GEOSPATIAL ANALYSIS AND MAPPING OF ANNUAL WEATHER VARIATION EFFECT ON SORGHUM YIELD

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ABSTRACT

Agricultural production in Nigeria like other developing countries is highly vulnerable to climate variability. Taking the effect of weather variability on the yield of sorghum into consideration and the difficulties attached to it, there is the need for an integrated method of the GIS modeling system to allow agricultural producers as well as policymakers to know the impact of spatial-temporal variation of weather on sorghum yield for better profitability, management and productivity. The study analyzed rainfall and temperature variations with sorghum yield data covering the period of 1991-2012 in seven states in North Central Nigeria namely Benue, Kogi, Kwara, Nasarawa, Niger, Plateau State and The Federal Capital Territory Abuja. Data on sorghum yield, rainfall and temperature cover only 22 years. This study used GIS (geographical information system) to examine the impacts of temperature and rainfall variation on the production of sorghum in North Central Nigeria. The results revealed that sorghum production correlated highly with rainfall amount, climatic variables examined have the impact to a certain limit on the selected crop yield in the study area. The GIS revealed that sorghum production and yield could be explained by the climatic variables examined. Nasarawa State recorded the highest correlation with a value of 1.59 and Niger state had the lowest correlation with an average value of -0.27 the highest record of rainfall occurred in 1993 with the volume of 1930.4 cm with the highest temperature in 2005 reading 68°C. The implication of the findings for sustainable agricultural development is discussed in the concluding part.

Keywords: *Climate change; Crop yield; GIS; Temperature; Rainfall*

INTRODUCTION

All life on earth, water, energy resources, agriculture, vegetation, air quality and sea level are significantly influenced by climate change and variability (US Geological Survey, 2007). Geologically, life has existed on planet Earth for approximately four billion years. During this time, the climate has swung between ice ages and warm periods. The Earth's atmosphere has generally been in chemical balance and the increasing global demand for energy and natural resources to meet the need of the ever-growing population is believed to be upsetting this atmospheric balance (Warner, 2007), and thus giving rise to climate change. Various studies by the Intergovernmental Panel on Climate Change (IPCC) suggest a discernible human influence on global climate change. Thus, climate change and variability have received increased global attention in the last three decades. This is largely due to the risk it poses to the environment and hence the global community.

Africa is distinctive in the combination of climate-change effects. Agriculture is the largest single economic activity in Africa, accounting for around 60 per cent of employment and, in some countries, more than 50 per cent of GDP. However, over the past half-century, Africa’s economies have not displayed a high degree of adaptability. Although households have considerable experience of coping with temporary shocks, such defensive flexibility has not been combined with sustained ability to adapt to new circumstances or adopt new technologies. The temperature trend in Nigerian since 1901 shows an increasing pattern as the increase was gradual until the late 1960s and this gave way to a sharp rise in air temperatures from the early 1970s, which continued until date. The mean air temperature in Nigeria between 1901 and

2005 was 26.6^{o}C while the temperature increase for the 105 years was 1.1^{o}C; this is higher than the global mean temperature increase of 0.74^{o}C recorded since 1860 when actual scientific temperature measurement started (Spore 2008; IPCC 2007). If this trend continues unabated, Nigeria may experience between the middle (2.5^{o}C) and high (4.5^{o}C) risk temperature increase by the year 2100. Climate variability influences weather elements such as temperature, rainfall, relative humidity, wind speed and direction. Rainfall trend in Nigeria between 1901 and 2005 shows a general decline within the 105years, rainfall amount in Nigeria dropped by 81mm. The declining rainfall became worst from the early1970s, and the pattern has continued to date (Odjugo, 2007). This is clear evidence of climate change because a notable impact of climate change is, increasing rainfall in most coastal areas and decreasing rains in the continental interiors (IPCC 1996; NEST 2003). According to Odjugo (2007), it was observed that the number of rain days dropped by 53% in Northeastern Nigeria and 14% in the Niger-Delta Coastal areas. These studies also showed that while the areas experiencing double rainfall maximally is shifting southward; the short dry season (August Break) is being experienced more in July as against its normal occurrence in August before the 1970s. These are major disruptions in climatic patterns of Nigeria showing pieces of evidence of a changing climate Rainfall has been seen as the most important factor in crop production in Nigeria. Some of the important factors guiding rainfall to crop include; the number of rainy days, time of fall, the total amount of fall and the type of soil. According to Olaoye (1999), regular occurrence of drought because of erratic rainfall distribution and/or cessation of rain during the growing season reduce Nigeria's capability for increased crop production. Temperature affects cereal production by controlling the rate of physio-chemical reaction and rate of evaporation of water from crops and soil surface (Ismaila *et al.,* 2010).

Description of sorghum

Sorghum (*Sorghum bicolor L moench*) is one of the most important staple crops in Nigeria and is the most important cereal food in the Northern states that covers the guinea savannah ecological zone (FAO, 2003). Sorghum is the major cereal consumed by the majority of the population (NAERLS, 2007). Its morphological and physiological characteristics contribute to its adaptability to drought conditions, including an extensive root system, waxy brooms on the leaves that reduce water loss, ability to stop growth in periods of drought and to resume when conditions are favourable, and tolerance to water logging (Oyedipe, 2001). Effects of heat stress on sorghum include reduced tile ring, reduced height, reduced spikelet number, sterility and reduced grain filling (Nguyen, 2006). Lack of basic knowledge on the effect of climate change and variability on crops still exist in Nigeria. This study assessed the effect of climatic variation (temperature and rainfall) on the yield of sorghum in North-central Nigeria using geospatial tools.

Objectives of study

The objectives of the study were to assess and analyze rainfall and temperature variation data withsorghum yield from 1991 to 2012 in North Central Nigeria to evaluate the effect of the rainfall and temperature variation on the yield of sorghum in North Central, Nigeria and thereafter develop yield maps of sorghum for the study area.

MATERIALS AND METHOD

Description of the study area

The North-central zone of Nigeria has a land area of 296, 898 km^{2} representing nearly 32 percent of the country's total land area (NBS, 2008). There are six states in the zone and the FederalCapitalTerritory, Abuja. The States include Benue, Kogi, Kwara, Nasarawa, Niger and Plateau. This geopolitical zone is situated between latitudes 6° 30" – 11° 20"N and longitude 7° – 10°E with a population of 20.36 million people; the rural population constitutes 77 percent of the entire population (NPC, 2006). The position of the study area in the map of Nigeria is shown in Figure 1 while Table 1 shows the coordinates of the zone (Benue, Kogi, Kwara, Nasarawa, Niger, Plateau and the Federal Capital Territory, Abuja).

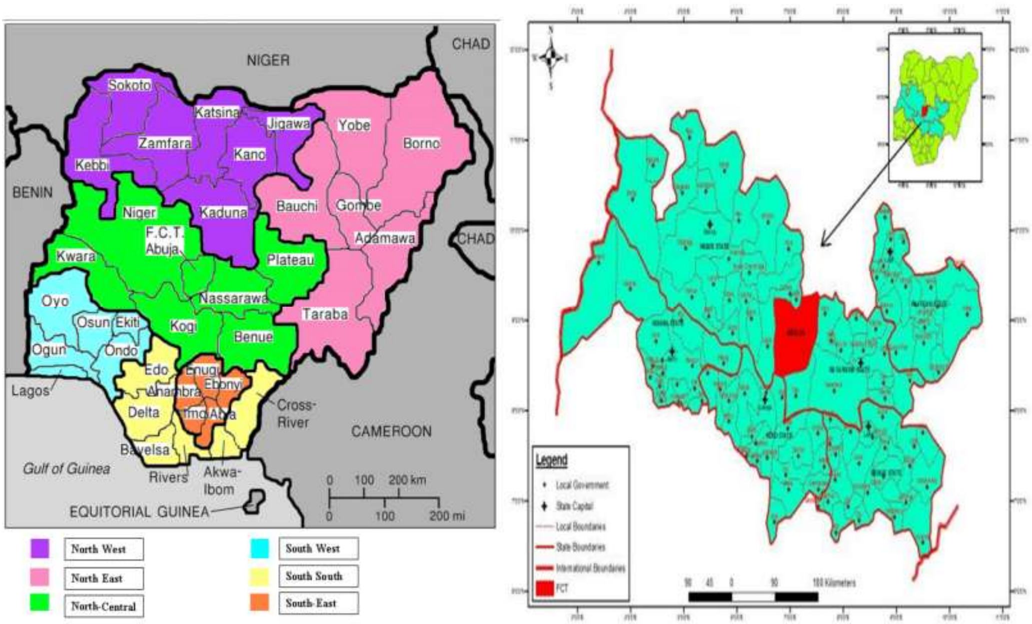

Figure 1: The position of the study area in the map of Nigeria (Adopted from Sklar, 2006)

Table 1: The coordinate of North Central states

S/N	Name of State	Longitude (Degree, Minute, seconds)	Latitude (Degree Minute, Seconds)
1	Benue	10°00’00”E	8°08’08”N
2	Kogi	6°45’00”E	7°45’00”N
3	Kwara	4°32’32”E	8°29’48”N
4	Nassarawa	8°31’10”E	8°28’60”N
5	Niger	3°30’00”E	8°20’00”N
6	Plateau	100°38’00”E	80°24’00”N
7	FCT Abuja	8°00’00”E	9°00’00”N

Data collection

The annual temperature and rainfall data of each state in the North Central of Nigeria are the climate data used for this study. The data used for the analysis were obtained from Nigeria Meteorological Agency (NIMET) from the year 1991 to the year 2012 and the crop yields, on the other hand, were collected from the Federal Ministry of Agriculture Nigeria on annual basis.

Data manipulation

The crop yield, temperature and rainfall data for the North Central states were inputted into a Microsoft Excel worksheet and the data was imported into ArcGIS software where it was converted into an ArcGIS file format. The imported data was then analyzed using the geographically weighted overlay in the spatial analyst tools using crop yield as the dependent while rainfall and temperature were used as the explanatory variables.

Geospatial analysis

ArcGIS version 11 was used to analyse annual temperature, rainfall and sorghum yield data geospatial variation using kriging interpolation method. After importing the Nigerian map into the GIS interface, it was pre-processed by geo-referencing, rectifying, updating and digitizing it. Geo-referencing was done by assigning the right coordinates to the Nigerian map. Changing the coordinates of a map from old to the newly assigned correct coordinates to register the map into Arc GIS version 10 internal environment is known as rectification and updating is re-adding the registered map. Digitizing which is the last phase in map processing is the act of carving out necessary features from an existing map. North-central map of Nigeria, its states, the state capital, local governments and boundaries were carved out from the existing maps. Temperature, rainfall and sorghum yield values were recorded in the state capital attribute table on the software. ArcGIS version 10 was used to develop the interpolated maps depicting the variation of annual temperature, annual rainfall and annual crop yields at a year interval within the North-central part of Nigeria using the kriging method of geospatial interpolation on the temperature, rainfall and crop yield data values. The interpolated maps that serve as the major outputs were then reclassified and post-processed by layingout and exporting them. Legend, scale bar, north arrow, grid lines, title and other map characteristic feature were derived through the laying out process. The interpolated maps were exported in Tag Image File Format (TIFF) format the flow chart of the interpolation process is presented in Figure 2.

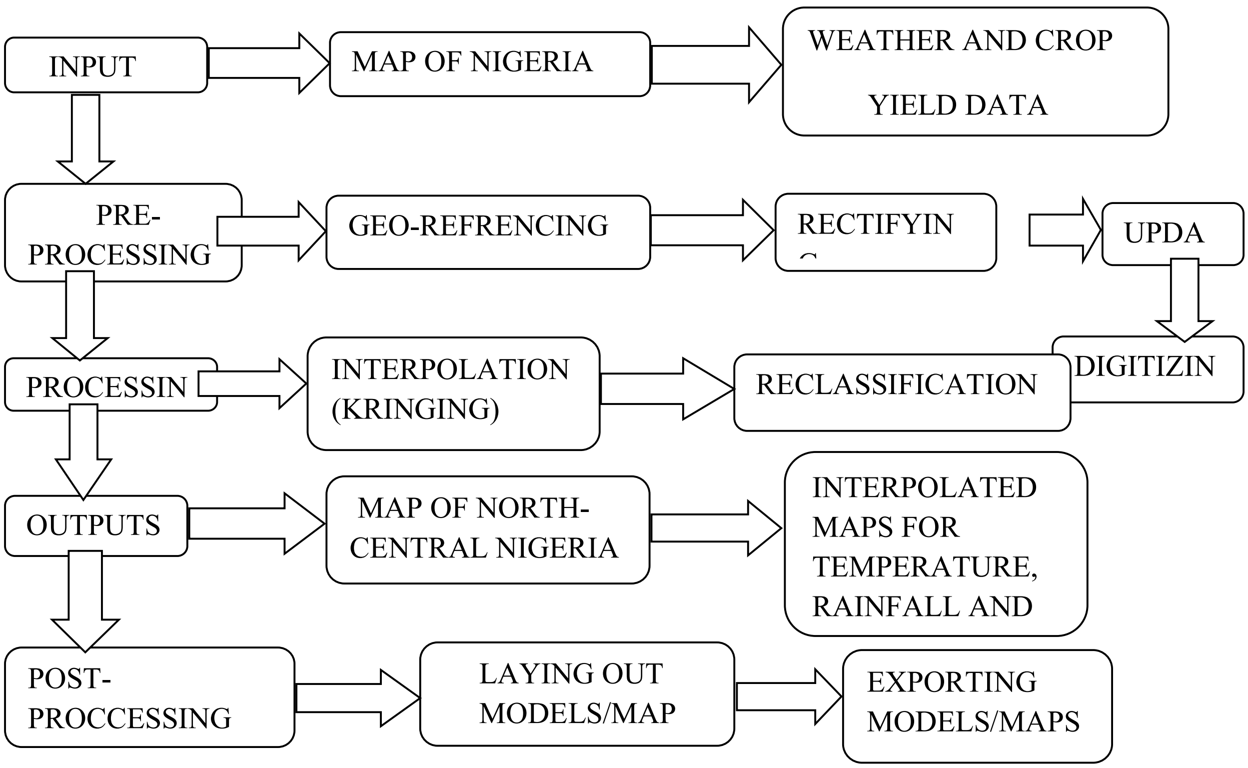

Figure 2: Kriging method of interpolation flow chat

RESULTS AND DISCUSSION

Annual Rainfall and annual sorghum Yield Maps

Annual rainfall and sorghum yield maps of 1991, 1992, 2000, 2005, 2009, and 2012 are taken into consideration. Figure 3 shows the annual rainfall and annual sorghum yield of Northcentral states for the year 1991 for annual rainfall variation; the area (Figure 3) with deep forest green indicates the highest seasonal rainfall with values ranging between 1438.8 cm – 1844.3 cm and its visible in Kogi and Nassarawa state while the area with tinted blue shows the area with lowest seasonal rainfall with values ranging between 944.9 cm – 1227.1 cm which is visible in the F.C.T Abuja. For the annual sorghum yield variation map, the area with deep orange indicates a high yield rate, which is visible in Kwara state and plateau state. The high yield of sorghum in Kwara state and plateau state is because of moderate rainfall in the two states and other favourable factors such as farm mechanization, and irrigation contributing to the increase in the yield of sorghum.

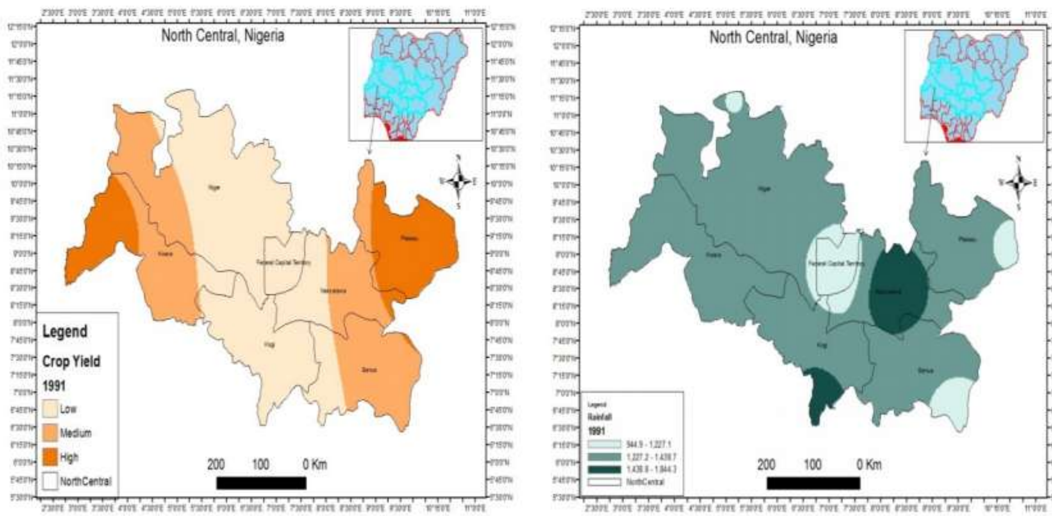

Figure 3: Geospatial variation map of annual rainfall and annual sorghum yield for 1991

Figure 4 shows the annual rainfall and sorghum yield for north central Nigeria in the year 1992. For the annual rainfall variation map, the area in deep blue colour shows an area with the highest rainfall which ranges between 25 cm – 47.5 cm and the area with the lowest rainfall is indicated by tinted blue ranging from 0.05 cm – 11.2 cm; Niger, Kwara, Kogi, Nassarawa, and Plateau fall under this category. From the yield map light orange represents medium yield, deep orange represents high yield while tinted orange represents low yield. High yield in plateau state and Kwara state is because of the moderate rainfall in the area.

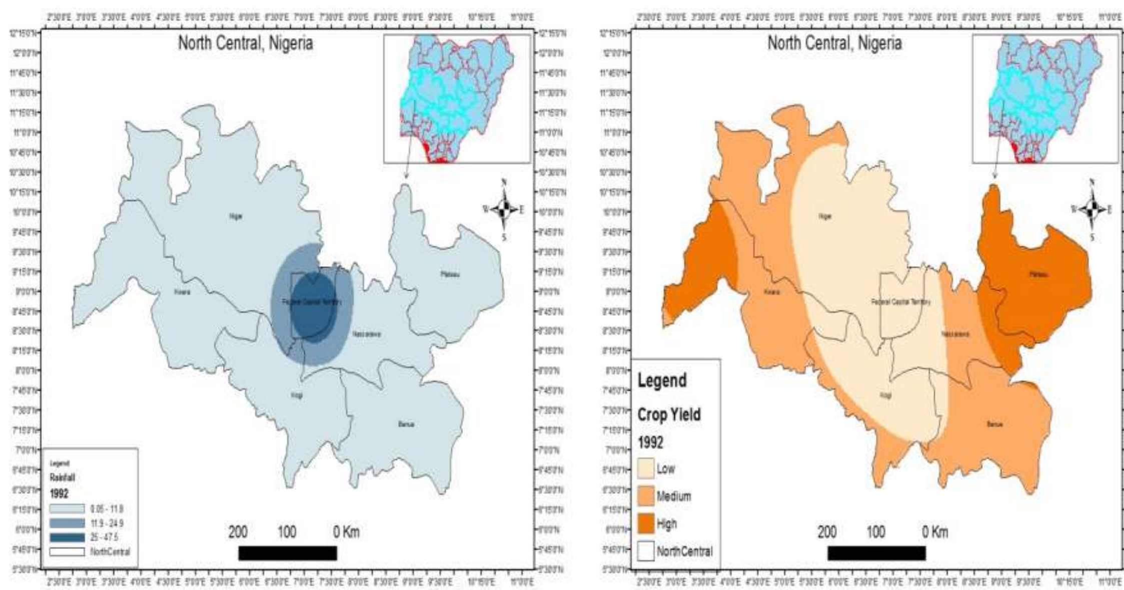

Figure 4: Geospatial variation map of annual rainfall and annual sorghum yield the year 1992

The annual rainfall and annual yield variation map for the year 2000 are shown in Figure 5 with deep blue representing a high rate of rainfall ranging from 1101.2 mm – 1269.4 mm which can be seen in Niger state while low rainfall with tinted blue colour ranging from 848.7 mm – 980.7 mm which can be seen in Nassarawa, Kogi and Abuja. Annual yield is the highest as indicated with deep orange in Plateau, Kwara and Benue state; this is because of the moderate rainfall in the respective states.

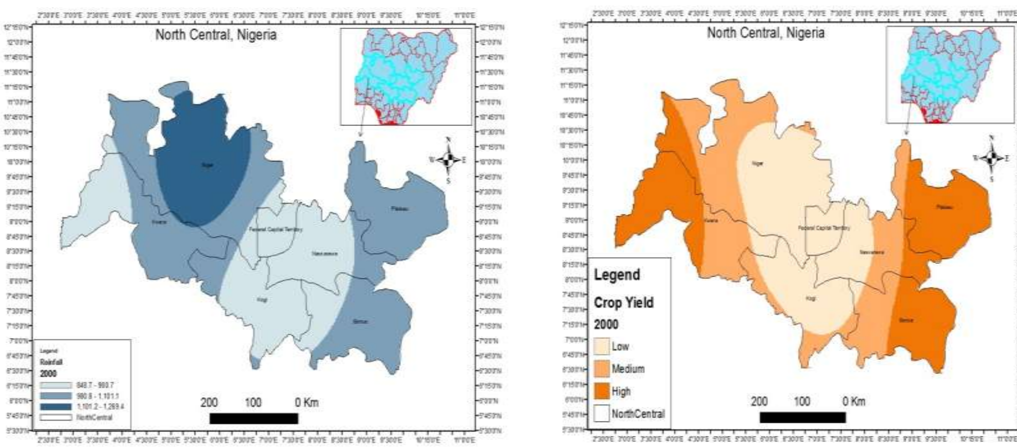

Figure 5: Geospatial variation map for annual rainfall and annual sorghum for the year 2000

Figure 6 shows the annual rainfall and temperature variation maps of the North-central states of Nigeria. In 2005 Kwara, Niger, and plateau records the highest range of rainfall which ranges from 945.4 mm – 1015.5 mm while the lowest annual rainfall ranges from 822.9 mm – 890.9 mm. the yield map shows that Plateau, Nassarawa and Benue are having the highest yield while Abuja with the lowest amount of rainfall has the lowest yield

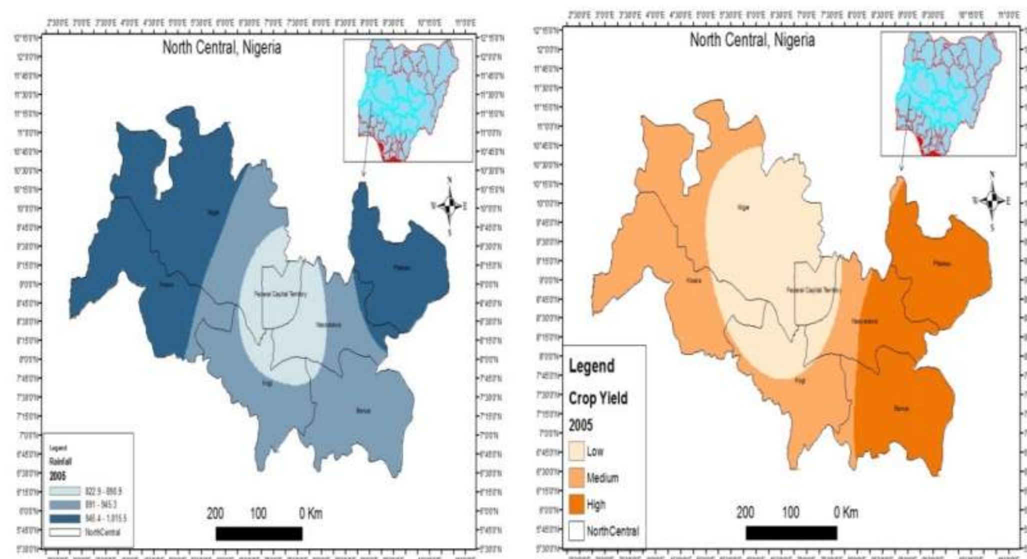

Figure 6: Geospatial variation map of annual rainfall and sorghum yield of the study area for the year 2005

The annual rainfall and yield variation map for 2009 is shown in Figure 7 with Abuja, Benue state and Niger state having the highest rate of rainfall in deep blue colour ranging from 1170.8 mm – 1330.3 mm and the lowest rate in tinted blue ranging from 903.6 mm – 1,075 mm and the yield variation showing plateau and Benue having the highest yield with deep orange colour as indicated due to the moderate rainfall in the area.

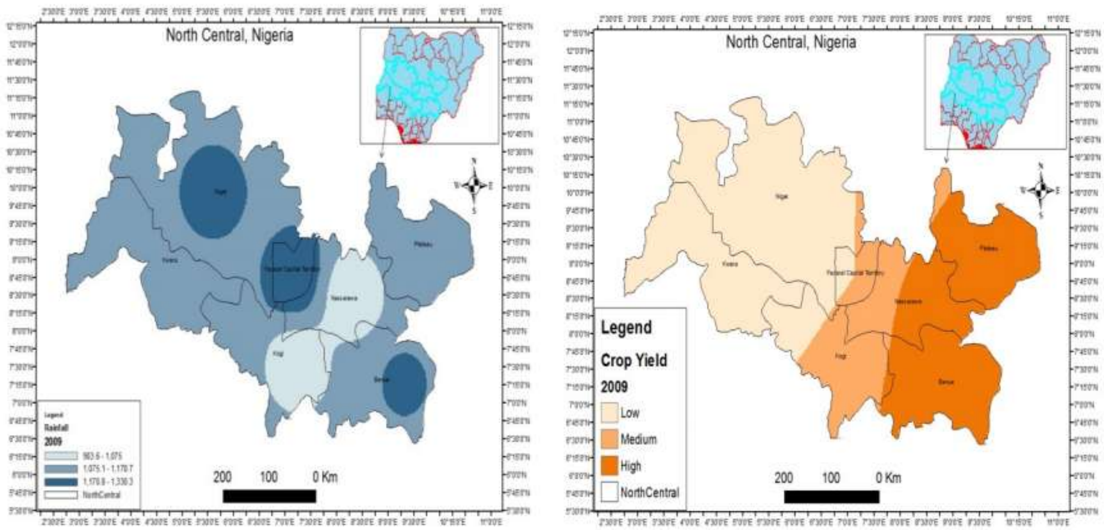

Figure 7: geo-spatial variation map of annual rainfall and sorghum yield for the year 2009

Figure 8 shows the annual rainfall and cowpea yield for north central Nigeria in the year 2012. For the annual rainfall variation map, the area in deep blue colour shows an area with the highest rainfall which ranges between 1106.1 mm – 1336.7 mm and the area with the lowest rainfall is indicated by tinted blue ranging from 683 mm – 931.7 mm; Niger, Kwara, Kogi, Nassarawa, and Plateau fall under this category (Figure 8). The light orange in the map represents medium yield, the deep orange represents high yield while tinted orange represents low yield. The high yield reported in Nassarawa state and Benue state is because of the moderate rainfall in the area.

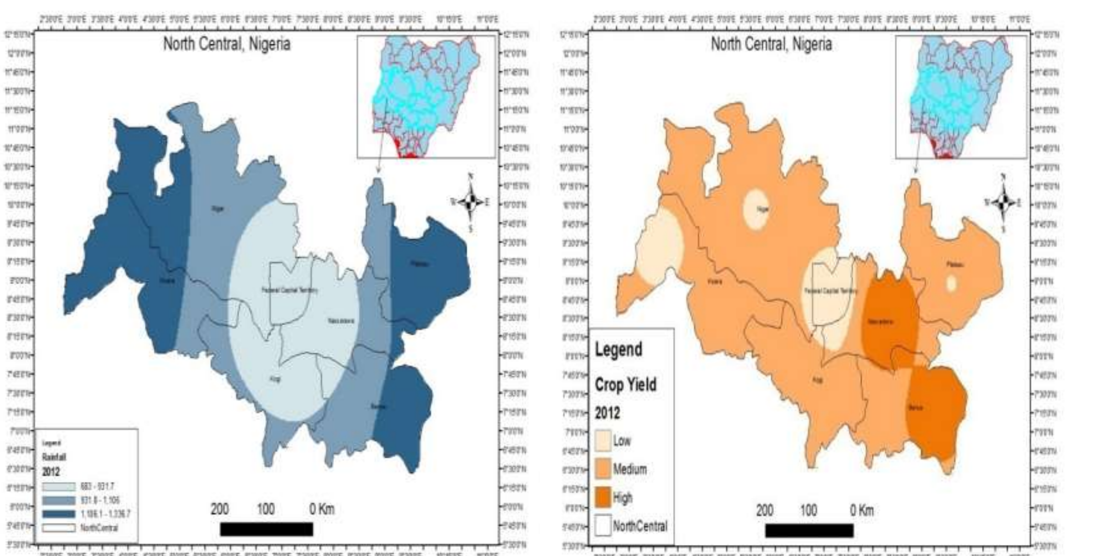

Figure 8: Geospatial variation map of annual rainfall and sorghum yield for the year 2012

Figures 9 to Figure 13 show the variation in annual temperature and the annual yield of sorghum of the North-central states of Nigeria. Deep red colour signifies the highest temperature while tinted red indicates the lowest temperature. Studying the maps shows that change in temperature does not affect the yield of sorghum.As shown in Figure 9; Abuja has the highest temperature and has the lowest yield for the year 1991 while Niger state has the lowest temperature and still the lowest yield.

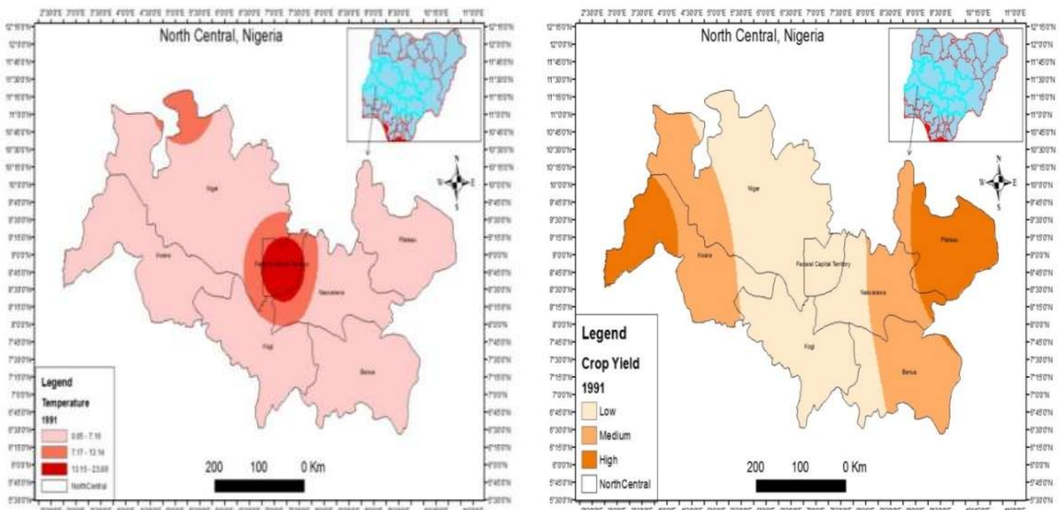

Figure 9: Geospatial variation map of annual temperature and annual sorghum yield for 1991

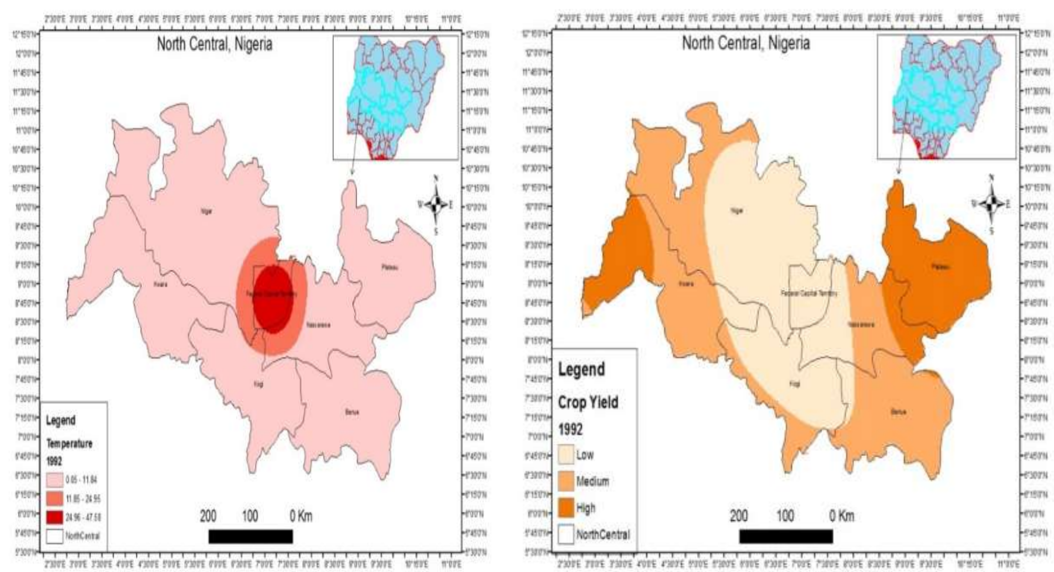

Figure 10: Geo spatial variation map of annual temperature and annual sorghum yield for 1992

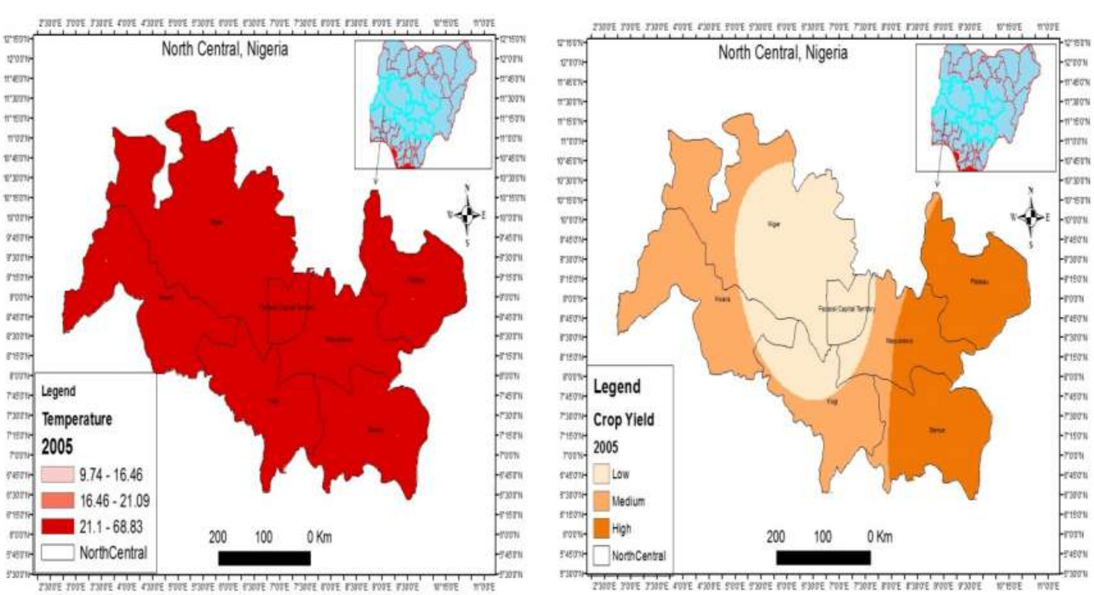

Figure 11: Geo-spatial variation map of annual temperature and sorghum yield for 2005

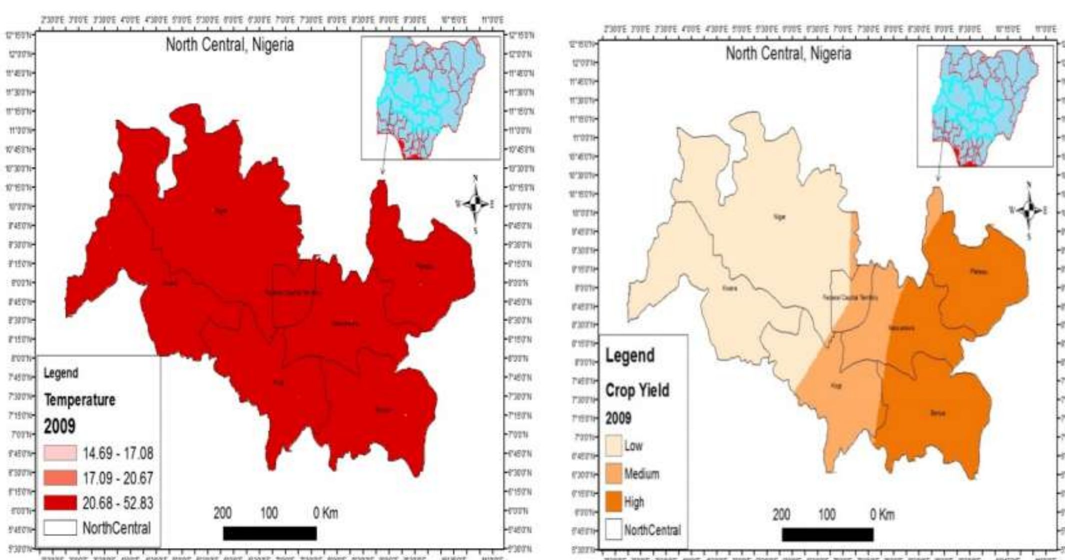

Figure 12: Geo-spatial variation map of annual temperature and sorghum yield for 2009

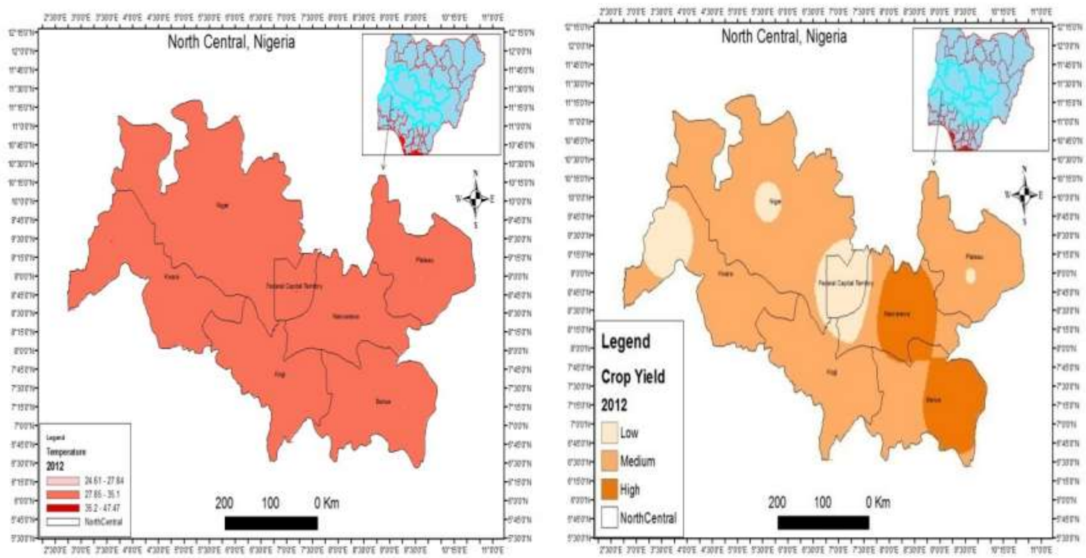

Figure 13: Geospatial variation map of annual temperature and sorghum yield for 2012

Geospatial projection values

Table 2, Table 3 and Figure 14 show the prediction values of annual temperature, annual rainfall, average prediction values of annual rainfall and annual temperature for the years 1991 – 2012 respectively. The standardized residual values ranging from <-2.5 to -1.5 indicates that the climatic variables (temperature and rainfall) under-predict the yield of sorghum in the study area and it shows that these climatic variables have little or no effect on the yield of sorghum indicating that other factors are the main determinant of the yield rate. Values ranging from -1.5 to 1.5 indicates that temperature and rainfall contribute effectively on a normal basis to the crop's yield showing that they have a visible effect on the crop's yield with other factors alongside. Values from 1.5 to >2.5 over-predicts, indicating that rainfall and temperature are the major determinants of the yield. Nassarawa states have the highest mean prediction value with a value of 1.59, the variation in annual rainfall and annual temperature affects to a great extent the yield of sorghum in this state while Niger state with -0.25 has the lowest prediction values

Table 2: Projected values of rainfall and temperature variation on sorghum yield

S/N	Year	Kwara	Niger	FCT Abuja	Kogi	Plateau	Nasarawa	Benue
1	1991	1.5	-1.5	2.5	0.5	1.5	1.5	0.5
2	1992	-1.5	-0.5	2.5	0.5	1.8	1.9	-0.6
3	1993	0.3	0.5	1.7	-0.5	2.8	1.5	-2.5
4	1994	0.5	2.3	-1.6	0.5	2.4	2.5	2.5
5	1995	0.6	0.5	0.3	0.4	1.2	-0.4	0.4
6	1996	-1.5	1.5	1.3	1.2	1.5	1.5	0.5
7	1997	0.5	0.5	-0.3	-0.7	-0.3	-0.3	-1.5
8	1998	1.5	0.5	2.8	0.5	2.4	2.3	0.5
9	1999	1.5	-0.5	-0.5	2.5	-0.5	0.5	1.5
10	2000	0.5	-1.5	2.5	-1.5	0.4	0.5	0.5
11	2001	1.5	-3	2.8	-0.5	0.5	0.5	0.5
12	2002	2.5	-2.8	2.5	0.5	1.4	0.5	2.3
13	2003	-1.5	-0.5	-0.6	0.5	1.5	2.5	2.5
14	2004	0.5	2.8	1.5	-0.5	2.5	0.4	1.5
15	2005	0.5	-1.5	0.5	0.5	2.5	2.4	0.5
16	2006	0.5	0.6	1.5	-1	0.5	2.4	1.5
17	2007	2.4	-1.8	-3	-0.5	-0.5	2.5	2.3

18	2008	0.5	-1.5	2.5	-1.5	0.5	2.5	1.5
19	2009	1.5	1.5	2.5	-0.5	-0.5	2.5	1.5
20	2010	-1.5	-1.5	1.5	0.5	0.5	2.5	1.5
21	2011	-0.5	-0.5	1.5	-0.5	0.5	2.5	1.5
22	2012	1.5	-0.4	-2.5	-0.5	-0.5	2.5	1.7

Table 3 shows that Kwara, Nassarawa, FCT Abuja, and Benue state have values within the range of 0.5 and >1.5 which indicates that variation in temperature and rainfall have a good prediction on sorghum yield in the study area. This leaves out Niger and Kogi state with -0.27 and 0.13 respectively.

Table 3: Projected values of rainfall and temperature on sorghum yield (mm)

Kwara	Niger	FCT Abuja	Kogi	Plateau	Nassarawa	Benue
0.60	-0.27	0.99	0.13	1.00	1.59	0.94

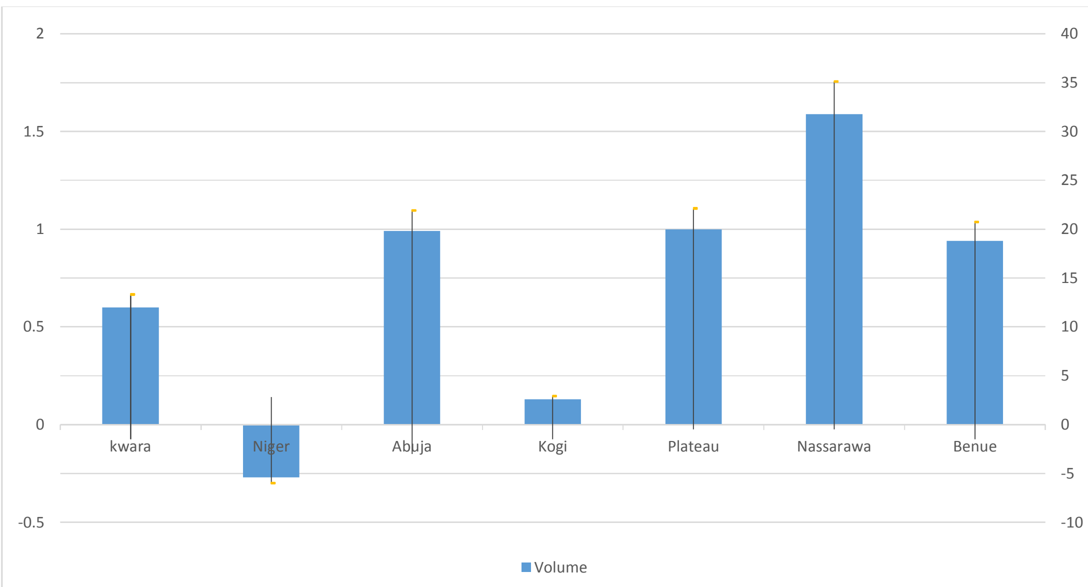

Figure 14: Mean projected values of annual rainfall and annual temperature variation effect on yield of sorghum for the year 1991 – 2012.

CONCLUSIONS

The climatic (rainfall and temperature) variation within the period under consideration hasan impact on the yield of sorghum in the North-Central states of Nigeria. Enlightenment campaign and short-term training by Government extension workers are recommended to be made available for farmers to educate them on the effect of climate change on their farming activities and crop yield. It is highly recommended to substitute fossil fuel with an alternative source of energy to reduce the global atmospheric gas emission contributing to global warming which in turn leads to climate instability. Forestation and planting of trees are recommended to reduce the effect of global warming thereby enhancing a stable climate. Introduction of changes in current farm management practices is recommended because this study shows that climatic conditions affect crop yield for a relatively long period.

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