Climate Change and Adaptation in Nigeria: Some Background to Nigeria’s Response – Part II

Francis A. Adesina and Theophilus O. Odekunle

1 Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria

Abstract. This part of the larger paper reports the analysis of long term rainfall and temperature data sets from synoptic stations, covering the Forest, Guinea Savanna and the Sudano-Sahelian zones of Nigeria. The data were analyzed, using the least square algorithm, the second order polynomial and Z-transformation. Although the results of the trends in rainfall, using a second order polynomial, show that there are declining trends since 1961 up to 1983 and an upward trend thereafter till 2008 in all the zones, tests of significance show that the observed downward trends are statistically significant in the Sudano-Sahelian and Forest while the upward trends were statistically significant in the Sudano-Sahelian alone. The results of the wet and dry year frequency show that the Sudano-Sahelian has the highest drought frequency while the situation remains the same in the other two zones; extreme wet conditions are highest in the Guinea Savanna, followed by Sudano-Sahelian and lastly, Forest zone. In the post climatological normal period, none of the zones experienced significantly dry condition. The study further show that the climate change scenarios on rainfall in West Africa are uncertain and that increased rainfall in the Sahel may be more than initially envisaged. The results obtained for the minimum and maximum temperatures generally indicate upward trends between 1961 and 2007.

Keywords: Nigeria, climate change, temperature, rainfall, climatological normal period, trend.

1. Climate Scenario

1.1. Data collection

Three relevant climatic data sets for this assessment are annual rainfall totals and annual mean minimum and maximum air temperatures. These were sourced from the archives of the Nigeria Meteorological Agency, Oshodi, Lagos. The intention was to analyse data for the variables under consideration for as long as data availability permits for all climatic stations. However, the available data sets were not complete in some stations. The period over which the rainfall data were available for most stations is 1961 to 2008. The stations whose data were consistently available over this period include: Yelwa, Sokoto, Gussau, Kaduna, Katsina, Zaria, Kano, Bauchi, Nguru, Potiskum, Maiduguri, Yola, Ilorin Bida, Minna, Jos, Lokoja, Makurdi, Ikeja, Lagos Roof, Ibadan, Ohogbo, Ondo, Enugu, Benin, Warri, Port-Harcourt and Calabar. With regards to temperature, most stations had data covering the period between 1961 to 2007. The stations whose temperature data are complete are: Yelwa, Sokoto, Gussau, Kano, Bauchi, Nguru, Maiduguri, Yola, Kaduna, Minna, Jos, Lokoja, Makurdi, Enugu, Lagos, Ibadan, Osogbo, Ondo, Benin, Warri, Port-Harcourt and Calabar. The synoptic stations were classified into three ecological zones in the country. Yelwa, Sokoto, Gussau, Katsina, Zaria, Kano, Bauchi, Nguru, Potiskum, Maiduguri and Yola, represent Sudano-Sahelian ecological zone; Kaduna, Ilorin, Bida, Minna, Jos, Lokoja, Makurdi and Enugu represent the Guinea Savanna while Ikeja, Lagos Roof, Ibadan, Osogbo, Ondo, Benin, Warri, Port-Harcourt and Calabar represent the Forest. The few missing data points were filled using the mean value of the preceding ten years data.

1.2. Data Analysis

Corresponding author. Tel.: + (+2348037193141).
E-mail address: (faadesin@yahoo.com).
The scenarios for the assessment of impacts of, and vulnerability and adaptation to, climate change were carried out at three levels. The first level involves extracting from the most recent literature, the specific scenarios/projections on the rainfall and temperature for each of the three ecological zones in Nigeria. The results obtained are shown in Table 1. However, unlike temperature whose scenarios/projections are available for the three ecological zones, rainfall has scenarios/projections for the Sudano-Sahelian and Forest Zones only. Given the fact that rainfall and the associated ecological elements graduate from the Forest through the Guinea Savanna to the Sudano-Sahelian zones in Nigeria, the average value of the projections for the Forest and Sudano-Sahelian zones were used for the Guinea Savanna. Furthermore, the values of rainfall projections are in a range and we adopted the highest projected value. The second level involves the use of the projected proportion or projected specific value to estimate the real value of the environmental elements, using observed data. As available in the literature, the baseline for the projection is 1980/99, while the projected time horizon is 2080/99 [14]. The results obtained were displayed with bar graphs.

The third level involves two forms of analysis: (a) juxtaposing the situation of each environmental element during the period of climatological normal (1961-1990) and in the last five years with both the projection baseline and projected data, and (b) analyzing the trends in both rainfall and temperature and determining the frequency of the significantly dry and wet years, using the observed data. The trend analyses were carried out with the use of least square and second order polynomial algorithms. The frequencies of the significantly dry and wet years were carried out with the use of Z-transformations.

<table>
<thead>
<tr>
<th>Environmental Elements</th>
<th>Location</th>
<th>Baseline</th>
<th>Projection Time Horizon</th>
<th>Projected Change</th>
<th>Source of Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Coastal Area</td>
<td>1980/99</td>
<td>2080/99</td>
<td>+2.5°C</td>
<td>[26, 1]</td>
</tr>
<tr>
<td>Temperature</td>
<td>Middle Belt area and NE of Nigeria</td>
<td>1980/99</td>
<td>2080/99</td>
<td>+3°C</td>
<td>[26, 1]</td>
</tr>
<tr>
<td>Temperature</td>
<td>NW areas of Nigeria</td>
<td>1980/99</td>
<td>2080/99</td>
<td>+3.5°C</td>
<td>[26, 1]</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Sudano-Sahelian Zone</td>
<td>1980/99</td>
<td>2080/99</td>
<td>+5 to 15%</td>
<td>[14, 26]</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Forest &amp; Coastal Areas</td>
<td>1980/99</td>
<td>2080/99</td>
<td>+0 to 5%</td>
<td>[14, 26]</td>
</tr>
</tbody>
</table>

1.3. Results

Trends in the total annual rainfall between 1961 and 2008 and the mean annual rainfall of 1961-1990 in the Sudano-Sahelian, Guinea Savanna and Forest ecological zones of Nigeria, are depicted in Figures 2a-c respectively. Based on the second order polynomial, there had been declining trends since 1961 up to 1983 and upward trends thereafter till 2008 in all the ecological zones. However, further assessment of the trend, using the least square method to determine the statistical significance of each limb of the trends (i.e. 1961-1983 and 1984-2008) suggested by the second order polynomial show that the observed downward trends are statistically significant in the Sudano-Sahelian (r=0.53; α=0.01) and Forest (r=0.47; α=0.01) zones only. The observed upward trends is significant in the Sudano-Sahelian (r=0.65; α=0.01) zone alone. Other trends observed, using second order polynomial, are not statistically significant. The results of the second order polynomial further show that in all the zones, rainfall is below the climatological normal (1961-1990 average) between 1975 and 1996.

the 2004-2008 average with that of the base year of the projection (1980-1999), indicated increases in the annual rainfall of 12.4%, 3% and 3.4% in the Sudano-Sahelian, Guinea Savanna and Forest zones, respectively. When these values are compared with the projected values in Table 1, the projection is in the right direction but not right in terms of the magnitude especially, for those of the Sudano-Sahelian and Forest ecological zones. The projection of 15%, 10% and 5% rainfall increase in the respective zones are meant for a century (1980/99-2080/99), but have already attained 12.4%, 3% and 3.4% in less than a decade (1980/99-2004/08).

Variability in the total annual rainfall between 1961 and 2008 in the Sudano-Sahelian, Guinea Savanna and Forest zones of Nigeria, are shown in Figures 4a-c respectively. The variabilities were analyzed, using z-transformation. The results show that Sudano-Sahelian zone was significantly wet in 1962, 1998 and 2001, and dry in 1973, 1983, 1984 and 1987. In the Guinea Savanna, 1962, 1963, 1969 and 1978 were significantly wet while 1961 and 1983 were dry. The forest zone was significantly wet in 1968 and 1995 but dry in 1977 and 1983. Three key issues were noticed in these results: a) the Sudano-Sahelian zone has the highest drought frequency; b) extreme wet conditions are most frequent in the Guinea Savanna, followed by Sudano-Sahelian and lastly, Forest zone; and c) in the post climatological normal period, none of the zones experienced any significantly dry condition. Significantly wet conditions were experienced in the Sudano-Sahelian (1998 and 2001) and Forest (1995) zones only.

Figures 5a-c show the trends in the mean annual minimum temperature between 1961 and 2007 and the 1961-1990 mean minimum temperature in the Sudano-Sahelian, Guinea Savanna and Forest zones of Nigeria, respectively. The second order polynomial generally shows that the minimum temperature has been on the increase from 1961 to 2007 in all the zones. However, a careful look at the graphs reveals that while the gradient of the trend is consistently gentle and upward throughout in the Guinea Savanna, they are very steep and upward between 1961 and 1983 but becomes gentle thereafter and downward towards 2007 in the Sudano-Sahelian and Forest zones. Also, while the trend line rose above the climatological normal temperature in 1976 in both the Sudano-Sahelian and Forest zones, it glides in the Guinea Savanna between 1976 and 1985 and above the climatological normal in 1986. Given the relationship between rainfall and temperature, the temperature time series were also partitioned into two like those of the rainfall for the test of significances, using the least square algorithm. The results show that there are statistically significant upward trends in the minimum temperature in all the ecological zones between 1961 and 1983. The correlation values obtained are 0.74 ($\alpha=0.01$), 0.62 ($\alpha=0.01$) and 0.67 ($\alpha=0.01$) in the Sudano-Sahelian, Guinea Savanna and Forest zones of Nigeria, respectively. However between 1984 and 2007, the trend is statistically significant in the Guinea Savanna only ($r=0.59; \alpha=0.01$).

Figures 6a-c show the observations (mean annual minimum temperature) in 1980/99 and climate change scenarios for 2080/99, observations in 1980/99 and 2003/07 and climate change scenarios for 2080/99 and observations in 1961/90, 1980/99 and 2003/07 and climate change scenarios for 2080/99, respectively in the three ecological zones of Nigeria. The results show that there is a slight increase in temperature between 1961-1990 and 1980-1999 in all the ecological zones, except Guinea Savanna where the two values
Fig. 2b: Total annual rainfall trend in Guinea Savanna Zone of Nigeria (1961-2008)

Fig. 2c: Total annual rainfall trend in Forest Zone of Nigeria (1961-2008)

Fig. 3a: Observations (1980/99) and climate change scenarios (2080/99) for total annual rainfall in the various Ecological Zones of Nigeria

Fig. 3b: Observations (1980/99 and 2004/08) and climate change scenarios (2080/99) for total annual rainfall in the various Ecological Zones of Nigeria

Fig. 3c: Observations (1961/90, 1980/99 and 2004/08) and climate change scenarios (2080/99) for total annual rainfall in the various Ecological Zones in Nigeria
Fig. 4a: Total annual rainfall variability in Sudano-Sahelian Zone of Nigeria, using Z-Transformation (1961-2008)

Fig. 4b: Total annual rainfall variability in Guinea Savanna Zone of Nigeria, using Z-Transformation (1961-2008)

Fig. 4c: Total annual rainfall variability in Forest Zone of Nigeria, using Z-Transformation (1961-2008)

Fig. 5a: Mean annual minimum temperature trend in Sudano-Sahelian Zone of Nigeria (1961-2007)

Fig. 5b: Mean annual minimum temperature trend in Guinea Savanna Zone of Nigeria (1961-2007)
largely approximate each other. However, there is a significant difference between the average of 1980-1999 and 2003-2007. When the average of 2003-2007 were compared with those of the base years for the projection (1980-1999), there were increases of 0.21°C, 0.42°C and 0.57°C in the minimum temperature in the Sudano-Sahelian, Guinea Savanna and Forest zones, respectively. When these values were compared with the projected values (see Table 1), the projection is in the right direction but the magnitudes seem underestimated. The projection of +3.5°C, +3°C and +2.5°C temperature increase in the respective zones are meant for a century (1980/99-2080/99), but have already attained 0.21°C, 0.42°C and 0.57°C respectively in less than a decade (1980/99-2004/08). The magnitude is even highest where the projection is least and least where the projection is highest.

Figures 7a - c depict mean annual maximum temperature trend between 1961 and 2007 and the mean maximum temperature in the Sudano-Sahelian, Guinea Savanna and Forest zones respectively. Like the minimum temperature, the second order polynomial generally shows that the temperature has been on the increase from 1961 to 2007 in all the zones. However, while the gradients of the trend are consistently gentle and upward throughout in the Sudano-Sahelian and Forest zones, it is very steep and upward between 1961 and 1983 but becomes gentle thereafter and downward towards 2007 in the Guinea savanna. The trend lines generally rose above the climatological normal temperature in 1976 in all the zones. The tests of significance, using the least square method show that it is only the trend in the maximum temperature of the Guinea Savanna between 1961 and 1983 that is statistically significant (r=0.45; α=0.01). The trends in the other zones between 1961 and 1983 and in all the zones between 1984 and 2007 are not significant.

Figures 8a-c show the observations (mean annual maximum temperature) in 1980/99 and climate change scenarios for 2080/99, observations in 1980/99 and 2003/07 and climate change scenarios for 2080/99 and observations in 1961/90, 1980/99 and 2003/07 and climate change scenarios for 2080/99, respectively in the three ecological zones of Nigeria. Like the minimum temperature, the results show that there is a slight increase in the maximum temperature between 1961-1990 and 1980-1999 in all the zones. However, there are some differences between the average of 1980-1999 and 2003-2007. When the averages of 2003-2007 were compared with those of the base years for the projection (1980-1999), there were differences of +0.22°C, -0.13°C and +0.11°C in the maximum temperature in the Sudano-Sahelian, Guinea Savanna and Forest zones, respectively.  When these values were compared with the projected values (see Table 1), the projection is in the right direction for the Sudano-Sahelian and Forest zones only but not for the Guinea Savanna. Also, the magnitudes for the Sudano-Sahelian and Forest zones seem underestimated. The projection of +3.5°C, +3°C and +2.5°C temperature increase in the respective zones are meant for a century (1980/99-2080/99), but have already attained +0.22°C and +0.11°C in the Sudano-Sahelian and Forest zones respectively in less than a decade (1980/99-2004/08).

1.4. Rainfall and Temperature trends

Although the results of the trends in rainfall, using a second order polynomial, show that there are declining trends since 1961 up to 1983 and an upward trend thereafter till 2008 in all the zones, tests of significance show that the observed downward trends are statistically significant in the Sudano-Sahelian and Forest zones while the upward trends were statistically significant in the Sudano-Sahelian ecological zone alone. The result on the Sudano-Sahelian zone further confirmed the earlier findings of Haarsma et al. [15] and Odekunle et al. [16]. The main rainfall-producing mechanism and thus factor of inter-annual variability in the Sudano-sahelian zone is the Inter-tropical Discontinuity (ITD) [17, 15, 18, 16]. The ITD moves further
north in wet years and significantly further south in dry years [19]. It follows therefore that the initial observed declining rainfall trend in the SSEZ of West Africa is a consequence of weak mT air mass and limited ITD incursion into the region [17, 20, 19]. The increased rainfall in the Sudano-Saharan ecological zone is as a result of strong mT air mass and further ITD incursion into the region.

Fig. 6a: Observations (1980/99) and climate change scenarios (2080/99) for mean annual minimum temperature in the various Ecological Zones in Nigeria

Fig. 6b: Observations (1980/99 and 2003/07) and climate change scenarios (2080/99) for mean annual minimum temperature in the various Ecological Zones in Nigeria

Figure 6c: Observations (1961/90, 1980/99 and 2003/07) and Climate Change Scenarios (2080/99) for Mean Annual Minimum Temperature in the various Ecological Zones in Nigeria

Figure 7a: Mean annual maximum temperature trend in Sudano-Sahelian Zone of Nigeria (1961-2007)
The further incursion of the ITD appears to have been initiated by the enhanced heating of the Sahara, which deepens the Sahara low [15]. The Sahara heat enhancement in turn is as a result of increased CO₂ concentrations in the atmosphere [21]. The forest zone rainfall inter-annual variability is dominated by Sea Surface Temperature (SST) of the Gulf of Guinea [17, 22, 23]. Anomalously warm SSTs in the Gulf of Guinea region generate copious rainfall in Forest zone and vice versa [17, 24, 25]. This study thus hypothesized that the significant declining trend observed in the rainfall of the Forest zone between 1961 and 1983 is probably due to decreased SST in the Gulf of Guinea.

The results of this study show that the projection is in the right direction but not correct in terms of magnitude especially, for the Sudano-Sahelian and Forest zones. This confirmed two main findings in the literature: a) that the climate change scenarios on rainfall in West Africa are uncertain [e.g. 26] and b) that
increased rainfall in the Sahel may be more likely than initially considered [21]. The magnitude of the increased rainfall is getting larger than anticipated probably as a result of increased concentration of CO$_2$ in the atmosphere.

The results of the wet and dry year frequency show that the Sudano-Sahelian zone has the highest drought frequency while the situation remains the same in the other two zones; extreme wet conditions are highest in the Guinea Savanna, followed by Sudano-Sahelian and lastly, Forest zone; and that in the post climatological normal period, none of the ecological zones has experienced any significantly dry condition. The literature is replete with the report of high drought frequency in the Sudan-Sahelian zone [27, 28, 29]. Some drought periods reported in West Africa since 20th century include 1913-1914, 1931-1932, 1942-1943, 1972-1973 and 1983-1984 [30, 31, 32]. In this study it is hypothesized that the highest wet year frequency found in the Guinea Savanna is likely to be caused by limited incursion of the ITD into the Sudano-Sahelian zone which makes the ITD and its associated copious rainfall band last longer over the Guinea savanna zone. Also, in the post climatological normal period, none of the zones has experienced any significantly dry condition while significantly wet conditions were experienced in two zones. This further confirmed the projection and general trend towards a wetter condition in the African sub-region.

The results obtained for the minimum temperature generally indicate upward trends, which can be ascribed to global warming. The details of the results however show that while the gradient of the trend is consistently gentle and upward throughout in the Guinea Savanna, they are very steep and upward between 1961 and 1983 but becomes gentle thereafter and downward towards 2007 in the Sudano-Sahelian and Forest zones. It is known that near the earth’s surface, the major partitioning of the solar energy is between sensible and latent heat [33]. The latter is the proportion used to raise the air temperature while the former is merely utilized to convert water from liquid to gas and so does not affect temperature [34]. Thus the higher the amount utilized to convert water from liquid to gas, the lower the temperature of the environment. Therefore as observed in this study that the gradient of the minimum temperature trends are very steep and upward between 1961 and 1983 but becomes gentle thereafter and downward towards 2007 in the Sudano-Sahelian and Forest zones are necessary consequences of the initial declining rainfall trends and subsequent increasing rainfall. Also, the results show that there are statistically significant upward trends in the minimum temperature in all the ecological zones between 1961 and 1983 and that between 1984 and 2007, the trend is statistically significant in the Guinea Savanna only. The upward trend is statistically significant most especially, in the Sudano-Sahelian and Forest zones because of the significant declining rainfall during the period. Only the Guinea savanna has a statistically significant upward trend between 1984 and 2007 because the zone’s rainfall is largely normal during the period and consequently dominated by the effect of the global warming as a result of greenhouse effect.

Like the minimum temperature, the results of the second order polynomial generally show that the maximum temperature was on the increase between 1961 and 2007 in all the ecological zones. This again can be ascribed to global warming. The tests of significance using the least square method show that it is only the trend in maximum temperature of the Guinea Savanna between 1961 and 1983 that is statistically significant. The trends detected in the other two zones between 1961 and 1983 and those detected in all the zones between 1984 and 2007 are not statistically significant. These results indicate that at present, the effects of both the global warming in general and rainfall in particular on the temperature in Nigeria is on the minimum rather that the maximum temperature. Further investigations are required to account for such differential effects the global warming and rainfall on the minimum and maximum temperatures.

Again, like the minimum temperature, there are some differences in the maximum temperature between the average of 1980-1999 and 2003-2007 (although generally smaller). The comparisons show that the projection is in the right direction for the Sudano-Sahelian and Forest zones only but not for the Guinea Savanna. Also, the magnitudes for the Sudano-Sahelian and Forest zones seem underestimated. Like minimum temperature, this is probably as a result population explosion and concomitant increased concentration of CO$_2$ concentrations in the atmosphere than projected.

The outcome of the analyses presented here feed into the vulnerability assessment and adaptation proposal presented in Part III.