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Regional climate model: Investigating the impacts of climate change on water availability in Nigeria

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Nigeria and the rest of African nations, despite the fact that they produce less than 4% of global greenhouse gas emissions, are considered the world's most vulnerable regions with regard to the effects of climate change due to the fragility of their economies. However, it is still very difficult to assess the extent of such changes and the specific environmental impacts particularly on water supply and management over most Africa nations due to poor technological development and inadequate research work on this topical subject. In this paper, the third version of the ICTP regional climate model (RegCM3) and the observed surface data were used to investigate the evidence of climate change over Nigeria in the past years (1958 to 2007) with a view to determining the impacts of climate change on the water supply and management - one of the key areas where the climate change impact is adjudged most. The results of the study showed that in the recent past, the region had been witnessing higher temperatures, increased fluctuations in annual rainfall and increase in the salinity of soils and large areas of surface and underground water due to the increasing aridity of the climate; inadequate water supply and control installations as well as intensified marine pollution which are inimical to the health of the millions of Nigerians particularly along the coast of the Atlantic ocean.

Key words: Climate change, impact, rainfall, temperature, water resources.

INTRODUCTION

Climate change is real and already happening. Average global surface temperatures has warmed 0.8°C in the past century and 0.6°C in the past three decades (Hansen et al., 2006), in large part because of human activities (IPCC, 2001). In fact that the last few decades of the 20th century were in fact the warmest in the past 400 years (National Research Council, 2006). The Intergovernmental Panel on Climate Change (IPCC) has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperatures will increase 1.4 to 5.8°C by the end of the 21st century (IPCC, 2001). The effects of climate change such as rising temperature and changes in rainfall are evident with attendant impacts already affecting ecosystems, biodiversity and people in Africa. This is especially true because of the lack of economic, development, and institutional capacity, Nigeria like other African countries are likely among the most vulnerable to the impacts of climate change (IPCC, 2001).

Arguably one of the most widespread and potentially devastating impacts of climate change in Africa will be changes to water quality and availability which will further define the path to be explored for sustainable water management in the country. Regional scale variation in natural climatic conditions (rainfall patterns and temperature) and local variation in soils generates spatial variation in "baseline" water quality and specific potential response to a given scenario of climate change. A warming climate is, in general, expected to increase water temperatures and modify regional patterns of

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rainfall, and these changes can have direct effects on water quality. However, a major challenge in attributing altered water quality to climate change is the fact that water quality is very sensitive to other non-stationary human activities, particularly land use practices that alter landscapes and modify flux of water, as well as thermal and nutrient characteristics of water. The most suitable and feasible approach to water management in the light of the predicted impacts of climate change on water resources may therefore be a focus on the quantity of water available for use by vulnerable populations. For water availability, concerns exist over altered frequency, intensity, and predictability of rainfall. Changes in regional rainfall will ultimately affect water availability and may lead to decreased agricultural production and potentially widespread food shortages.

Policy recommendations that promise adaptation strategies to vulnerable populations to the impact of climate change are based on laboratory-simulated models that relate several possible scenarios and outcomes. Although there are often associated technical inconsistencies owing to arrays of uncertainties that perplexes successful decision making, climate change models remain important tools that promote the birth of sustainable adaptation measures for scientific communities, policy decision makers and vulnerable populations alike. In this paper, the third version of the International Centre for Theoretical physics (ICTP) regional climate model (RegCM3) and the observed surface data were used to investigate the evidence of climate change over Nigeria in the past years (1958 to 2007) with a view to determining the impacts of climate change on the water supply and management - one of the key areas where the climate change impact is adjudged most.

MATERIALS AND METHODS

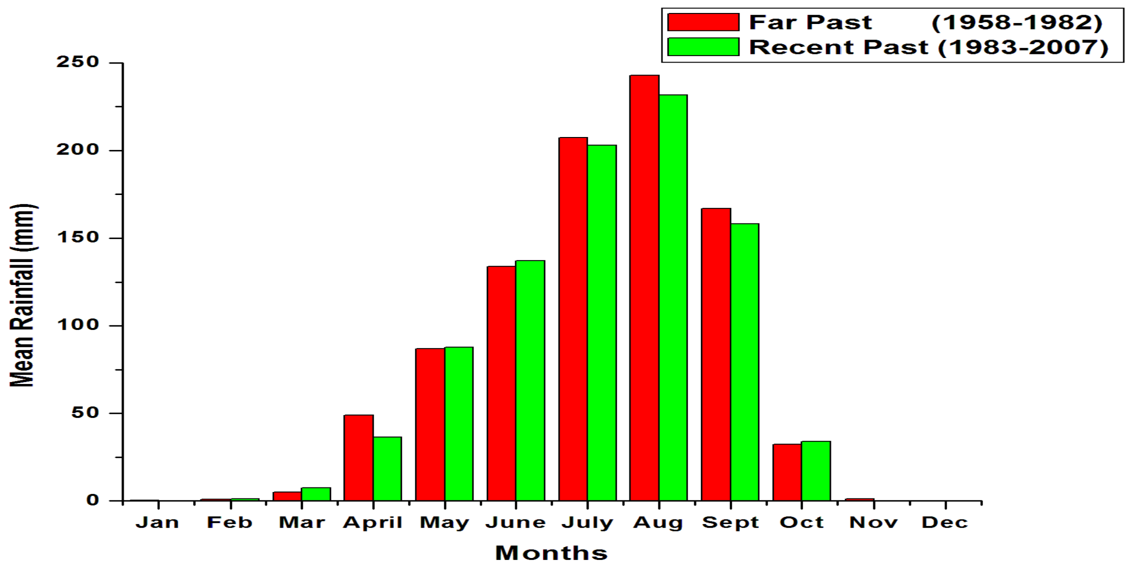
For this study, the observed surface data from the Nigerian Meteorological Agency (NIMET) between 1958 and 2007 as well as the RegCM3 simulations (as described in Pal et al., 2005) for 1981 to 1990 and 1995 to 2004 time periods were used to investigate the recent past climate change over Nigeria. The model configuration and physics options for the study were identical to that described in Afiesimama et al. (2006) and Omotosho and Abiodun (2007). Radiative transfer parameterization is represented by the package in the NCAR Community Climate Model, Version 3 (Kiehl et al., 1996), the biosphere-atmosphere transfer scheme (BATS) is as described by Dickinson et al. (1993) for the land surface processes and the Holtslag et al. (1990) scheme was used for planetary boundary layer parameterisation. For moist processes, the sub-grid explicit moisture and cloud scheme (SUBEX) developed by Pal et al. (2000) is adopted as is the Grell (1993) mass-flux based cumulus convection scheme with the Fritsch and Chappell (1980) closure. The model domain for the simulations was selected to be much wider than our focus region, Nigeria (2.3° E: 15° E, 2° N: 15° N). This was done to move the direct effect of boundary conditions far from the region of study, and also to capture important features that control the annual cycle of the West African monsoon and rainfall. The model horizontal resolution is 50 km. In the vertical, the model extends from surface to 70 hPa with 18 vertical log-spaced grid points. The numerical experiment uses the land cover as characterized by the United States Geological Survey (USGS) global land cover characterization (GLCC) Version 2 data. The model was integrated from 1981 to 1990 and 1995 to 2004 in order to cope with the large financial and technical expenses involved in the dynamical model simulations. The atmospheric initial and lateral boundary conditions from the US National Centers for Environmental Prediction-Department of Energy (NCEP-DOE) reanalysis version 2, 6-h interval datasets (Kalnay et al., 1996) were used. At the ocean surfaces, the US National Ocean and Atmosphere Administration Optimum Interpolation Sea Surface Temperature weekly data were specified (Reynolds et al., 2002).

The study examined the trends of the observed Nigerian climate over both the far past (1958 to 1982) and recent past (1983 to 2007). The seasonal mean temperature and rainfall amount over all the available weather stations in the northern part of Nigeria were computed. The same data analysis procedure was performed for the southern part of country and the results from the two distinct climatic zones were presented. Due to fact that the regional climate modelling is computer expensive and that the current situation of the electric power supply in the country was very poor, the RegCM3 could only be run for two periods of ten years each (that is, 1981 to 1990 and 1995 to 2004).

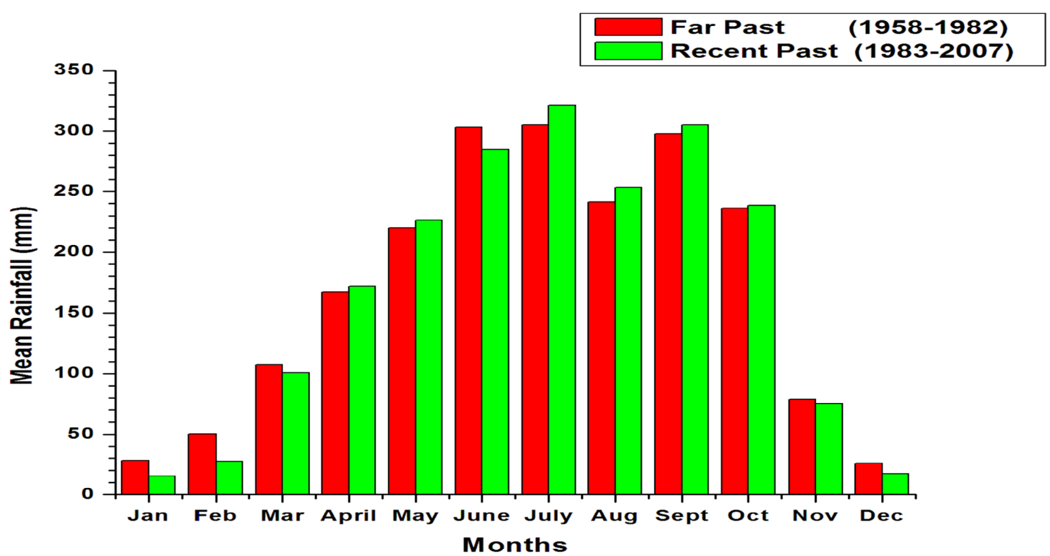
RESULTS

Figure 1 depicts the observed seasonal rainfall amount for the far (1958 to 1982) and near (1982 to 2007) time periods over the northern and southern parts of Nigeria. The figures show that the rainfall distribution during the observation period (1958 to 2007) over the northern parts of the country was bimodal with the peak value of about 240 mm in the month of August (Figure 1a). Over the south, however, the rainfall distribution was bimodal with the peaks in July (330 mm) and September (310 mm; Figure 1a). In addition, observation shows that rainfall amount was higher in the south than in the north and it rained throughout the year over the south. Similarly, Figure 2 shows the plots of seasonal mean surface air temperatures over the northern and southern parts of Nigeria as observed by NIMET. In the north, April was observed to be warmest (30°C) and January the coldest (23°C). However, it was coldest (26°C) in the months of July and August over the south and warmest (29°C) in March. Also, the annual range of the surface air temperatures was higher in the north (~7°C) than in the south (~3°C).

Furthermore, RegCM3 simulations for both the air temperatures and rainfall during the (1981 to 1990) and (1995 to 2004) time periods were presented in Figures 3 and 4 respectively. The figures show that RegCM3 adequately replicated the climate of Nigeria. In agreements with the observations, the northern parts of the country were warmer and drier than the south. Also, the percentage changes in temperatures and rainfall between 1981 to 1990 and 1995 to 2004 time periods were presented in Figure 5. The results indicated that the change in temperature was generally positive (0.2 to 0.6%) over the country. However, the warming was more



(a)



(b)

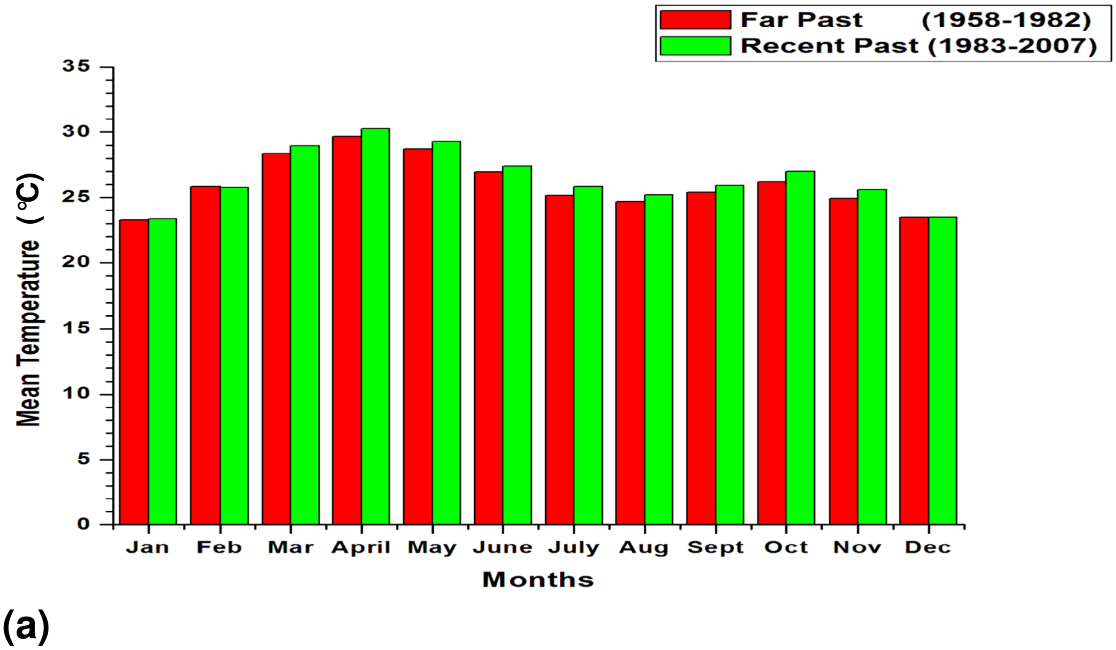
Figure 1. Observed seasonal rainfall over the (a) Northern and (b) Southern parts of Nigeria for Far (1958 to 1982) and recent (1983 to 2007) past.

in the northern parts than the south. Similarly, the rainfall amount was simulated to be increasing over the south (5 to 60%), particularly along the coastline, but decreasing over the north (5 to 20%).

DISCUSSION

Both the observed and RegCM3 dynamical model sufficiently describe the temperature and rainfall distributions over Nigeria. The results indicated that rainfall amount was higher over the south than in the north and it rained throughout the year over the south (Figure 1a and 1b). This was as a result of the fact that the strength of the Inter-Tropical Discontinuity (ITD) that principally responsible for rainfall over the region weakens as it migrates northward (Olaniran, 1983) due to surface friction. Similarly, the results showed that there was high variability in the seasonal rainfall amount. It was observed that the country was generally warm throughout the year but the warming increased from the south to north (Figure 2a and 2b).

Furthermore, evidences from this study suggested a change in the observed seasonal climate of Nigeria from



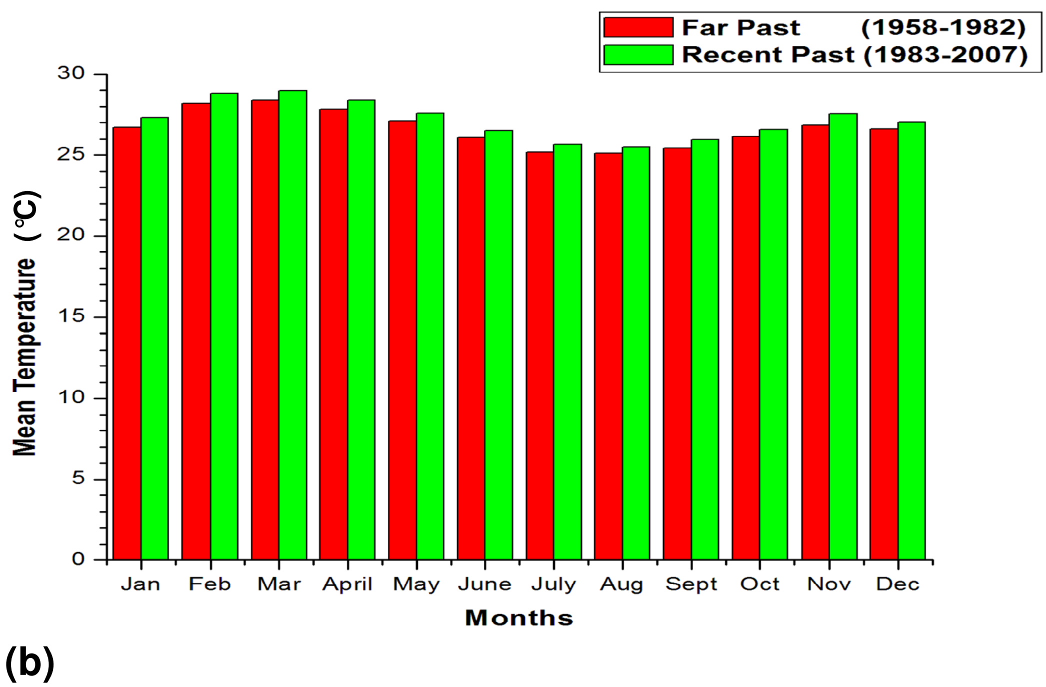


Figure 2. Observed seasonal surface air temperatures over the (a) Northern and (b) Southern parts of Nigeria for Far (1958 to 1982) and Recent (1983 to 2007) past.

1958 to 2007. Similarly, RegCM3 simulation suggests a change in both the annual rainfall amount and temperature over the country between 1981 and 2004. Comparison between the seasonal rainfall and temperature for the far (1958 to 1982) and recent (1983 to 2007) past indicated that the north was getting drier while the south becoming wetter particularly at the peaks of the raining seasons (Figure 1a and 1b). For example, there was about 20 mm reduction in the peak rainfall amount in August over the north (Figure 1a) while an increase of about 25 mm was observed over the south in the month of July (Figure 1b). Observations showed that while the north was generally warmer than the south, the country was generally getting warmer over the years. For example, temperature ranged between 23 and 31°C over the north but the range was between 25 and 28°C over

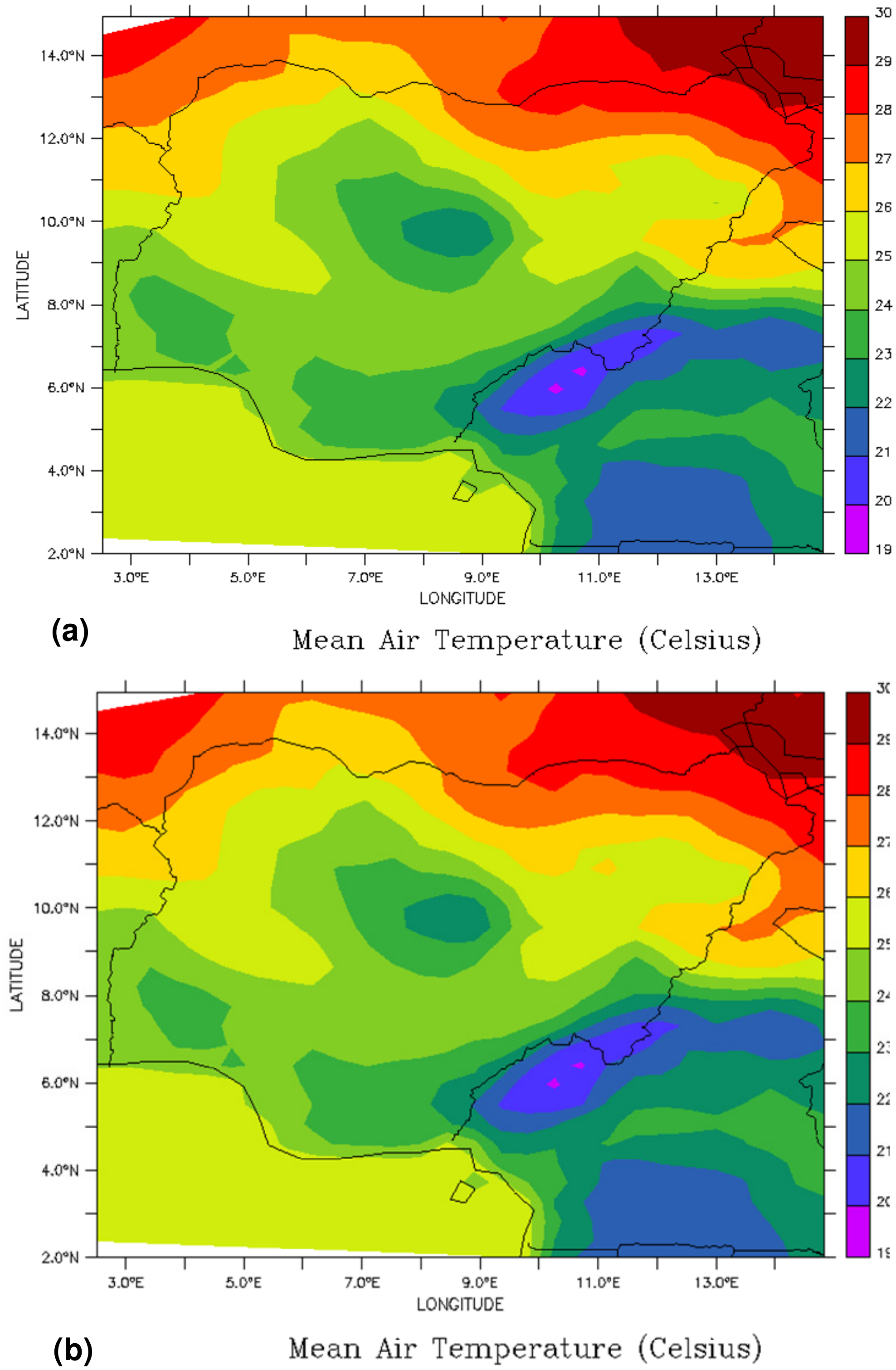


Figure 3. Simulated annual mean air temperature over Nigeria for (a) 1981 to 1990 and (b) 1995 to 2004 time periods.

the south (Figure 2a and 2b). Also, there was increase of about 1°C in all the months over the country during the period of observation. However, there were no changes in temperatures over the north from December to

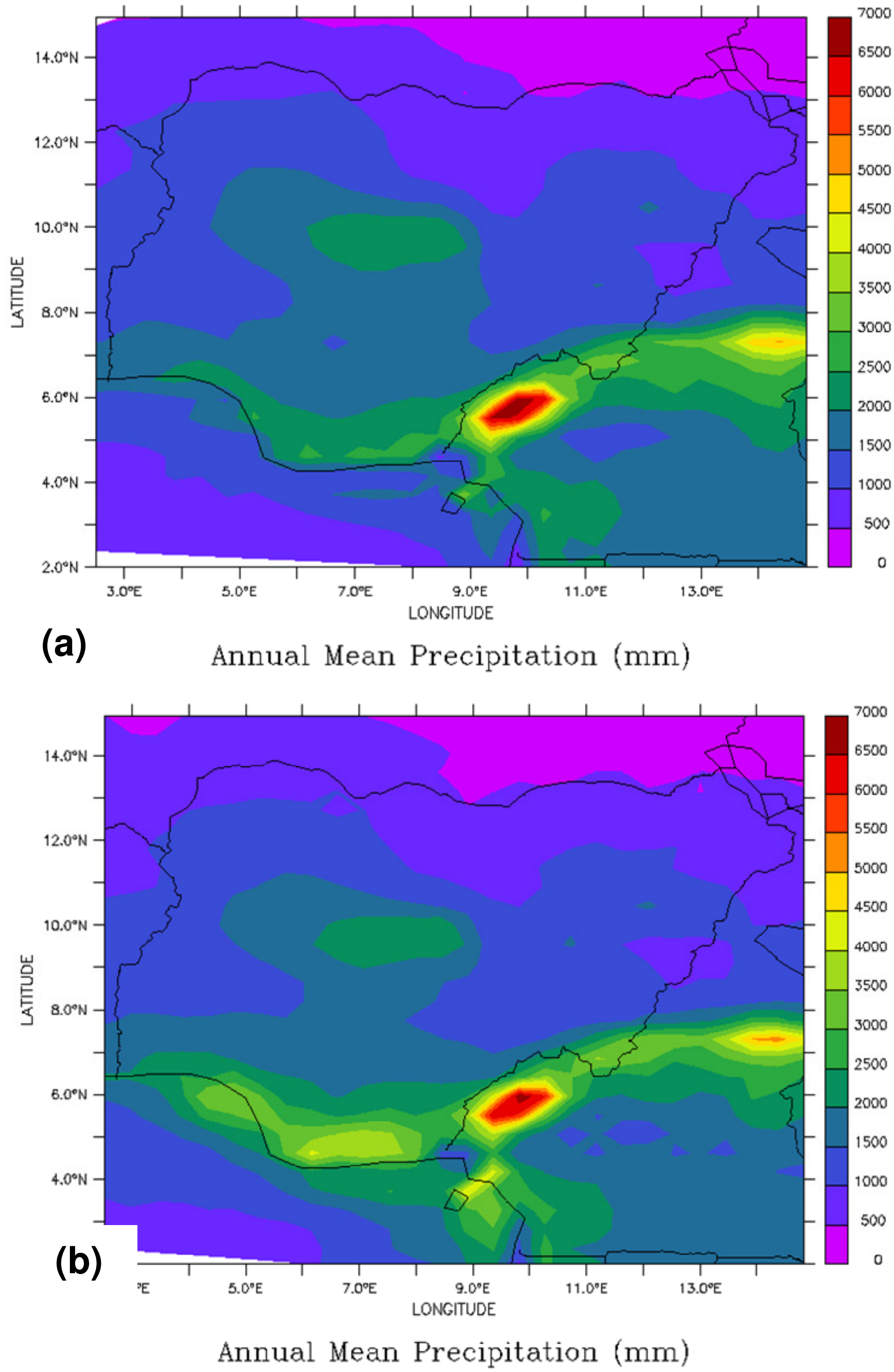


Figure 4. Simulated annual mean rainfall over Nigeria for (a) 1981 to 1990 and (b) 1995 to 2004 time periods.

February (Figure 1a). The relatively lower maximum temperatures observed over the south could be attributed to the inland flow of cold air from the Atlantic Ocean which invariably lowers the temperature in the coastline areas.

The plots of the model's output for both the

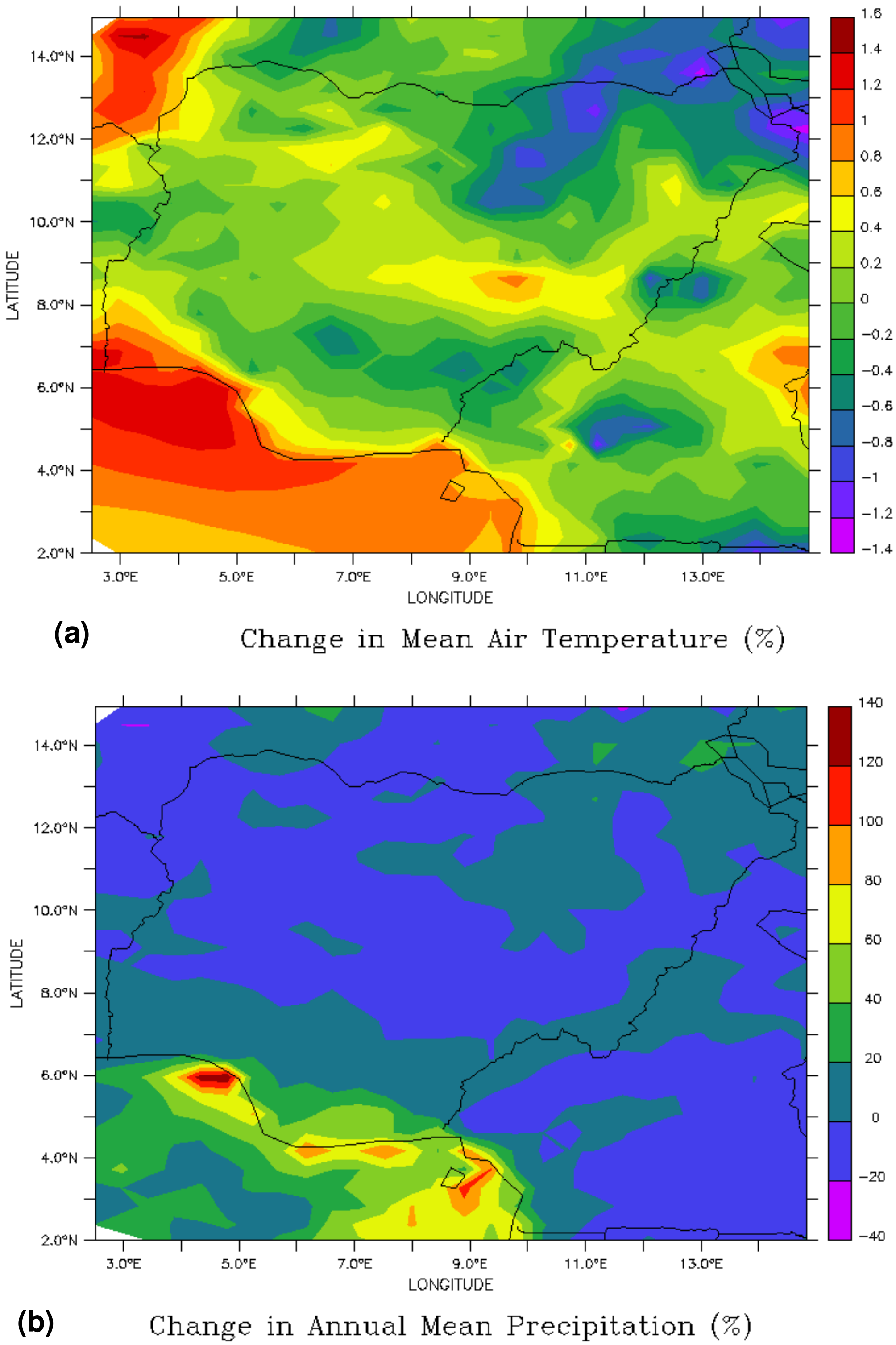


Figure 5. Change in simulated annual (a) mean air temperatures and (b) rainfall over Nigeria (1981 to 2004).

temperatures (Figure 3) and rainfall (Figure 4) during the selected time periods of simulations [(1981 to 1990) and (1995 to 2004)] were in agreements with the observations. The models confirmed that that the temperature was generally increasing over the country. For example, the results suggested that the change in temperature was generally positive (0.2 to 0.6%) over the country (Figure 5a). However, the model simulation showed that the warming was more in the northern parts than the south. Similarly, the rainfall amount was simulated to be increasing over the south (5 to 60%), particularly along the coastline, but decreasing over the north (5 to 20%; Figure 5b). The negative percentage changes in the rainfall over most parts of the north were suggestive of decrease in rainfall over the region and increase in rainfall amount over the southern parts particularly the coastline.

Thus, it can be deduced that the changing climate over these periods of time must have impacted water supply and management in Nigeria so greatly. Generally speaking, both RegCM3 simulations and the observed surface data used in this study established a changed Nigerian climate in the past years (1958 to 2007). The results of the study shows that in the recent past, the region has been witnessing higher temperatures, increased fluctuations in annual rainfall and increase in the salinity of soils and large areas of surface and underground water due to the increasing aridity of the climate; inadequate water supply and control installations as well as intensified marine pollution which are inimical to the health of the millions of lives (both plants and animals) inhabiting the region particularly along the Nigerian coastline in southern Nigeria.

For the far south where general increase was also noted for the recent and far past years, our findings also suggest a trend of increasing rainfall. Increased rainfall events will bring floods and increased erosion such as more 'gullies' and more silting in rivers. Increased floods and gullies and the silting of rivers will affect people living near or alongside water ways such as rivers and streams. It is glaring that Nigeria's low-lying coastline makes the country prone to sea-level water intrusion into coastal fresh water resources as Climate Change brings with it a rise in sea level that will seriously affect our coastline. Coastal erosion and flooding is not uncommon, and contributes to the “polluting” of fresh-water systems. The impact of changes in water resources will be overwhelming. Although not documented, local farmers attest to the fact that Climate change has brought about changes in rainfall patterns and variability, changes in water level and water volume in ponds, lakes, rivers and streams, and in the frequency of storms and drought. With increasing Climate Change and higher temperatures, the water volume in streams and rivers will change for the worse, drying up (for example the case of Lake Chad in north-east Nigeria) and contributing to poor sanitary and health conditions. Wetlands comprise a wide range of coastal and marine habitats such as estuaries, flood plains, freshwater marsh, peat lands, swamp forests, open coasts and lakes. They are rife with life and serve as important spawning grounds for fish, attracting migratory seabirds. The freshwater ecosystems are also home to diverse species of plants and fish-life. These fragile areas will be devastated by climate change.

The unique position of water in the world predicated the need for a search for sustainable alternative to conventional water resources, especially in the enhancement of subsistence farming (Gioda et al., 1993) as it affects resource poor rural families. The same position holds for the Nigerian situation. Sustainable water management systems that will address all the raised issues must therefore be water resources conserving, socially supportive, commercially competitive and environmentally sound. Natural resources abound in Nigeria. These include lands, rivers, underground water, rainfall and sunshine hours coupled with solid minerals. However, the life wire of this seemingly limitless resource is water because life becomes difficult and uncomfortable without it. Generally, the most prevalent challenge is that management of the resource rather than concerns with availability of the resource in Nigeria.

Climate Change is expected to exacerbate this situation. Currently Nigerians do not enjoy adequate water supply. This problem is more prominent and devastating in the northern areas of the country with its limited sources of water and harsh weather conditions. Results from our study revealed increases in mean surface temperature which consequentially would infer increased evapotranspiration. Our findings also reveal a general decrease in rainfall events especially for Northern Nigeria. Worse case scenarios will again infer increased occurrence and intensity of drought especially in Northern areas of the country.

Drought – the total absence of rain – for a very long time to the detriment of agricultural and other water-related activities is of concern in Nigeria. It drastically affects agricultural yield and it kills livestock (local farmers attest to the fact that two drought incidences in Nigeria in the 1970's and 1980's led to the death of millions of cows, goats and sheep, while food production was adversely affected). Drought also contributes to increased desert encroachment and excessive heat, both of which have an inescapable impact on humankind and the use of water in the ecosystem.

Currently, most of the foodstuff sold in cities in the south are largely cultivated in the Northern part of the country using a combination of rain — fed and irrigation — based agriculture. Arguably, it could be said that the North feeds the nation. From a holistic point of view, the amount of water allocated to agriculture and water management choices in such settings will determine, to a large extent, whether our society will achieve economic and social development and environmental sustainability. For both rain-fed and irrigated agriculture, the spatial and temporal variation of rainfall is very important. The short-term variability of rainfall is a major risk factor. Soil moisture deficits, crop damage and crop disease are all driven by rainfall and associated humidity. The variability in rainfall intensity and duration makes the performance of agricultural systems in relation to long term climate trends very difficult to anticipate. This is particularly the case for rain-fed production. Although the different climate change models are not clear with respect to rainfall and periods of drought, temperature projections are generally more reliable. Increased evaporation and evapotranspiration with associated soil-moisture deficits will impact rain-fed agriculture (Bates et al., 2008). Recent estimates show that for each 1°C rise in average temperature dry-land farm profits in Africa will drop by nearly 10% (FAO, 2008). In addition, increased evaporation of open water storage can be expected to reduce water availability for irrigation and hydropower generation (ODA, 2009).

Summarily, based on the aforementioned, water management in Nigeria is thus a critical component that needs to adapt in the face of both climate and socio-economic pressures in the coming decades. Changes in water use will be driven by the combined effects of (i) changes in water availability, (ii) changes in water demand for agriculture, as well as from competing sectors including urban development and industrialisation, and (iii) changes in water management.

Conclusions

Both the model outcomes of the third version of the ICTP regional climate model (RegCM3) and the observed surface data used in this study established a change Nigerian climate in the past years (1958 to 2007). The impacts of climate change on the water supply and management over the selected region were investigated and found to be greatly affected by the changing climate. Similarly, the results of the study showed that in the recent past, the region had been witnessing higher temperatures, increased fluctuations in annual rainfall and increase in the salinity of soils and large areas of surface and underground water due to the increasing aridity of the climate; inadequate water supply and control installations as well as intensified marine pollution which are inimical to the health of the millions of lives (both plants and animals) inhabiting the region particularly along the Nigerian coastline.

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