*Malaysian Journal of Civil Engineering 28(3):365-381 (2016)*

# SPATIAL AND TEMPORAL TRENDS IN MEAN, MAXIMUM AND MINIMUM TEMPERATURE IN THE NIGER-SOUTH BASIN, NIGERIA

Ajayi Johnson Oloruntade[1,3]*, Thamer Ahmad Mohammad[2], Abdul Halim Ghazali[2] & Aimrun Wayayok[1]

[1]*Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, 43400 Selangor, Malaysia.*
[2]*Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, 434OO Selangor, Malaysia.*
[3]*Department of Agricultural and Bio-Environmental Engineering Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria.*

*Corresponding Author: *johntades1@yahoo.com*

**Abstract:** Analysis of trends in temperature can provide important information required for the understanding of climate in any geographical setting. In this study, trends of mean (TMEAN), maximum (TMAX) and minimum (TMIN) air temperature series were investigated based on monthly, seasonal and annual time-scales over the Niger-South Basin (NSB) during 1948–2008. Standard statistical tests and Mann-Kendall trend technique were used to analyse the temperature series. The results revealed a uniform warming over the basin with an average coefficient of variability of 1.36%. Three periods of warming and cooling were identified as: 1948-1956 (cooling), 1957-1978 (moderate warming) and 1979-2008 (increased warming) - with year 1998 being the warmest (TMEAN=27.8 $^{o}$C), while 1975 was the coldest (TMEAN=26.2 $^{o}$C). The warmest season was during March-April-May (spring) and June-July-August (summer) the coldest, whereas February and March were the warmest months of the year. Trends were positively significant over the basin on monthly, seasonal and annual bases for all series, while increasing trend in TMIN series was strongest. The trend in TMEAN, TMAX and TMIN averaged over the whole basin were 0.83, 0.79 and 0.90 °C per annum, respectively. The increasing warming trends for all series were also stronger in autumn and summer than in spring and winter. On the monthly basis, the highest TMEAN, TMAX and TMIN increase were in February (1.13 $^{o}$C/yr), September (1.22 $^{o}$C/yr) and January (1.41 $^{o}$C/yr), respectively. On the whole, average increased warming over the entire basin was 0.83 $^{o}$C per annum. The study showed that the increased warming in the basin that has been further intensified since the year 2001 can be attributed to the influence of global warming.

**Keywords:** *Trend analysis, temperature series, Mann-kendal test, climate change, NSB*

## 1.0 Introduction

Increased warming due to rising temperature during the 20th century was reported by the Intergovernmental Panel on Climate Change (IPCC, 2001) and its intensification has also been observed in the new century (IPCC, 2007; IPCC, 2013). However, the warming of the global earth surface is not uniform across the world because of the differences in geographical location, environmental and anthropogenic factors. For instance, a major source of global warming is increased anthropogenic greenhouse gas (GHG) emission to the atmosphere that is majorly aggravated by industrialization, while little is emitted through agricultural activities. In this regard, while it may be plausible to argue that increased warming could be more noticeable in highly industrialized regions of the world, nevertheless, it has been observed that the least responsible for global GHG emission are the most vulnerable to the impacts of climate change, including increasing temperature (UNFCCC, 2007). This is particularly true with the developing regions of the world, especially the sub-Sahara Africa where adaptation and mitigation capacities are very low due to poor technical know-how and high level of illiteracy (Callaway, 2004; IPCC, 2007). Thus, there is the need to continuously study the pattern and trend of temperature to assess the projected warming in this part of the world, even at the basin scale.

Trends in temperature series have been investigated in many parts of the world with different direction of change reported (e.g. Hasanean, 2001; Turkes *et al*., 2002; Gadgil & Dhorde, 2005). More recently, Brunetti *et al*. (2006) in their study over Italy found a positive trend of about 1.0 K per century for mean temperature which was higher for minimum temperature than maximum temperature. However, when the study applied trend test progressively, the result showed that over the previous 50 years, maximum temperature trend was stronger than that of minimum temperature. Bhutiyani *et al.* (2007) studied the long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century. Their result revealed significant rise in all temperature series in the northwest Himalayan region by about 1.6 °C in the last century, with winters warming at a faster rate while diurnal temperature range also displayed a significantly increasing trend. Using a 2×2 km gridded dataset from 1959 to 2008, Ceppi *et al*. (2012) examined trend of temperature series in Switzerland and observed positively significant seasonal trends with an annual average warming rate of 0.35 °C/decade. Nasher and Uddin (2013) studied trends variation in maximum and minimum temperature over northern and southern parts of Bangladesh, the results showed both positive and negative trends that were highly dependent on seasons and geographical location. At the basin scale, a study on hydro-climatic variables over 50 years in the Tarim River Basin, China was carried out by Tao *et al*. (2011), reporting increasing trend for temperature during the last five years of the period.

Studies on the spatio-temporal variability and trend in temperature are very few within Africa and especially in the West Africa sub-region. Nevertheless, Tshiala *et al*. (2011) analysed temperature trends in Limpopo Province, South Africa and their result showed an increase of 0.12 °C per decade in the mean annual temperature for the 30 catchments, over the 50 year period. They also reported seasonal trends that revealed variability in mean temperature increase, of about 0.18 °C per decade in winter and 0.09 °C per decade in summer. With regard to Nigeria, most trend analyses have been devoted on precipitation time series, however, a few other studies which dwelt on temperature suffer temporal and spatial limitations. Nevertheless, Oguntunde *et al*. (2012) in their study of temperature trends over Nigeria found an increased warming of about 0.03 °C, with warming more confined to the southern part of the country. Although the foregoing study dealt widely on the trend of temperature over the country, it can hardly provide answers to the temperature dynamics that are peculiar to the present study area, given the geographical spread of Nigeria. In addition, the study only covered the last century even as IPCC (2007) has predicted persistent warming in the 21st century. Therefore, the main objective of the present study was to detect trend in annual, seasonal and monthly temperature series in the Niger-South Basin, Nigeria.

## 2.0 Materials and Methods

### *2.1 The Study Area*

The Niger-South Basin (NSB) is located in Nigeria between Latitudes 5.8° – 8.0° N and Longitudes 6.00° – 7.8° E, with a total area of about 26,324 km$^2$. It is the last part of the Niger River Basin (NRB) before its final flow into the Atlantic Ocean and falls within the Nigerian Hydrological Area V, excluding the Niger Delta Area (Figure 1). The basin covers three Nigerian agro-ecological zones- tall grass Savanna, rain forest and fresh water swamp, but with the larger part in the rain forest zone. The basin is characterized by sub-humid tropical climate with distinct wet and dry seasons. Rainfall commences at the onset of the raining season around March/April and reach its peak between July and September, but eventually stop in November/December. Mean annual rainfall ranged between 1000 mm and 2000 mm with a maximum temperature of 37.9°C, and a relative humidity of 60%. Since the early 1990s, both natural ecological processes and hydrological cycle in the study area have been deeply modified by human activities, which include, but are not limited to, urbanization, road constructions and river dredging. The population is about 12.9 million (National Population Commission, 2006), while the main activities are agriculture, including fish farming with maize and other grain crops being the dominant products.

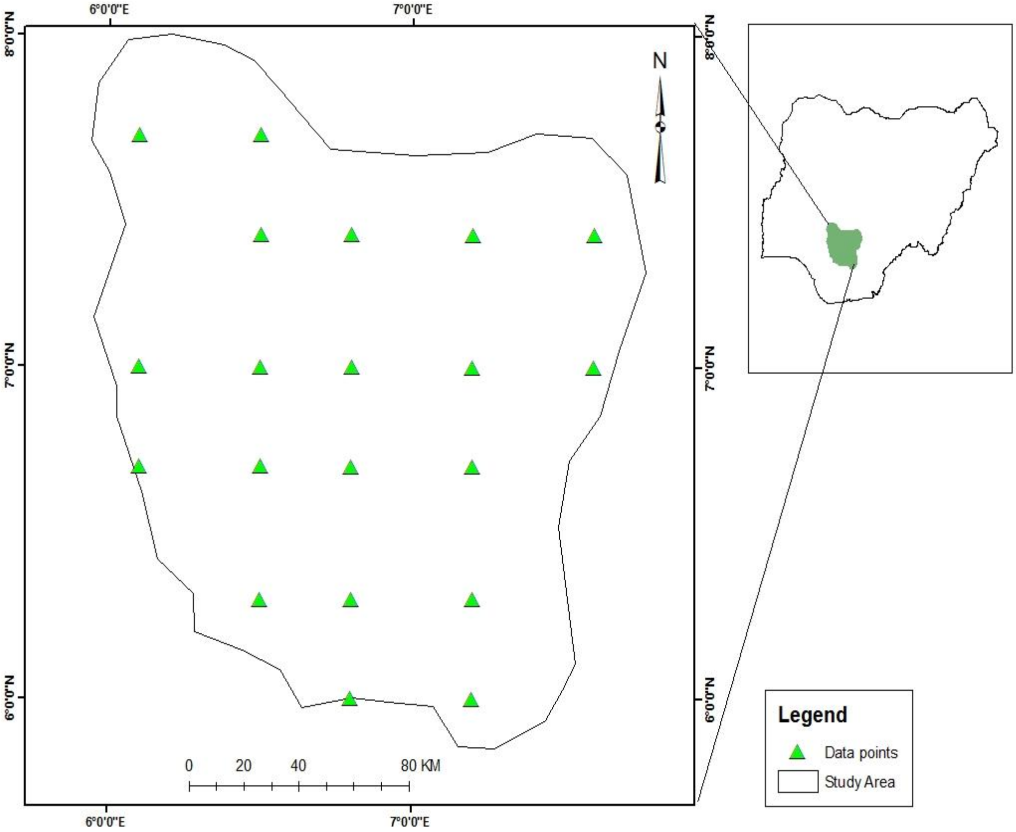

Figure 1: Location of Niger-South Basin in Nigeria and the data points used for the study

### *2.2 Datasets*

This study relied on temperature data taken from the Global Gridded Climatology (CRU TS 2.1) obtainable at a new high resolution and made available by the Climate Impacts LINK project, Climate Research Unit, University of East Anglia, Norwich, UK (Mitchell *et al.*, 2001; Mitchell and Jones, 2005). The Climate Research Unit (CRU) data set is composed of monthly 0.5$^o$ latitude/longitude gridded series of climatic parameters over the periods 1901-2008. There is general poor coverage of meteorological stations in Africa, hence detailed information on CRU data quality control and interpretation are available in relevant publications (e.g. New *et al.*, 2000; Conway *et al*., 2009). Kahya and Kalayct (2004) argued that a period of 30-year is long enough for the evaluation of climatic trend for a reasonable conclusion to be drawn.

Therefore, the use of 61 year data (1948-2008) for this analysis is assumed sufficient to reach any reasonable conclusion for the present study.

## 2.3 *Data analysis*

### 2.3.1 *Exploratory Data Analysis and Descriptive Statistics*

The use of exploratory data analysis (EDA) can help in gaining an insight into the direction and pattern of change in hydro-climatic variables. Besides the common mathematical methods, it is often included in comprehensive trend detection (Anghileri *et al.*, 2014). EDA refers to any technique of data analysis aside formal statistical methods. It uses graphical tools, e.g., time series plots and scatter plots, and it is aimed at better understanding the available data and the underlying processes. In addition, simple descriptive statistics such as the mean, range, standard deviation (SD), coefficient of variation (CV) and the determination of maximum and minimum values are also employed to gain preliminary understanding of the data.

### 2.3.2 *Trend Analysis*

The rank-based nonparametric Mann–Kendall (M-K) test has been widely used to assess the significance of monotonic trends in hydro-meteorological time series (e.g. Hamed, 2008; Kumar *et al.*, 2010; Anghileri *et al.*, 2014). The World Meteorological Organization (WMO, 1988) has also suggested the use of M-K test for the detection of trends in meteorological data. It was preferred to other techniques such as the parametric tests because of its merits which include (1) ability to handle non-normality or seasonality, outliers and missing values in series and (2) its high asymptotic efficiency (Fu *et al.*, 2009). It is applicable in cases when the data values of a time series can be assumed to obey the model:

$$X = f(t) + \sum t \tag{1}$$

where $f(t)$ is a continuous monotonic increasing or decreasing function of time and the residual $\sum t$ can be assumed to be from the same distribution with zero mean. The Mann–Kendall test statistic $S$ is given as:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{2}$$

where $n$ is the length of the time series $x_i \ldots\ldots x_n$ and $sgn(.)$ is a sign function used to count the difference between two values ($x_j$ and $x_k$), $x_j$ and $x_k$ are values in years $j$

and $k$, respectively. The expected value of $S$ equals zero ($E\lfloor S\rfloor = 0$) for series without trend and the variance is computed as:

$$\sigma^2(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5)\right] \tag{3}$$

where $q$ is the number of tied groups and $t_p$ is the number of data values in $p^{th}$ group. The test statistic $Z$ is then given as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\sigma^2(S)}} & if\ \ S > 0 \\ 0 & if\ \ S = 0 \\ \frac{S+1}{\sqrt{\sigma^2(S)}} & if\ \ S < 0 \end{cases} \tag{4}$$

Positive values of $Z$ indicate increasing trends while negative Z values depict decreasing trends. To estimate the true slope of an existing trend, the Sen's non-parametric method, widely acclaimed for its robustness (Salmi *et al.*, 2002; Dinpashoh *et al.*, 2011), also estimated by a slope estimator as extended by Hirsch *et al*. (1982) from that proposed by Sen (1968) was applied. It is computed as:

$$Q_i = \frac{x_j - x_k}{j-k}\ for\ = 1, \ldots \ldots N, \tag{5}$$

where $x_j$ and $x_k$ are the data values at times in years $j$ and $k$ ($j > k$), respectively.

### 2.3.4 Trend Free Pre-Whitening

A major requirement of the Mann-Kendall (M–K) test is that time series should be without serial correlation. Significant positive serial correlation influences the power of M–K and thereby leads to major source of uncertainty. To remove or reduce this effect, pre-whitening of the original dataset before applying the M–K test is recommended (Jhajharia *et al.*, 2012). The procedure which has been well-documented in Kumar *et al.* (2010) is represented as:

$$z_i = x_i - (\Delta \times i) \tag{6}$$

where $\Delta$ is Sen's estimator and have been described in different reports (Kahya and Kalayci, 2004; Dinpashoh *et al.*, 2011). The value of $r_1$ of the new time series is first computed and later used to determine the residual series as

$$V_i = z_i - r_1 \times z_{i-1} \tag{7}$$

Then the value of $\Delta \times i$ is added again to the residual data set of Eq. (7) as

$$y_i = V_i + (\Delta \times i) \qquad (8)$$

The M–K test was then used to detect trend in the final $y_i$ (or pre − whitened) series.

### 2.3.5 Change Point Detection

First the residual mass curve, a statistical procedure widely used in the studies of climatic variations, was plotted. It is a plot of cumulative deviations from a given reference, e.g. mean, against time or date. In addition, the cumulative sum (CUSUM) was used for abrupt change point detection in the series. The change points in the temperature time series for monthly, seasonal and annual temporal scales were detected following Kielly (1999) as applied by Oguntunde *et al*. (2012) and computed as:

$$S_i = \sum_{i=1}^{N} (y_i - \bar{y}) \qquad (9)$$

where $\bar{y}$ is the average value of the time series. The possible change has occurred when $S_i$ is at the maximum. A period where the CUSUM chart follows a relatively straight line indicates a period where the average does not change, while an abrupt change in the direction of the CUSUM indicates an abrupt shift in the average (Gocic and Trajkovic, 2013).

## 3.0 Results and Discussion

### 3.1 Summary of EDA and Descriptive Statistics

Temporal time distributions for the mean (TMEAN), maximum (TMAX) and minimum (TMIN) temperature are shown in Figure 2 (a, b and c). For all series, the pattern generally revealed rising temperature in the basin, with the rate highest in TMIN, followed by TMEAN and TMAX. Highest values were observed in all cases in 1998 as TMEAN (27.8 $^{o}$C), TMAX (32.7 $^{o}$C) and TMIN (22.8 $^{o}$C). Spatial averages over the basin showed that maximum values varied from 28.1 $^{o}$C to 27.4 $^{o}$C, minimum from 26.5 $^{o}$C -26.1 $^{o}$C, mean from 27.2 $^{o}$C to 26.5 $^{o}$C and SD from 0.38 $^{o}$C to 0.35 $^{o}$C. Moreover, over the entire basin, maximum, minimum, mean and SD were respectively, 27.8 $^{o}$C, 26.2 $^{o}$C, 26.9 $^{o}$C and 0.36 $^{o}$C as seen in Table 1. Spatial variability of temperature series was relatively low, with CV which ranged between 1.42% and 1.32%, but 1.36% on the average. Annual TMEAN showed three distinct cooling and warming periods over the series length. Periods 1949-1956 exhibited cooling; 1957-1978 moderate warming with intermittent cooling and 1979-2008, increased warming with random cooling. The years with highest temperature were 1998, 1987, 2007 and 1949, while the lowest were 1975, 1956, 1971, 1961 and 2001 (from the highest to the least), over the basin. Plot of cumulative deviation of temperature (Figure 2d) also showed that the entire basin changed from cooling to persistent warming since 1979.

Table 1: Geographical characteristics of the data used and the descriptive statistics

| Station Code | Lat. | Long. | Alt. (m.a.s.l) | Max (°C) | Min (°C) | Mean (°C) | SD (°C) | CV (%) |
|---|---|---|---|---|---|---|---|---|
| TEMP47 | 6.0 | 6.8 | 28.3 | 27.9 | 26.3 | 27.0 | 0.37 | 1.35 |
| TEMP48 | 6.0 | 7.2 | 113.5 | 27.8 | 26.1 | 26.8 | 0.38 | 1.41 |
| TEMP59 | 6.3 | 6.5 | 257.7 | 27.8 | 26.3 | 26.9 | 0.36 | 1.34 |
| TEMP60 | 6.3 | 6.8 | 23.9 | 27.7 | 26.2 | 26.9 | 0.36 | 1.36 |
| TEMP61 | 6.3 | 7.2 | 42.4 | 27.8 | 26.2 | 26.9 | 0.38 | 1.41 |
| TEMP77 | 6.7 | 6.1 | 331.1 | 27.7 | 26.1 | 26.8 | 0.35 | 1.32 |
| TEMP78 | 6.7 | 6.5 | 138.5 | 27.7 | 26.2 | 26.9 | 0.36 | 1.34 |
| TEMP79 | 6.7 | 6.8 | 26.0 | 27.8 | 26.2 | 26.9 | 0.37 | 1.36 |
| TEMP80 | 6.7 | 7.2 | 221.5 | 27.5 | 25.9 | 26.6 | 0.38 | 1.42 |
| TEMP97 | 7.0 | 6.1 | 178.3 | 27.5 | 25.9 | 26.6 | 0.35 | 1.33 |
| TEMP98 | 7.0 | 6.5 | 52.0 | 27.7 | 26.1 | 26.8 | 0.36 | 1.34 |
| TEMP99 | 7.0 | 6.8 | 32.5 | 27.9 | 26.4 | 27.1 | 0.37 | 1.35 |
| TEMP100 | 7.0 | 7.2 | 129.5 | 27.8 | 26.2 | 26.9 | 0.38 | 1.40 |
| TEMP101 | 7.0 | 7.6 | 395.9 | 28.0 | 26.3 | 27.1 | 0.38 | 1.42 |
| TEMP123 | 7.4 | 6.5 | 186.1 | 27.6 | 26.1 | 26.8 | 0.36 | 1.34 |
| TEMP124 | 7.4 | 6.8 | 92.9 | 28.0 | 26.5 | 27.1 | 0.36 | 1.34 |
| TEMP125 | 7.4 | 7.2 | 285.1 | 28.0 | 26.5 | 27.2 | 0.38 | 1.39 |
| TEMP126 | 7.4 | 7.6 | 397.0 | 28.0 | 26.4 | 27.1 | 0.38 | 1.41 |
| TEMP148 | 7.7 | 6.1 | 431.3 | 27.4 | 25.8 | 26.5 | 0.36 | 1.35 |
| TEMP149 | 7.7 | 6.5 | 145.3 | 27.6 | 26.1 | 26.8 | 0.36 | 1.34 |
| Basin Average | - | - | - | 27.8 | 26.2 | 26.9 | 0.36 | 1.36 |

Temporal series averaged for monthly, seasonal and annual scales are shown in Table 2. Monthly TMEAN ranged between 28.8 °C and 25.2 °C, and CV 4.8 and 1.8%. Also, TMAX fluctuated between 30.6 °C and 26.6 °C, and CV 4.7-1.9%, while TMIN ranged from 23.8 °C-20.2 °C, and CV 6.6-1.9%. Plot of monthly time series also showed that higher values of temperature were obtained in the months of February and March in comparison with other months (Figure 2e). Furthermore, based on four seasons classification, i.e. December-January-February (DJF), March-April-May (MAM), June-

July-August (JJA) and September-October-November (SON); TMEAN varied between 27.9 °C and 25.4 °C, and CV 2.0-1.7%. In addition, TMAX ranged between 29.4 °C and 26.7 °C, and CV 2.2-1.9%; while average TMIN fluctuated between 23.3 °C and 21.4 °C, and CV 3.4-1.7%. However, on annual scale, the average for TMEAN, TMAX and TMIN were 26.9, 27.7 and 22.1 °C, respectively. While TMIN had CV of 1.7%, it was the same for both TMEAN and TMAX (1.3%) whereas SD was similar for all the three (0.4 °C). The result indicated that while MAM has been the hottest of all seasons, JJA was the coldest, with variability higher at the monthly scales than both seasonal and annual. Temporal plots of cumulative deviation of seasonal TMEAN, TMAX and TMIN (Figure 2f) also showed similarity in their pattern of cooling and warming. For example, between 1948 and 1978 there was a random warming in 1973 and the change point for all the series are relatively close; whereas both TMEAN and TMAX changed from cooling to warming in 1978, TMIN persistent till 1985 before it finally reversed.

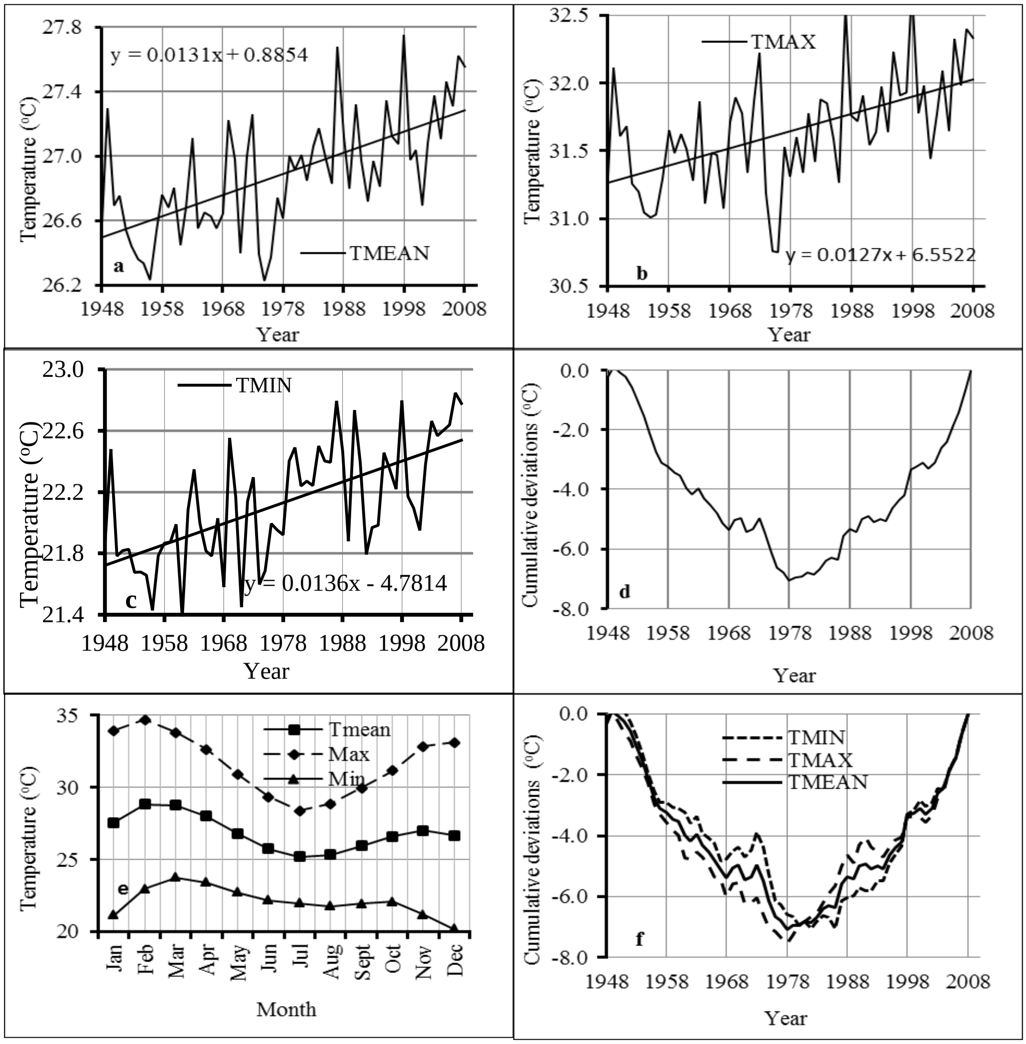

Figure 2: Temporal plots of **a** (TMEAN), **b** (TMAX) & **c** (TMIN); **d (**cumulative deviations of average temperature); **e** (monthly time series) and **f** (cumulative deviations of temperature series)

Table 2: Descriptive statistics of monthly, seasonal and annual temperature series

| Temperature Series | TMEAN | | | TMAX | | | TMIN | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean (°C) | SD (°C) | CV (%) | Mean (°C) | SD (°C) | CV (%) | Mean (°C) | SD (°C) | CV (%) |
| Jan | 27.6 | 0.6 | 2.1 | 28.9 | 0.6 | 1.9 | 21.2 | 1.0 | 4.5 |
| Feb | 28.8 | 0.6 | 2.2 | 30.6 | 0.9 | 2.6 | 23.0 | 0.8 | 3.6 |
| Mar | 28.8 | 0.7 | 2.3 | 30.5 | 1.0 | 2.8 | 23.8 | 0.6 | 2.6 |
| Apr | 28.0 | 0.6 | 2.2 | 29.7 | 0.8 | 2.6 | 23.4 | 0.5 | 2.3 |
| May | 26.8 | 0.5 | 1.9 | 28.0 | 0.6 | 2.0 | 22.7 | 0.5 | 2.1 |
| Jun | 25.8 | 0.5 | 1.8 | 27.1 | 0.6 | 2.1 | 22.2 | 0.4 | 1.9 |
| Jul | 25.2 | 0.6 | 2.3 | 26.8 | 0.8 | 2.7 | 22.0 | 0.5 | 2.1 |
| Aug | 25.3 | 0.5 | 1.8 | 26.6 | 0.8 | 2.7 | 21.8 | 0.4 | 2.0 |
| Sept | 26.0 | 0.5 | 1.8 | 27.0 | 0.8 | 2.5 | 22.0 | 0.6 | 2.8 |
| Oct | 26.6 | 0.5 | 1.8 | 27.8 | 0.8 | 2.5 | 22.1 | 0.7 | 3.0 |
| Nov | 27.0 | 0.6 | 2.1 | 28.8 | 0.8 | 2.5 | 21.2 | 0.8 | 3.8 |
| Dec | 26.7 | 1.3 | 4.8 | 28.8 | 1.6 | 4.7 | 20.2 | 1.3 | 6.6 |
| DJF | 27.7 | 0.5 | 2.0 | 29.1 | 0.6 | 1.9 | 21.4 | 0.7 | 3.4 |
| MAM | 27.9 | 0.5 | 2.0 | 29.4 | 0.7 | 2.2 | 23.3 | 0.5 | 2.0 |
| JJA | 25.4 | 0.4 | 1.8 | 26.7 | 0.6 | 2.2 | 22.0 | 0.4 | 1.7 |
| SON | 26.5 | 0.5 | 1.7 | 27.6 | 0.7 | 2.1 | 21.7 | 0.5 | 2.4 |
| Annual | 26.9 | 0.4 | 1.3 | 27.7 | 0.4 | 1.3 | 22.1 | 0.4 | 1.7 |

### *3.2 Trends*

The results presented in Table 3 for all the 20 data points and the entire basin showed significant warming trend for all stations ($\alpha < 0.001$). The magnitudes of change ranged from 0.91-0.74 °C/yr (TMEAN), 0.88-0.70 °C/yr (TMAX) and 1.01-0.79 °C/yr (TMIN). Averages of the temperature series over the entire basin were 0.83 °C/yr, 0.79 °C/yr and 0.9 °C/yr for TMEAN, TMAX and TMIN, respectively. This also suggests that the basin might have experienced increased TMIN warming over the years. In the same vein, monthly series generally showed predominantly increasing trends in all cases, though at varied significant level (Table 4). For example, both TMEAN and TMIN displayed positive trends that are significant in all months except December, increasing trends in TMAX were insignificantly positive in both April and December. Change magnitudes ranged from 1.13-0.37 °C/yr in TMEAN; 1.19-0.25 °C/yr for TMAX and 1.4-0.35 °C/yr in TMIN, while the average increased warming were 0.83 °C/yr (TMEAN), 0.79 °C/yr (TMAX) and 0.90 °C/yr (TMIN). Similarly, significant increasing trends were observed for all the four seasons in all temperature series (Table 4). However, magnitudes of change also ranged from 0.92-0.64 $^{o}$C/yr (TMEAN), 1.00-0.57 $^{o}$C/yr (TMAX) and 0.87-0.78 $^{o}$C/yr in TMIN. Highest magnitude of change was exhibited in all cases during SON, thus suggesting that annual warming in the basin is majorly controlled by increased warming in autumn. Meanwhile, change during the winter season (DJF) has been relatively minimal at 0.64 and 0.57 $^{o}$C for both TMEAN and TMAX, respectively, while the least change was observed during JJA for TMIN. Furthermore, analysis on annual basis also depicted the same positive trends that are significant ($\alpha$<0.001) in all series (Table 4), with magnitudes of change obtained as 0.75 $^{o}$C/yr (TMEAN), 0.68 $^{o}$C/yr (TMAX) and 0.82 $^{o}$C/yr (TMIN). This also tends to confirm that increased warming has been stronger in TMIN than in both TMEAN and TMAX. It should be noted that slope of change generally hovered between 0.01 $^{o}$C/yr and 0.02 $^{o}$C/yr in all cases, thus preventing its use as the basis for comparison.

Table 3: Trend statistics for the entire basin

| Station Code | TMEAN | | | TMAX | | | TMIN | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Z | Q | Change | Test Z | Q | Change | Test Z | Q | Change |
| TEMP47 | 5.37 | 0.01 | 0.80 | 4.87 | 0.01 | 0.83 | 5.17 | 0.01 | 0.86 |
| TEMP48 | 5.62 | 0.01 | 0.87 | 4.90 | 0.01 | 0.88 | 5.38 | 0.02 | 0.92 |
| TEMP59 | 5.20 | 0.01 | 0.79 | 4.69 | 0.01 | 0.80 | 4.96 | 0.01 | 0.83 |
| TEMP60 | 5.36 | 0.01 | 0.81 | 4.82 | 0.01 | 0.81 | 5.20 | 0.01 | 0.85 |
| TEMP61 | 5.59 | 0.01 | 0.87 | 4.76 | 0.01 | 0.87 | 5.48 | 0.02 | 0.92 |
| TEMP77 | 4.95 | 0.01 | 0.74 | 4.41 | 0.01 | 0.72 | 4.80 | 0.01 | 0.79 |
| TEMP78 | 5.02 | 0.01 | 0.78 | 4.45 | 0.01 | 0.76 | 5.00 | 0.01 | 0.84 |
| TEMP79 | 5.13 | 0.01 | 0.81 | 4.55 | 0.01 | 0.80 | 5.02 | 0.01 | 0.88 |
| TEMP80 | 5.41 | 0.01 | 0.87 | 4.61 | 0.01 | 0.81 | 5.32 | 0.02 | 0.96 |
| TEMP97 | 4.91 | 0.01 | 0.74 | 4.34 | 0.01 | 0.73 | 4.81 | 0.01 | 0.81 |
| TEMP98 | 5.00 | 0.01 | 0.78 | 4.30 | 0.01 | 0.76 | 5.03 | 0.01 | 0.84 |
| TEMP99 | 5.15 | 0.01 | 0.81 | 4.46 | 0.01 | 0.78 | 5.21 | 0.01 | 0.90 |
| TEMP100 | 5.36 | 0.01 | 0.86 | 4.47 | 0.01 | 0.79 | 5.33 | 0.02 | 0.96 |
| TEMP101 | 5.49 | 0.01 | 0.90 | 4.55 | 0.01 | 0.82 | 5.52 | 0.02 | 1.01 |
| TEMP123 | 5.02 | 0.01 | 0.77 | 4.24 | 0.01 | 0.74 | 5.11 | 0.01 | 0.86 |
| TEMP124 | 5.10 | 0.01 | 0.81 | 4.23 | 0.01 | 0.75 | 5.23 | 0.01 | 0.90 |
| TEMP125 | 5.33 | 0.01 | 0.87 | 4.45 | 0.01 | 0.77 | 5.37 | 0.02 | 0.98 |
| TEMP126 | 5.36 | 0.01 | 0.91 | 4.57 | 0.01 | 0.80 | 5.58 | 0.02 | 1.01 |
| TEMP148 | 4.72 | 0.01 | 0.74 | 3.96 | 0.01 | 0.68 | 5.07 | 0.01 | 0.81 |
| TEMP149 | 4.91 | 0.01 | 0.78 | 3.93 | 0.01 | 0.70 | 5.15 | 0.01 | 0.85 |
| *Basin Average* | *5.17* | *0.01* | *0.83* | *4.57* | *0.01* | *0.79* | *5.17* | *0.01* | *0.90* |

All significant at $\alpha$ = 0.001

Table 4: Trend statistics of monthly, seasonal and annual temperature series

| Temperature Series | TMEAN | | | TMAX | | | TMIN | | |
|---|---|---|---|---|---|---|---|---|---|
| | Test Z | Sig. | Change | Test Z | Sig. | Change | Test Z | Sig. | Change |
| Jan | 3.22 | ** | 0.83 | 1.86 | + | 0.51 | 3.35 | *** | 1.41 |
| Feb | 4.51 | *** | 1.13 | 3.52 | *** | 1.19 | 3.04 | ** | 1.16 |
| Mar | 4.00 | *** | 0.90 | 2.57 | * | 0.83 | 4.18 | *** | 1.11 |
| Apr | 1.96 | * | 0.43 | 0.77 | - | 0.25 | 3.29 | ** | 0.74 |
| May | 3.59 | *** | 0.81 | 2.89 | ** | 0.86 | 3.39 | *** | 0.76 |
| Jun | 3.06 | ** | 0.64 | 2.68 | ** | 0.72 | 3.49 | *** | 0.63 |
| Jul | 4.32 | *** | 0.91 | 3.75 | *** | 1.01 | 4.54 | *** | 0.88 |
| Aug | 3.80 | *** | 0.73 | 3.34 | *** | 0.80 | 3.30 | *** | 0.62 |
| Sept | 4.54 | *** | 1.01 | 4.23 | *** | 1.22 | 3.03 | ** | 0.73 |
| Oct | 4.55 | *** | 0.94 | 2.93 | ** | 0.95 | 3.45 | *** | 0.87 |
| Nov | 3.49 | *** | 0.89 | 2.79 | ** | 0.95 | 2.57 | * | 0.86 |
| Dec | 1.44 | - | 0.37 | 0.91 | - | 0.28 | 0.70 | - | 0.35 |
| DJF | 3.44 | *** | 0.64 | 2.67 | ** | 0.57 | 2.42 | * | 0.78 |
| MAM | 3.73 | *** | 0.69 | 2.27 | * | 0.61 | 4.59 | *** | 0.85 |
| JJA | 3.96 | *** | 0.78 | 3.81 | *** | 0.86 | 4.44 | *** | 0.75 |
| SON | 4.66 | *** | 0.92 | 3.95 | *** | 1.00 | 3.88 | *** | 0.87 |
| Annual | 4.88 | *** | 0.75 | 4.06 | *** | 0.68 | 4.88 | *** | 0.82 |

*** significant at α = 0.001, ** significant at α = 0.01, * significant at α = 0.05,
+ significant at α = 0.1 and - not significant

### 3.3 Discussion

In this study, analyses of TMEAN, TMAX and TMIN time series were carried out to examine the pattern of evolution and detect changes in temperature series for the period 1948 to 2008 in the NSB. Over the basin generally, variability is low both spatially and temporally with its coefficient less than 2% for all series, while mean temperature did not vary more than 1 °C, SD was generally less than 0.5 °C. Comparable low temperature variability has been reported by other studies in the country (e.g. Odjugo, 2010; Oguntunde *et al.*, 2012). Although Oguntunde *et al.* (2012) found a less than 3% and 2 °C values respectively, for CV and mean temperature range; Odjugo (2010) observed a temperature rise and decrease of 1.2 °C and 2 °C, respectively for Port Harcourt in the south and Nguru in the northern Nigeria. Nevertheless, temperature variability was highest on monthly basis in TMIN at 6.6%; while the range of temperature series was at the peak at 4 °C in TMAX, SD went up to 1.6 °C. This also suggests that temperature in the basin was varied more temporally than spatially, especially at the monthly scale. Moreover, as expected and in consistent with Oguntunde *et al*. (2012), temperature was higher in the months of February and March.

On the seasonal scale, mean series values did not vary more than 4 $^{o}$C and SD at most 0.3 $^{o}$C, while the variability was less than that of monthly series with CV reaching 1.4%. The hottest season was in the spring (MAM) while the coldest was during summer (JJA). This result could be due to the temperature build-up that usually precedes the onset of raining season in the basin. In addition, given the agrarian nature of the area, the spring season coincides with the period of intense land preparation activities with less rainfall and irrigation which could also expose the basin to extreme daytime heating and thus increased temperature. For the annual temperature series, there was no much difference in the statistical characteristics of all the three series as they all shared the same SD (0.4 $^{o}$C) and very low variability (CV= 1.7%) as well, indicating more uniform temperature across the years. With respect to the periods of warming and cooling in the basin, the cooling period which persisted to 1978 reversed to a range of intensified warming since 1979, with 1975 being the coldest while 1998 was the warmest. This also agrees with the study of Sarr (2012) who reported increasing observed temperatures greater than the global warming since the 1970s over West Africa. Similarly, Vose *et al.* (2005) in their study of maximum and minimum temperature trends for the globe had earlier reported increasing temperature over the whole world between 1979 and 2004.

A generally significant increased warming of the basin has been obtained from the trend test in conformity with the increased warming observed towards the end of the last century (IPCC 2001) and its intensification in the 21st century (IPCC, 2007), especially for West Africa. The magnitude of change which ranged between 0.91 $^{o}$C/yr and 0.73 $^{o}$C/yr also agrees with the finding of Sarr (2012) who reported temperature rise of between 0.8 $^{o}$C/yr and 0.2 $^{o}$C/yr in West Africa since the end of the 1970s. Similar results have also been reported by other studies in Nigeria (e.g. Oguntunde *et al.*, 2012), while increasing trends have also been detected in air temperature in Turkey (Turkes and Sumer, 2004) and Serbia (Gocic and Trajkovic, 2013). Likely causes of this could be traced to the increased urbanization and industrialization across many cities in the basin since the late 1970s which also contributed to global warming. Increasing trends in air temperature series are caused by numerous factors such as global warming, improved urbanized area and changes in atmospheric circulation (Tabari *et al.*, 2011). Significant increasing trends in temperature can cause rise in evapotranspiration (Gocic and Trajkovic, 2013) which may increase irrigation water demand. Besides, rising temperature can lead to heat stress in animals causing drop in egg and milk production in poultry and dairy animals, respectively. In addition, high temperature can encourage the breeding of disease vectors and thereby cause increased spread of existing vector borne diseases.

Furthermore, the magnitude of increasing warming was found to be higher in TMIN than both TMEAN and TMAX indicating that warming during the nighttime has increased relative to daytime. Likewise, Oguntunde *et al*. (2012) also discovered a nighttime (TMIN) warming higher than the daytime (TMAX) over Nigeria. Similar higher significant trend in minimum temperature (TMIN) was reported over Italy (Brunetti *et al*., 2006), India (Kothawale *et al*., 2010) and Brazil (Rosso *et al*., 2015). In addition, Tabari and Hosseinzadeh Talaee (2011) also reported more warming trends in TMIN compared with those in TMAX series between 1966 and 2005 over the arid and semi-arid regions of Iran. Meanwhile, rising TMIN has been attributed to GHG effects caused by warming gases (Tabari and Hosseinzadeh Talaee, 2011).

On monthly scale, trends of temperature series are strongest during February and weakest in June in consistent with the result of Xu *et al*. (2010). While February falls within the hottest season, June is a month in the summer when the rainy season has fully commenced in the basin. Seasonally, significant warming trends have also been observed for all the four seasons in the basin. Moreover, increased magnitudes of warming during SON (autumn) were higher than those in other seasons. This is contrary to the findings of many other studies in other parts of the world (e.g. Xu *et al*., 2010; Sonali and Kumar, 2013). Increased warming in autumn can have both positive and negative impacts on agriculture. While it can hasten ripening and decomposition of fruits, it may also hamper dry season farming and reduce the production of fingerlings. Nevertheless, Gocic and Trajkovic (2013) reported similar high temperature trends in both autumn and spring seasons in Serbia. However, while the present result could be attributed to the temperature gradient that is created due to change of season from cold to warm, investigation into this could be the subject of further research. Trends on annual scale in all the series were significant and magnitudes of change ranged between 0.82 $^{o}$C/yr and 0.68 $^{o}$C/yr inferring an overall warming in the basin during the period under study. Although the annual trend is within the estimates for Africa (Hulme *et al*., 2001), the magnitude is relatively above the global average of 0.74 $^{o}$C (IPCC, 2007).

## 4.0 Conclusion

The study investigated the spatial and temporal trends of TMEAN, TMAX and TMIN over the NSB for the period 1948-2008. On the average, temperature has increased by about 0.83 $^{o}$C/yr while warming during the night has been greater than in the daytime. Trends of temperature series also exhibited strong warming over the entire basin since 1979 and in all the 12 months and seasons, but strongest in February and autumn, respectively. Increased warming in the basin has been further intensified since 2001 and more likely to continue in the same manner in consistent with the projection of IPCC (2001; 2007). Most changes that have been observed in the study can be attributed to the influence of global warming exacerbated by human impacts on the eco-environment in forms of urbanization, industrialization and agricultural activities. However, there is the need for further investigation to confirm if the results have been caused by change in climate or land use. Nevertheless, the study may serve as a basis for a detail investigation in order to understand climate change in the NSB.

## 5.0 Acknowledgements

The first author is grateful to the Management of Rufus Giwa Polytechnic, Owo and the Tertiary Education Trust Fund (TETFUND) Abuja, Nigeria for sponsoring the PhD research which produced this paper.

## References

Anghileri, D., Pianosi, F., and Soncini-Sessa, R. (2014). Trend detection in seasonal data: from hydrology to water resources. Journal of Hydrology 511: 171–179.

Bhutiyani, M.R., Kale, V.S., and Pawar, N.J. (2007). Long-term trends in maximum, minimum and mean annual air temperatures across the Northwestern Himalaya during the twentieth century. Climate Change 85: 159–177.

Brunetti, M., Maugeri, M., Monti, F., and Nanni, T. (2006). Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. International Journal of Climatology 26: 345–381.

Callaway, J.M. (2004). Adaptation benefits and costs: how important are they in the global policy picture and how can we estimate them? Global Environmental Change 14: 273–284.

Ceppi, P., Scherrer, S.C., Fischer, A.M., and Appenzeller, C. (2012). Revisiting Swiss temperature trends 1959–2008. International Journal of Climatology 32: 203–213.

Conway, D., Persechino, A., Ardoin-Bardin, S., Hamandawana, H., Dieulin, C., and Mahé, G. (2009). Rainfall and water resources variability in sub-Saharan Africa during the twentieth century. Journal of Hydrometeorology 10: 41–59.

Dinpashoh, Y., Jhajharia, D., Fakheri-Fard, A., Singh, V.P., and Kahya, E. (2011). Trends in reference crop evapotranspiration over Iran. Journal of Hydrology 399: 422–433.

Fu, G.B., Charles, S.P., Yu, J.J., and Liu, C.M. (2009). Decadal climatic variability, trends and future scenarios for the North China Plain. Journal of Climate 22: 2111–2123.

Gadgil, A. and Dhorde, A. (2005). Temperature trends in twentieth century at Pune, India. Atmospheric Environment 39: 6550–6556.

Gocic, M. and Trajkovic, S. (2013). Analysis of changes in meteorological variables using Mann-Kendall and Sen's slope estimator statistical tests in Serbia. Global Planetary Change 100: 172–182.

Hamed, K.H. (2008). Trend detection in hydrologic data: the Mann–Kendall trend test under the scaling hypothesis. Journal of Hydrology 349: 350–363.

Hasanean, H.M. (2001). Fluctuations of surface air temperature in the east Mediterranean. Theoretical and Applied Climatology 68: 75-87.

Hirsch, R.M., Slack, J.R., and Smith, R.A. (1982). Techniques of trend analysis for monthly water quality data. Water Resources Research 18(1): 107–121.

Hulme, M. Doherty, R., Ngara, T., New, M., and Lister, D. (2001). African climate change: 1900-2100. Climate Research 17: 145-168.

IPCC (2001). Summary for Policymakers. A Report of the Working Group I of the Intergovernmental Panel on Climate Change Geneva, Switzerland: Intergovernmental Panel on Climate Change.

IPCC (2007). Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In Climate Change 2007: Impacts, Adaptation and Vulnerability, Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press: Cambridge, UK; 976.

IPCC (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jhajharia, D., Dinpashoh, Y., Kahya, E., Singh, V.P., and Fakheri-Fard, A. (2011). Trends in reference evapotranspiration in the humid region of northeast India. Hydrological Processes 26: 421–435.

Kahya, E. and Kalayci, S. (2004). Trend analysis of streamflow in Turkey. Journal of Hydrology 289: 128–144.

Kielly, G. (1999). Climate change in Ireland from precipitation and streamflow observations. Advances in Water Resources 23: 141–151.

Kothawale, D. R., Revadekar, J. V., and Kumar, R.K. (2010). Recent trends in pre-monsoon daily temperature extremes over India. Journal of Earth System Science 119: 51–65.

Kumar, V., Jain, S. K., and Singh, Y. (2010). Analysis of long-term rainfall trends in India. Hydrological Science Journal 55: 484–496.

Mitchell, T.D., Hulme, M., and New, M. (2001). Climate data for political areas. Area 34(1): 109-112.

Mitchell, T.D. and Jones, P.D. (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25: 693–712.

Nasher, N.M.R. and Uddin, M.N. (2013). Maximum and Minimum Temperature Trends Variation over Northern and Southern Part of Bangladesh. Journal of Environmental Science & Natural Resources 6: 83-88.

National Population Commission (2006). The Nigeria Population Commission NPC Official Result for 2006 Population and Housing Census Figures. Bureau for National Statistics, Abuja, Nigeria. http://www.nigerianstat.gov.ng.

New, M., Hulme, M., and Jones, P.D. (2000). Representing twentieth century space-time climate variability. Part II: Development of a 1961–90 Mean monthly terrestrial climatology. Journal of Climate 13: 2217–2238.

Odjugo, A.O. (2010). Regional evidence of climate change in Nigeria.Journal of Geography and Regional Planning 3: 142-150.

Oguntunde, P.G., Abiodun, B.J., and Lischeid, G. (2012). Spatial and Temporal temperature trends in Nigeria, 1901-2000. Meteorology and Atmospheric Physics 118: 95-105.

Rosso, F.V., Boiask, N.T., Ferraz, S.E.T., Dewes, C.F., and Tatsch, J.D. (2015). Trends and Decadal Variability in Air Temperature over Southern Brazil. American Journal of Environmental Engineering 5(1A): 85-95.

Salmi, T., Maatta, A., Anttila, P., Ruoho-Airola, T., and Amnell, T. (2002). Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen’s Slope Estimates. Publications on Air Quality, No. 31. Helsinki, Finland, 25 pp.

Sarr, B. (2012). Present and future climate change in the semi-arid region of West Africa: a crucial input for practical adaptation in agriculture. Atmospheric Science Letters: 1-5.

Sen, P.K. (1968). Estimates of the regression coefficient based on Kendall’s tau. Journal of American Statistical Association 63: 1379–1389.

Sonali, P. and Kumar, D.N. (2013). Review of trend detection methods and their application to detect temperature changes in India. Journal of Hydrology 476: 212–227.

Tabari, H. and Hosseinzadeh Talaee, P. (2011). Analysis of trends in temperature data in arid and semi-arid regions of Iran. Global Planetary Change 79(1–2): 1–10.

Tabari, H., Shifteh Somee, B., and Rezaeian Zadeh, M. (2011). Testing for long-term trends in climatic variables in Iran. Atmospheric Research 100(1): 132–140.

Tao, H., Gemmer, M., Bai, Y., Su, B., and Mao, W. (2011). Trends of streamflow in the Tarim River Basin during the past 50 years: human impact or climate change? Journal of Hydrology 400: 1–9.

Tshiala, M.F., Mukarugwiza Olwoch, J.M., and Engelbrecht, F.A. (2011). Analysis of Temperature Trends over Limpopo Province, South Africa. Journal of Geography and Geology 3: 13-21.

Turkes, M., Sumer, U.M., and Demir, I. (2002). Re-evaluation of trends and changes in mean, maximum, and minimum temperatures of Turkey for the period 1929–1999. International Journal of Climatology 22: 947–977.

Türkes, M. and Sümer, U.M., (2004). Spatial and temporal patterns of trends and variability in diurnal temperature ranges of Turkey. Theoretical and Applied Climatology 77: 195–227.

UNFCC (2007). United Nations Framework Convention on Climate Change, United Nations Climate Change Conference, Nusa Dua, in Bali, Indonesia, 3rd- 5th December 15, 2007. http://unfccc.int/meetings/cop_13/items/4049.php.

Vose, R.S., Easterling, D.R., and Gleason, B. (2005). Maximum and minimum temperature trends for the globe: An update through 2004. Geophysical Research Letters 32: 1-5.

WMO (1988). Analyzing long time series of hydrological data with respect to climate variability. World Meteorological Organization (WMO): WCAP-3, WMO/TD-No: 224, Switzerland, pp. 1–12.

Xu, Z., Liu, Z., Fu, G., and Chen, Y. (2010). Trends of major hydroclimatic variables ithe Tarim River basin during the past 50 years. Journal of Arid Environment 74: 256–267.