Modeling Climatic Variation Parameters of Nigeria Using the Statistical Downscaling Approach

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ABSTRACT

Climate unpredictability and change in climatic parameters have direct influence on environment and human existence. A negative change in the climate, always have its corresponding dysfunctional impacts on man and the ecosystem globally or locally. Flooding, poor agricultural yields, famine, and even death are some of the catastrophic effects of drastic climate change. Knowledge and information on the climatic variation parameters in an environment is very vital for environmental study assessment and proper planning. Therefore, the importance of knowing the future climatic variation parameters cannot be under-estimated.

This research was aimed at determination of the future climatic variation parameters of Nigeria for the next fifty years (2000-2050). Due to the complex and multidimensional nature of the variables involved, the parameters considered in the work were limited to temperature and rainfall. Statistical downscaling concept was adapted to the WORLDCLIM past and future data for 50years to obtain climatic parameters for Nigeria. Past temperature and rainfall data were also obtained from the Nigeria Meteorological Agency (NIMET) to check the validity of the past WORLDCLIM data at the national level. DIVA-GIS and Arc-GIS were basically used in this research. Further corrections were applied to the future WORLDCLIM data to model the future climatic variation parameters for Nigeria.

Polynomials were developed to represent the predicted climatic variation parameters of some parts of Nigeria, as case study. A database of the projected climatic variation parameters of all Local Government Areas in Nigeria was developed. Also, twelve (12) base-maps of Nigeria were created which attributes and depicts the predicted climatic variation parameters for every month. Results of future climatic prediction, 2000-2005, show that the Northern region will experience more decrease in rainfall even during wet season resulting in desertification while the Southern region will experience a reverse situation. The socio-economic consequences of the climatic variations were discussed. The results obtained provide advance information for various stakeholders to make adequate provision for the future.

1.0 INTRODUCTION

The most general definition of *climate change* is a change in the statistical properties of the climate system when considered over long periods of time, regardless of cause. Accordingly, fluctuations over periods shorter than a few decades, such as El Niño, do not represent climate change. On the broadest scale, the rate at which energy is received from the sun and the rate at which it is lost to space determine the equilibrium temperature and climate of Earth. This energy is distributed around the globe by winds, ocean currents, and other mechanisms to affect climates of different regions (Wikipedia, 2012; Awosika, Ojo and Ajayi, 1994; Ayoade, 1988; Buba, 2004),

Understanding the spatial and temporary variations in climate within a zone or region, and their relationships with other factors, is important in activities related to climate change and the management of the natural resources, such as environmental planning, land-use planning, watershed management and territorial ordering (Zuviría, 2011).

According to Tamuno (2009), there are two major causes of climate change, namely: anthropogenic and natural. Anthropogenic causes relate to those activities of man which help to change the chemical composition of the atmosphere as they relate to increasing the volume of greenhouse gases like Carbon dioxide (CO_2), Methane (CH4), Sulphur Dioxide (SO_2), etc. While the natural causes of climate change are based on: (a) Terrestrial (Earth) causes which are affected through- Changes in the distribution of land and water surface, Changes in the earth's topography, Changes in atmospheric chemistry and Changes in the cryosphere; (b) Astronomical causes (Milankovitch theories) which are effected through- Changes in the eccentricity of the earth's orbit, Changes in the precession of the equinoxes and Changes in the obliquity of the plane of ecliptic; (c) Extra terrestrial causes effected through- Variations in the solar radiation amount and Variation in the absorption of solar radiation outside the earth's atmosphere. The combined effects of the anthropogenic and natural causes actually bring about climate change in the ratio of about 60:40 respectively.

There has been growing awareness that the earth's climate is changing at an alarming rate and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007) affirms that climate change is no longer in doubt but is now unequivocally apparent based on evidence from scientific observations of increases in global average air and ocean temperatures (Odjugo, 2010; Porbeni, 2004).

Researchers have shown that Nigeria is already being plagued with diverse ecological problems, which have been directly linked to the on-going climate change. The most crucial things about the concept of climate change is not only the time periods involved but also the degree of variability that the change is subjected to as well as the duration and impact of such variability on man and the ecosystem (Odjugo, 2010; Kalkstein and Vailimont, 1987; McQuire, Macon, Kilburn, 2002; Nwafor, 2006).

This paper discussed a research on modelling future (predicted) climate of Nigeria from 2000 – 2050 using Geographic Information Systems (GIS). Present climate data from WorldClim Model (1950-2000) were downscale and compared with Present national climate data from Nigeria Meteorological Agency (NIMET) (1950-2000). The differential was applied to the Future WorldClim Model (2000-2050) to obtain Polymonial for predicting Future Temperature and Rainfall change for any part of Nigeria (2000-2050). Results revealed that the Future Range of the Changes in Rainfall and Maximum Temperature are between -192 to 198 (mm) and -1.59 to 2.48 (°C) respectively. The socio-economic consequences of the climatic variations were discussed. Analysis on the possible effects of the predicted temperature and rainfall change were made.

2.0 STUDY AREA

The total area of Nigeria is 923,768km² of which 910,768km² is land, while water takes up 13,000 km². Nigeria's total boundaries are 4,047km in length. The border with Benin is 773 km, with Cameroon is 1,690km, Chad's is 87km, and Niger is 1,497km. Nigeria's climate is characterized by strong latitudinal zones, becoming progressively drier as one moves north from the coast. Nigeria's climate is marked by two seasons, dry and rainy seasons, the dry season is also known as Harmattan (Wikipedia, 2012; The Library of Congress Country Studies, 1991).

3.0 METHODOLOGY

In this research, the following methodology was adopted:

3.1 Data Acquisition

Present and Future climate data were acquired from WORLDCLIM model and Nigeria Meteorological Service (NIMET).

Worldclim Model Data: Worldclim data was chosen and downscaled from Global Circulation Models. The data were in .clm and .cli formats and the database can be accessed through Diva-GIS. The datasets obtained were:

- Present Climate (Minimum Temperature, Maximum Temperature, Mean temperature, Precipitation) 1950-2000.
- Future Climate (Minimum Temperature, Maximum Temperature, Mean temperature, Precipitation) 2000-2050.

Meteorological Climate Data: Data was acquired from Nigeria Meteorological Service (NIMET), Oshodi Lagos State. The data obtained were from four meteorological stations (Lagos, Owerri, Port Harcourt, Bauchi). The datasets includes:

- Maximum and Minimum Temperature (1950-2000)
- Rainfall (1950-2000)

The maximum and minimum temperatures were in degree Fahrenheit, but were converted to degree Celsius, and the rainfall was in Inches, but was converted to Millimeters.

3.2 Data Processing

The datasets from Worldclim (*.clm* and *.cli* files) were opened in DIVA-GIS, to extract the Bioclim world maps in grid file. This was carried out for both the present and future climate data. A gridfile consists of two separate files .*GRI* and .*GRD*, both integrated in DIVAGIS as one file. The .GRI file has the actual data, and the .*GRD* file has metadata and a number of parameters that are needed to read the .GRI file properly.

In creating the raster maps, the climate database was specified i.e. Present dataset (1950-2000) and Future dataset (2000-2050). The climate grid maps were created by selecting the desired parameters such as minimum, mean and maximum temperature and rainfall as output, for the different months in a year. This made a total of ninety-six (96) grid maps created. The grid (raster) maps created were converted to shape-file, World, which is the dominant file format used for spatial data analysis.

3.2.1 Data Manipulation in ArcGIS

Using Arc-catalog, the various shape-files, World, were based on Geographic Coordinate System (GCS), WGS 1984. Nigeria boundary map was overlaid on the shape-files to query regions within its boundary. The various Average Temperature and Rainfall for each Local Government Area (LGA) were extracted and exported to Microsoft Excel.

3.2.2 Working with Meteorological Data

The data obtained from NIMET were daily data of minimum temperature, maximum temperature, and rainfall for the four different stations over a period of 50 years (1950-2000). Monthly data were obtained by averaging the daily data for temperature data and summation for the rainfall data. For the various stations, the local data from NIMET was compared with the present climate data obtained from Worldclim model, and analysis were carried out using Microsoft Excel.

3.2.3 Modelling Nigeria's Future Climatic Variation Parameters

When the present NIMET data (1950-2000) obtained from the meteorological stations were compared with that obtained from the Worldclime model, the model was confirmed to be very close (Figures 1-3). Therefore, the local climate (NIMET) data validated the Worldclim model data. The differentials were randomly applied to the future temperature and rainfall from the Worldclim model to obtain the database for the future temperature and rainfall for Nigeria (Figure 5).

From the database obtained for the various climatic parameters and exported to Microsoft Excel, polynimials were derived with their R^2 value from the Best-Fit trendlines (Figure 4).

4.0 RESULTS AND ANALYSIS

4.1 Comparison of Worldclim Data and Local Metro Data (NIMET)

Sample results of the comparison between the Past NIMET Bauchi data (1950-2000) and the past temperature and rainfall of the Worldclime data model are shown in Figures 1-3.

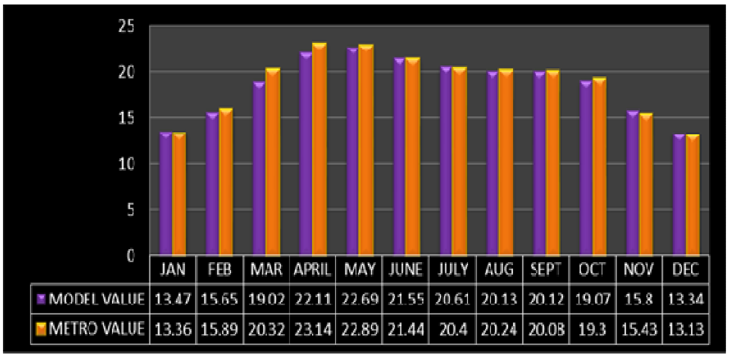

Figure 1. Comparison between Worldclim and Meteorological (NIMET) data of Bauchi Minimum Temperaure (℃).

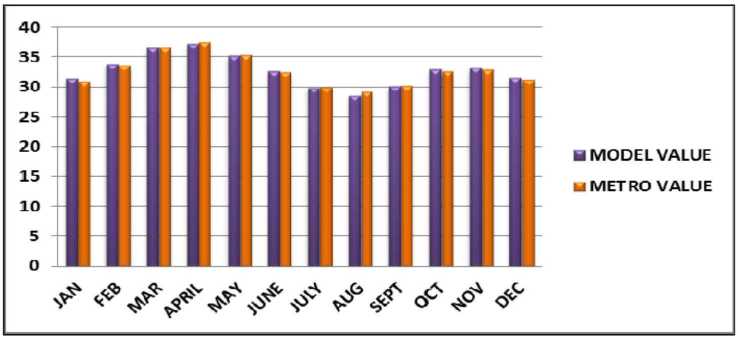

Figure 2. Comparison between Worldclim and Meteorological (NIMET) data of Bauchi Maximum Temperaure (℃).

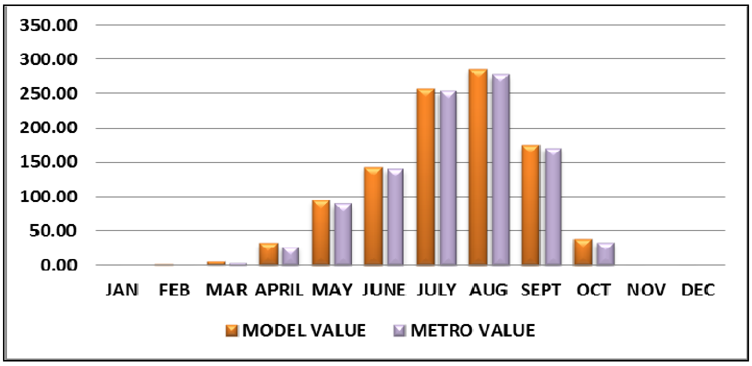

Figure 3. Comparison between Worldclim and Meteorological (NIMET) data of Bauchi Rainfall (mm).

4.2 Modelling Future Climate Base-map

For the Future Bauchi Maximum Temperaure, a Polynomial of Order 6 gave the “Best-Fit” as shown in Figure 4.

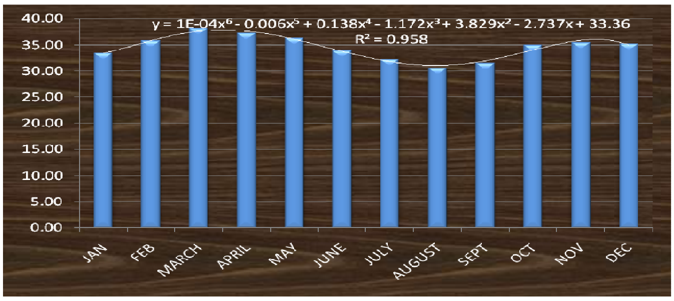

Figure 4. Model of Bauchi Future Maximum Temperature (°C)

The equation of the model is:

$y = 1E\text{-}04x^6 - 0.006x^5 + 0.138x^4 - 1.172x^3 + 3.829x^2 - 2.737x + 33.36$

where: $R^2 = 0.958$

R^2 represents the root mean square, which is approximately equal to 1. This indicates the fitness of the trend-line. ‘Y’ represents the output, maximum temperature; and ‘X’ represents the input for the all the months, January to December.

Models were also developed on other factors such as minimum temperature and rainfall, for other states and selected local governments. These model gives a clearer description of the trend in the climatic factors through the year.

The spatial joining of the different climate maps of each month resulted in the production of twelve (12) base maps. For every Local Government Area (LGA), base maps for each month with the following attributes were created:

1. Mean Temperature 2. Minimum Temperature
3. Maximum Temperature 4. Rainfall (Precipitation)

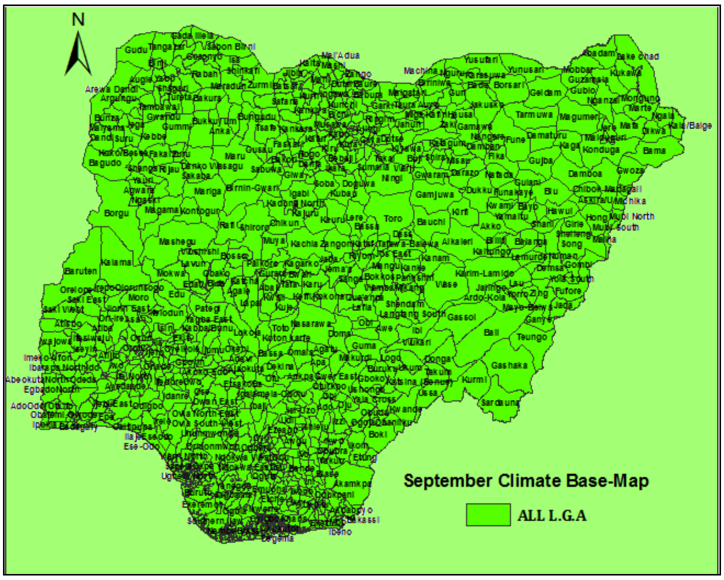

Figure 5. Future September Base-map for Nigeria.

Figure 5 represents a base-map of all the future climate (mean, maximum, minimum temperatures and rainfall) of Nigeria for the month of September. From the above base-map, any local government area in the country can be queried to obtain its respective climate data.

For the month of April, Future Nigerian Climate maps (Minimum, Maximum, Mean Temperatures and Rainfall), for all the Local Government Areas (LGAs), were created (Figures 6a – 6d).

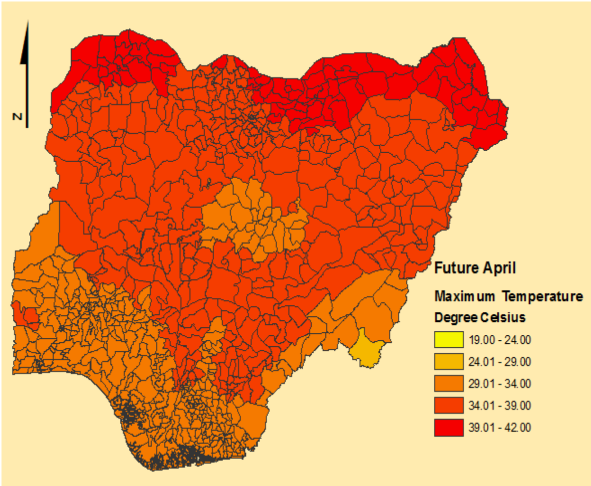

Fig. 6a. April Future Minimum Temperature.

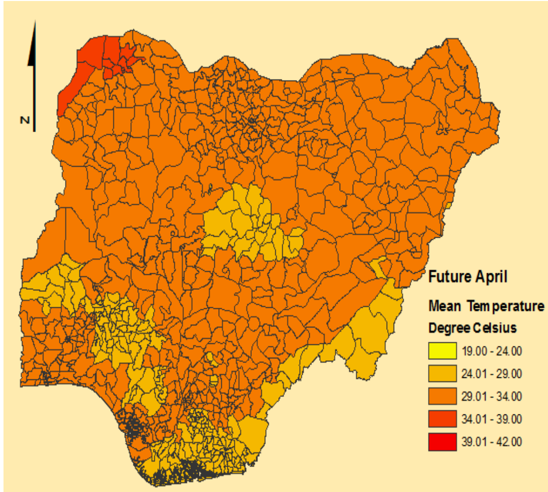

Fig. 6b. April Future Mean Temperature.

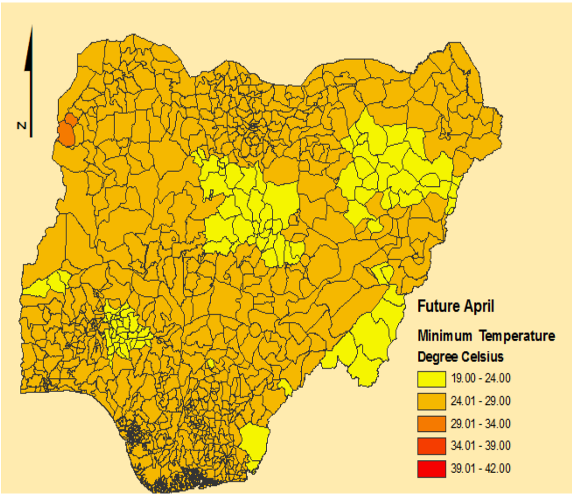

Fig. 6c. April Future Maximum Temperature.

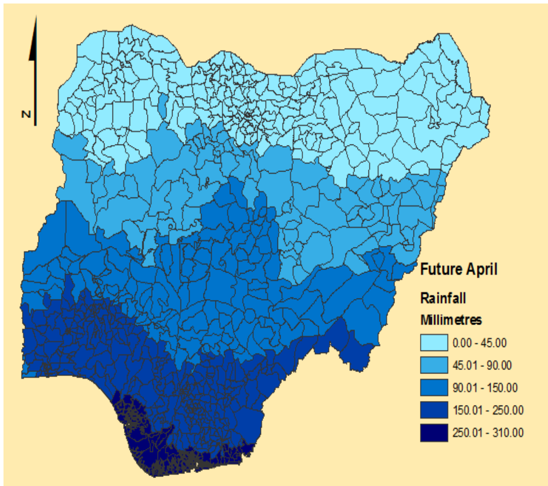

Fig. 6d. April Future Rainfall.

Figures 6a - 6d show the future maps of the different climatic factors, for the month of April. This was also achieved for all months , making a total of 48 maps produced.

4.3 Predicted Changes in Future Rainfall and Maximum Temperature for Nigeria

From the final climate base-maps for the future, changes that will occur over time in temperature and rainfall were calculated. These changes in Rainfall and Temperature were obtained by determining the differences between the past and the future Rainfall and Maximum Temperature.

Table 1. Range of the Changes in Rainfall and Maximum Temperature.

MONTH	Range of Rainfall Change (mm)	Range of Max Temperature Change (°C)
JANUARY	-1 to 32.5	0.7 to 2.2
FEBRUARY	-1.9 to 7.8	-0.5 to 2.15
MARCH	-10 to 63.9	0.1 to 2.22
APRIL	1.2 to 73.5	-1.59 to 1.74
MAY	-24 to 60.4	-0.08 to 2.03
JUNE	-192 to 198	-0.84 to 1.32
JULY	-117 to 144	-0.2 to 2.48
AUGUST	-98 to 89	0.55 to 3.32
SEPTEMBER	-88 to 70.5	0.32 to 1.56
OCTOBER	-50 to 159	0.39 to 2.33
NOVEMBER	-4.3 to 128.5	0.13 to 2.3
DECEMBER	0 to 105.16	0.7 to 2.2

Table 1 describes the Range of Changes in Rainfall and maximum Temperature for every month in every part of the country. The negative sign indicates a decrease while the positive sign indicates an increase. Maps indicating these changes, not range of changes, were also created (Figures 7a – 7b).

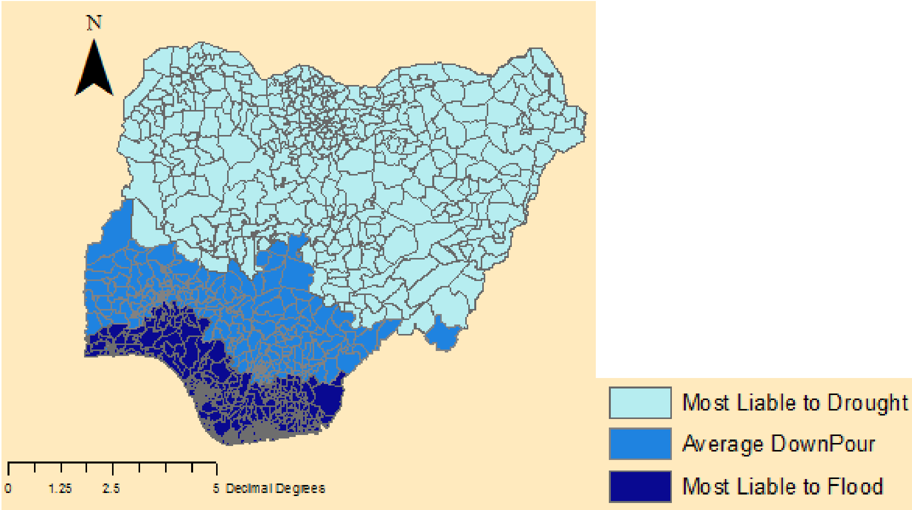

Figure 7a. Map showing Projected Distribution of Rainfall

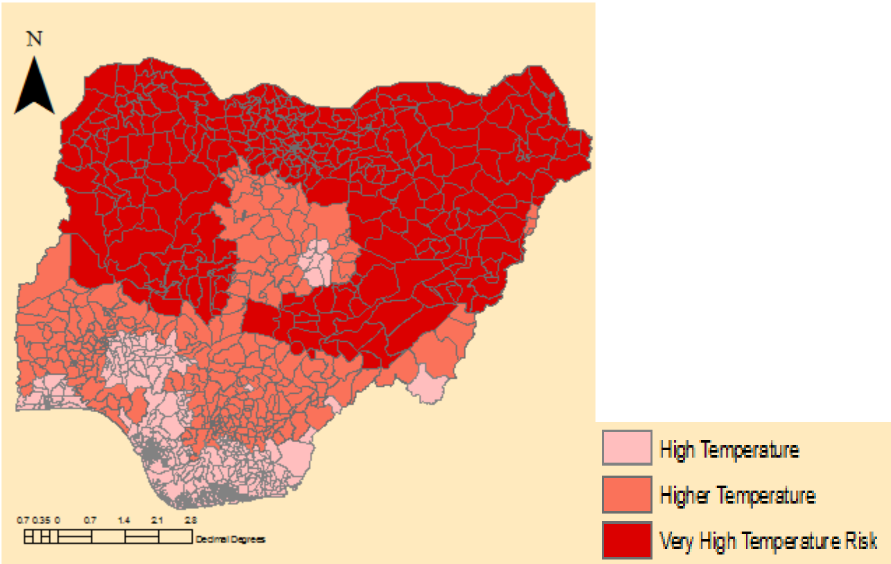

Figure 7b. Map Showing the Projected Maximum Temperature

5.0 ANALYSIS

With respect to the predicted changes in Rainfall and Temperature in Nigeria, for 2000-2050, the following analysis could be made:

(1) From the Rainfall-Change Maps, there will be both decrease and increase in rainfall in different parts of the country. The Northern regions will experience more decrease in rainfall during the wet season while the Southern regions will experience more increase in rainfall during the wet season too.

(2) The MaximumTemperature-Change Maps indicate a general increase in temperature in every part of the country.

(3) During the wet season, especially between the months of April and October, areas along the coast will experience an average monthly increase of 100mm rainfall. These areas include: Eti-Osa and Ibeju-Lekki in Lagos State, Ogun Water-side in Ogun State, Ilaje Ese-Odo in Ondo State, Warri-South in Delta State, Ijaw in Bayelsa State, Bonny in Delta State, Ibeno in Akwa-Ibom State and Akpabuyo in Cross-River State, as shown in Figure 7a.

(4) Also Figure 7a shows areas in the Northern region that will experience an average monthly decrease of 90mm in rainfall, between the months of June and September. This region covers every part of North-West, 95% of North-East and 50% of North-Central.

(5) Figure 7b shows the variation in Maximum Temperature of different parts of the Country. During the Dry season, areas marked 'Very High Temperaure Risk' indicates regions with maximum temperature of above 37 degree Celsius (°C). This region covers every part of North-West, 80% of North-East and 30% of North-Central.

6.0 CONSIQUENCIES OF CLIMATE CHANGE

(1) The increase in rainfall, especially along the coastal areas may experience the following possible effects:

- Increase in Sea-level and Inudation of wetlands and low-lying lands along Nigerian coast.
- Erosion of beaches such as Ibeno Beach in Akwa-ibom, Coconut Beach in Badagry, Lekki and Eleko Beach in Lagos island, and the Bar Beach.
- There may be intensified flooding of coastal areas such as Badagry, Eti-osa, Ibeju Lekki in Lagos State, Burutu, Warri South-West in Delta State, Ekeromor, Southern Ijaw,

Nembe, Brass in Bayelsa State, Bonny, Akakutor in Rivers State, Ikot Abasi, Eket, Ibeno, Mbo in Akwa-Ibom, and Akamkpa in Cross-River during storm.

- Increase in salinity of rivers, bays such as Tarkwa Bay along Lagos Habour and groundwater.

(2) Health

- The body responds to thermal stress by forcing blood into peripheral areas to promote heat loss through the skin, therefore health disorders are expected at higher temperature. Regions with very high temperature risk such as Sokoto, Bauchi, Zamfara, Katsina, Kano, Jigawa, Niger, will likely experience high rate of morbidity. Medical disorder such as heart failure, bronchitis, peptic ulcer, adrenal ulcer, glaucoma, goiter, eczema, and herpes zoster are liable to these regions.
- In areas along the coast with high risk of intensified flooding, there will likely be risk of some infectious diseases, particularly those diseases that are spread by mosquitoes and other insects.

(3) Drought- Nigeria as a nation may experience the following drought in future:

(a) Economic

- Loss of national economic growth, slowing down of economic development, damage to crop quality, less food production, increase in food prices, Increased importation of food (at higher costs), insect infestation, plant diseases, loss from dairy and livestock production, unavailability of water and feed for livestock which leads to high livestock mortality rates, increased predation, range fires and wild land fires, damage to fish habitat, loss from fishery production, income loss for farmers and others affected,
- Unemployment as a result of production declines, loss to recreational and tourism industry, loss of hydroelectric power, loss of navigability of rivers and canals.

(b) Environmental and Social

- The Northern region may witness an increased desertification, damage to animal species, reduction and degradation of fish and wildlife habitat, lack of feed and drinking water, disease, Increased number and severity of fires, wind and water erosion of soils.

Food shortage, heat, mental and physical stress, water user conflicts, social unrest, inequity in the distribution of drought relief, loss of cultural sites, reduced quality of life which leads to changes in lifestyle, increased poverty and population migrations.

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This research was carried out to be able to predict what the future weather, temperature and rainfall, conditions will be in Nigeria for the next 50 years (2000-2050). From the work, climate change scenarios indicate that the climatic variability currently being experienced is likely to increase and intensify in future. Droughts, floods and storms are likely to increase in both frequency and intensity.

By this prediction, Nigeria will fit into the following categories of extreme events:

- Warmer and more frequent hot days and nights over most land areas;
- Warm spells/heat waves-frequency increases over most land areas;
- Heavy precipitation events-frequency (or proportion of total rainfall from heavy falls) increases over most areas; and
- Area affected by droughts may increase.

The on-going climate change and its associated global warming are expected to cause characteristic climate patterns in different climatic regions and will have its negative impact on the ecosystem. Therefore, changes in climate factors such as temperature and rainfall should not be taken for granted.

7.2 Recommendations

In general, Nigeria like many developing nations, will need to prepare adequately for the negative impact of climate change. All hands must be onboard in order to achieve a positive result in combating adverse change in climate. Government agencies, private sector, civil societies, communities and individuals must be involved. Researchers must be involved in modeling climate change periodically, government agencies must create the awareness through information dissemination including early warning, financial and logistic supports, while the local communities must cooperate with other stakeholders.

It is therefore recommended that:

- the various projected climate maps and database developed, should present a platform for all concerned disciplines to better understand our climate system and to offer a means to access, plan and implement sustainable programs that will assist in combating these changes and to make our nation less vulnerable, and
- as more climatic data are available, further research needs to be carried out to model variations based on decades, yearly, monthly and daily.

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