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Full Length Research Paper

Application of GIS to assess rainfall variability impacts on crop yield in Guinean Savanna part of Nigeria

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The scientific evidence on rainfall variability with its significant impacts on crop yield is now stronger than ever. It is even more so on maize that serves as staple food in most parts of Sub-Sahara Africa. Hence, this study aim at examines and map spatio-temporal impacts of rainfall variability on water availability for maize yield using Geographic Information System (GIS). Major regions where maize is highly produced in Nigeria were selected and rainfall data for 30 years (1970 to 2000) were used for the Geospatial analysis. GIS Interpolation and other geospatial Analysis techniques were carried out to map the impacts of rainfall variability on maize yield. The results of the analysis and the maps produced show that inter-annual rainfall variability brings about the differences in water availability consequently affect the rate of maize yield in Nigeria.

Key word: Rainfall variability, maize yield, GIS.

INTRODUCTION

Rainwater variability impact analysis is a way of looking at the range of consequences of a given rainfall event or change (Adejuwon, 2004). This study of inter-annual rainfall variability impact assessments begins by mapping out direct physical consequences of rainfall variability on water availability and its effects on crop yields. Generally, the scientific evidence on rainfall variability with its significant impacts on crop yield is now stronger than ever (Hare, 1985; WMO, 2000; IPCC, 2001, 2004a, 2004b; Adejuwon and Odekunle, 2004, 2006). One undisputable causes of 'famine' in Guinean Savanna Nigeria is the failure of crops resulting from insufficient or untimely rainfall. But is it true that “rainfall is the husband of maize yield” according to Nigerian slogan- that is rainfall supply all needed resources for maize yield. IPCC (2004a) has studied the inter-annual variability in climate of West African countries, and particularly the magnitude of rainfall variability impact on human activities, including crop production.

Previous studies on the impacts of rainfall variability on crops yield were focused on some specific crops and make use of only statistical-based technique in their analysis. Among these are the works by Tim (2000), FAO (2001), Chiew (2002), Adejuwon (2004), Adejuwon and Odekunle (2006), and Haimson and Ennis (2004). For example, Tim (2000) observed that over the period 1961 to 1990 the north east arid zone of Nigeria experienced a decline in annual rainfall which led to decline in millet based farming systems. The zonal variability of rainfall, especially, is observed to bring about not only the differences in the types of crops cultivated but also the rate of yield of such crops (Osagie, 2002; Adejuwon and Odekunle, 2006). Moreover, a lot of studies on inter-annual rainfall variability impact on crop yield used model-base simulations in their analysis. Nonetheless, to relate rainfall variability with actual crop yield model-base simulations are not sufficient. Modeling with a GIS offers a mechanism to integrate many scales of data developed in/for agricultural research. Surprisingly, little systematic research has focused on the distribution patterns of the impacts of rainfall variability in terms of mapping the spatio-temporal impact using the modern GIS equipment. There is no doubt that farmers and Agricultural Agencies increasingly need detailed GIS maps of this kind as a means of Spatial Decision Support System (SDSS) to plan crops planting schemes and to monitor yield rates.

In general, the aim of this study is to use GIS technique to examine and map the spatio-temporal impact of rainwater variability on water availability for crop maize

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Table 1. Names and locations of the stations used.

S/N	Name of station	Code	Latitude (°N)	Longitude (°E)
1	Enugu	ENG	6° 27’	7° 29’
2	Ilorin	ILO	8° 55’	4° 11’
3	Jalingo	JGO	8° 30’	11°20’
4	Lokoja	LKJ	8° 02’	6° 02’
5	Makurdi	MKD	7° 50’	8° 05’
6	Minna	MIN	9° 36’	6°34’
7	Mokwa	MKW	9° 10’	4° 43’
8	Ogoja	OGA	6.40’	8.42’
9	Shaki	SHK	8° 03’	3° 05’
10	Yola	YLA	9.12’	12.30’

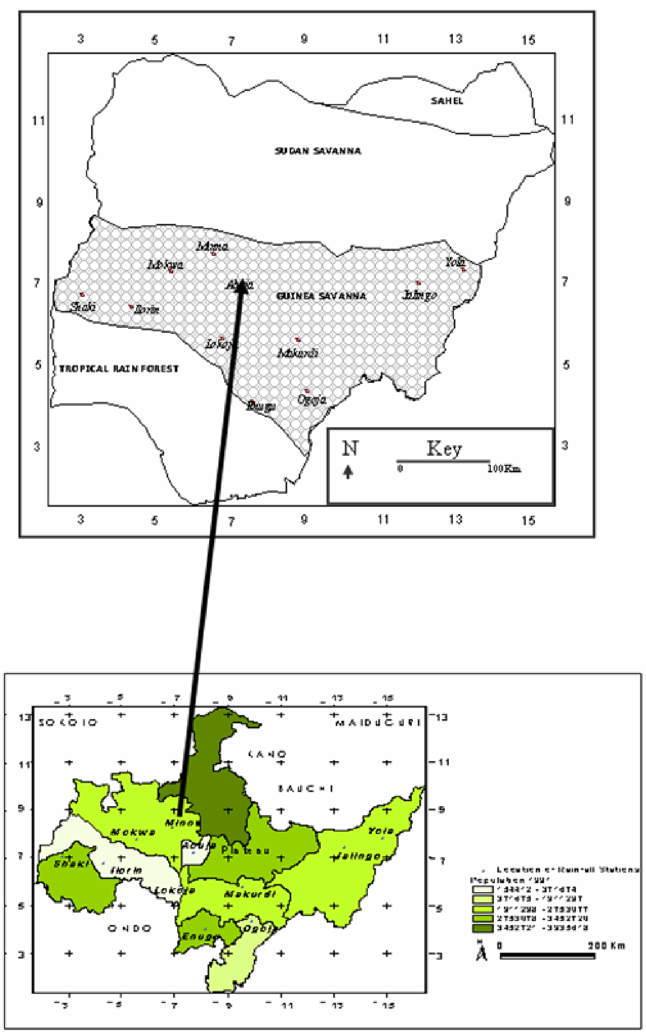


Figure 1. Map of Nigeria showing study area.

yields in the Guinea Savanna Ecological Zone of Nigeria. In more specific terms, the paper is designed to examine and map inter-annual changes in maize yield as response to inter-annual rainfall (water) variability using geospatial analysis.

STUDY AREA

The study area is Guinea Savanna Ecological Zone, which lies between the semi-arid north and the wet southern part of Nigeria. The study area lies approximately between longitudes 3° and 14°E and latitudes 7° and 10°N (see Table 1 and Figure 1). Rainfall in the zone is largely seasonal and highly variable from year to year, with mean annual rainfall between 1000 mm and 1200 mm. Two distinct seasons are observed, dry and wet. The dry season extends over a period of about 6 - 7 months, from October to March/April while the wet season extends over a period about 5 - 6 months, from May to September. The area is made up of traditional small-holder farmers, who use simple techniques of production and the bush-fallow system of cultivation, account for around two-thirds of Nigeria's total agricultural production (Field work). Subsistence food crops (mainly sorghum, maize, yams, cassava, rice and millet) are grown in the area.

METHODOLOGY

Data acquisition

Data on annual Maize yield (for the period of 1970 to 2000) were obtained from the Federal Office of Statistics (FOS), which is the central organisation for data collection in Nigeria. Rainfall data were collected from the archives of the Nigerian Meteorological Services, Oshodi, Lagos. These thirty (30) years data were collected (for the period of 1970 - 2000) from annual collection of data on agricultural production through household sample surveys by the FOS, National Household Survey Capability Program (NHSCP), State Agricultural Programme (e.g. Oyo State Agricultural Development Programme), Nigerian National Integrated Survey of Households (NNISH), Rural Agricultural Sample Survey (RASS) and Central Bank of Nigeria (CBN) annual survey. Nigerian Meteorological Services using Dines Tilting Rainguage and the British Standard Rainguage collected the rainfall data used in this study. The positions of these rainguages have not been tainted since the commencement of the record keeping. Therefore, rainfall data may not have suffered from non-homogeneity. A year is divided into two growing seasons for better data acquisition and analysis. These seasons are: early growing season (April - June); and late growing season (July - October).

Geospatial analysis methods

The Geographic Information Systems (GIS) database creation and mapping techniques were used to create interactive maps of the crops production areas, areas harvested and the yield. GIS is a computer-based technology that helps in management, manipulation, analysis, display (mapped) data and decision-making process. GIS offers a relatively efficient way for rainfall/crop yields modeling. GIS technology has the ability to integrate spatially explicit information into different formats from multiple sources. Through interpolation maps of sensitivity was drawn using Arc View GIS- the product of Environmental System Research Institute (ESRI). Thus, the results are presented geographically for better understanding. Arc

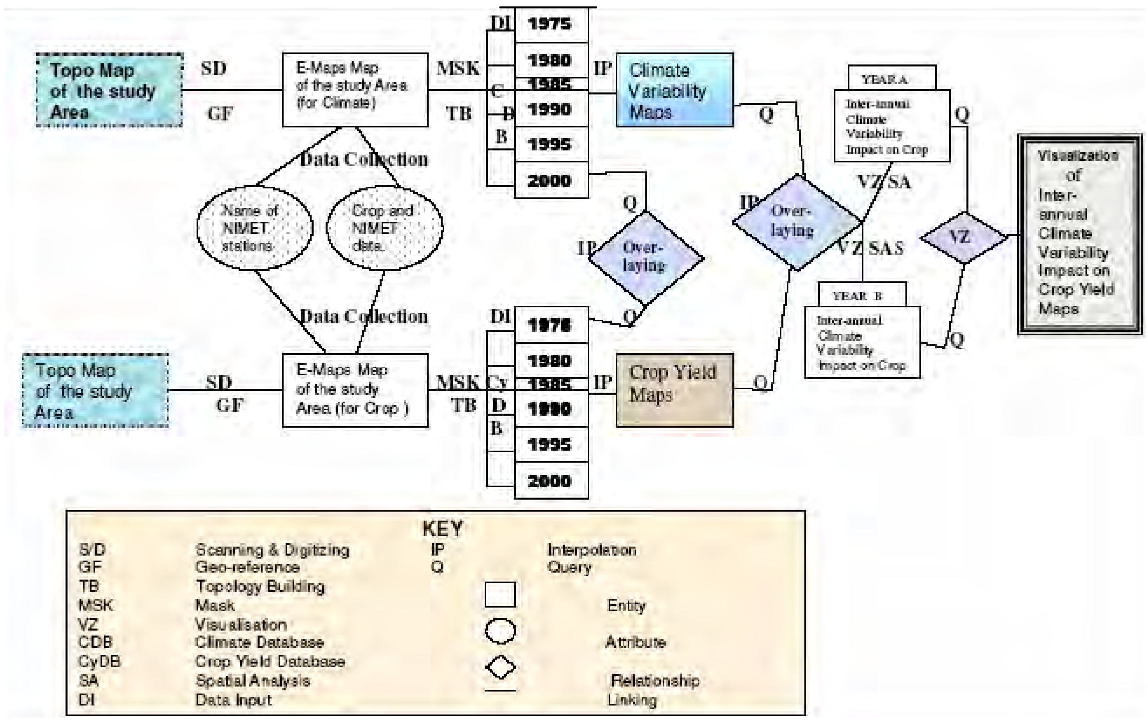


Figure 2. GIS entity-relationship model for inter-annual climate variability impact on crop yield (GCMICVIC).

View makes it easy to work with spatial data, to see patterns, which could not be seen originally, and revealing hidden trends and distributions, thus gaining new insights.

Building spatial-dominant models through GIS tools is frequently a time-consuming process, and a common requirement of much rainfall/crop yields research is the assimilation of physical data and biological data from many sources (Kufoniyi, 2003, 2004). Therefore, the search for a relatively easy method to integrate this information is ongoing and it is thought that Interpolation, Quarry, Overlying and an Object-Oriented approach, as mentioned above, are useful systems to asses the impact of rainfall variability on maize yields (Figure 2).

The statistical methods that were employed for this study include correlation of crop yield with annual rainfall total and Z- distribution anomalies. Z- distribution anomalies are the only valid statistical technique to use when the data is normally distributed. Generally, the rainfall total in Nigeria is normally distributed especially in a situation where the mean annual rainfall is greater than 750 mm (Adejuwon and Odekunle, 2006). In this study, however, rainfall variability was assessed using the Z-distribution anomalies. This measurement of variability was found suitable because both monthly and annual rainfall total data used were confirmed normally distributed. To show the impacts on chart, Z-distribution chart was adopted for this study. The crop yield array was converted to a Z-distribution format varying in magnitude from – 3 to +3. From this format, significant positive and significant negative impacts, separated by the normal yield level could be discriminated. Whenever the anomaly is significant, it is counted as an impact. This Z- distribution anomalies (Which was used to draw Z-distribution chart) is mathematically expressed as:

Index variation **(Z)** = $\frac{[s - m]}{SD}$

$s = \sum y_1, y_2, y_3, \ldots y_n$, Where y = yield of maize

$$m = \sum fy / n$$

This shows the mean of maize yield.

$$SD = \sqrt{\sum \{y - m\}^2 / \sum fy}$$

This shows the standard deviation of the yield.

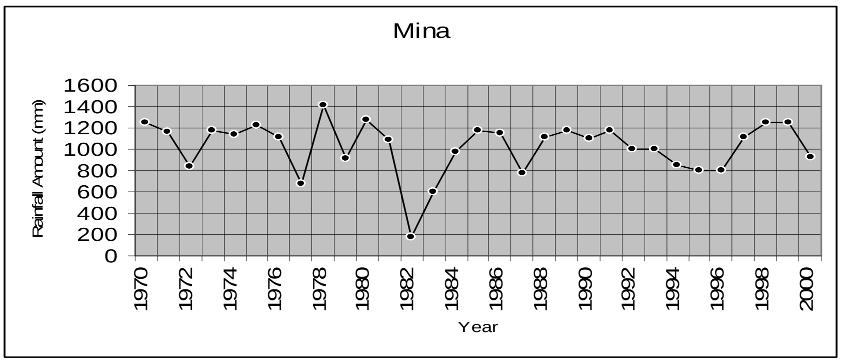
RESULTS

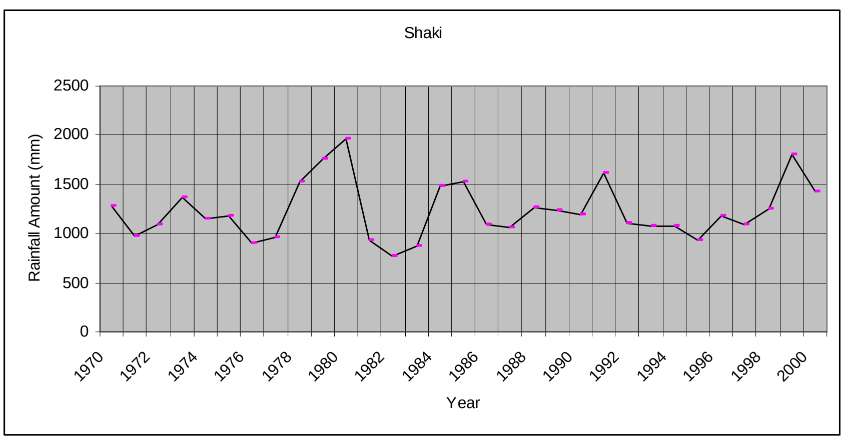
Rainwater variability and water availability

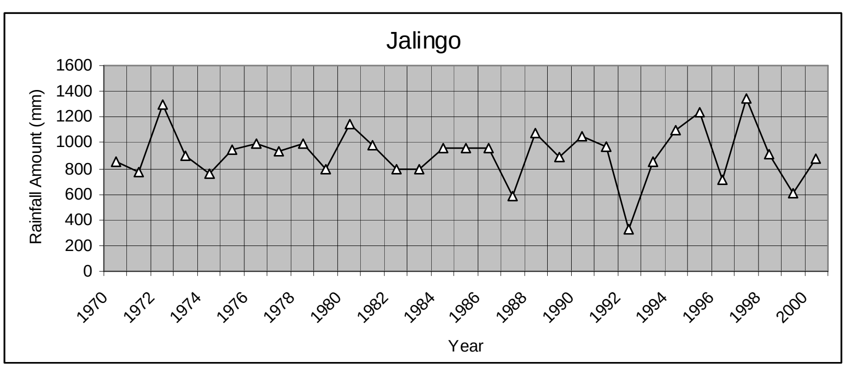
From Table 2 and the figures, it is observed that rainfall variability is very high in most of Northern Guinea Savanna with Yola, Minna, Abuja and Mokuwa having values of coefficient variation between 26 – 49%. In Southern Guinea Savanna, however, the coefficient of variation is very low especially, in Ogoja, Enugu and Shaki. This actually confirm that the lower the inter-annual rainfall total, the higher the value of coefficient of variation which imply great variability in water availability. More so, the variation is very significant in Makurdi, Ilorin, and Yola (Table 2 and Figure 3) with lower rainfall values for the period of 1983 to 1993. Generally, rainfall value was increased in 1999 and 2000 for all the stations, which signified the peak. In Shaki, Lokoga, Ogoja and Minna rainfall total is observed to be very low within the period of 1982, 19983, 1992 and 1993 (Figures 4 to 8). Figure 3 shows a good example of rainfall variability from 1970 to

Table 2. Result of coefficient of variation and regression modeling parameters.

E3 Dependent variable (Y) (Crop yield)	Explanatory variable (X) (Rainfall)	Coefficient of variation (%)	Constant (C)	Unstandardized coefficient B
Maize	Markurdi	61	8242.723	4.863
Maize	Yola	44	6580.782	3.690
Maize	Ilorin	42	6056.359	2.783
Maize	Makowa	26	4736.807	1.695
Maize	Minna	49	2985.213	0.235
Maize	Lokoja	17	5097.321	- 1.681
Maize	Shaki	8	2959.577	0.231
Maize	Abuja	25	591.703	2.289
Maize	Enugu	9	3997.446	0.481
Maize	Ogoja	18	603.786	- 1.478
Maize	Jalingo	39	3721.197	0.523







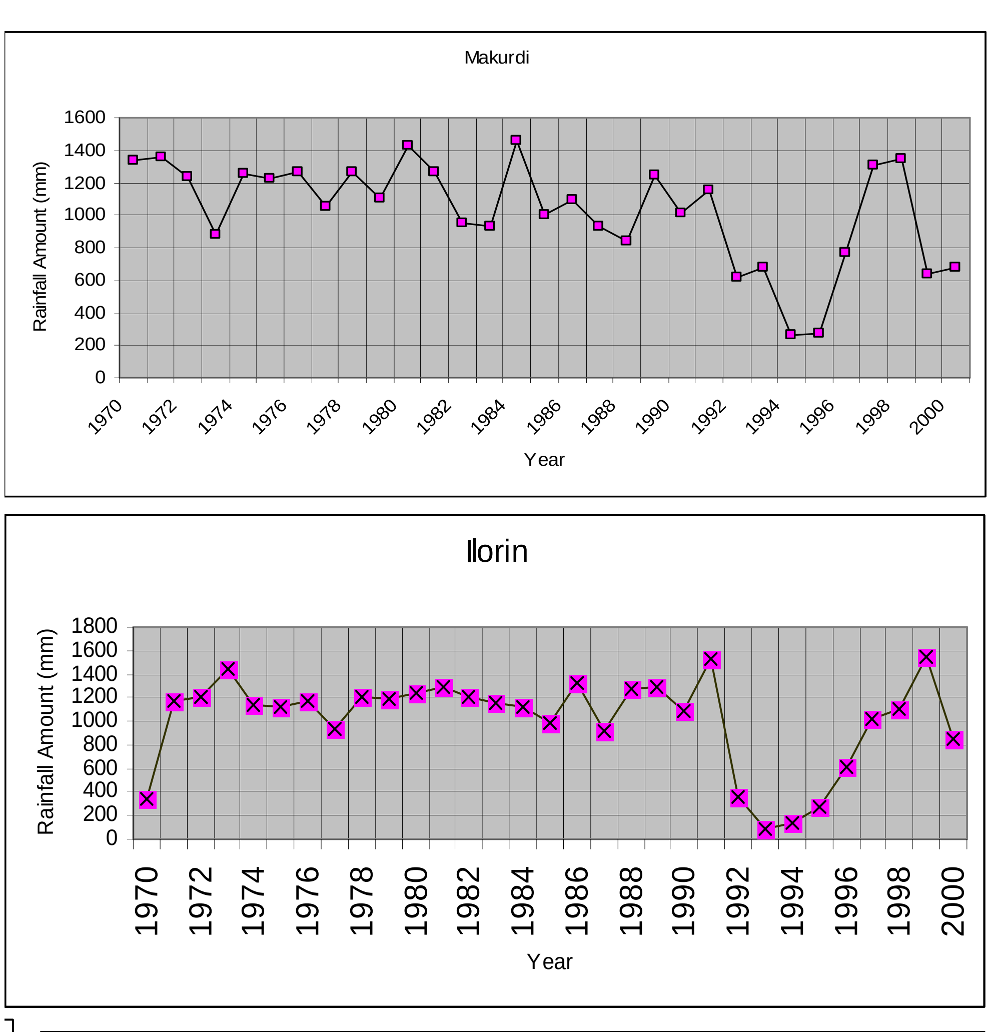


Figure 3. Annual rainfall variability

2000 in Yola, Minna and Makurdi with mean amount of about 1700 mm per annum (p.a). The figure also shows abnormal low rainfall in 1983 and 1993 with amount less than 900 mm in almost all the stations. Further more, there is increase in Mokurdi within the period of 1996 - 2000, which reveals an increase with amount ranging between 1200 and 2200 mm p.a., except in 1983 and 1993, which has less than 900 mm p.a. In Mokwa, Shaki, Ogoja and Minna, Figures 6 and 7 also show that between 1981 - 1985 there is low rainfall of below 700 mm p.a while Figures 8 to 11 show that, from 1998 to 2000, rainfall value is as high as 1800 mm p.a. The evidence of rainfall variability is observed as a result of the impacts of climate change and variability that consequently affects water availability for maize yield.

Impacts of rainwater variability on maize yield

Figures 12 to 15 show variation in annual maize yields and as responses from rainfall variability for the periods of 1972/73, 1982/83, 1992/93 and 1999/2000. Generally, the figures show that maize yields behave in a similar manner, i.e., increase in rainfall results to increase in yield. A significant observation in all the stations is that a continuous increase in maize yield is noted between 1970 and 1978 while there are significant reductions in yield observed between 1982/82 and 1992/93. Reduction in yields is as result of prolong “Little Dry Season” (Adejuwon and Odekunle, 2006) activities that occurred in 1983, 1992 and 1993, which brought a reduction in rainfall and resulted in decrease in maize yield. Such effect is not significant at Ilorin and Lokoja except in 1993.

Figure 16 shows significant fluctuations in annual maize yield in all the ten stations (Shaki, Ilorin, Mokwa, Minna, Ogoja, Yola, Lokoga, Jalingo, Enugu and Makurdi). Low yield is pronounced in 1982/83 and 1992/93 in Makurdi, Minna, Mokwa, Shaki and Yola while high yield are observed in 1983 at Ilorin and Lokoja. An important observation is that the yield does not depend on the cli-

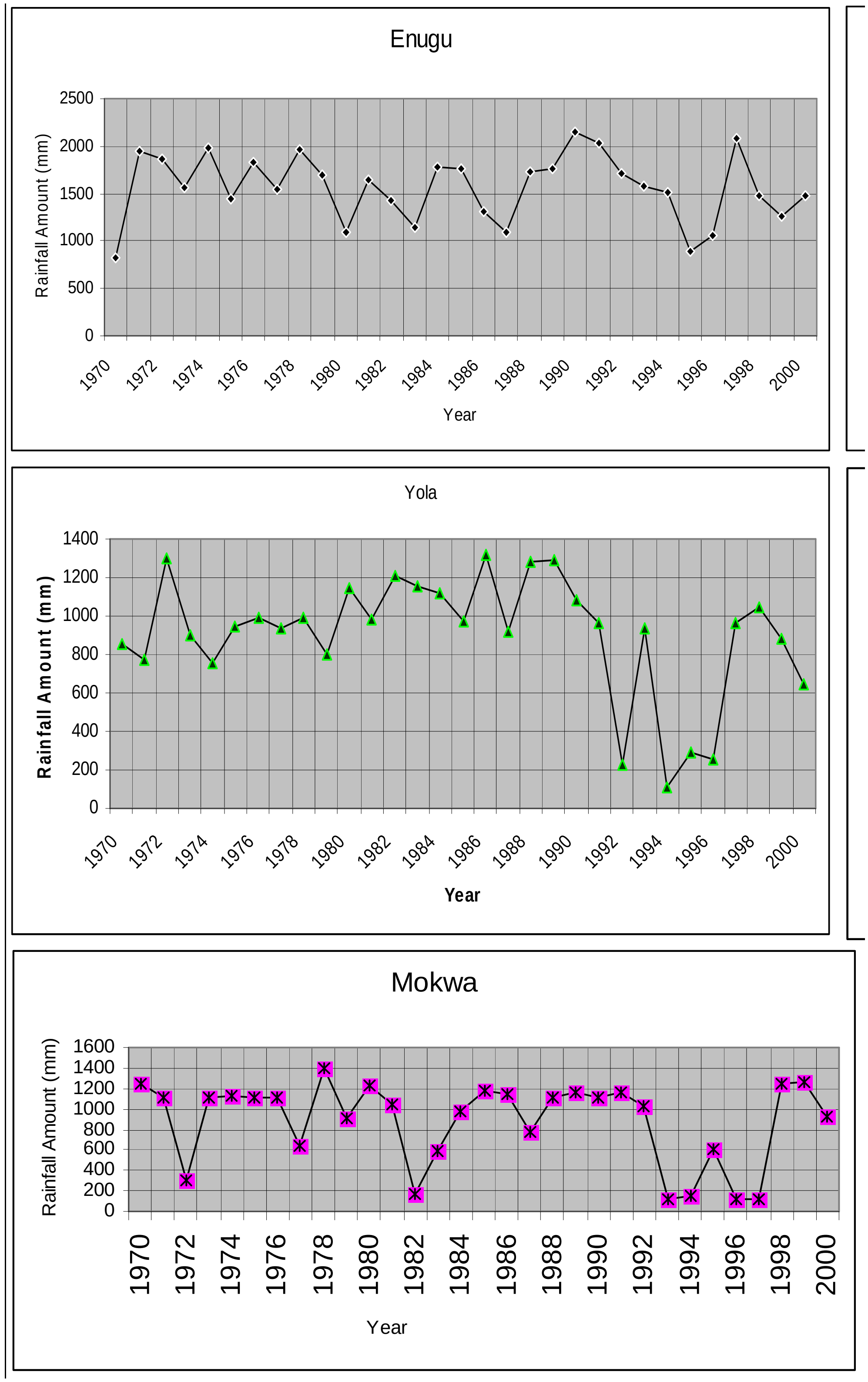
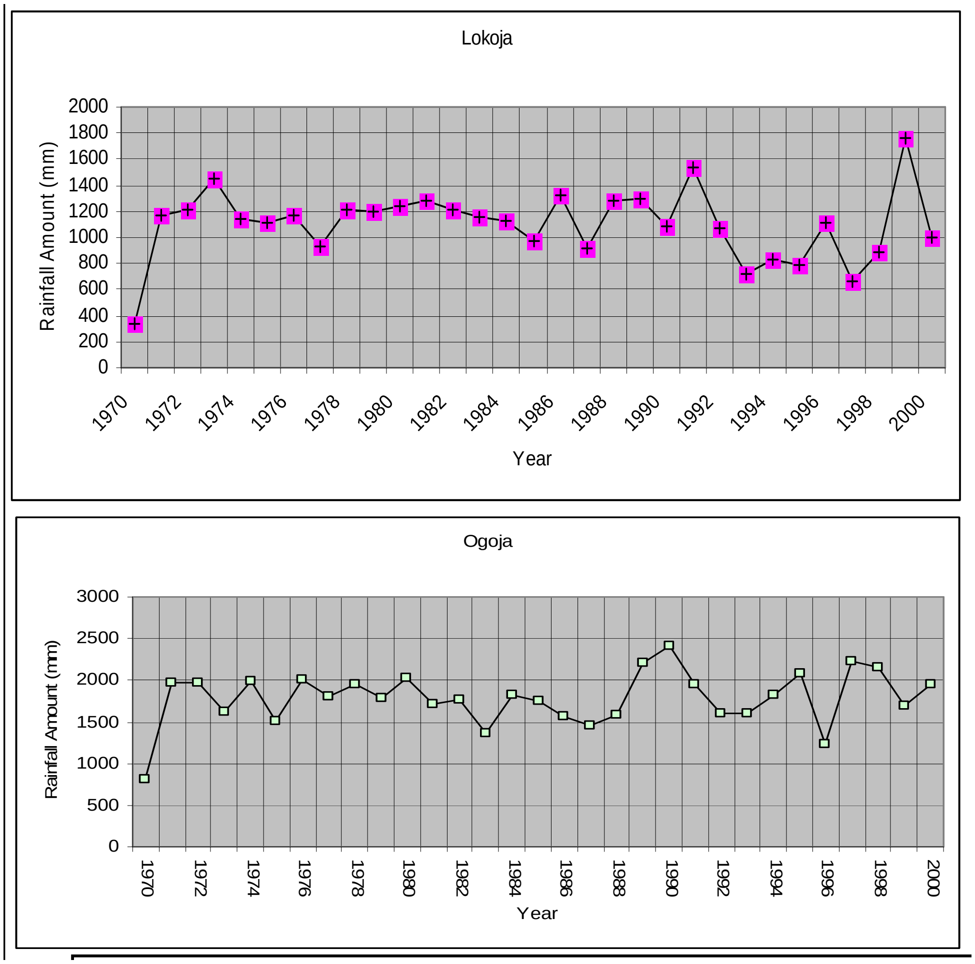


Figure 3 Contd. Annual rainfall variability



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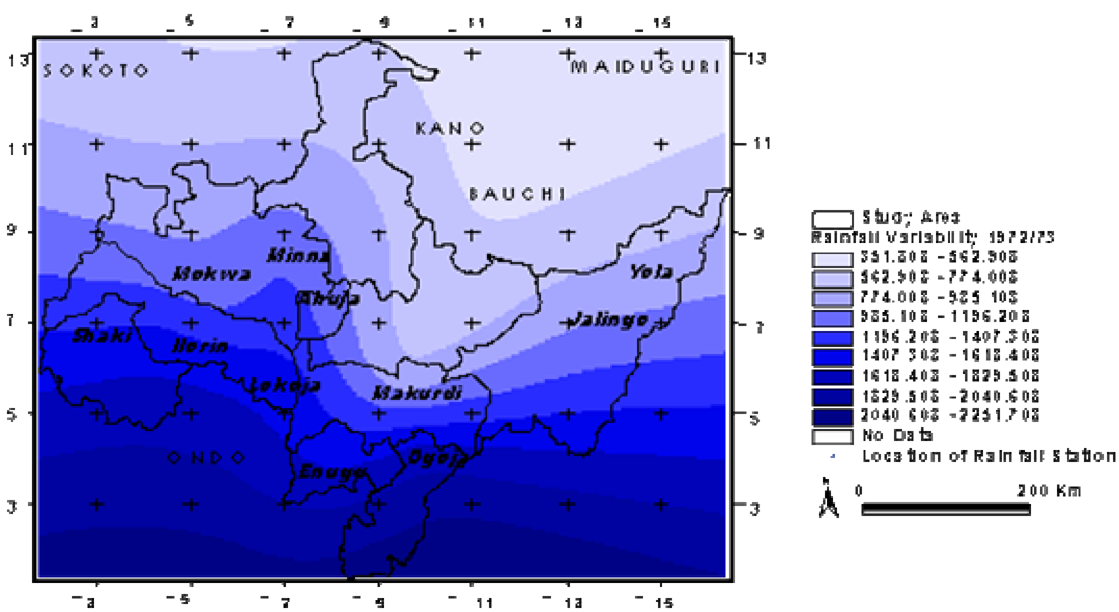

Figure 4. Rainfall variability (1972).

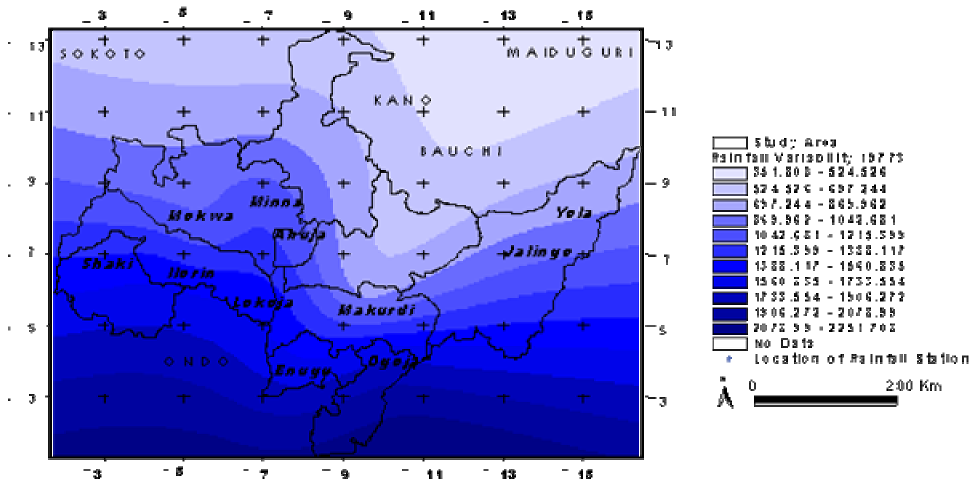

Figure 5: Rainfall Variability (1973).

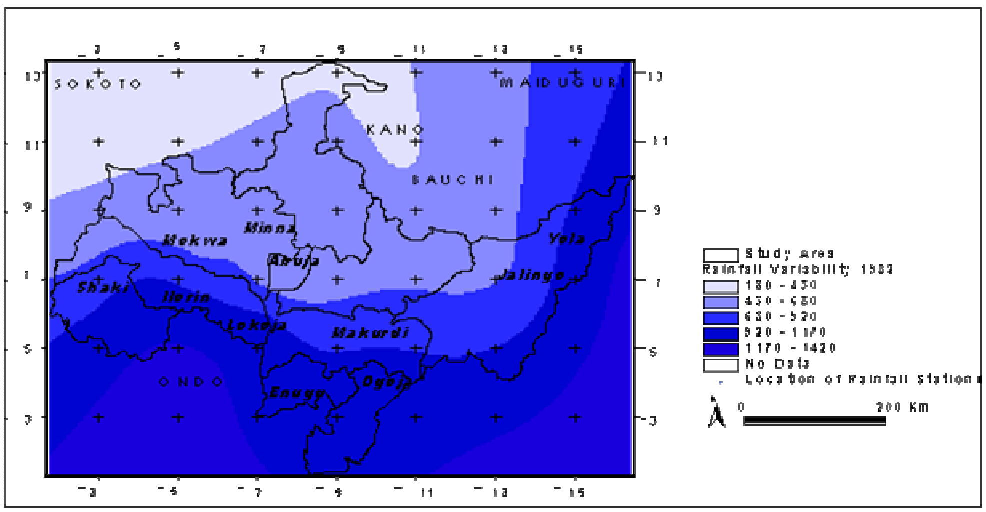

Figure 6. Rainfall variability (1982).

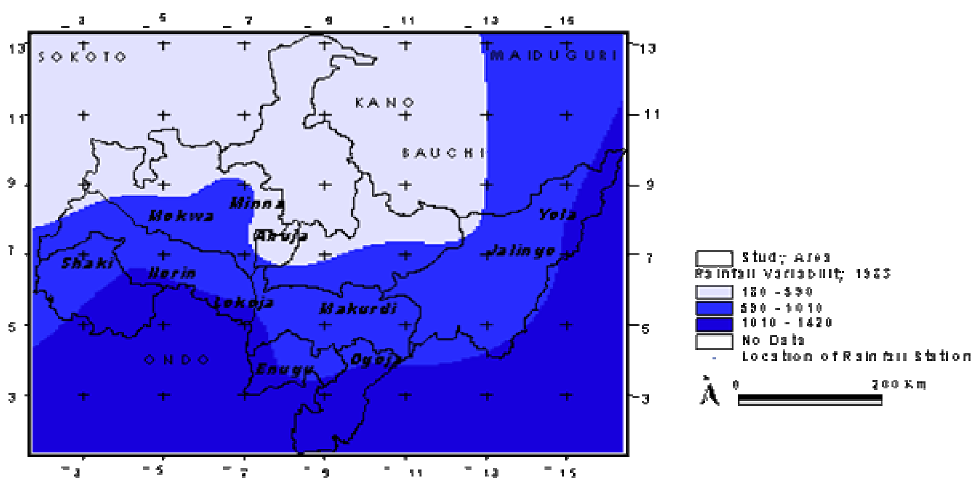

Figure 7. Rainfall variability (1983).

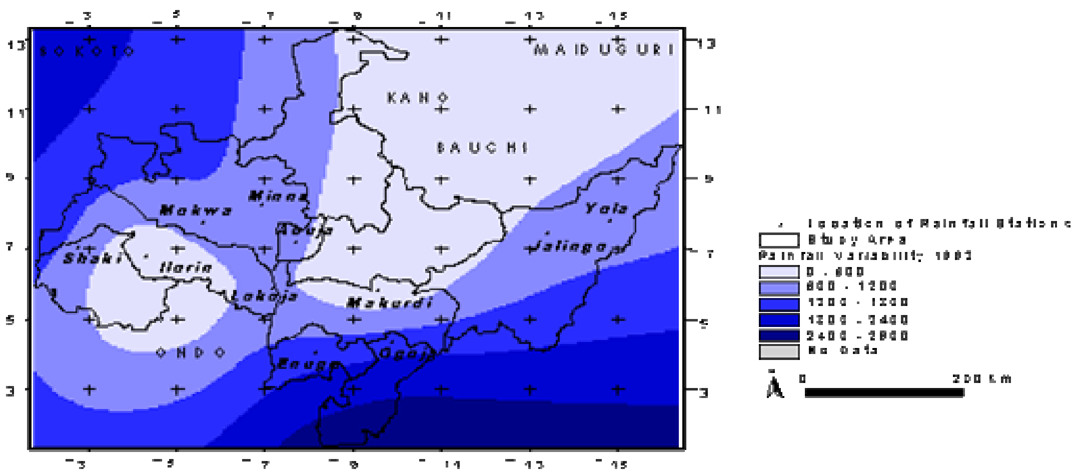

Figure 8. Rainfall variability (1992).

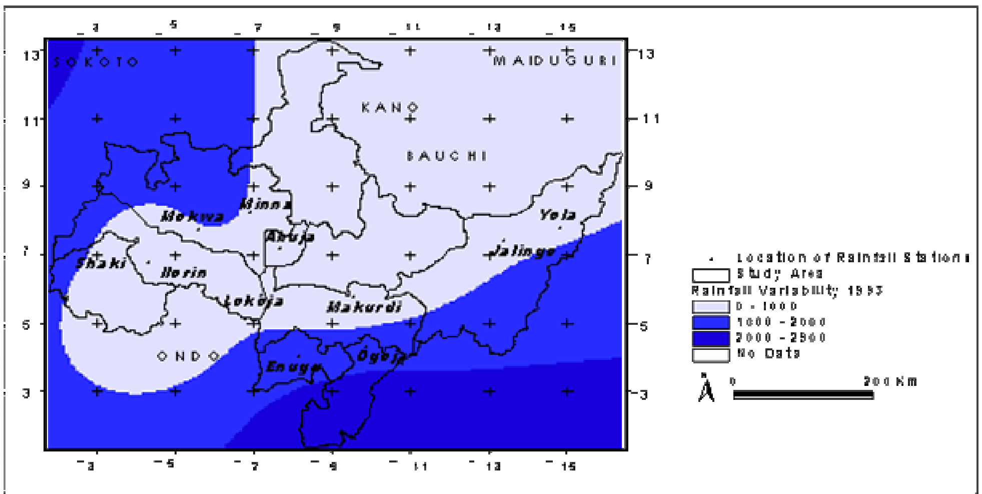

Figure 9. Rainfall variability (1993).

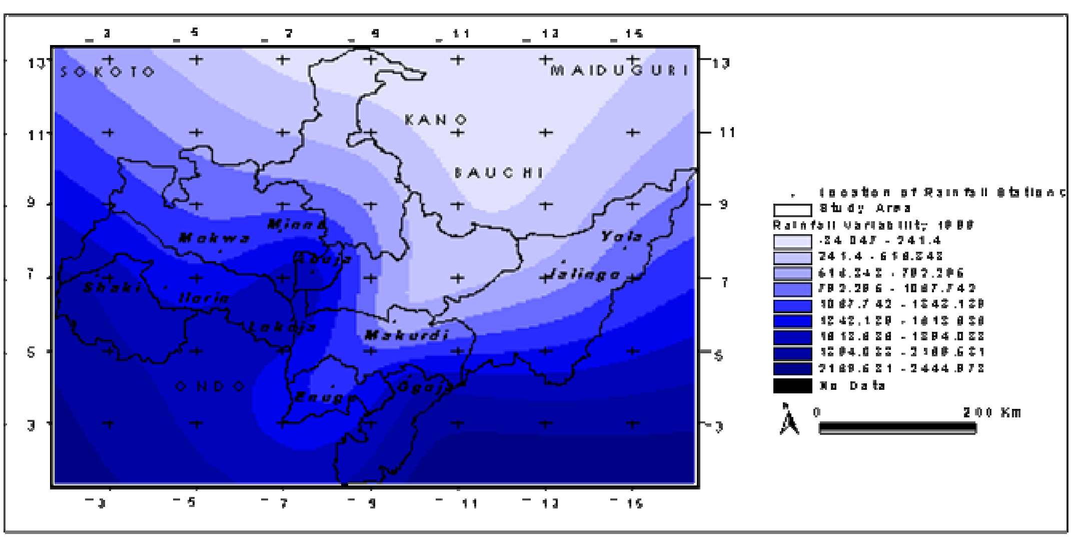

Figure 10. Rainfall variability (1999).

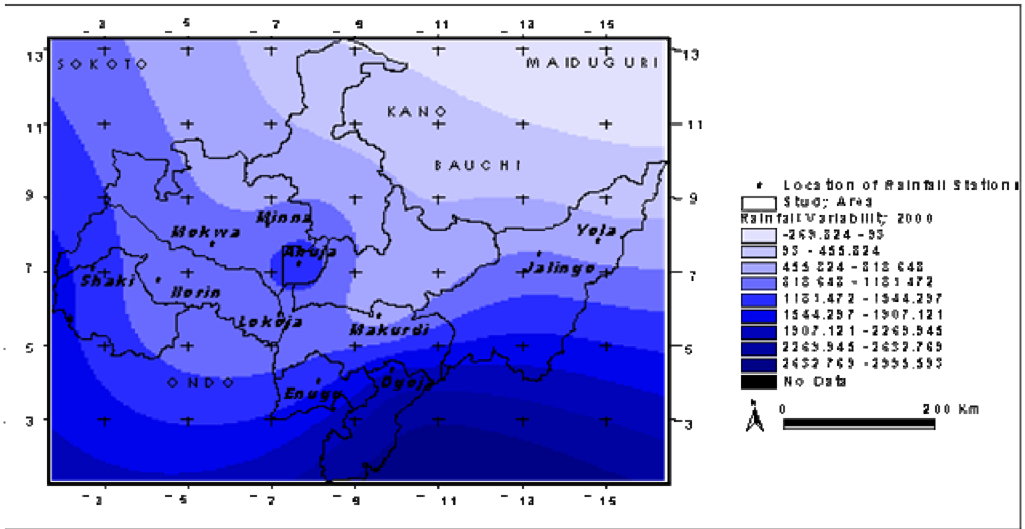

Figure 11. Rainfall variability (2000).

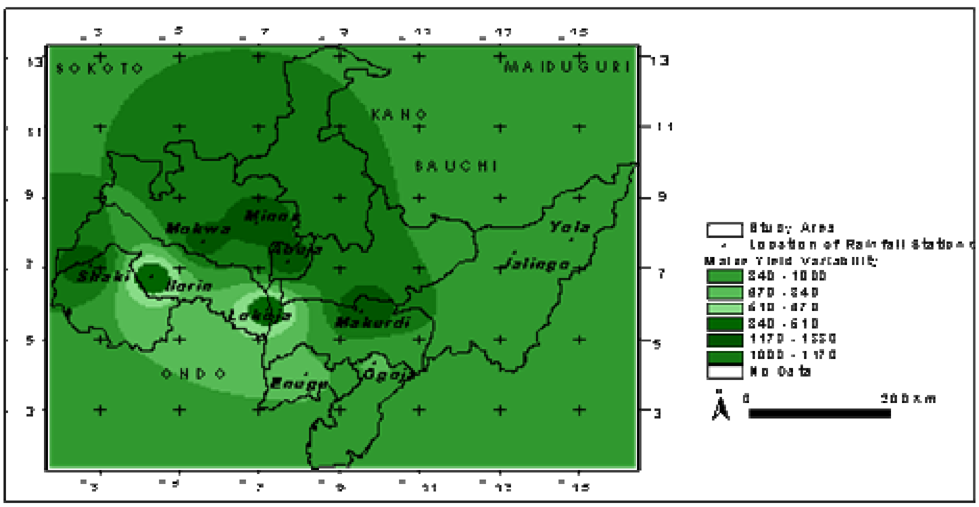

Figure 12. Maize yield variability (1972/73).

matic zone but on the behaviour of climatic elements (Especially rainfall). Figure 15 also shows an increase in maize yield during 1999/2000 while Figure 13 depicts lower yield in 1982/83 than 1999/200 in all the stations. An exceptional increase in maize yield is, however witnessed in 1999 and 2000 (Figure 16). Generally, maize yield and production are on the increase during these years especially, 1972 to 1974 and 1998 to 2002 (Figure 12 and 15). It is very clear that increase in variation in rainfall leads to variation in maize yield and vice versa. The trend lines are on increase, however, the increase maize yield in Lokoja is more pronounced except 1992/1993 (Figure 14) which behaves in the opposite sense as seen in the maps. The behaviour of rainfall elements are in the same direction in all the stations, except at Lokoja where the yield was not badly affected by rainfall in 1983 to 1993 as that of 1991 to 2000. The increase in yield recorded in 1990 to 2000 in all stations listed above may be attributed to the increase in rainfall during the planting season within the period. The years 1983 and 1993 experienced very low rainfall during planning season that had been due to greater number of drought episodes (Obasi, 2003a; 2003b). From Table 3, it is very clear that the disaggregates of the rainfall, specifically, June, July, August and September (i.e. GS), show significant correlations with the variation in maize yield. Higher or more significant correlations were achieved when these disaggregates were related to maize yield in correlations. Assessments of rainfall variability impacts were represented in the Z-distribution chart (Figure 17). The results of z-analysis were converted to z-charts varying in magnitude from –3 to +3. From this format, signifi-

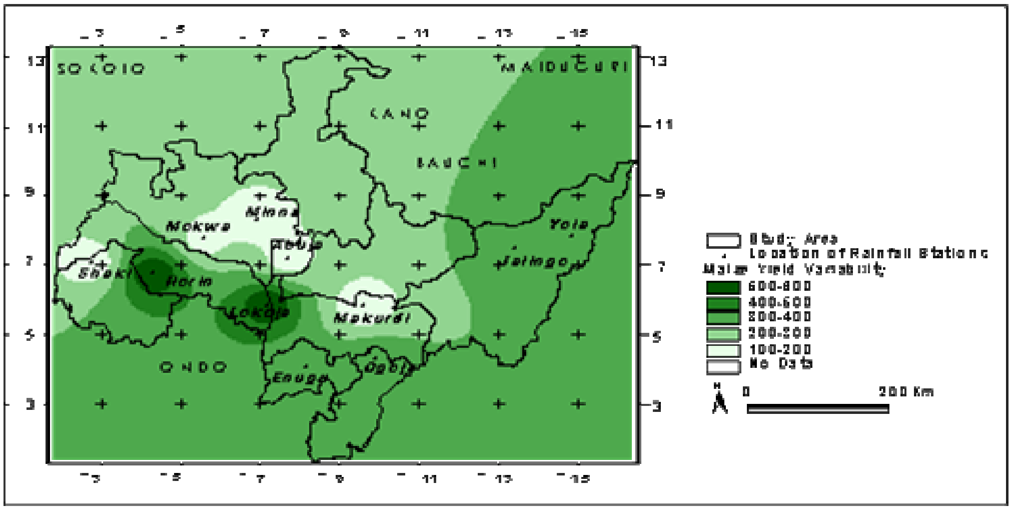

Figure 13. Maize yield variability (1982/83).

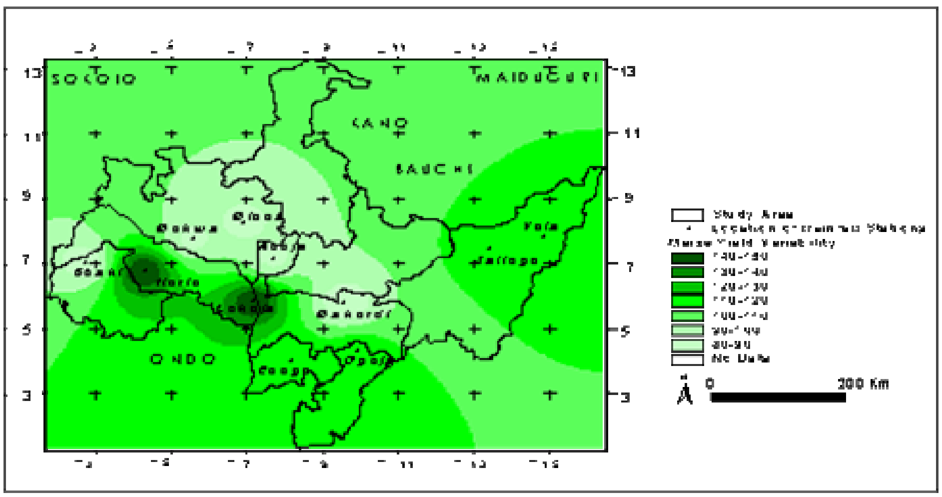

Figure 14. Maize yield variability (1992/93).

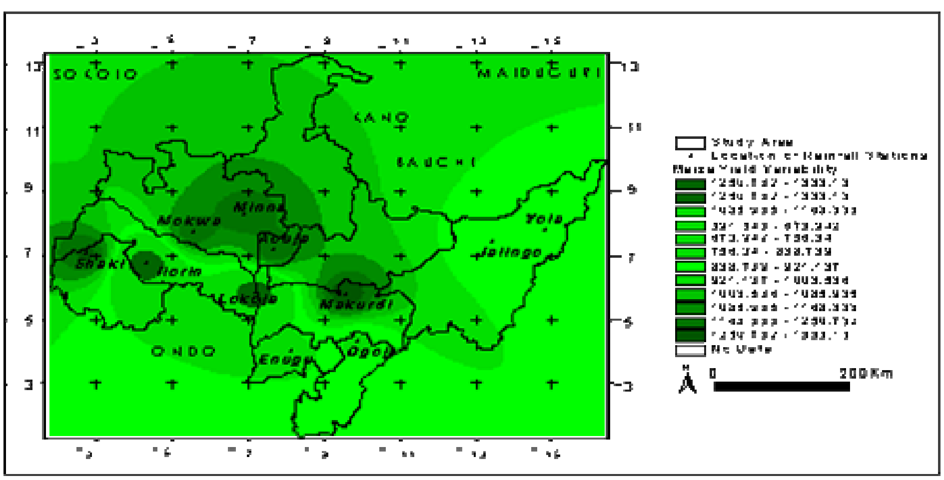

Figure 15. Maize yield variability (1999/2000).

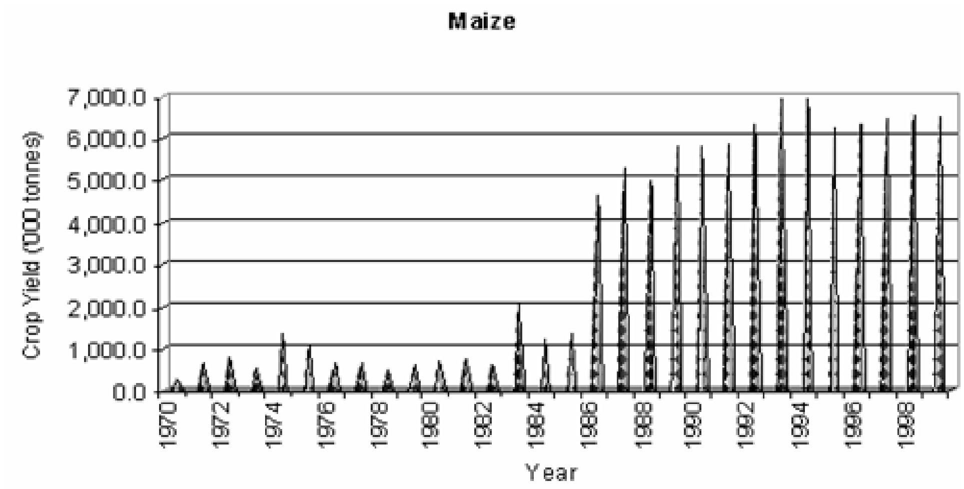

Figure 16. Maize Interannual variability (1970 to 2000).

Table 3. Correlation of Maize Yield with Growing Season Rainfall.

Station	Total	May	June	July	Aug	Sept
Yola	0.47**	0.33	0.72**	0.09	0.65**	0.76**
Minna	0.57**	0.39*	0.54**	0.28	0.68**	0.65**
Mokwa	0.56**	0.43**	0.48**	-0.24	0.26	0.61**
Ogoja	0.03	0.14	0.12	0.06	0.17	0.20
Makurdi	0.55**	0.51**	0.61**	-0.43	0.40*	0.55**
Jalingo	0.52**	0.36	0.62**	0.20	0.65**	0.60**
Shaki	0.48**	0.41	0.55**	0.38*	0.51**	0.36*
Lokoja	0.32	0.16	0.47	0.42*	0.60**	0.45**
Ilorin	0.43*	0.46**	0.52**	0.39*	0.71**	0.58**
Enugu	0.47**	0.27	0.09	0.32	0.33	0.22

**Correlation is significant at $\alpha \leq 0.01$.
*Correlation is significant at $\alpha \leq 0.05$.

cant positive and negative impacts were recognized. It is observed that the yields of most of the years between 1979 and 1999 belong to near normal category of impacts. Using z-chart it is very clear that 1982 and 1993 were the years with the highest negative anomaly of crop yields (See Figure 17).

DISCUSSION

The results of the analysis and the maps produced show that inter-annual variability of rainfall brings about the differences in the rate of maize yields in Guinea Savanna of Nigeria. Observation shows that the rainfall variation generally increases with decreasing in annual totals of rainfall, which is observed in the result of coefficient of variation (Ojo, 1977). This study demonstrated that the effect of the growing season rainfall, specifically, May, June, July, August and September rainfall (See also Adejuwon, 2005), divulge significant influence on inter-annual rainfall variability hence affect maize yield. It is observed that rainfall in Guinea Savannah zones of Nigeria is on the percentage increase but the amount varies (Ojo, 1977). Despite rainfall horrific scenario maize is still an important food crop in the Guinea Savannahs of Nigeria where it is gradually replacing the traditional cereal crops such as sorghum and millet. Despite its high yield potential, maize production is however faced with numerous constraints. One of the major constraints is intermittent drought during the growing season, which, significantly reduce maize yield. Drought at beginning of the growing season will affect crop establishment and reduce plant population while drought during the flowering period of the maize crop will lead to complete crop failure. To reduce the negative effects of drought and improve food security efforts are being made at International Institute of Tropical Agriculture (IITA) to develop or identify drought-tolerant maize varieties that are adapted

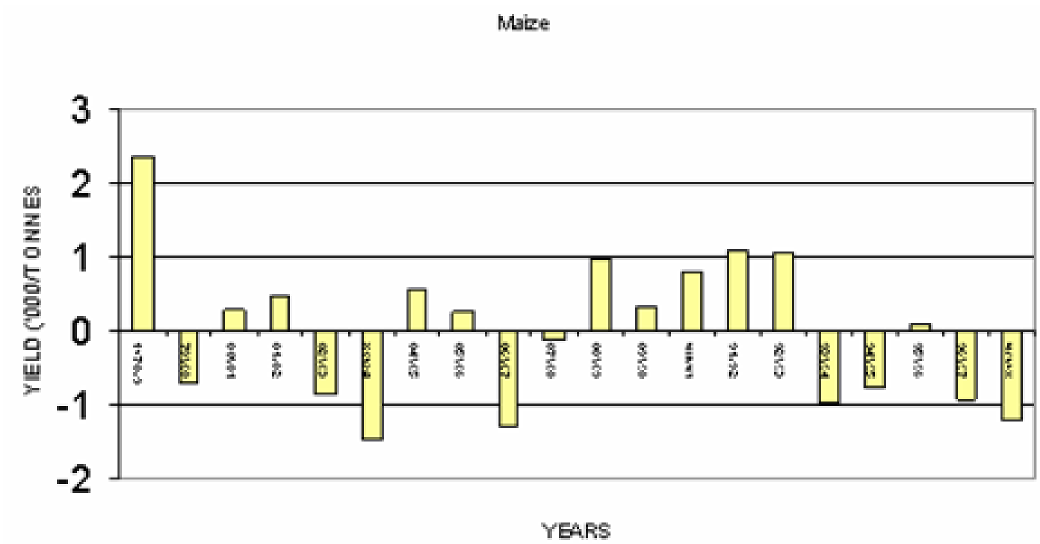

Figure 17. Maize yield anomalies responses to rainfall variability.

to the Guinea savannahs of West Africa (IITA, 2004). This study evaluated three maize varieties that have been identified to either tolerate or escape drought. The drought tolerant maize varieties were evaluated on farmers' fields. Generally, the farm yield of the maize varieties evaluated was higher than the average grain yield reported for Guinean savanna part of Nigeria (Fakorede et al., 2001).

Many people and most undernourished households in Nigeria depend on cereal (most especially, maize) as a contributing, if not principal, source of food and nutrition [see, for example, Central Bank of Nigeria (CBN) 2005]. In fact, these farm households value maize because it produces large quantities of dietary energy and have stable yields under conditions in which other crops may fail (FAO, 2001). The fact remains the same that maize (***Zea mays*** L.), also known as corn is the most important cereal crop in Nigeria, one of the three most important cereal crops in the world. Maize is high yielding, easy to process, readily digested, and costs less than other cereals. It is also a versatile crop, allowing it to grow across a range of agro ecological zones. Every part of the maize plant has economic value: the grain, leaves, stalk, tassel, and cob can all be used to produce a large variety of food and non-food products.

Conclusion

The impacts of rainfall variability on water availability for maize yield in Guinean Ecological Zone of Nigeria have been analyzed and mapped using Geographical Information Systems in this study. This confirm Nigerian slogan that “rainwater is the husband of maize yield”. That is production and the yield of maize actually depends on the spatio-temporal distribution, nature, variability and reliability of rainfall. It has been shown that rainfall variability affect water availability consequently affects maize yields by reducing length of growing season, especially in the drought years. This impact is more pronounced in the period 1980 - 1990 when compared with that of 1991 - 2000 resulting to fluctuations in water availability for maize yield. Generally, there is a reduction in maize yield in the 1980s and gradual improvement in the 1990s as observed in most of the stations except Yola, which shows a reduction in 1990s. The research work has also analysis the decline that has been dominated by reduction in the number of rain days during the middle of the rainy season and there is evidence of a significant change in maize yield as climate varied. Other climatic parameters (e.g. vapour pressure, solar radiation and wind speed) appear to have remained stable, although the paucity and dubious quality of much of the historical meteorological data make rigorous statistical analysis difficult. About 95 percent of all cropland of this zone depend on rainwater as the sole sources of water for crop yield. In these rain-dependent agro-ecosystems, the interaction of rainfall and other climatic elements determine the availability of water for maize yield.

There has been an increased variability of rainfall in response to the trend in rainfall patterns. This is because the natural variability of rainfall has become more susceptible to changes probably due to additional human influence to natural changes as observed in maize yield in most of the stations. Meanwhile, the facts to note here are that; the severity of impacts of climate variability and change on the maize yield in relation to activities of rainfall vary from region to region and from year to year as some stations are observing increase in yield, others witness reduction, depending on crop type/variety.

Despite the importance of this crop in the drought-prone areas of Nigeria, they are also commercially important nonetheless; small-scaled farmers who are quite poor and frequently experience food shortfalls are producing them. Poor adoption of improved technologies in this ecological zone due to combination of poverty, severe environmental conditions and high variability in annual rainfall make it difficult to improve productivity. In the light of the above facts, there is the need for more research and investment in crops production and distribution as a means of increasing productivity and reducing suffering during droughts.

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REFERENCES

Adejuwon JO (2004). Crop yield Response to Climate Variability in the Sudano- Sahelian Ecological Zones of Nigeria in southwestern Nigeria. In AIACC Report of Workshop for Africa and Indian Ocean Island. Dakar, Senegal, pp. 15-16.

Adejuwon JO (2005). Food Crop Production in Nigeria: Present effects of Climate Variability. Climate Research, inter-Research, Germany.

Adejuwon JO, Odekunle TO (2004). Variability and Intensity of the “little Dry Season” in southwestern Nigeria. In AIACC Report of Workshop for Africa and Indian Ocean Island. Dakar, Senegal, pp 8-9.

Adejuwon JO, Odekunle TO (2006). Variability and the Severity of the “little Dry Season” in southwestern Nigeria. Am. Meteorogical Soc. 483-493.

Chiew FHS (2002). Climate Variability Program. CRC for Catchment’s Hydrology.Dewey and Wayn ; Pearl Millet for Grain. USDA-ARS. Central Bank of Nigeria (2005). Production year book; Central Bank of Nigeria Annual Agricultural Survery.

Fakorede MAB, Badu-Apraku B, Coulibaly O, Fajemisin JM (2001). Maize research and development priorities in sus-Saharan Africa in the next millennium. pp. 31–58 in Badu-Apraku B, Fakorede MAB, Ouedraogo M, Carsky RJ (eds.) Impact, challenges and prospects of maizeresearch and development in West and Central Africa. Proceedings of a Regional Maize Workshop, 4–7 May 1999, IITA-Cotonou, Benin Republic.

FAO (2001). Climate Variability and Change: A Challenge for Sustainable Agricultural Production. Committee on Agriculture.

Hare FK (1985). Climate variability and change: pp. 37-66, in (Kates RM, Ausubel JH, Berberian M Eds) Climate Impact Assessment: Studies of the interaction of Climate and Society**.** Chichester, Wiley Press.

IITA (2004). Annual Report for 2004, International Institute of Tropical Agriculture, Ibadan, Nigeria

IPCC (2001). Changes around the Antarctic Peninsula Available at <http://www.grida.no/climate/ipcc_tar/wg2/601.htm#1622>

IPCC (2004a). Climate Change 2003: Impacts Adaptations and Vulnerability<http://www.grida.no/climate/ipcc_tar/wg2/601.htm#1622>

IPCC (2004b). Climate Change 2003: Synthesis Report. Available at <http://www.grida.no/climate/ipcc_tar/wg2/601.htm#1622>

Kufoniyi O (2003). Proposed National Geoinformation Policy: Executive Summary, Proceedings of the National Geospatial Data Infrastructure, NARSDA, Abuja, pp.90.

Kufoniyi O (2004). Development of Geospatial Data Infrastructure in Nigeria. A Paper presented at the National Workshop on Satellite Remote Sensing (Nigeria Sat – 1) and GIS: A solution to sustainable National Development Challenges, 15th – 17th June, 2004, Le Meridien Hotel Abuja, p. 4.

Obasi GOP (2003a). Statement at the International Symposium on Climate Change (ISCC) Beijing, China, 31 March 2003.

Obasi (2003b). Regional conference on climate change and food sustainability in the 21st century: Keynote Address, Lagos, Nigeria, 11 November 2003.

Ojo O (1977). The Climate of West Africa. Hesnemam Publication. pp. 191-193.

Osagie OI (2002). Cereal Output to Plunge Next Year, in: AgroBusiness. THISDAY Online.

Tim H (2000). The impact of climatic variability over the period 1961 1990 on the soil water balance of upland soils in the North East Arid Zone of Nigeria, U.K. Met Office (2000): Climate Change: An Update of Recent Research from the Hadley Centre.

WMO (2000). Strategic Plan for the Enhancement of National Meteorological Services in Regional Association II (Asia) (2001–2004).