CLIMATE CHANGE IMPLICATIONS FOR AGRICULTURAL SUSTAINABILITY IN ENUGU IN THE GUINEA SAVANNA ECO-CLIMATIC ZONE OF SOUTHEASTERN NIGERIA: INPUT FROM CLIMATE CHANGE PROXIES

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ABSTRACT: Climate change poses debilitating effects for agriculture and food security in low technology countries such as sub-Saharan Africa. The trends and variations of some climatic variables that influence agriculture were analysed using integrated statistical techniques. The aim is to examine the possible effects of climate change on agricultural sustainability in Enugu, southeastern Nigeria using lessons drawn from trend analysis of historical time series of meteorological variables in monthly time step in the area. The area whose economy is largely agrigarian has continued to witness incidence of poor crop productivity. Significant long-term trends were identified in some of the variables and non-significant trends in others. Inferences were made with considerable support of evidence and high degree of confidence. The climate of the area is changing in a manner that concern for agricultural sustainability is on the front burner of the long-term resulting consequences. The need for pre-season and on-season climate information dissemination system is advocated to provide timely and accurate agro-meteorological information.

KEY WORDS: Climate change, Agricultural sustainability, Climatic parameters, Trends, Statistical techniques, Enugu, Nigeria.

INTRODUCTION

Climate change as defined by the Intergovernmental Panel on Climate Change (IPCC) (2007) is "the change in the state of climate that can be identified (e.g. by statistical tools) by changes in its mean or the variability of its properties" and that persists for a long time (usually decades or longer). Parry *et al* (2007) referred to climate change as "change in the climate which is caused directly or indirectly by human activities that cause an alteration in the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable periods". Variation in climate parameters whether induced by humans or natural forcing can bring about changes in the likelihood of the occurrence or strength of extreme weather events and their resulting deleterious effects.

Climate change has varying debilitating effects on agricultural, environmental and socio-economic activities. The negative effects have been predicted to have more adverse impacts on countries with low-technology base and low level of coping capability such as sub-Saharan Africa. These countries belong to the less developed or developing economies, characterized by low living standards and heavy reliance on agriculture and related sectors that are weather sensitive, rather than the manufacturing of industrial products.

Climate change proxies are climate change indicators, the parameters which drive weather and climate. Climate research aims at developing and understanding the causes of climate change and extent to which human activities and a spectrum of environmental phenomena are climate-sensitive. In this regard, climatological information is applied to the benefit of the human society. Climate sensitivity analyses provide the basis for assessing the potential consequences of natural or human- driven climate change and variability.

The earth's atmosphere plays a central role in energy transfers between the sun and the surface of the planets and from one region of space to another. The maintenance of thermal equilibrium and the determination of the planet's climate are based on these transfers. The uniqueness of the earth's atmosphere is its close relationship with the oceans and surface phenomena, which in conjunction with the atmosphere form the basis of life. As the atmosphere is a fluid system, it has the capability to support a wide variety of motions or circulations of different dimensions. Such circulations influence many other atmospheric components such as air re-arrangement, water vapour and clouds which figure significantly in radiative and chemical phenomena. In this way, atmospheric circulation is an essential ingredient in the world energy budget.

Describing the mean state or spatio-temporal variation of the atmosphere at a location usually involves the use of a number of statistical descriptors in terms of how hot or cold, wet or dry, windy or calm, sunny or cloudy etc with respect to the atmosphere, using climatic parameters such as temperature, rainfall, wind speed, sunshine hours, solar radiation, relative humidity (moisture), cloud cover, pressure etc. These climatic elements do not operate in the atmosphere independently of one another since changes in one parameter usually induce changes in the others. Tuller (2004) observed that the real effects of trends and variations do not entail a single parameter but are combined result of multiple parameters working in synergy. It is this interactive nature of the climatic variables that produce the climate experienced at any point in space and time.

The invigorated quest for sustainable development is being hampered by the negative effects of climate change especially in sub-Saharan Africa where agriculture is mainly driven by rainfall and other climatic factors. In this study, the aim is to assess the probable effects of climate change on agricultural sustainability in Enugu in the Guinea savanna agro-ecological zone of Nigeria using climate change indices. Climate information is important to agriculture and related sectors. With the current trends and challenges of climate change and its obvious implications for agro-meteorological applications, there is the apt and timely need to assess the trends and variations of climatic element because of their link with agricultural productivity.

Food and Agricultural Organization (FAO) (1989) defined sustainable agriculture as the effective management of resources for agriculture to satisfy present human needs without compromising the future quality of the environment and natural resources. Keaney (1989) in Nwaiwu *et al* (2014) defined sustainable agriculture as agricultural activities that are environmentally friendly, profitable and productive in tandem with maintaining the social fabric of the rural community. Rural communities dependent on economic systems driven

Print ISSN: 2059-2396, Online ISSN: 2059-240X

by weather and climate are exposed to climate change and variability associated risks. In Nigeria, agriculture has subsistence orientation and predominantly rain- driven. Agriculture and food security are crucially dependent on the sufficient amount of water and conducive climate required for crops and livestock to thrive.

Many studies have been carried out in respect of climate change impacts on agriculture and food security in Nigeria using different parameters and a spectrum of techniques over various time scales. Nwaiwu *et al* (2014) investigated climate change effects on agricultural sustainability in southeastern tropical rain forest zone of Nigeria based on data from Umudike for forty years (1972-2011). They observed low food production as a result of climate change, adding that rainfall and temperature are significantly related to agricultural sustainability. In their study, Nwajiuba and Onyeneke (2010) focused on the climate change effects on the agriculture of sub-Saharan Africa using the results drawn from the south eastern rain forest zone of Nigeria featuring Abia, Anambra, Imo and Ebonyi States for a period of thirty years (1978-2007). They identified a statistical significant relationship between climate parameters and crop production in the region.

Afangideh *et al* (2010) studied the preliminary investigation into the annual rainfall trends and patterns in parts of south eastern Nigeria comprising Calabar, Uyo and Umuahia for a period of thirty-five years (1991-2006). Enete and Amusa (2010) examined the challenges of agricultural adaptation to climate change in Nigeria using lessons drawn from the literature. Furthermore, Udo-Inyang and Edem (2012) analysed rainfall trends in Akwa Ibom State Nigeria with a crop yield orientation and found a gradual decline in rainfall from coastal to inland areas. Again, Obot *et al* (2011) characterized rainfall trends in Abeokuta Nigeria for twenty-two years and found that Abeokuta rainfall regime was stable and favoured agricultural sustainability. Similar studies abound such as Amadi and Chigbu (2014), Amadi *et al* (2014a, 2014b, 2014c), Enete and Ebenebe (2009), Malhi and Wright (2004), Ewona *et al* (2014), Ogolo and Adeyemi (2009), Obot *et al* (2010), Omogbai (2010), Akinsanola and Ogunjobi (2014), Oyewole *et al* (2014) and Umoh *et al* (2013) *etc*. Enugu has not received adequate attention, hence the justification of this study. In this study, a holistic approach is presented using multiple parameters to incorporate the interactive nature of the atmosphere and a variety of data analysis tools to provide an integrated approach to the analysis.

Study Area

Enugu is the capital of the present Enugu State of Nigeria. It coordinates on latitude 6.28^{o}N and longitude 7.34^{o}E and an altitude of 137m above mean sea level. Enugu State is located in the Guinea savanna eco- climatic zone of Nigeria with tropical wet and dry climate. The climatic zone is characterized by trees that form a rich mixture of grass species and legumes. This climate exhibits well marked rainy and dry seasons. The rainy season is sometimes marked with a single maximum known as summer maximum and sometimes with a bi-modal maximum usually within June to September. Temperatures are above 20^{o}C throughout the year and a small range of temperature prevails. The annual rainfall totals are predominantly between 1300mm to 2000mm, although it lies outside this range in years of extreme rainfall and drought events. The rainy season is prevalent from April to October while the dry season extends from November to March. Sometimes during the summer monsoon (usually in August), there is a record of little dry season (LDS) during which low rainfall amounts are recorded and short dry spell is experienced. This is connected with the

Print ISSN: 2059-2396, Online ISSN: 2059-240X

northern excursion of the Inter Tropical Convergence Zone (ITCZ) which is in its most northern station during the period giving more rain to the north and anomalous dryness in the south (Barry and Chorley, 1992). The relative humidity distribution strongly follows the rainfall pattern and peaks during the summer monsoon, exceeding 80%. During December to February, the climate is dominated by north east trade winds called harmattan in the local parlance (though not peculiar to this zone) which originates from the Sub-Tropical Anticyclones (STA). This harmattan is usually associated with occurrence of thick dust haze and early morning fog and mist as a result of radiation cooling at night under clear sky conditions. Figure 1 is the map of Nigeria showing the location of the study area.

DATA AND METHODOLOGY

Data

The data for the study were accessed from the Nigerian Meteorological Agency, Oshodi, Lagos and spanned 63 years. The data were sourced as mean daily monthly values of the parameters except rainfall that comprise monthly rainfall totals. Table 1 gives the parameters along with their summary information.

Table1: Information on the meteorological parameters used in the study.

Climatic parameters	Period (years)	Sequence length (months)	% Missing records
Rainfall totals	1950-2012	734	2.91
Maximum air temperature	1950-2012	756	0.00
Minimum air temperature	1950-2012	756	0.00
Sunshine duration	1961-2012	588	5.77
Relative humidity	1961-2012	528	15.38
Wind speed	1961-2012	588	5.77

Methodology

Data Quality Check and Database Construction

The monthly data were checked for missing observations and outliers. Missing observations were detected but were not replaced. The missing data ranged from about 2% to 15% of the data length. Shongwe *et al* (2006) recommended the use of data from stations with missing entries not exceeding 5%. Ngongondo *et al* (2011) adopted the use of data with up to 10% missing entries suggested by Hosking and Wallis (1997). Furthermore, Helsel and Hirsch (1992) in National Nonpoint Source Monitoring Program (2011) suggested that monotonic trend analysis could be applied if the missing records do not exceed one-third of the data length. This recommendation was based on the use of non-parametric statistical trend tests that are robust against outliers and large data gaps. This was adopted in the study. Outlier problems were handled by using statistics that are resistant to their presence. Suspicious data were set to missing entries before analyzing the data. The remainders of the random errors in the data were significantly reduced during the averaging to obtain the annual mean data from the monthly observations because of the large data volume. This method is effective in eliminating random events significantly to achieve data smoothening.

Print ISSN: 2059-2396, Online ISSN: 2059-240X

Analytical Procedure

The monthly data were converted to annual data for the analysis. The descriptive statistics were evaluated using *SPSS Version 17* package. The seasonal variations of the parameters were represented in bar charts using the *R* programming language. The Mann-Kendall's (M-K) rank correlation test was used to detect the presence, nature and significance of the trends. The M-K is a non-parametric statistical tool which has significant advantages over their parametric counterparts (Turkes *et al,* 2008; Karaburun *et al*, 2011; Karabulut *et al*, 2008; Ustaoglu, 2012; Zhihua *et al*, 2013). These include the provision of higher statistical power in cases of skewed distributions, robustness to outliers and missing data, and the ability to represent a measure of monotonic or linear dependence. The M-K tests were executed using the *SPSS Version 17* package. The trend magnitudes were determined using the linear regression model. The statistical significance of the estimated trend magnitudes were tested by the student's *t*-test for significance with *n-1* degrees of freedom. The linear regression model was executed using *MATLAB 2008* software package. The time series plots were done using the *MATLAB 2008* package. The trend lines of the time series plots were fitted using the least squares linear fitting to give a general indication of the trend nature over the period.

The M-K Rank Correlation Test.

For a set of data (x_1, x_2, x_3…..x_n) of time series where $n \geq 10$ and the time series are independent, the M-K test statistic *S* is presented as follows (Rai *et al*, 2010, Zhihua *et al*, 2013;).

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

x_j *and* x_k are the j^{th} and k^{th} terms of the sequential data for $j > k$.

$$Sgn\ (x_j - x_k) = \begin{cases} 1 & if\ x_j > x_k \\ 0 & if\ x_j = x_k \\ -1 & if\ x_j < x_k \end{cases} \quad (2)$$

If *S* value is large and positive, later values exceed earlier values and increasing trend is indicated. If *S* value is large and negative, earlier values exceed later values and decreasing trend results. For a small absolute value of *S*, no trend is indicated. The variance of *S,* σ^2 in the absence of ties is computed as:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad (3)$$

Where ties, exist σ^2 is expressed as:

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)\right] \quad (4)$$

q represents the number of tied groups and t_p represents the number of data values in the p^{th} group. S *and* σ^2 values are used to compute the *Z* statistic as:

Print ISSN: 2059-2396, Online ISSN: 2059-240X

$$Z = \begin{cases} \frac{S-1}{\sigma} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sigma} & if \quad S < 0 \end{cases} \qquad (5)$$

Under the null hypothesis of independent and randomly distributed random variables, *Z* is approximately normally distributed. The null hypothesis, H_o, for a two-tailed test is that there are no trends, indicating that the data are independent and randomly ordered. The alternative hypothesis, H_1, is that a trend exists. The null hypothesis, H_o, is rejected if the *Z*-value competed by (5) is greater in absolute value than the critical (table) value $Z_{\alpha/2}$ at the α level of significance i.e. $Z > Z_{\alpha/2}$, in which case the alternative hypothesis, H_1, of the presence of trends is accepted. In this work, the *Z* values were tested at the 1% and 5% levels of significance and the tests are two-tailed. The trend is positive (increasing) if *Z* is positive and vice versa.

The Kendall's rank correlation coefficient (coefficient of time trends) called Kendall's *tau b* coefficient (τ) is a statistic used to measure the correlation between two variables. A *tau* test is a non-parametric hypothesis test for statistical dependence on the basis of *tau* coefficient. Values of *tau b* statistic range from -1 (100% negative correlation or perfect inversion) to +1 (100% positive correlation or perfect agreement). A *tau b* value of zero shows the absence of trends. The null hypothesis of no trend is rejected when τ is significantly different from zero ($p < \alpha$) and the alternative hypothesis of presence of trend is upheld.

The *p*-value (probability value) gives the area in the tails of the probability distribution above the observed value of the test statistic. When a high value of the test statistic is observed, the *p*-value is very small. The null hypothesis is rejected if the *p*-value is less than the chosen significance level ($p < \alpha$).

The Linear Regression Model

The magnitudes of the trends were estimated using the least squares method of the linear regression model of the form:

$$\gamma = \beta_o + \beta_1 x + \varepsilon \qquad (6)$$

$\beta_0 \, and \, \beta_1$ are called the parameters of the model and ε is the error or residual term. Details on how $\beta_0 \, and \, \beta_1$ and their standard errors $\partial(\beta_0) and \, \partial(\beta_1)$ are determined have been given by Durlo (2006). The significance of the model parameters were tested on the basis of the student's *t-test* statistic, calculated as the ratio of the parameter estimates to their standard errors as follows:

$$t = \frac{\beta_1 - 0}{\partial(\beta_1)} \qquad (7)$$

$$t = \frac{\beta_0 - 0}{\partial(\beta_0)} \qquad (8)$$

The null hypothesis was rejected if $\tau > \tau_{\alpha/2}$ for two-tailed test $(p < \alpha)$.

Print ISSN: 2059-2396, Online ISSN: 2059-240X

RESULT AND DISCUSSIONS

Results

The results are presented in tables, graphs and charts. Table 2 shows the descriptive statistics while Tables 3 and 4 contain the trend results. Figures 2(a) - (f) are the time series anomaly graphs while Figures 3(a) – (f) depict the seasonal variations of the various parameters.

Table 2: Descriptive statistics of the meteorological data used in the study.

Climatic parameters	No of years	Mean	Standard deviation	C.V (%)	Coefficient of Skewness	Coefficient of Kurtosis.
Rainfall totals	63	1745.2 mm	291.93	16.73	0.313	2.79
Max. air temperature	63	31.96 ^{o}C	0.55	1.72	-0.32	-0.16
Min. air temperature	63	22.27 ^{o}C	0.47	2.12	0.65	1.91
Sunshine hours	49	5.49 hrs	0.29	5.23	-0.21	-0.79
Relative humidity	44	73.68%	1.71	2.33	-0.97	2.33
Wind speed	49	5.28 m/s	1.03	19.42	-0.90	0.73

Table 3: The M-K trend results for the various parameters.

Climatic parameters	*S* statistic	Kendall's *tau b*	*Z* statistic	*p*-values
Rainfall totals	94	0.048	0.552	0.581
Max. air temperature	730	0.374**	4.324	0.000
Min. air temperature	797	0.408**	4.721	0.000
Sunshine hours	-26	-0.022	-0.215	0.822
Relative humidity	-73	-0.077	-0.728	0. 466
Wind speed	256	0.218*	2.198	0.028

** *tau b* is significant at 1% level (*2-tailed*). * *tau b* is significant at 5% level (*2-tailed*).

Table 4: Results of the linear trend estimation of the parameters.

Climatic parameters	Slope estimates per year	Standard Error	Student's *t*-statistic	*p*-values
Rainfall totals	0.715mm	4.670	0.153	0.879
Max. air temperature	0.025^{o}C**	0.006	4.166	0.000
Min. air temperature	0.02^{o}C**	0.007	2.74	0.001
Sunshine hours	-0.001hr	0.004	-0.173	0.863
Relative humidity	-0.010%	0.029	-0.356	0.724
Wind speed	0.096m/s**	0.023	4.205	0.000

** slope is significant at the 1% level (*2-tailed*).

DISCUSSION OF RESULTS

Table 2 indicates availability of sufficient rainfall amounts but with high coefficient of variation (C.V) of 16.73% which indicates high annual rainfall variability. This implies

Print ISSN: 2059-2396, Online ISSN: 2059-240X

rapid variability in annual rainfall totals signaling unreliability of rainfall as a result of variation in intensity or frequency of rainfall on inter annual basis. The table also shows that Enugu has a low mean daily temperature range of 9.69°C over the 63 years span. Wind speed data also depict high wind speed variability with a C.V of 19.42%. The coefficients of skewness and kurtosis show that the data are approximately normally distributed in line with the central limit theorem which is a justification of the use of the parametric *t*-statistics test for significance of the trend estimates of the parameters.

Table 3 expresses rainfall totals as having non-significant upward trend over the period. Maximum and minimum air temperatures have upward trends significant at the 1% level. Wind speed indicates an upward trend that is significant at the 5% level. Sunshine duration and relative humidity portray non-significant downward trends.

The trend estimation results displayed in Table 4 shows an upward trend of 0.715mm per year in rainfall which is not significant based on the student's *t*-test result. Maximum and minimum air temperatures have estimated upward trend magnitudes of 0.025°C and 0.02°C per year respectively, both significant at the 1% level. Wind speed shows an estimated upward trend magnitude of 0.096m/s per year significant at the 1% level. Sunshine duration and relative humidity have non-significant downward trends of -0.001 hour per year and -0.01% per year respectively.

Comparing the results of Table 3 and Table 4 indicates that they are in tandem with each other and complement each other in trend analysis. There is a synergy between the M-K trend results and the linear trend estimation results with the least squares regression. The M-K test competently identified the existence, direction and the significance or otherwise of the trends while the least squares regression in addition determined the trend magnitudes. The M-K test cannot provide the estimate of the trend magnitudes and this inadequacy is complemented with the regression analysis. Although the regression analysis falls short in skewed data, it is nevertheless a vital tool in trend estimation and prediction for large data $(n \geq 30)$ for which the central limit theorem is adopted.

Fig. 2 displays the time series anomaly plots and their trend lines for the various parameters. Inspection of the plot of the annual rainfall totals reveals clear year to year variability of rainfall which reflects the high C.V in Table 2, often portraying high frequency fluctuations. The trend line is in tandem with no trends shown in Table 3 and Table 4. The dry spell of 1982-1983 *El-Nino* event is vividly captured in the plot when Enugu recorded the minimum rainfall totals of 913mm in 1983. The 1982-1983 *El-Nino* event is on record as the most intense in the 20th century (McGregor and Nieuwolt, 1998). This points to the fact that Enugu can be influenced by severe *El Nino- Southern Oscillation* (ENSO) events and that droughts are not freak events because they are a product of the same oceanic and atmospheric processes which in turn give rise to the inter annual variability of monsoons. Other years of extreme rainfall events are evident in the plot such as 1958 (1312mm), 1990 (2083mm), 1995 (2167mm), 1997 (2262mm), 2006 (2096mm), 2011 (1031mm), 2012 (2140mm). The maximum rainfall amount in the series was recorded in 1970 (2827mm). These figures indicate high inter annual rainfall variability.

Print ISSN: 2059-2396, Online ISSN: 2059-240X

The time series anomaly plots of maximum and minimum air temperatures portray steadily increasing trends coupled with years of extreme high and low temperature events and a general inter annual variability. The trend lines also portray the results of the trend tests of Table 3 and Table 4. The time series plots of sunshine duration and relative humidity show general declining trends with clear year to year fluctuations. The time series plot of wind speed indicates a positive trend over the period. The 1965-1984 periods had more rapid inter annual fluctuations whereas 1984 onward experienced low frequency fluctuations. The trend is concentrated on the early parts of the records as indicated in the plot.

Comparing the Figure 2 results with the Tables 3 and 4 clearly shows that the results are in very good agreement. Nevertheless, the time series plots show that the trends make little meaning for time series in the variables where the trends are concentrated in a limited interval. An overall trend distorts the information. A more coherent and reliable information is provided by the elaborate examination of the time series especially for year to year or decade by decade analysis. Thus, time series analysis complements the M-K and the regression test results. The beauty of this approach is that different methods can complement one another and make the results clearer, more holistic and clearer to appreciate. This is just as the use of multiple climatic variables has a more capability of representing the interactive nature of the atmospheric mechanisms than a single variable because it is the synergistic nature of these atmospheric variables that eventually shape the climate and drive agriculture and related activities.

Figure 3 shows that rainy season in Enugu spans April to October with monthly rainfall amounts exceeding 150mm. It is revealed from the bar charts that Enugu rainfall peaks in the month of September followed by June. The maximum air temperature is highest during the months of November to April exceeding 32^{o}C during the period. Comparing figures 3(a) and 3(d) shows that the hottest months usually come before the start of the rains (February and March) and after the rains (November and December). This shows the effect of cloudiness (low-level clouds) in enhancing warming. The seasonal variation of minimum air temperature depicts a more uniform distribution with a noticeable drop in December and January, indicating low night temperatures during the period (slightly above 20^{o}C). This is the consequence of harmattan which is associated with radiation cooling during the night under clear sky conditions. The seasonal variation of sunshine hours shows that the maximum mean daily sunshine hours occur during November to February and the minimum observed during the summer monsoon months (July -September). This implies that the period of minimum sunshine hours coincides with the period of maximum rainfall totals indicating the effect of clouds in absorption and scattering of solar radiation and subsequent solar dimming, The relative humidity seasonal distribution roughly follows the rainfall pattern, peaking during the summer monsoon during which it exceeds 80%. Minimum values are recorded in December through February with values up to 60%. Enugu wind speed suffers marked seasonal variation, peaking in March (above 6m/s) and least in November (about 5m/s), and a testimony of small wind speed range.

Implications of the Results to Agriculture

Implications of Rainfall Results

The annual rainfall totals is the most important factor in agricultural meteorology. The characterization of rainfall trends for Enugu for the 63 years period appears to indicate stable

Print ISSN: 2059-2396, Online ISSN: 2059-240X

rainfall regime and sustainable agricultural productivity. Nevertheless, the prevailing rainfall regime should be viewed with great caution. Although the mean of the annual rainfall amount is generally accepted as an indicator of rainfall conditions, it has some inherent limitations and disadvantages when it is used to assess agricultural development possibilities and estimation of future rainfall for water balance studies. The positive skewness of the frequency distribution of rainfall totals as shown in Table 2 means that the negative departure from the annual mean (occasions when annual rainfall is below the mean) are more numerous than the positive ones. The annual mean is therefore inflated by a very few high annual totals. The high coefficient of variation (Table 2) supported by the high frequency fluctuations (Figure 2) portray existence of extreme rainfall events such as flooding and drought in the rainfall series. Drought and flooding can affect agriculture adversely. Droughts are not freak event because they are products of the same oceanic and atmospheric processes that give rise to the inter annual variability of monsoons. Furthermore, crop production is expected to decrease under intense *El Nino – Southern Oscillation* (ENSO) conditions.

The seasonal rainfall regime is the second most important factor in agricultural meteorology and is a major controlling factor of the agricultural calendar in most tropical climates. The start, duration and cessation of the rainy season are decisive in the struggle for sufficient food supply because it drives the natural vegetation and the agricultural possibilities. The definition of rainfall events based on agricultural meteorology usually emphasizes effective rainfall which refers to rainfall amount that adequately satisfies daily plant needs. Generally, months with a mean rainfall total over 50 mm can provide sufficient moisture for the cultivation of most tropical crops. On this premise, a reliable rainy season extending for seven months (April- October) in Enugu is adequate for sustaining agriculture. Nonetheless, rainfall intensity controls the probability and severity of local flood. Hence it has a strong influence on the effectiveness of rainfall for agriculture. Though not incorporated in the analysis in this work, it is a major factor of consideration. If the intensity of the rainfall exceeds the maximum infiltration capacity of the soil, surface runoff results, and a proportion of the rain is lost, with other concomitant events such as erosion, flooding and landslides.

Implications of Temperature Results

Temperature has a strong effect on crop yield because it affects the rate of photosynthesis. For each crop, certain temperature limit exists. According to McGregor and Nieuwolt (1998), most tropical low land (below 500 m above sea level) crops grow fastest when the air temperature is around 30 - 37°C, while no growth occurs below 15 - 18°C and around 41 - 50°C. According to the source, C_3 crops which include most tropical crops (yam, cassava, wheat, rice, potatoes *etc*) reach a maximum rate of photosynthesis around the middle of the optimum temperature range while C_4 crops (millet, sorghum, sugar cane, maize etc) reach a maximum rate of photosynthesis at higher temperatures. The significant increase in the trends of minimum and maximum air temperatures has serious implications. Unusually high temperatures can have harmful and damaging effects on plants and animals because high temperatures and heat stress cause unduly accelerated physiological development. This leads to certain physiological abnormalities, hastened maturation and decreased yields. Respiration increases with air temperature which peaks during the day. Significant increasing trend in minimum air temperature implies increasing night temperature which increases dark (night) respiration in plants. This causes loss of carbohydrates and decreased net biomass production. Increasing temperature will increase the rate of evapotranspiration, changes in soil moisture and forest fires which would cause soil depletion. This would cause crop failure and reduced

Print ISSN: 2059-2396, Online ISSN: 2059-240X

yields which are a threat to food security. Furthermore, increasing trends in air temperature, declining relative humility (though not significant) and non- significant trend in rainfall would alter all aspect of the hydrological cycle and water supply, leading to minimum recharge and drying of water bodies that might be needed for irrigation. This brings about water stress. This could cause a shift in the farming pattern and choice of crop species to sustain productivity.

Implications of Sunshine Duration Results

All agricultural crops require solar radiation for photosynthesis. Sunshine hours are an excellent proxy measure of solar radiation. The photosynthetic rate is proportional to the intensity of insolation up to a certain maximum called the saturation light intensity. The maximum differs considerately for different crop species since some crops require much sunlight whereas others prefer shady conditions. The non-significant trend in sunshine duration, the seasonal distribution and the value of the mean annual daily sunshine hours of 5.49 hours represent a stable condition that will adequately sustain agricultural productivity.

Implications of Wind Speed Results

High wind speeds can cause severe damage to tree crops and staked plants. The significant increasing trends in wind speeds coupled with the high coefficient of variation could unleash threats to these crop species. Particularly, freak events are evident in the time series plot. They are most likely caused by tropical cyclones with extremely high wind speeds or gusts and they unleash the most damage.

Climate-Induced External Interferences

Amadi *et al* (2014a) analyzed the rainfall pattern across the eco –climatic zones in Nigeria and observed decreasing trends in precipitation in the Sudano-Sahelian zone of Nigeria with its attendant vegetation stress and increase in the total area of bare and higher albedo surfaces. Amadi and Udo (2015) further observed that the probable loss of conducive climate for grazing activities in the Sudano-Sahelian zone of Nigeria prompted massive emigration of the Fulani herdsmen to more favourable areas southwards. Such migrations have brought on their toll socio-economic tendencies such as the increasing spate of clashes among the Fulani cattle rearers and the aborigine farmers that have become very rampant in Enugu State in recent episodes. These herdsmen unleashed attack on Ukpabi Nimbo in Uzo- Uwani L.G.A., Atakpa Akegbe-Ugwu in Enugu East L.G.A., several communities in Awgu L.G.A., and a foiled attempt at Aku in Igbo-Etiti L.G.A., all in Enugu State just to mention a few. These tendencies pervade across the entire landscape of the State and have continued unabated, resulting in several rapes, maiming and deaths of the aborigen farmers. Many farmers are wary of going to the farms because of the continued threats of attack, kidnap and rape as the herdsmen brandish their sophisticated weapons. These sporadic and incessant attacks are, more than anything else, a climate-related menace. An enabling environment ought to be provided for people to farm without molestation. Most importantly, government should make enabling laws against herdsmen grazing their cattle on people’s farms.

Print ISSN: 2059-2396, Online ISSN: 2059-240X

CONCLUSION

The statistical analyses of the climatic parameters from 1950-2012 in Enugu show significant increasing trends in minimum and maximum air temperature and wind speed. Rainfall shows a non-significant increasing trend while sunshine duration and relative humidity show non-significant decreasing trends. Thus, the climate is changing and consequently has the tendency to affect agricultural sustainability. The assessment of total rainfall trends in Enugu over the period suggests stable rainfall regime that is favourable to sustainable agricultural productivity. However, the existence of high frequency variation means that drought and flooding occur in the area which could adversely affect agricultural productivity. There is need for pre-season and on-season climate information dissemination to guide them during seasons of uncertain rainfall. The increasing trends in minimum and maximum air temperatures have deleterious effects on plants and livestock. The temperature trends in Enugu are not favourable for agricultural sustainability and needs to be continuously monitored to select the crop species that would thrive under the prevailing temperature conditions. Trends in sunshine duration and relative humidity are favourable to adequate agricultural productivity. Wind speed analysis suggests a fairly stable wind system, though freak wind events could unleash great threats to tree crops and staked plants especially during tropical cyclones. Enabling legislation is necessary to create an enabling environment for farmers without molestation by the Fulani herdsmen. The holistic analyses of temperature and rainfall trends suggest an uncertainty in agricultural sustainability in Enugu in the face of climate change.

RECOMMENDATIONS

I. Climate information related to agriculture should be disseminated by the government agencies in such a way that it is user-centred and relevant to the farmers who are the end-users to guide them during seasons of uncertain rainfall.

II. With the erratic rainfall pattern and drought occasioned by the climate change, drought resistant and early maturity high yielding crop species should be developed through research efforts by agricultural research institutes and made available to the famers.

III. There is the need for the establishment of state-of-the-art equipped weather stations as against the ill-equipped ones by government. This will engender accurate weather forecast and prevent weather related disasters through early warning alerts and proper response systems.

IV. There is the need for agricultural ministries to invest heavily in irrigation farming rather than rain-fed agriculture alone. This needs to be accompanied by dynamic farming system including development of successful indigenous adaptation mechanisms backed by stable policy environment to adapt to climatic change threats.

V. Massive public awareness programmes should be organized by relevant agencies and promptly backed by strong political will. In addition, there should be regular and effective capacity building to strengthen the farmers with requisite knowledge, information and orientation necessary for climate change adaptation and mitigation.

VI. Above all, the government should make enabling laws against herdsmen grazing their cattle on people’s farms and stiff penalties meted out to defaulters. This will protect farmers from molestations in the hands of the irate herdsmen. The establishment of cattle ranches as practiced in other countries would bring sovereign remedy.

Print ISSN: 2059-2396, Online ISSN: 2059-240X

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Acknowledgement
The authors are grateful to the operational headquarters of Nigeria Meteorological Agency Oshodi, Lagos State Nigeria for providig the data for this research work

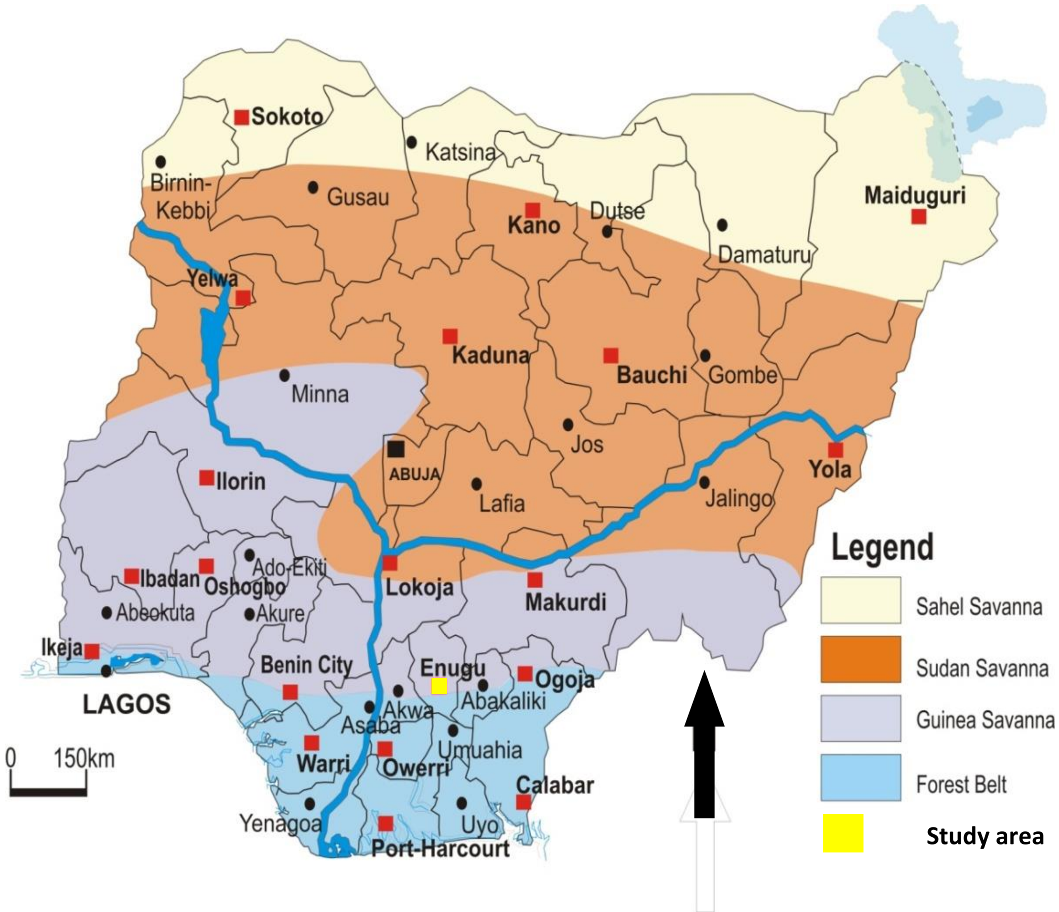

FIG. 1: Map of Nigeria showing the study area and the hydro eco -climatic zones (Modified from Adefolalu (2002)

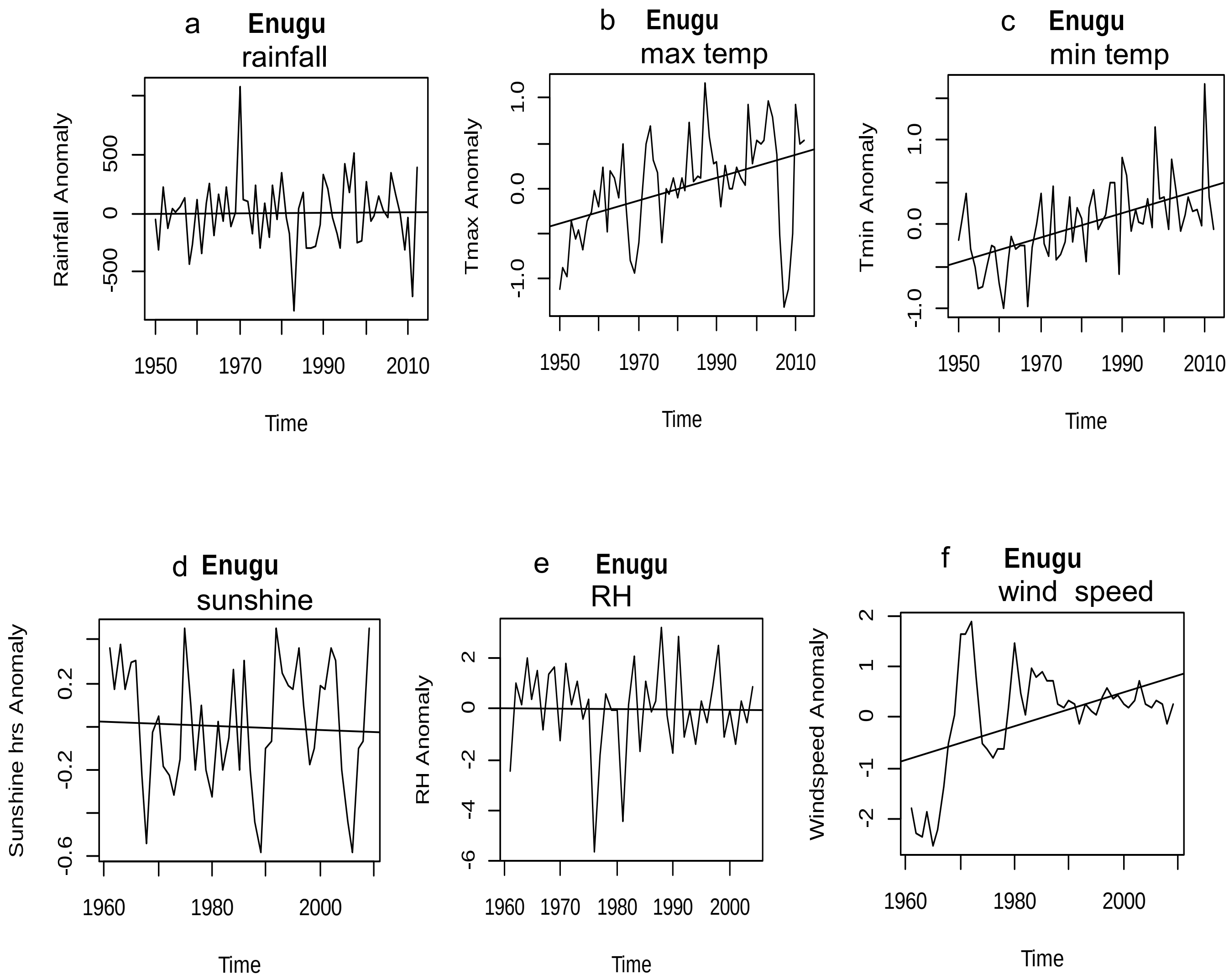

Fig. 2: The time series anomaly plots and their trend lines for the various parameters.

Print ISSN: 2059-2396, Online ISSN: 2059-240X

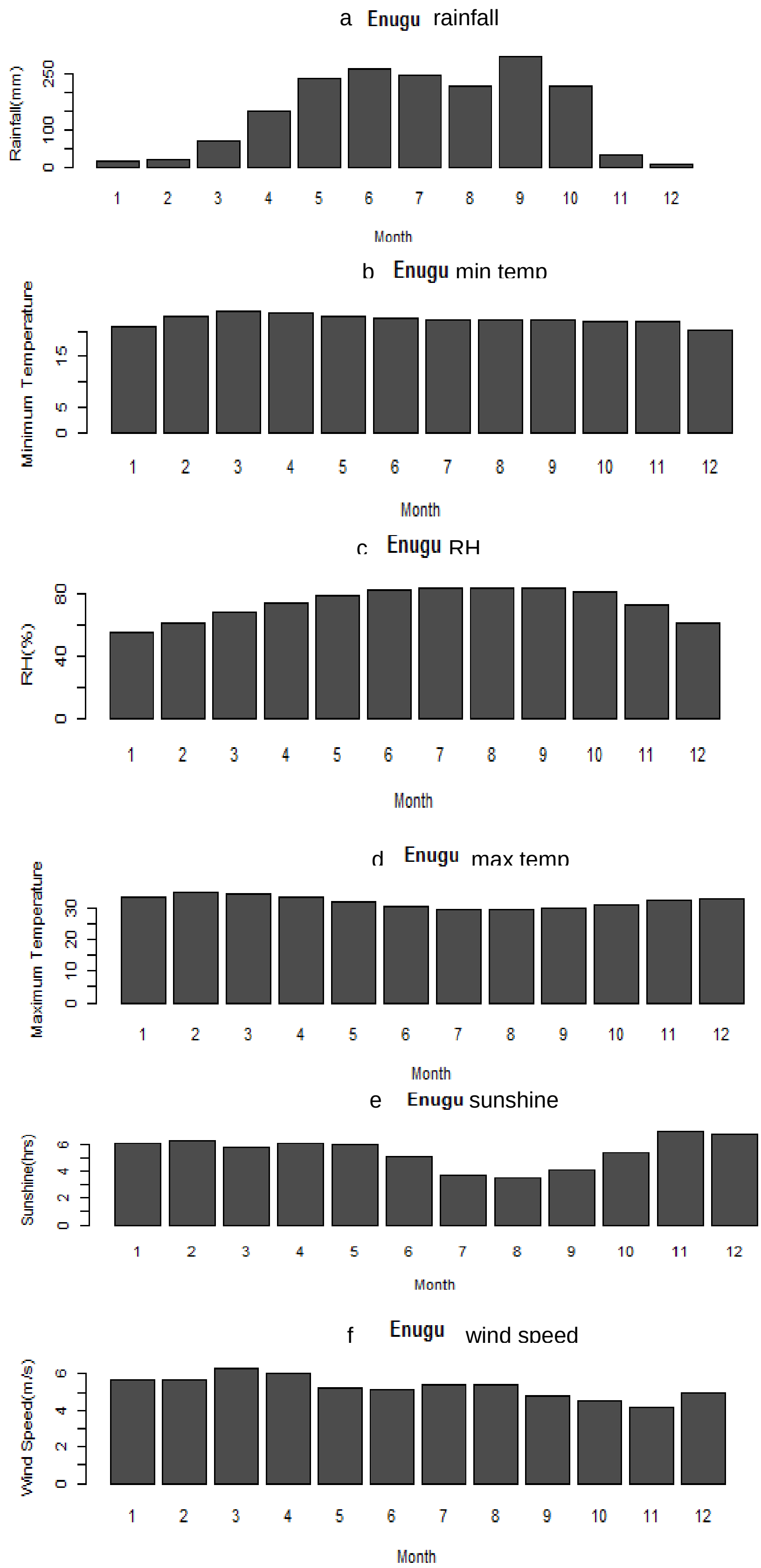

Fig. 3: seasonal variations

Print ISSN: 2059-2396, Online ISSN: 2059-240X