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Assessing Climate Change Impacts on Vegetation and Crop Production (Maize and Groundnut) in Billiri/Kaltungo, Gombe State, Nigeria: Remote Sensing and GIS Approach

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Abstract

This study assessed the impacts of climate change on vegetation cover, water resources, and crop production specifically maize and groundnut in Billiri and Kaltungo Local Government Areas of Gombe State, Nigeria, using Remote Sensing and Geographic Information Systems (GIS). The research employed a spatial-temporal approach, integrating both primary and secondary data sources. Landsat ETM+ satellite imagery from 1986 and 2005 was processed and analyzed in ArcGIS 10.7.1 for land use/land cover classification and change detection. Ground-truthing was conducted using GPS devices, while climatic data (temperature and rainfall) and crop yield statistics were sourced from the Nigerian Meteorological Agency (NIMET) and Gombe State Agricultural Development Project (GADP), respectively. The findings revealed significant land cover changes over the two decades: maize and groundnut farmlands increased by 41.858 hectares and 6.537 hectares, respectively, while vegetation cover declined by 72.125 hectares. These changes were driven by both climatic factors and anthropogenic influences such as population growth, urbanization, and expanded agricultural activities. A strong positive correlation (r = 0.89) was observed between rainfall and maize yield between 1986 and 1994, whereas the correlation weakened (r = -0.317) between 1995 and 2005, reflecting the onset of climatic fluctuations. Groundnut yields exhibited continuous growth throughout the study period, with minimal sensitivity to rainfall and temperature variations, aligning with the crop's optimal climatic thresholds. Temperature variations (29°C–33.8°C) remained within favorable ranges for both crops, indicating limited negative impact on productivity. The reduction in vegetation cover, however, reflects adverse environmental impacts, including possible pressure on water resources, though direct water resource data was limited. The study concludes that while climate change has influenced vegetation and crop production, the adaptive strategies of farmers, including early planting and use of improved crop varieties, may have mitigated negative effects. This research recommends the need for sustainable land and water resource management, as well as continued climate monitoring using geospatial technologies.

Introduction

Rapid urban population growth has significantly altered natural vegetation through human activities, contributing to climate change and negatively affecting crop production. This shift affects local weather patterns and agricultural yields, especially of cereal and legume crops such as maize and groundnut, which are sensitive to changes in temperature, rainfall, and humidity (Apata, Ogunyinka, Sanusi & Ogunwande. 2010). These climatic elements are critical for planning farming operations in the short and medium term.

In recent years, the use of Remote Sensing and Geographic Information Systems (GIS) has become vital for monitoring vegetation changes and climate variability (Bancy, 2000). These technologies enable effective change detection tracking land use and cover modifications using multi-temporal, geo-referenced data. Such analysis helps identify shifts beyond natural variations, supporting studies on deforestation, urban sprawl, and crop yield changes (Kufoniyi, 2023).

Vegetation indices are reliable tools for detecting environmental changes. Climate shifts directly impact vegetation, which in turn influences local climates, affecting crop productivity. Climate change refers to long-term significant variations in average weather conditions, driven by natural processes or human-induced activities such as land use changes and increased greenhouse gas emissions (IPCC, 2021). This challenge continues to affect Nigeria's ecological zones, already under pressure from urbanization and industrialization. Studies have recorded increased greenhouse gases like carbon dioxide and methane since pre-industrial times, exacerbating global warming and altering vegetation patterns (IPCC, 2021). Yet, many assessments focus solely on climate impacts without addressing how farmers adapt. Addressing food security and sustainable development requires understanding both climatic impacts and community resilience. Nigeria, spanning 923,766 km², comprises seven ecological zones defined by climate and vegetation: mangrove swamp, rainforest, montane forest/grassland, derived savannah, guinea savannah, Sudan savannah, and Sahel savannah. The southern zones face flooding and erosion challenges affecting agriculture. In addition, government focus on oil has overshadowed agricultural development, despite the growing need to address climate change's impact on food production. GIS tools, including ArcGIS, provide powerful means to map and analyze the spatial and temporal effects of climate change on crops. These tools support Spatial Decision Support Systems (SDSS), aiding farmers and agricultural agencies in planning planting schemes and monitoring yields (Kufoniyi, 2023).

Statement of Research Problem

GIS technology is a recent tool increasingly used to assess the impact of climate change on vegetation and crop yield in Nigeria. According to the IPCC (2021) report, poorer countries, especially in the tropics and subtropics, face the greatest risk, with anticipated reductions in crop yields due to decreased water availability and increased pest infestations. In Africa and Latin America, many rain-fed crops are already near their temperature tolerance limits, making them highly vulnerable to even slight climate shifts (Hoffer, 1978).

By 2030, it is projected that 75 to 250 million people will face increased water stress due to climate change impacts on vegetation. Rain-fed agricultural yields in some regions may decline by up to 50%, worsening food insecurity. In addition, by 2080, arid and semi-arid land in Africa could expand by 5–8%. These changes are also likely to affect the spread of infectious diseases and reduce crop production. Rising sea levels, estimated at 25 cm by 2050, threaten Africa's coastal areas with erosion and flooding, further endangering livelihoods. Peasant households, heavily reliant on agriculture, are particularly vulnerable to declining yields. A related study in Gombe State, Nigeria (Anthony, 2025), highlighted vulnerability but did not specify affected crops. This study aims to address that gap by focusing on the effects of climate change on maize and groundnut production and vegetation in the study area.

Objectives of the Study

i. To examine changes in the areas land use/land cover from 1986 to 2005.
ii. To assess the effects of climate change on maize and groundnuts yields in the study areas.

Research Questions

i. To what extend have the vegetation taking changed over the last three decades in the study areas?
ii. How can GIS be used in monitoring vegetation and crop yields changes over the years in the study areas?
iii. What are the effects of climate change on maize and groundnut in Billiri/Kaltungo LGAs in Gombe State?

Significance of the Study

This study explores the impact of climate change particularly rising temperatures and shortened growing seasons on vegetation and crop yields, specifically maize and groundnuts, in the Billiri/Kaltungo areas. By highlighting the risks of reduced yields, food insecurity, and environmental degradation, the research raises awareness among farmers about the effects of climate change on agricultural production and guides them in selecting crops better suited to current climatic conditions. In addition, the study offers valuable GIS-based tools for spatial decision support, aiding farmers and agricultural agencies in planning and monitoring crop yields. It also contributes to academic knowledge and planning efforts by enhancing the existing database on climate change impacts in the study area.

Scope and Delimitation

The research focused mainly on climatic change effects on vegetation, maize and groundnut yields in Billiri and Kaltungo areas of Gombe State. It involved the application of Remote Sensing (RS) and GIS techniques. The study was delimited to the area within Billiri/Kaltungo political boundaries on the basis of funds and spatio-temporal coverage constrains. However, not all the climatic elements were considered in this research, those considered are temperature, rainfall and relative humidity.

Methodology

Study Area

Billiri and Kaltungo are Local Government Areas in Gombe State which lies between latitudes 9°39′14″N and 10°01′42″ north of the equator and longitudes 11°8′ 18″E and 11°38′ 00″E east of the Greenwich meridian (Figure 1). Billiri LGA headquarters is in the town of Billiri in the northeast of the area along the A345 highway while Kaltungo LGA headquarters is in the town of Kaltungo in the west of the area along the A345 highway. Both has an estimated area of 1618 km² and a population of 351,949 at the 2006 census. The climate of Billiri/Kaltungo of Gombe State falls under the tropical climate with market wet and dry seasons. The rainy season begins from the month of April to October as shown in the graph below showing the mean monthly rainfall from 1986 to 2005 (Federal Government of Nigeria (FGN) 1999). Rainfall in the area comes in torrential form. The highest rainfall is mostly recorded in the months of Julys' and August (Mitra, 2007). Temperatures are high in the months of March, April and may while, minimum temperatures are recorded in the month of December and January.Rainfall is the most significant climatic factor affecting groundnuts production, 70% of the crop in the area is under semi-arid tropics characterized by low and erratic rainfall (Chiew, 2002). Low rainfall and prolonged dry spells during the crop growth period were reported to be main reasons for low average yields in most of the regions of Asia and Africa, for example in India (FAO, 2019) especially in parts of northern China where rainfall is less than 500 mm. Naing (1980) reported that rainfall was the main factor determining yield in Nigeria.

Temperatures have been identified as a dominant factor for controlling the rate of development of groundnuts (Cox, 1979). Every crop has its cardinal temperatures optimum, and maximum temperatures. Williams et al (2003) reported that the optimum temperature for vegetative growth of groundnut plants were in the range of 25-300C while optimum temperature for reproductive growth lowers (20-25° C). The interactive effects of temperature and other environmental factors are less understood and need further attention. Prasad et al (2003) studied the effects of temperature in combination with elevated CO_2 on various physiological and Yield processes of groundnut.

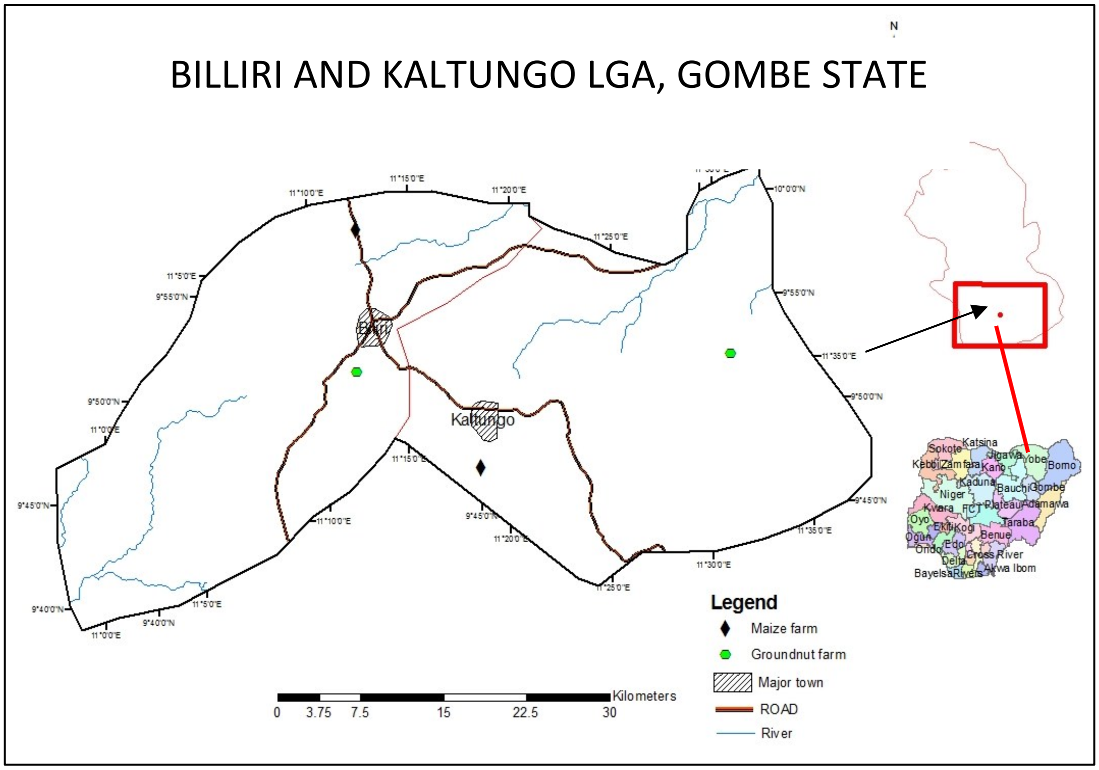

Figure 1: The map of the study area. Source: modified after Ministry of Land and Survey Gombe State, 2009)

This study adopted a spatial-temporal research design using both primary and secondary data to assess the impact of climate change on vegetation and crop yields (maize and groundnuts) in Billiri and Kaltungo Local Government Areas of Gombe State (Rahman, 2020). Primary data were collected through field observations and GPS-based ground-truthing, with coordinates obtained for selected farms. Secondary data sources included maize and groundnut yield records (1986 to 2005) from Gombe State Agricultural Development Project (GADP), climatic data from the Nigerian Meteorological Agency (NIMET, 2013), and Enhanced Thematic Mapper (ETM+) Landsat images (1986 to 2005) from the Global Land Cover Facility

(GLCF, 2005). Additional literature was sourced from books, journals, and online resources.

The equipment used included Garmin 12-channel handheld GPS, Dell Inspiron laptop, and multifunction printers. Software tools included ArcGIS 10.7.1, and Microsoft Excel 2016. Image processing began with importing Landsat ETM+ images into ArcGIS 10.7.1, where bands 3, 4, and 5 were used for color composites and supervised classification. Seven land use/cover classes built-up areas, bare surfaces, rock outcrops, water bodies, vegetation, maize farms, and groundnut farms were identified (Singh, 1989). Change detection analysis was conducted to determine land cover changes from 1986 to 2005. The classified images were done in same ArcGIS 10.7.1 for area calculations in hectares, while changes were quantified using percentage area formulas. Vegetation changes were then analyzed in relation to climatic variables such as temperature and rainfall through descriptive comparison (Wisner, Blaikie, Cannon, & Davis, 2004). The same approach was used to evaluate the relationship between climate change and maize/groundnut yield. Graphical analyses were also conducted to illustrate the relationship between crop yields and climatic factors Correlation was used to calculate relationship between the variables.

Results and Discussion

Change detection analysis by area difference revealed a significant change in the areas land use and land cover had occurred between 1986 to 2005 as shown on the table 1. Information obtained from the classified imageries of 1986 to 2005 of Billiri and Kaltungo LGA of Gombe State, indicated that there was an increase in land sizes for maize and groundnuts by production by 41.858 hectares and 6.537 hectares respectively. While vegetation cover had reduced by -72.125 hectares between 1986 to 2005 (Table 1). The results of findings could be attributed to favorable climatic conditions in the study areas, which seems to favour the cultivation of both crops.

Table 1: showing land use and land cover changes of Billiri and Kaltungo Areas in hectares (Ha).

S/N	Land cover/land use classes	1986 Area (Ha)	2005 Area (Ha)	Differences (Ha) 1986-2005	Remark
1	Maize farm	31.621	73.479	41.858	Increased
2	G/nut farm	7.296	13.833	6.537	Increased
3	Vegetation	118.567	46.442	- 72.125	Decreased
4	Others	4316	28046	23730	Decreased

Source: Field Work and GIS Analyst 2013.

On the contrary, reduction in vegetation cover could be as a result of increasing urbanization and population growth which resulted in construction activities such as roads, housing and other infrastructural activities as well as increased demand for forest products such as fuel wood, timber and so on. Also, with the rapid growth in population in these areas we can equally deduced that there had being a negative impact of human activities which exposed the vegetation to have adverse effects of -72.125 hectares as clearly showed in table 2 in 2005.

As human population size in these areas continued to increase from 1986 to 2005, also demand for survival be, there by leading so many people engaged themselves in large scale farming operations in other to meet their daily needs. In the past maize was mainly considered as food crop only, but in recent time it is a food as well as food crop. This could be one of the major reasons for increase in maize production in the recent years. Other land uses mostly built-up areas, farm lands for the other crops, rivers and rock outcrops make up 4.316 hectares in 2004.This increase by 23.730 hectares owing to the population increase among other factors. Below in figures (2, 3, and 4) also shows clearly that changes that took place from 1986 to 2005 most especially the vegetation cover in 2005 had changed or reduced with - 72.125 hectares due to some anthropogenic activities and the both crops.

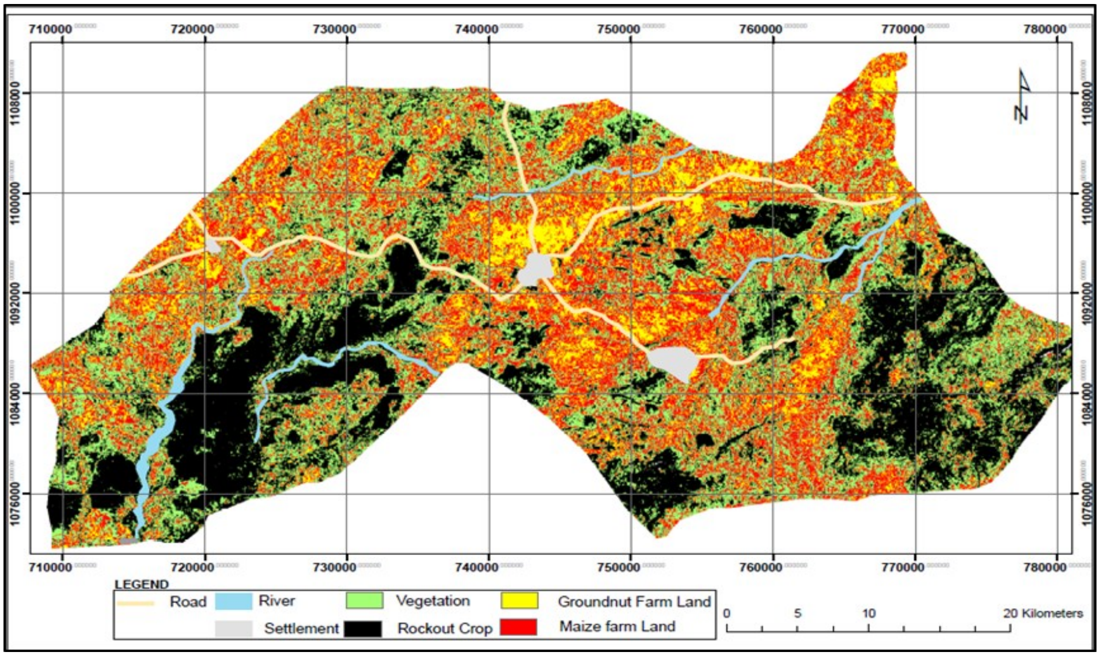

Figure 2: Image Classification Using Landsat ETM + Image of Billiri and Kaltungo 2013.

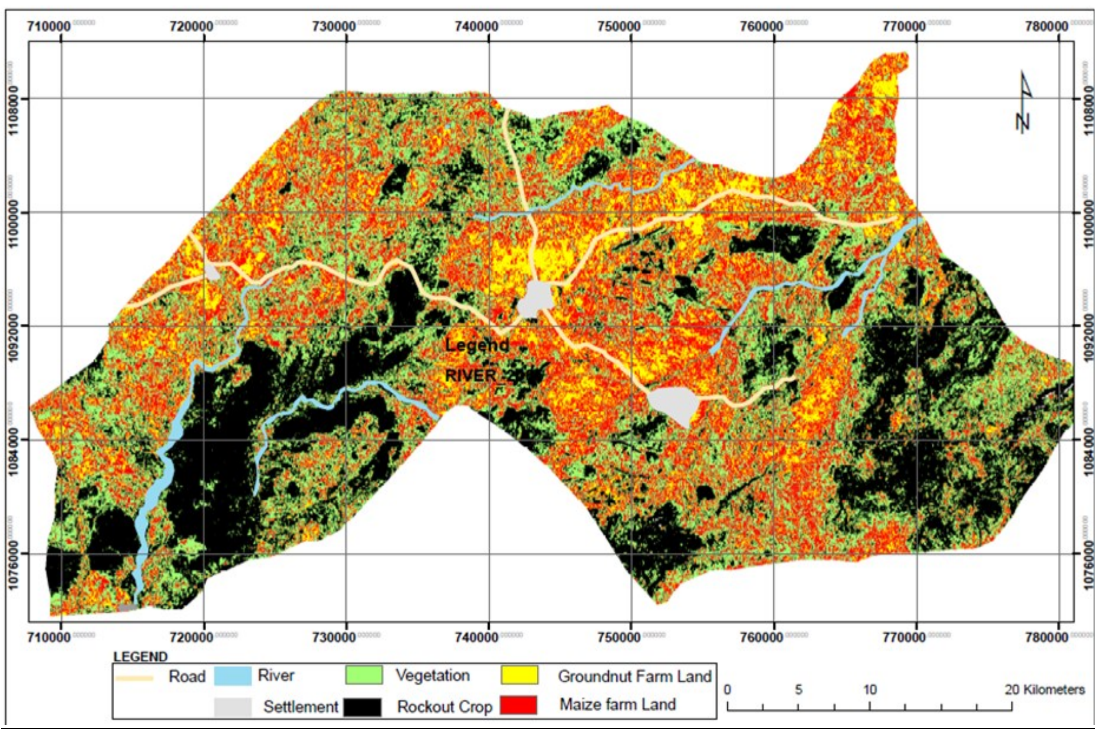

Figure 3: Image Classification Using Landsat ETM + Image of 2004 of Billiri and Kaltungo LGA Gombe State.

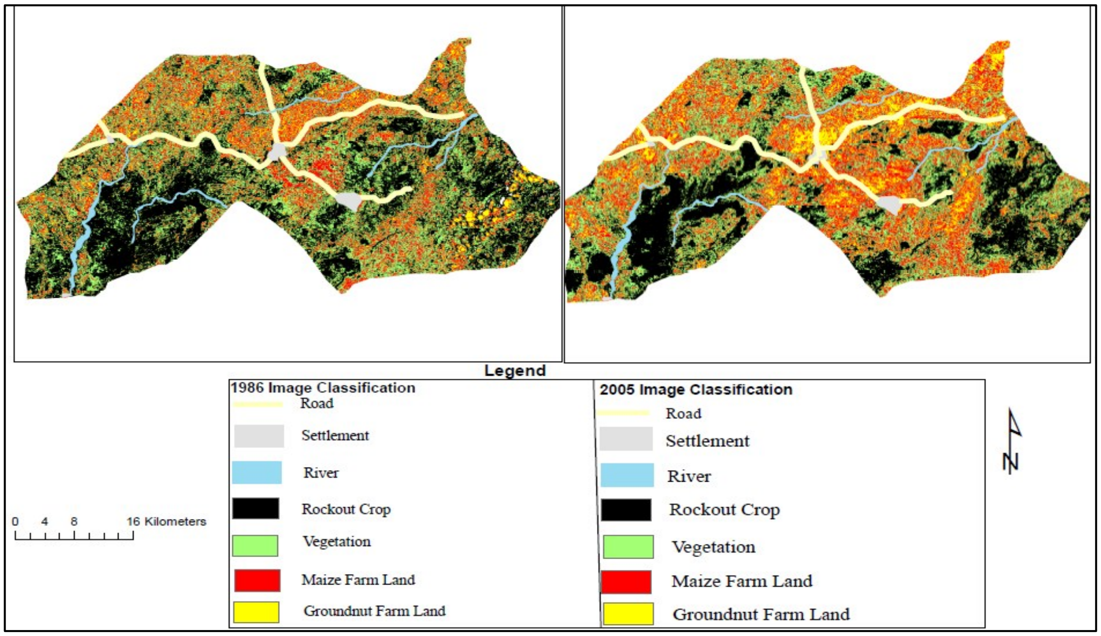

Figure 4: Image Classification Differencing of Billiri and Kaltungo LGA 1986 to 2005. Source; Landsat Imagery of 1986 and 2005.

In figure 4, there is a change in vegetation of Billiri and Kaltungo from 1986 to 2005 as can be seen clearly on the image when placed side by side. The 1986 and 2005 images as it is compared in figure 3 above indicated vividly the changes in vegetation cover of the areas over the years. The image of 2005 shows clearly the reduction in vegetation cover of the area with - 72.125 hectares resulting from anthropogenic activities and other climatic factors. This means that climate change had adverse effect on the vegetation in 2005.

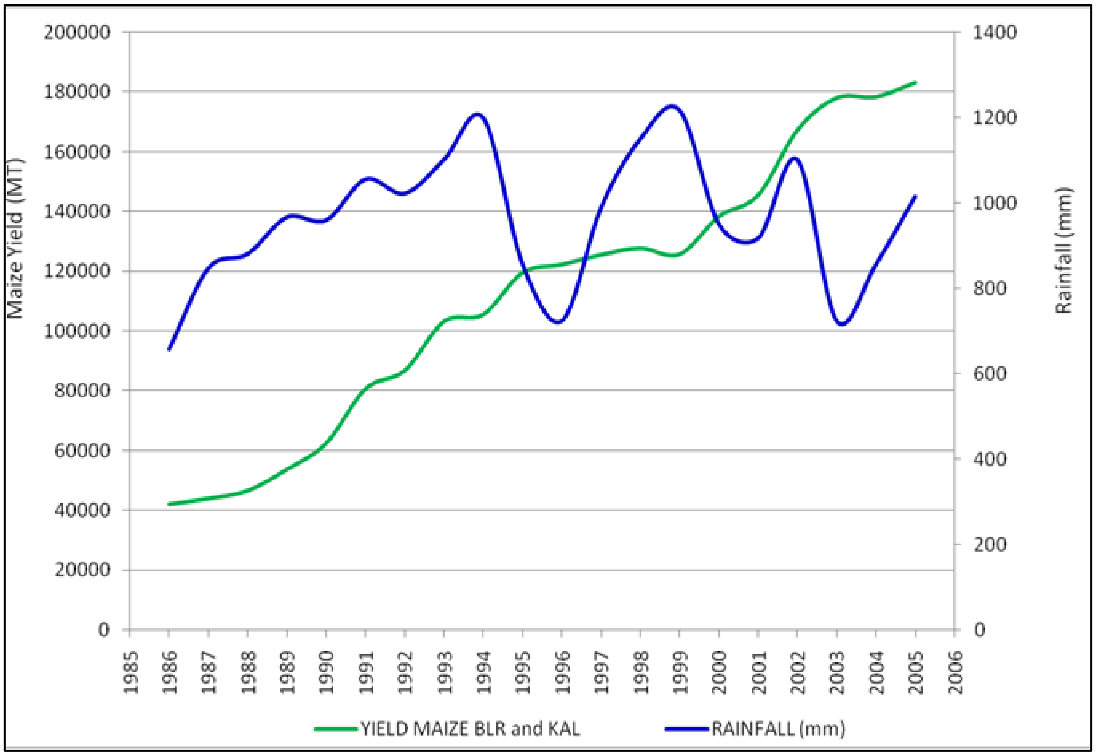

Figure 5: Relationship between Rainfall and Maize Yield

Figure 5 shows a graphical representation of the relationship between rainfall and maize yield in the area. The data revealed that there was a steady increase in rainfall regime from 1986 to 1994, which contributed to increase in maize yield as well. The findings showed a strong positive correlation coefficient of r = 0.89, indicating that rainfall had a significant influence on maize yield over that period. However, the area began to witness fluctuations in rainfall regime between 1995 to 2005.This may be attributed to emergence of harsh climatic conditions became eminent from 1994 to 2005 see (figure 2). The findings for the periods revealed a week negative correlation of r= -0.317, which implied that the commencement of fluctuations in rainfall regime in 1994 on maize yield became insignificant. This could be attributed to drought resistant crops as well as early planting of crops by the farmers. Notwithstanding, maize continued to increase over years possibly due other favorable factors such as soil conditions, used of improved varieties and agricultural inputs (Agro chemicals).

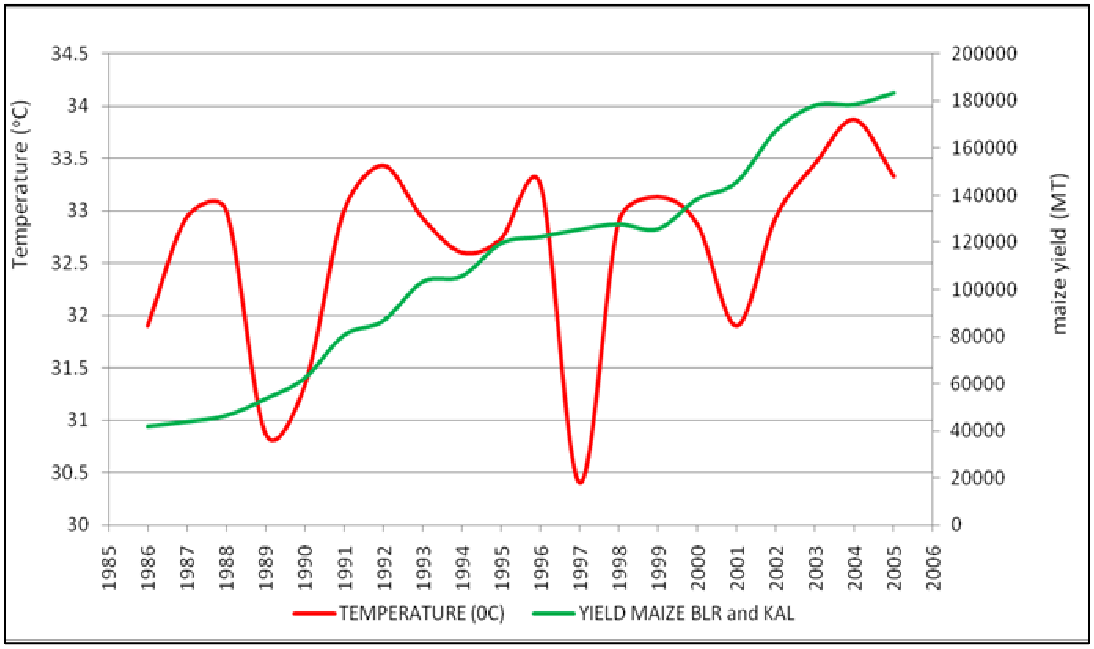

Figure 6: Relationship between Temperature and Maize Yield.

Figure 6 above shows the relationship between temperature and maize yield in the study area. The analysis of the data revealed that the minimum temperature ever experienced in the study area between 1986 to 2005 was 29.0 °C with 33.8 °C as the maximum. Mean annual temperature in the study area over the period of study ranged from 29.4 to 33.87 °C with periodic mean of 32.6 °C. Meanwhile. there was an increase in the growth and production of maize during the period. The implication of the findings above is that variations in temperature had no negative impact on maize growth during the period. Studies by Birch (1997), however showed that high temperature which exceed 38 °C can lead to crop decline in maize. Given the data above, the area mean temperature on the study area could be considered as favorable for maize production.

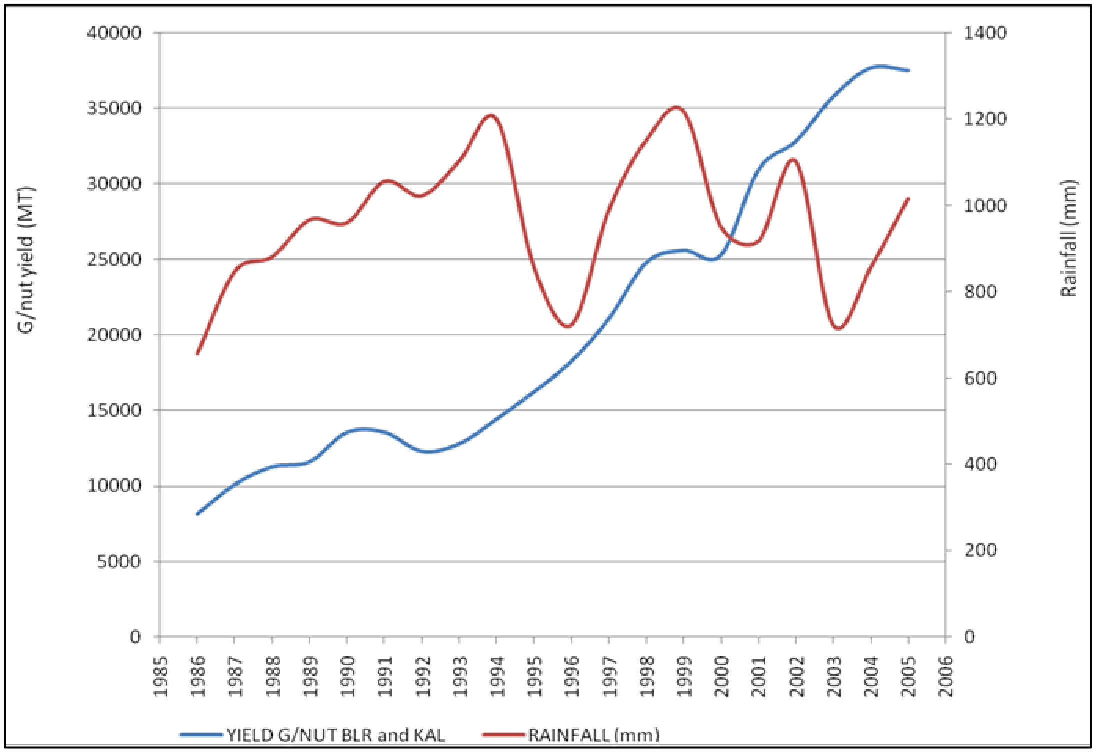

Figure 7: Relationship between Rainfall and Groundnuts Yield.

From figure 7, it can be seen that rainfall increased in the study area between 1985 to 1993 and declined in 1994 to1996. It then rose again in 1997 and continued to fluctuate throughout the period between 1998 to 2005 groundnut yields, however continued to be on the increase from 1985 to 2005. The results of the findings therefore indicate that that rainfall pattern did not affect the yields of groundnut production in the study area. The minimum rainfall recorded during the period was 1700 mm in 1986 while the maximum recorded was 34,000 mm in1999. This was sufficient enough to favour the growth of groundnuts in the study area. This finding corroborates earlier studies by Apata, Ogunyinka, Sanusi and Ogunwande, (2010) which showed that the optimum rainfall requirements for groundnuts ranges from 300 to 500 mm.

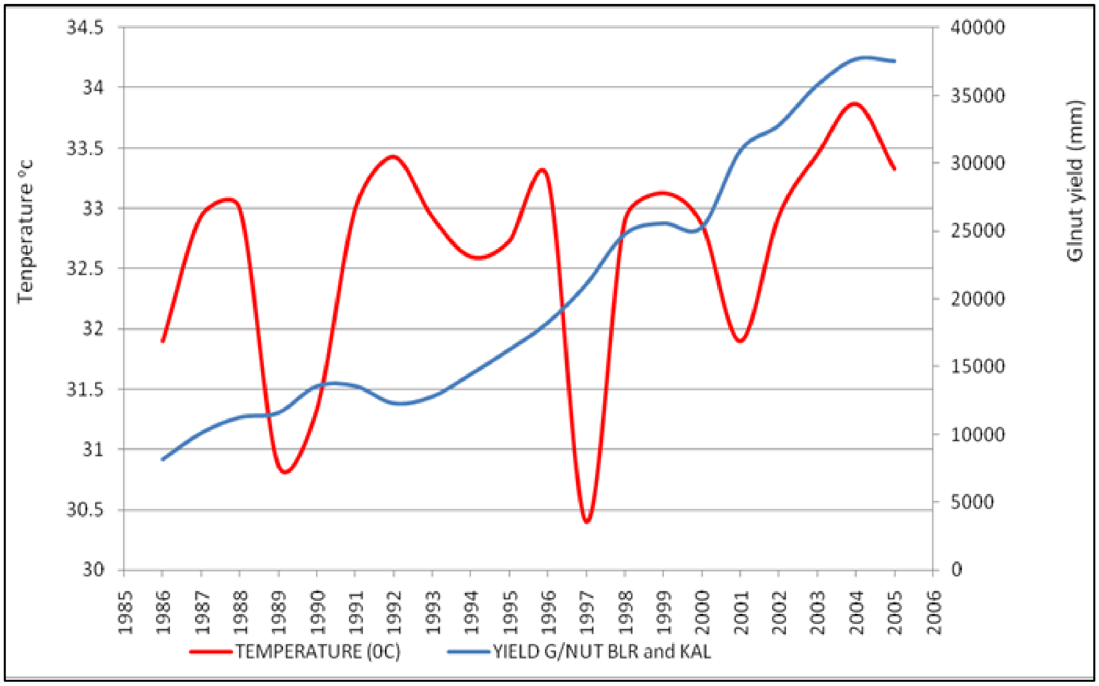

Figure 8: Relationship between Temperature and Groundnuts Yield

Figure 8 shows the relationship between temperature and groundnut yields in the study area. The analysis revealed that temperature rose in 1986 and average of 31.8 to 33.1 oC and dropped down to 30.7 oC in 1989. From 1989, temperature began to fluctuate over a period of time and dropped again sharply with an average 28.5 oC in 1997, and later increased between 1998 to 2000 and dropped again in 2001. By 2002, the temperature began to increase again up to 2005. Despite the fluctuation in temperature required over the years, the yield of groundnut continuously kept rising indicating that temperature had little or no influence on the yield of groundnut in the study area. This is because the optimum temperature so far recorded in the study area had favored the cultivation and growth of groundnuts. This finding is consistence with earlier studies by Nigam and Ramanatha (1997), which found that the optimum temperature requirement for the growth of groundnut ranged from 25 to 35 oC.

Conclusion

Studies and research have confirmed that the planet earth is undergoing a severe climatic change. The strongest effects of global warming are on vegetation and agriculture with the rise in temperature that come with global warming, growing season become shorten, thereby reducing crop yield or production which eventually leads to food insecurity, starvation and death of human, plants and animals. Climate change has become so problematic today all over the World and Urban growth in population has been a major factor that alters natural vegetation cover, through anthropogenic activities which in turn result to climate change. This has serious timely effects on crop production. The results of these have left significant effects on local weather and climate.

The significance of this study is to examine how climatic changes have effects on vegetation and crop production maize and groundnuts yield or productivity in the study area, and the likely changes that may occur due to the dynamic effect of climatic changes over time. This research will be beneficial to farmers as it will alert them to be conscious of the influence or risk of climate changes on vegetation and crop production. It will create awareness to farmers such that they will adopt a variety of crops that do better in a given climatic condition. There is no doubt that farmers and Agricultural Agencies increasingly need detailed GIS technique or package as a means of Spatial Decision Support System (SDSS) to plan crops planting schemes and to monitor yield rates. The research will equally be valuable to academics, planners and those willing to make research in the area of climate change using GIS ideas. This study will also generate and upgrade the existing database of the climatic change effects on vegetation and crop production of the study area made study area made available by other researchers.

Recommendations

In view of the findings, the following recommendations are made; based on the issue of global warming which alter the natural balance of climate, and the ongoing anthropogenic activities by man as follows:

i. The Nigerian Government and all the stakeholders involved in the climate change issues should increase public awareness, promote research and establish a commission or an agency that will handle issues related to impact of climate change on yield in the study area.

ii. The International, Federal, State and Local Government agencies and other development partners are required to funds climate change projects in Nigeria for sustainable solution.

iii. Also, let there be an alternative to the usual way of using even our vehicles to reduce too much of toxic pollutants being released to the atmosphere as air pollution.

iv. The government and other agencies should ensure proper law enforcement on deforestation and forest reserve in Kaltungo and Billiri.

v. Research institutes should be established and well-founded to device new techniques and methods of reducing climatic changes.

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