Assessing Rainfall Variability Impacts on Maize Yield in Guinean Savanna Part of Nigeria, Using GIS Technique

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Abstract

The scientific evidence on rainfall variability with its momentous impacts on crop yield is now stronger than ever. It is even more so on grains(Maize) that serve as staple food in most parts of the world. Hence, the objectives of this study are to assess spatio-temporal impacts of rainfall variability on maize yield and map the impact with the aid of state-of-the-art 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 analysis. Mapping was done by creating GIS Database for both climate and maize yield data. Arc-View GIS Interpolation and other geospatial Analysis techniques were later 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 variability of rainfall brings about the differences in the rate of maize yield in Nigeria. There is no doubt that farmers increasingly need detailed maps of this kind to plan crops planting schemes and monitor rate of yield. This technique is known as "precision agriculture"

1. INTRODUCTION

Rainfall variability impact analysis is a way of looking at the range of consequences of a given rainfall event or change (Adejuwon, 2004). Inter-annual rainfall variability Impact assessments begin by mapping out direct physical consequences of rainfall event or change, such as, reduced crop yields. The scientific evidence on rainfall variability with its significant impacts on maize yield are now stronger than ever (Hare, 1985; WMO, 2000; Adejuwon and Odekunle, 2006; The Intergovernmental Panel on Climate Change [IPCC], (2001; 2004a; 2004b). One undisputable cause of 'famine' in Guinean Savanna Nigeria is the failure of crops resulting from insufficient or untimely rainfall. 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 have primarily examined the impacts on some specific crops only statistical modeling. Among these are the works by Tim, (2000), FAO (2001); Chiew (2002); Adejuwon, 2004; Adejuwon and Odekunle, (2006); 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 objective of this paper is to use Geographical Information Systems technique to examine and map the spatio-temporal impact of rainfall variability on maize 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 variability in the area using geospatial analysis.

2. 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 $3.^0$ and 14^0E and latitudes 7^0 and 10^0N (see Table1 and Fig. 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.

3. 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 (for the period of 1970 to 2000) 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 Progrramme), 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 maize 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/maize yields modeling. GIS technology has the ability to integrate spatially explicit information into different formats from multiple sources. Through interpolation, maps of sensitivity were drawn using Arc View GIS- the product of Environmental System Research Institute (ESRI). Thus, the results are presented geographically for better understanding. GIS 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/maize yields research is the assimilation of physical data and biological data from many sources (Kufoniyi, 2003 and 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.

The statistical methods that were employed for this study include bivariate correlation of crop yield with annual rainfall total, multiple correlation analysis of 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 750mm (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 to be used were confirmed to be normally distributed. This Z- Distribution anomalies 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

Bivariate correlation analyses were carried out to determine the strength of the relationship between rainfall data and maize yield at each crop station.

4. Results and Discussions

Maize Yield Variations: Sensitivity to Rainfall Variability

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 Guinean Savanna part of Nigeria. This study demonstrated that the disaggregate of the growing season rainfall, specifically, June, July, August and September rainfall (See Table 2 and Figure 2, 3 and 4), demonstrate significant correlations with maize yield.

The maps produced using Arc-view GIS show that the years during which impacts of rainfall variability on maize yield were observed varied from one year to the other (Figures 2 and 3). For example, in Figure 5 and table 2 negative anomalies were recorded for the maize in1982 and 1986, the negative maize yield anomaly also amounted to an impact. The result of the analysis show that rainfall in Guinea Savannah zones is on the increase but the amount differs. Figures 2, 3 and 4 show a good example of rainfall variability from 1970 to 2000 at Enugu in Guinea Savannah with mean amount of about 1700mm per annum (p.a). The figures also shows abnormal low rainfall in 1976 and 1983 with amount less than 900mm. Rainfall in Enugu for the period 1981-2000 reveals an increase with amount ranging between 1200-2200mm p.a., except in 1983, which has less than 900mm p.a. At Minna, between 1981-1987 there is low rainfall of below

700mm p.a while from 1988 it is above with 1998 having as high as 1800mm p.a. The evidence of droughts and floods are observed as a result of the impacts of climate change and variability. This result is in line with the result obtained by Nichols et al (2000).

The result of the geospatial analysis as established that rainfall variation affects all the stages crops development and yields adversely. The natural variability in rainfall is the major cause of variability in crop yield in the study area. Therefore the degree of vulnerability of maize varies, depending upon the nature of rainfall variability, the maize growth stage when it occurs and the area where the crop is grown, hence the yield. Also high yield depends on the favorable weather, planning and application of agro meteorological information, in all Agricultural activities, especially in variable climate elements.

In Guinean Savanna Ecological Zone of Nigeria, maize is cultivated throughout the area; this is because of its short duration and availability of its ecological requirements, e.g. maize yield requires rainfall of 750-1500mm p.a. and temperature of 26-30^{o}C (Iwena, 2000). As earlier stated, rainfall is one of the determinant factors for crop growth, development and finally maize yield. Generally, the figures show that maize yields behave in a similar manner, where increase in rainfall results to increase in yield. A significant observation at Yola and Jalingo are that a continuous increase in yield is noted between 1995 and 1999 while at Ilorin such was observed between 1996 and 1999. The prolong “Little Dry Season” (Adejuwon and Odekunle 2006) activities that occurred in 1983, 1987 and 1994 that brought a reduction in rainfall resulted in decrease in maize yield. Such effect is not significant at Minna except in 1993. Figure 6.

Shows significant fluctuations in annual rainfall and its effects on maize yield in all the ten stations (Shaki, Ilorin, Mokwa, Minna, Ogoja, Yola, Lokoga, Jalingo, Enugu and Makurdi all in Guinea Savannah). It is observed that rainfall variability is very high in most of Northern Guinea Savanna; Yola, Minna, Abuja and Mokuwa with value of coefficient variation between 26-49 percent (see also, table 2). In Southern Guinea Savanna, however, the coefficient of variation is very low especially, in Ogoja, Enugu and Shaki. This actually means that the lower the inter-annual rainfall total, the higher the value of coefficient of variation which implies great variability in rainfall. The 10-year mean rainfall was highest in the period 1970- 1979 and least in 1980-1999. Low yield is pronounced in 1982 and 1983 in Enugu, Minna, Shaki and Ilorin while high yield is observed in 1983 at Ogoja, Yola and Mokwa. An important observation is that the yield does not depend on the climatic zone but on the behaviour of climatic elements.

Rainfall Variability, Maize Yield Variations and its impacts on Population

Maize is 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 IITA to develop or identify drought-tolerant maize varieties that are adapted to the Guinea savannahs of West Africa. 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.

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, 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.

5. Conclusion

The impacts of rainfall variability (resulting from climate variability and change) on the yield of selected crops in Guinean Ecological Zone of Nigeria have been analyzed and mapped using Geographical Information Systems. It has been shown that rainfall variability affect crop 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 crop yield. Generally, there is a reduction in crop 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 especially in maize yield. The research work has also mapped 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 rainfall 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 crop yield in most of the stations. Meanwhile, the facts to note here are that; the severity of impacts of climate variability and change on crop 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 these crops in the drought-prone areas of Nigeria they are also commercially important nonetheless, they are being produced by small-scaled farmers who are quite poor and frequently experience food shortfalls. 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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Table 1: Names and locations of the stations used.

S/N	NAME OF STATION	CODE	LATITUDE (^{0}N)	LONGITUDE (^{0}E)
1	Enugu	ENG	6^0 27’	7^0 29’
2	Ilorin	ILO	8^0 55’	4^0 11’
3	Jalingo	JGO	8^0 30’	11^0 20’
4	Lokoja	LKJ	8^0 02’	6^0 02’
5	Makurdi	MKD	7^0 50’	8^0 05’
6	Minna	MIN	9^0 36’	6^0 34’
7	Mokwa	MKW	9^0 10’	4^0 43’
8	Ogoja	OGA	6.40’	8.42’
9	Shaki	SHK	8^0 03’	3^0 05’
10	Yola	YLA	9.12’	12.30’

Table 2: Result of Coefficient of Variation and Correlation of Maize with Growing Season Rainfall

DEPENDENT VARIABLE {Y} (CROP YEILD)	EXPLANATORY VARIABLE {X} (RAINFALL)	COEFFICIENT OF VARIATION (%)	Correlation of Maize Yield with Growing Season Rainfall					
			TOTAL	MAY	JUNE	JULY	AUG	SEPT
MAIZE	MAKURDI	42	0.55**	0.51**	0.61**	0.43	0.40*	0.55**
	YOLA	44	0.47**	0.33	0.72**	0.09	0.65**	0.76**
	ILORIN	42	0.43*	0.46**	0.52**	0.39*	0.71**	0.58**
	MAKOWA	26	0.56**	0.43**	0.48**	0.24	0.26	0.61**
	MINNA	49	0.57**	0.39*	0.54**	0.28	0.68**	0.65**
	LOKOJA	17	0.32	0.16	0.47	0.42*	0.60**	0.45**
	SHAKI	8	0.48**	0.41	0.55**	0.38*	0.51**	0.36*
	ENUGU	9	0.47**	0.27	0.09	0.32	0.33	0.22
	OGOJA	18	0.03	0.14	0.12	0.06	0.17	0.20
	JALINGO	39	0.52**	0.36	0.62**	0.20	0.65**	0.60**

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

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

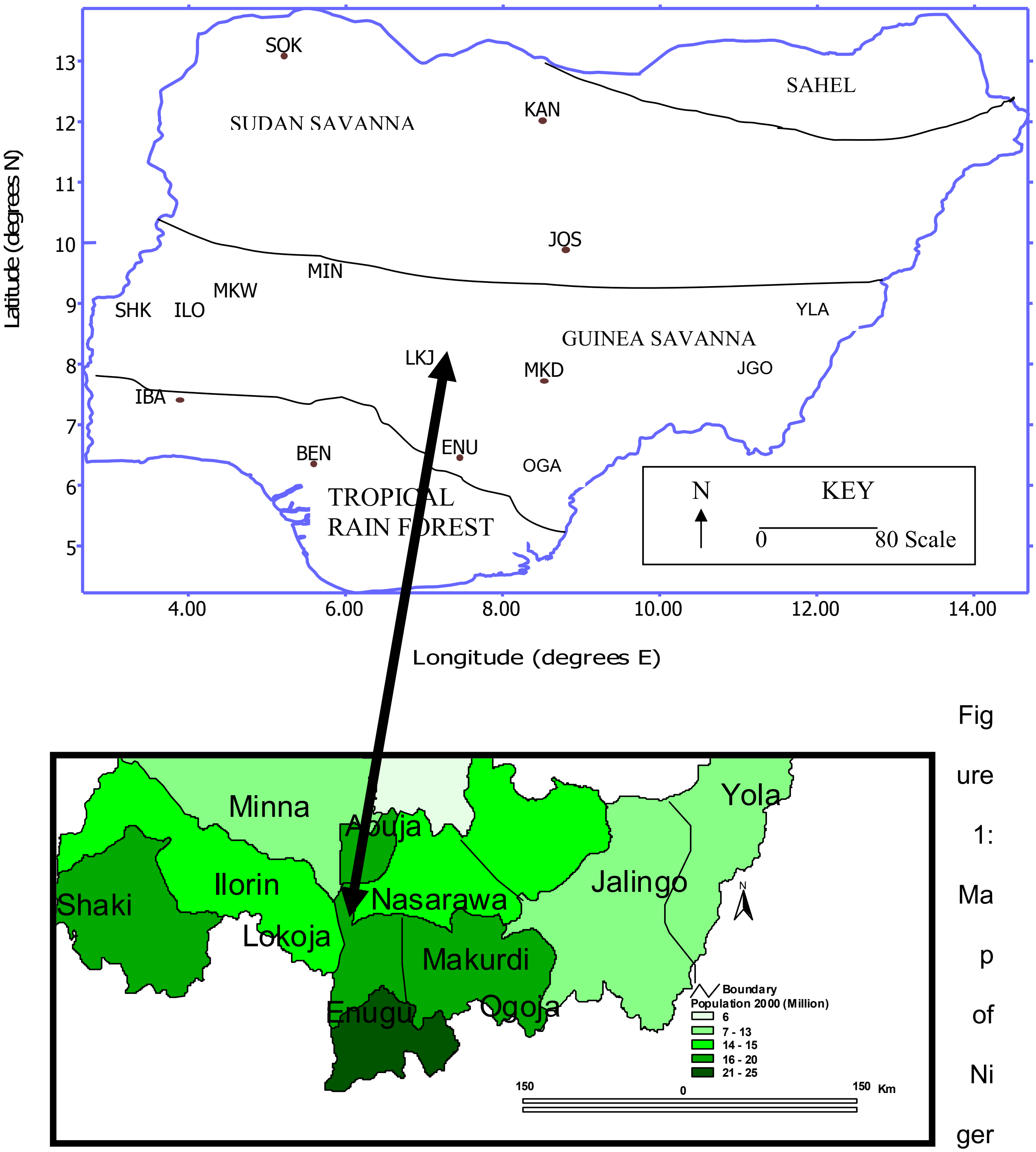

Figure 1: Map of Niger

ia Showing the Study Area.

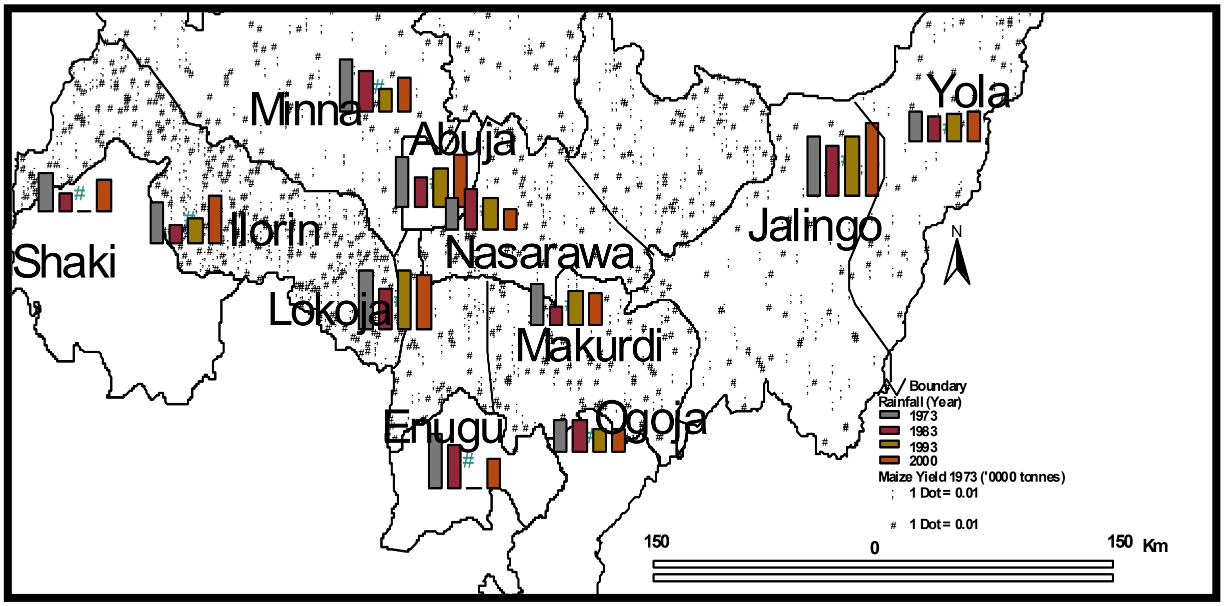

Figure2: Map of the Study Area Showing Maize Yield (1973) and the Rainfall Variability.

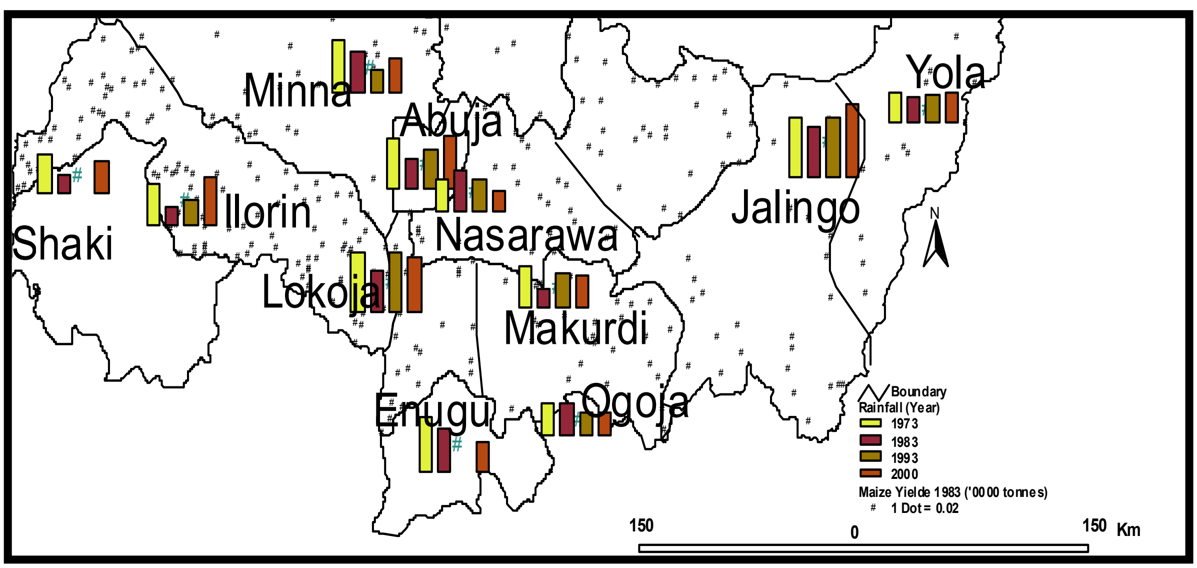

Figure 3: Map of the Study Area Showing Maize Yield (1983) and the Rainfall Variability.

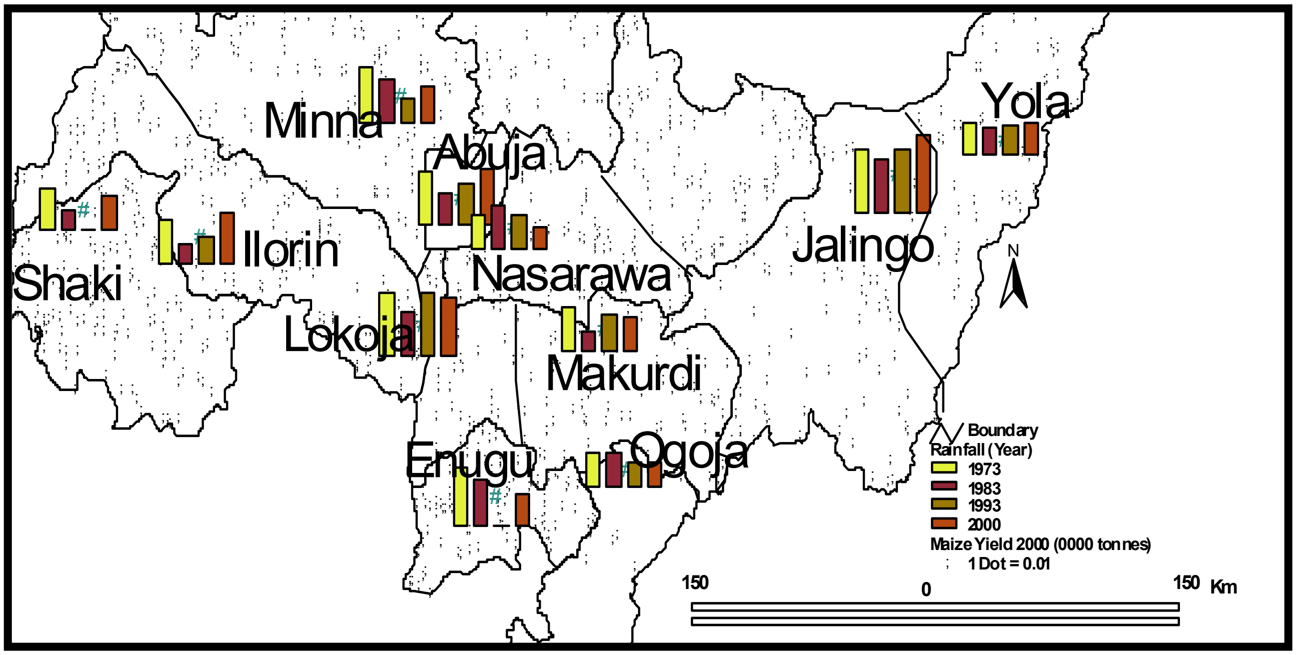

Figure 4: Map of the Study Area Showing Maize Yield (2000) and the Rainfall Variability.

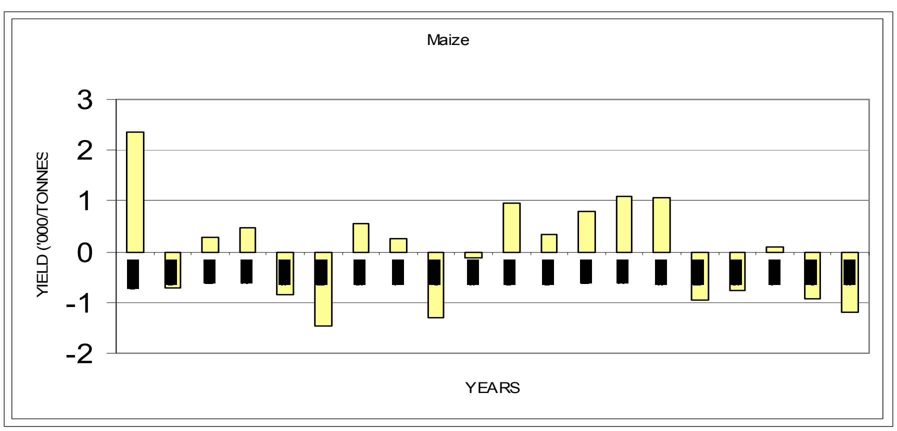

Figure 5: Maize Yield Anomalies Responses to Rainfall Variability.

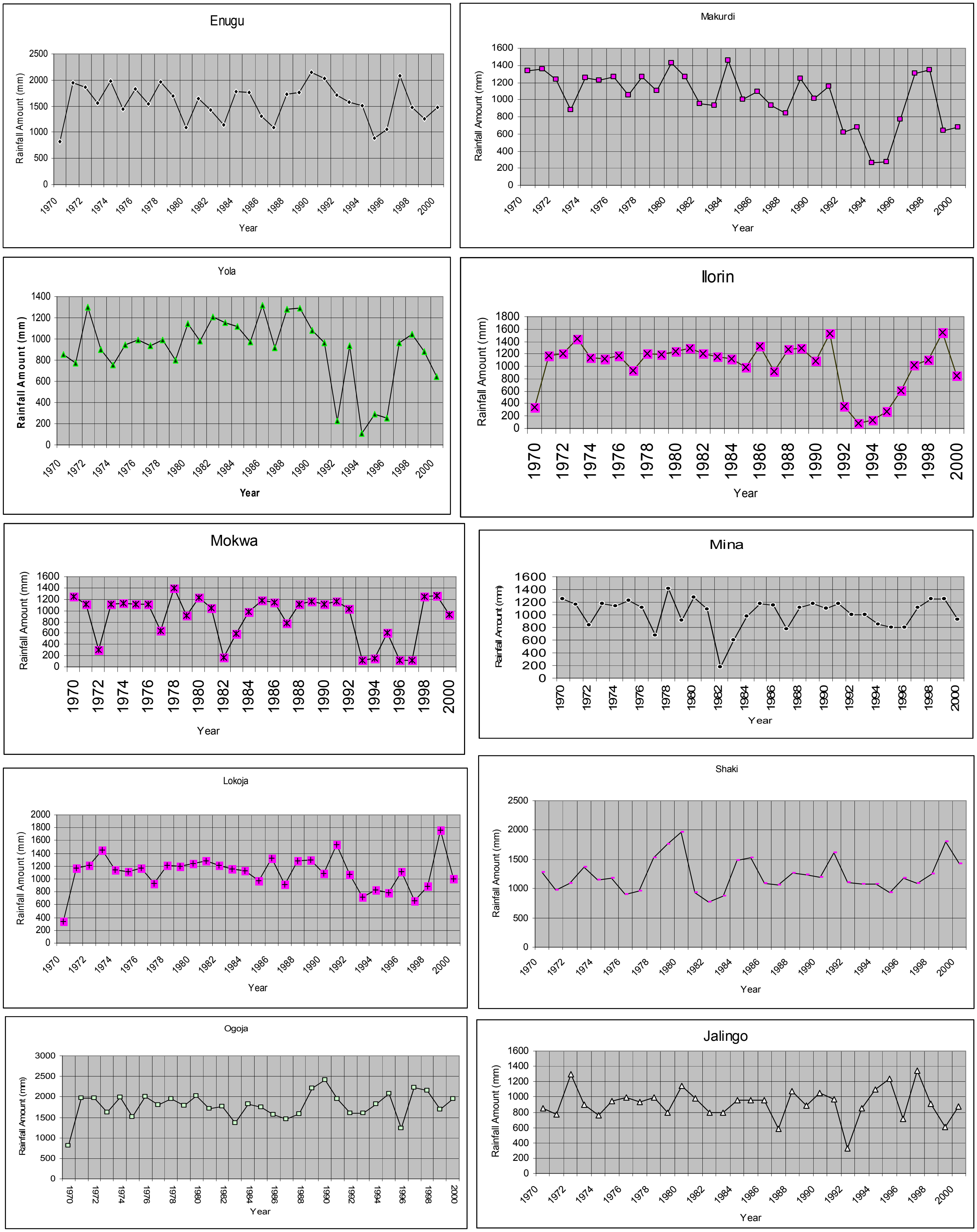

Figure 6: Annual Rainfall variability.