of climate change

Storage months	Distribution	Parameters	P ($20^0c \leq T \leq 25^0c$)	Impact of climate change
October	Normal	Mean = 27.33 SD = 0.5344	6.502232 e $^{-06}$	Above 50%
November	Normal	Mean = 27.39 SD = 0.8682	0.002954201	Above 50%
December	Normal	Mean = 25.96 SD = 0.8682	0.127677	Above 50%

January	Normal	Mean = 27.02 SD = 1.146	0.03897954	Above 50%
February	Normal	Mean = 29.77 SD = 1.218	4.496735 e^{-20}	Above 50%
March	Normal	Mean = 31.40 SD = 0.7024	4.058144 e^{-20}	Above 50%
April	Normal	Mean = 30.47 SD = 1.065	1.402118 e^{-07}	Above 50%
May	Normal	Mean = 28.52 SD = 0.9043	4.960548 e^{-05}	Above 50%
June	Normal	Mean = 27.14 SD = 0.5049	1.125276 e^{-05}	Above 50%

Table 15: The distribution of the chance of occurrence of the Relative Humidity condition for the storage of Pearl Millet and the impact of climate change

NB: '-' means that relative humidity data for the months of April – June, October and

Storage months	Distribution	Parameters	P ($60\% \leq R_H \leq 80\%$)	Impact of climate change
October	-	-	-	
November	Gamma	∝=52.09 β=1.168	0.002724032	Above 50%
December	-	-	-	
January	Gamma	∝=13.19 β=2.871	0.0001358801	Above 50%
February	Gamma	∝=11.46 β=3.532	0.0007576118	Above 50%
March	Gamma	∝=22.82 β=2.229	0.0015988100	Above 50%
April	-	-	-	-
May	-	-	-	-
June	-	-	-	-

December do not fit any known distribution.

Overall, the analysis revealed that if climate change is not checked, Makurdi will lose its climate for the growth and storage of Yam, Rice and Pearl Millet on the long run.

4.0 Conclusion and Recommendation

4.1 Conclusion

The following conclusions were drawn from this study;

(i) Two probability indicator functions have been developed. The first, for quantifying the impact of climate change on the climatic condition for crop growth and the second for quantifying its impact on the climatic condition for crop storage.

(ii) The probability indicator functions were successfully applied in assessing the impact of climate change on the growth and storage conditions for Yam, Rice and Pearl Millet in the city of Makurdi, Nigeria.

The assessment is that; if climate change is not checked, the city of Makurdi will lose its climate for the growth and storage of Yam, Rice and Pearl Millet. Hence, farmers should prepare for low yield as well as post harvest losses on the long run.

4.2 Recommendations

The following recommendations were made in this study;

(i) The probability indicator functions should be applied to other crops grown in the area to further assess the impact of climate change.

(ii) When no known probability distribution fit the data on climatic variables, empirical distributions should be used via the simulation methodology, in developing climate impact quantifying indicators .

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