**Trend analysis in climatic variables and impacts on rice yield in Nigeria**

C. O. Akinbile, G. M. Akinlade and A. T. Abolude

**ABSTRACT**

The effects of changes in meteorological parameters on rice yield variations were considered. Weather parameters, temperature (T), rainfall (R), relative humidity (RH) and solar radiation (SR), and rice yield variation for Ibadan were analyzed. Meteorological parameters were obtained from the International Institute for Tropical Agriculture while rice yield data were obtained from the Africa Rice Centre both in Nigeria for three decades (1980–2010). Trends analysis of past and recent variations using the weather parameters obtained showed trends of variability of each parameter with respect to rice yield. Mann–Kendall trend and Sen’s slope tests were performed on the respective meteorological variables while correlation, multiple regression and variability index (VI) were also computed for these parameters. Results showed that T, RH and rice yield were negative and decreased significantly ($P < 0.001$) while R and SR showed statistically non-significant increasing trends in the last three decades. R and T decreased at the rate of 3% per year and 0.03% per decade, respectively. Results of annual VI showed that decreases observed in RH, SR and rice yield were rather recent. T, SR and R were found to have the most significant effect on rice yield of all the meteorological parameters considered.

**Key words** | Nigeria, rice yield, trend analysis, weather parameters

**INTRODUCTION**

Rice constitutes one of the most important staple foods for over half of the world’s population (Akinbile et al. 2011). It is a globally important cereal crop and the primary source of food for more than 3 billion people living mostly in Asia and Africa. The world’s population is projected to be 10 billion by the year 2050 (Krishman et al. 2011) and based on this projection, there is a great demand to increase production of rice to meet the growing population demand. There are various challenges in improving yield and increasing the production of rice. Recent research reports showed that year to year variations in crop yields are normally associated with fluctuation in weather patterns (Wassmann et al. 2009). The climatic variability and change, its impacts and vulnerabilities are of major growing concern worldwide (Rimi et al. 2011) and it is becoming more unpredictable every year particularly in Nigeria. Edeh et al. (2011) remarked that rainfall characteristics (intensity and duration), relative humidity (RH) and temperature constitute these environmental factors that affect rice yield and its variability. These three factors were not the only climatic factors that affect rice yield but were considered as some of the major variable factors that affect the yield of rice in Nigeria.

Rice production is majorly influenced by a set of agro-climatic variables such as rainfall, temperature, solar radiation (SR) and RH (Ji et al. 2007). Many studies have discussed the impact of rainfall variation on rice, such as Rose (1999), Jensen (2000) and Newhouse (2005). Das et al. (2006) explained the dependence of rice yield on rainfall and sea surface temperature anomalies of the equatorial Pacific as a case study from Orissa in observing the sensitivity relation between rainfall and rice yield. The climatic extremities, particularly temperature, affect the growth and reduce rice yield significantly (Satake & Yoshida 1978).
Increases in temperature contribute significantly to the decline of rice yield as Xiao et al. (2010) reported that higher temperature will increase the rice plant respiration rate and reduce the net photosynthesis, hence ultimately reducing plant yield. IPCC (2007) remarked that increasing temperatures are harmful, but the increase in rainfall might be beneficial to agriculture. Hence, rice yields are greatly influenced by temperature (T), rainfall (R), SR and RH.

Considering the importance of the agricultural sector to the Nigerian economy and food requirements, there is the need for reliable estimate of crop (majorly rice) production under varied climate change scenarios and circumstances in order to have dependable estimates of rice yield for food security. Therefore, the objective of the study is to evaluate the varying effects of temperature, rainfall, SR and RH on yield of upland rice based on 30 years' climatic data. This was to analyze recent trends of mean annual rainfall, temperature, RH and SR. The study will also compare yield variability and the agro-climatic parameters in order to determine the effects of one on the other.

MATERIAL AND METHODS

Description of the study area

Ibadan, a city in southwestern Nigeria, is located about 110 km northeast of Lagos and located at latitude 7°22’N and longitude 3°54’E (Sangodoyin 1992). Ibadan has grown rapidly in recent times and the population increased from about 1 million in 1963 to about 3.6 million in 2007. The climate is generally monsoon with bimodal rainfall pattern. Average rainfall is about 1,300 mm/year and mean monthly temperature varied from 24.5 °C in August to 28.8 °C in February (Sangodoyin 1992). The soil class is oxic paleustaff which belongs to the Egbeda Series and is described as Alfisol (Aponu sandy loam). The vegetation is humid rain forest with an average RH of between 56 and 59% during the dry season and 51–82% during the wet season (IITA 2002). The rice field spans 2 acres (5 ha) of land which spans a considerable portion of the farmyard of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria as presented in Figure 1.
Datasets

Data for the four weather parameters, temperature, rainfall, SR and RH, used in this study were obtained from IITA, Ibadan, Oyo State, Nigeria. IITA is located between latitude 3°54'E and 7°30'N, at an elevation of 200 m above mean sea level. It has an annual rainfall range of between 1,300 and 2,000 mm, while its rainfall distribution pattern is bimodal. The annual mean temperature is 27.2°C during dry season and 25.6°C during the rainy season (IITA 2002). The data collected for Ibadan were for 30 years from 1980 to 2010 and was measured daily. Rainfall measurement was expressed in mm/day, temperature in degrees Celsius, RH in percent moisture while SR was expressed in MJ/m²/day. The datasets were later expressed monthly and then yearly before use. Similarly, rice yield for the same period of interest was obtained monthly before scaling up to yearly estimates from the Africa Rice Centre (formerly West Africa Rice Development Association, WARDA) which is also located within the IITA compound. The variety of upland rice used was NERICA 2 (an acronym for the New Rice for Africa) developed by WARDA (2003).

Analysis of data

Time series for the four datasets were tested for trends and slopes annually using the Mann–Kendall test. The Mann–Kendall test is often used to test for trends in hydrological time series (Salmi et al. 2002; Oguntunde et al. 2006; Oguntunde et al. 2011; Kumar et al. 2012) and its test statistic S is given by Salmi et al. (2002) as

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

where \( n \) is the length of the time series \( x_1 \ldots x_n \), and \( \text{sgn}() \) is a sign function, \( x_j \) and \( x_k \) are values in years \( j \) and \( k \), respectively. The expected value of \( S \) equals zero for series without trend and the variance is computed as

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

and \( q \) is the number of tied groups; \( t_p \) is the number of data values in \( P \)th group. The test statistic \( Z \) is then given as

\[ Z = \begin{cases} 
\frac{s-1}{\sqrt{\sigma^2(s)}} & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
\frac{s+1}{\sqrt{\sigma^2(s)}} & \text{if } S < 0 
\end{cases} \]  

There are no assumptions as to the underlying distribution of the data since it is a non-parametric test. The \( Z \) statistic is then used to test the null hypothesis, \( H_0 \), that the data are randomly ordered in time, against the alternative hypothesis, \( H_1 \), where there is an increasing or decreasing monotonic trend. To estimate the true slope of an existing trend Sen’s non-parametric method was used (Salmi et al. 2002).

Variability index (VI) for the climatic variables considered and the yield likewise was estimated as the standardized variable departure (Oguntunde et al. 2006; Oguntunde et al. 2012) using the expression below where \( \text{VI}_i \) is variability index for year \( i \), \( X_i \) is annual value of the variable for year \( i \), \( \mu \) and \( \sigma \) are the mean annual value and standard deviation (SD) for the study period considered.

\[ \text{VI}_i = \frac{(X_i - \mu)}{\sigma} \]  

Other descriptive statistical analyses were done and they include the minimum and maximum values, arithmetic mean, SD and coefficient of variation (CV%) for all the variables considered. The following statistical tools were also used in the study: multiple regression analysis for predicting future rice yield and the least squares method for linear regression analysis which were considered at 95% significance levels.

RESULTS AND DISCUSSIONS

Annual changes in rainfall with other climatic variables and rice yield

Summary of descriptive statistics of rainfall and all other variables considered were as presented in Table 1.
R ranged from 794.2 to 1,926.3 mm/year with mean value of 1,311 ± 43 mm/year, CV of 18% and SD value of 241. T ranged from 26.2 to 27.7°C with 27 ± 0.06°C mean, SD 1.05 and CV 1.3%. RH ranged from 64 to 78% with a mean of 71 ± 6.77%, SD 9.57 and CV 7.26%. For SR, the values ranged from 12 to 25 MJ/m²/day with mean value of 18 ± 0.4 MJ/m²/day CV 16%, and SD 8.92. As for the rice yield, the values ranged from 1.4 to 2.4 t/ha with a mean value of 1.9 ± 0.5 t/ha, SD and CV were 0.71% and 12%, respectively.

Annual time series of rainfall and other variables including rice yield were as shown in Figure 2 while summary of the trend estimates was as presented in Table 2. The time series and linear trends of annual rainfall over Ibadan for the 30-year period was as given in Figure 2(a) which shows an estimated steady but gradual increase in annual rainfall at 3% variance. This is despite decreasing trends observed during the scenarios 1978–1980 and 1980–2000. However, none of the trends were statistically significant. This annual increase is slightly less than 1.6% per decade estimated by Oguntunde et al. (2011) in the same study area but followed similar patterns. Following the descriptions of other authors (Nicholson et al. 2000, L’Hote et al. 2002, Kumar et al. 2012), an apparently random succession of dry periods, ‘normal’ periods and wet periods characterized the rainfall series (Figure 3(a)). Previous studies have reported the absence of any significant trends in rainfall but the presence of large inter-annual variability (Liu et al. 2004; Roderick & Farquhar 2004) as reported by Oguntunde et al. (2012) and Kumar et al. (2012). From the study, it was observed that the error margin was of insignificant magnitude which is similar to sampling errors recorded by Shucksmith et al. (2011) during spatial and temporal resolutions of progressively downgraded rainfall events.

Average air temperature at Ibadan was found to reduce slightly at the rate of 0.03% per decade though the yearly scenario was undulating and statistically non-significant (Figure 2(b)). Diurnal temperature range (DTR) increased significantly by 3.3% per decade and this agreed with the findings of Oguntunde et al. (2011) who carried out similar studies in the same study area from 1973 to 2008. The increase in DTR observed agreed with the trends reported for India (Chattopadhyay & Hulme 1997) but different to reports for China (Liu et al. 2004) and the United States of America (Rimi et al. 2011). In order to elucidate better on the observed changes in DTR, minimum and maximum air temperature were examined. A temperature range of between 26 and 28°C was found with 0 ± 0.01°C per year for the changes (Figure 2(b)) indicating that Ibadan has experienced colder nights and warmer afternoons in the last four decades. This is also consistent with the observations of Oguntunde et al. (2011). Fricker et al. (2013) reported evaluation as an important tool for improving climate prediction systems as illustrated using decadal temperature hindcasts in their studies which had similarities with the findings of this study.

There was a significant reduction in RH for the period examined. In order words, a statistically significant decreasing trend (P < 0.005) with about 7% variance was observed (Figure 2(c)). This is in sharp contrast to the findings of Oguntunde et al. (2011) which reported that RH was fairly constant but agreed with the works of Xiao et al. (2008) who reported similar trends in their studies carried out in northwestern China. Wassmann

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Table 1: Summary of climatic variables at Ibadan

<table>
<thead>
<tr>
<th>Time Series</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard error</th>
<th>Standard deviation</th>
<th>Coefficient of variation (CV) %</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>794.2</td>
<td>1,926.3</td>
<td>1,311.92</td>
<td>43.43</td>
<td>241.82</td>
<td>18.43</td>
<td>0.24</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>26.22</td>
<td>27.7</td>
<td>26.96</td>
<td>0.06</td>
<td>1.05</td>
<td>1.34</td>
<td>1.28</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>64.29</td>
<td>77.83</td>
<td>71.06</td>
<td>6.77</td>
<td>9.57</td>
<td>7.26</td>
<td>–3.17</td>
</tr>
<tr>
<td>Solar radiation (MJ/m²/day)</td>
<td>12.07</td>
<td>24.68</td>
<td>18.38</td>
<td>0.40</td>
<td>8.92</td>
<td>16.31</td>
<td>1.52</td>
</tr>
<tr>
<td>Rice yield (t/ha)</td>
<td>1.4</td>
<td>2.4</td>
<td>1.9</td>
<td>0.5</td>
<td>0.71</td>
<td>12.11</td>
<td>0.37</td>
</tr>
</tbody>
</table>
et al. (2009) reported that a moderately high RH of 60–70% is beneficial for optimum rice yield, meaning that the gradual reduction is inimical to rice growth while Chattopadhyay & Hulme (1997) reported that compared to irradiance, RH was found to play a major role in India.

A statistically significant increase ($P < 0.001$) was observed in SR ($R^2 = 0.62$) which increased marginally during a 5-year moving average analysis (Figure 2(d)). This disagreed with Oguntunde et al. (2011) but agreed with the findings of Tao et al. (2008) and Hidema et al. (2005) which ascertained that a decrease in SR affects the potential for changes in the yield and seed quality. Kumagai et al. (2001) investigated the effects of supplementary ultraviolet B (UVB) radiation on the growth and yield of Japanese rice cultivars in a paddy field, at a middle latitude in Japan, over a 5-year period and discovered that supplementary UVB radiation inhibited growth and yield as well as grain development. Supplementary UVB radiation was also found to influence storage protein status in the rice grains, whereas grain size decreased significantly, total nitrogen and proteins...
A general but gradual reduction trend was observed for rice yield for the period examined which was largely due to the impact of climatic parameters associated with its growth and development in the study area. The highest rice yield was recorded in 1987 while the lowest yield was recorded in 1994 (Figure 2(e)). The correlation between rice and rainfall was 3%, an indication of a statistically non-significant relationship between rice yield and rainfall which could be attributed to climate change. O’Toole (2004) and Lv et al. (2013) clearly underscored the underlying relationship between rice yield and water in his study which is similar to the trend observed in this study. A linear decreasing but insignificant trend was observed in rice yield variation with temperature in the period examined. Krishman et al. (2011), Krishman et al. (2007), Das et al. (2006) and Matsui et al. (2000) all reported similar trends in their studies thus confirming the status of temperature effect on rice yield. A similar decreasing trend was recorded in rice yield variation with RH with highest and lowest values of 77.83 and 64.29% recorded in the years 1999 and 2009, respectively (Figure 2(c)). Rimi et al. (2011) and Tao et al. (2008) expressed similar views with respect to RH’s influence on rice crop in their studies. However, Xiao et al. (2008) differed in his views due to the peculiarity in altitudes in the semi-arid region of the northern part of China where his studies were carried out. A statistically significant increase was recorded for SR with highest and lowest values of 24.68 and 12.07 MJ/m² in 1984 and 1980, respectively (Figure 2(d)). Hidema et al. (2005) and Kumagai et al. (2001) reported the tremendous effect of SR especially UVB radiation on the growth and yield of rice under natural environmental conditions.

The observed slopes of T, RH and rice yield were negative and decreased significantly ($P<0.001$) while R and SR especially showed statistically non-significant and significant increasing trends, respectively. Annual variability indices for R, SR, RH, T and rice yield were as presented in Figure 3. The results showed that 2010 was the wettest year while 1998 was the driest year. Two extreme temperature conditions were observed with (specifically glutelin) increased significantly (Hidema et al. 2005).
Figure 3 | Annual plots of variability index (VI) for (a) rainfall, (b) temperature, (c) relative humidity, (d) solar radiation, and (e) rice yield.
their high VI in 1987 and 1998 with the hottest VI in 1998 while the coldest was in 1986. RH had the highest VI in 1999 and lowest in 2009. The VI for SR was highest in 1989 and lowest in 2010. Similarly, 1987 had the highest positive variability in rice yield while 1994 had the lowest.

Multiple regression results (Table 3) confirmed a strong correlation between rice yield and temperature at 0.105 while the intercept was –4.066. This was the basis of the linear equation relating all the four weather parameters with the rice yield (Table 3). Table 4 provides regression information supporting Equation (5), which was obtained from Table 4.

A model was generated for estimating rice yield annually using multiple regression analysis, which is expressed as follows:

\[ Y = 0.1(X_1) + 0.009(X_2) + 0.105(X_3) + 0.003(X_4) - 4.066 \]

(5)

where \( Y \) = rice yield (t/ha), \( X_1 \) = solar radiation (MJ/m²), \( X_2 \) = relative humidity (%), \( X_3 \) = temperature (°C) and \( X_4 \) = rainfall (mm).

**CONCLUSION**

The effects of selected meteorological parameters on rice yield in three decades were considered and from the study, the majority of these parameters had a significant effect on rice yield during the period under consideration. Reduction in mean temperature was considered a threat to the future of rice yield while the effect of decrease in RH also reduced rice growth and development. The effect of SR on yield was strongly influenced by seasonal variations in weather parameters such as temperature and the frequency of rainfall while its reduction affected potential for changes in the yield and seed quality. All these were responsible for the gradual decline in rice yield over the three decades considered.

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**REFERENCES**


Chattopadhyay, N. & Hulme, M. 1997 Evaporation and potential evapotranspiration in India under conditions of recent and future climate change. *Agric. Forest Meteorol.* 87, 55–73.


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