



DRYLANDS RESEARCH

Working Paper 25

PROFILE OF RAINFALL CHANGE AND VARIABILITY IN THE KANO- MARADI REGION, 1960-2000

Michael Mortimore

2000

Drylands Research
Crewkerne, Somerset, UK

The research reported in this working paper forms a part of the Kano-Maradi Study of Long-term Change, which is funded by the Economic and Social Committee on Research (ESCOR) of the Department for International Development (DFID), United Kingdom (Project R7221) and the Leventis Foundation. DFID and the Leventis Foundation can accept no responsibility for any information provided or views expressed.

ISSN 1470-9384

© Drylands Research 2000

Typeset at Drylands Research and printed at Press-tige Print, Crewkerne.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior written permission of the publishers.

Preface

Drylands Research Working Papers present, in preliminary form, research results of studies carried out in association with collaborating researchers and institutions.

This Working Paper is part of a study which aims to relate long-term environmental change, population growth and technological change, and to identify the policies and institutions which are conducive to sustainable development. The study builds upon an earlier project carried out by the Overseas Development Institute (ODI) in Machakos District, Kenya, whose preliminary results were published in a series of *ODI Working Papers* in 1990-91. This led to a book (Mary Tiffen, Michael Mortimore and Francis Gichuki, *More people, less erosion: environmental recovery in Kenya*, John Wiley, 1994), which was a synthesis and interpretation of the physical and social development path in Machakos. The book generated a set of hypotheses and policy recommendations which required testing in other African dryland environments. Using compatible methodologies, four linked studies have been carried out in:

Kenya	Makueni District	
Senegal	Diourbel Region	
Niger	Maradi Department	(in association with ODI)
Nigeria	Kano Region	(in association with ODI)

For each of these study areas, there is a series of working papers and a synthesis, which have been reviewed at country workshops. An overall synthesis was discussed at an international workshop at London on 17 January, 2001.

Due to the limited number of working papers on Nigeria, they are included in a combined Niger-Nigeria Series. The Nigeria study is limited to one in-country study on food marketing in the Kano Region (leader Dr J. Ayodele Ariyo). The remaining studies explore other aspects of long-term change in natural resource management, livelihoods and policy, and are based on published and unpublished material. The Research Leader for these studies is Michael Mortimore. He, Mary Tiffen or J. Ayodele Ariyo may be contacted at the following addresses.

Michael Mortimore
Cutters' Cottage, Glovers' Close
Milborne Port, Sherborne DT9 5ER

Mary Tiffen
Orchard House, Tower Hill Road
Crewkerne, Somerset TA18 6BJ

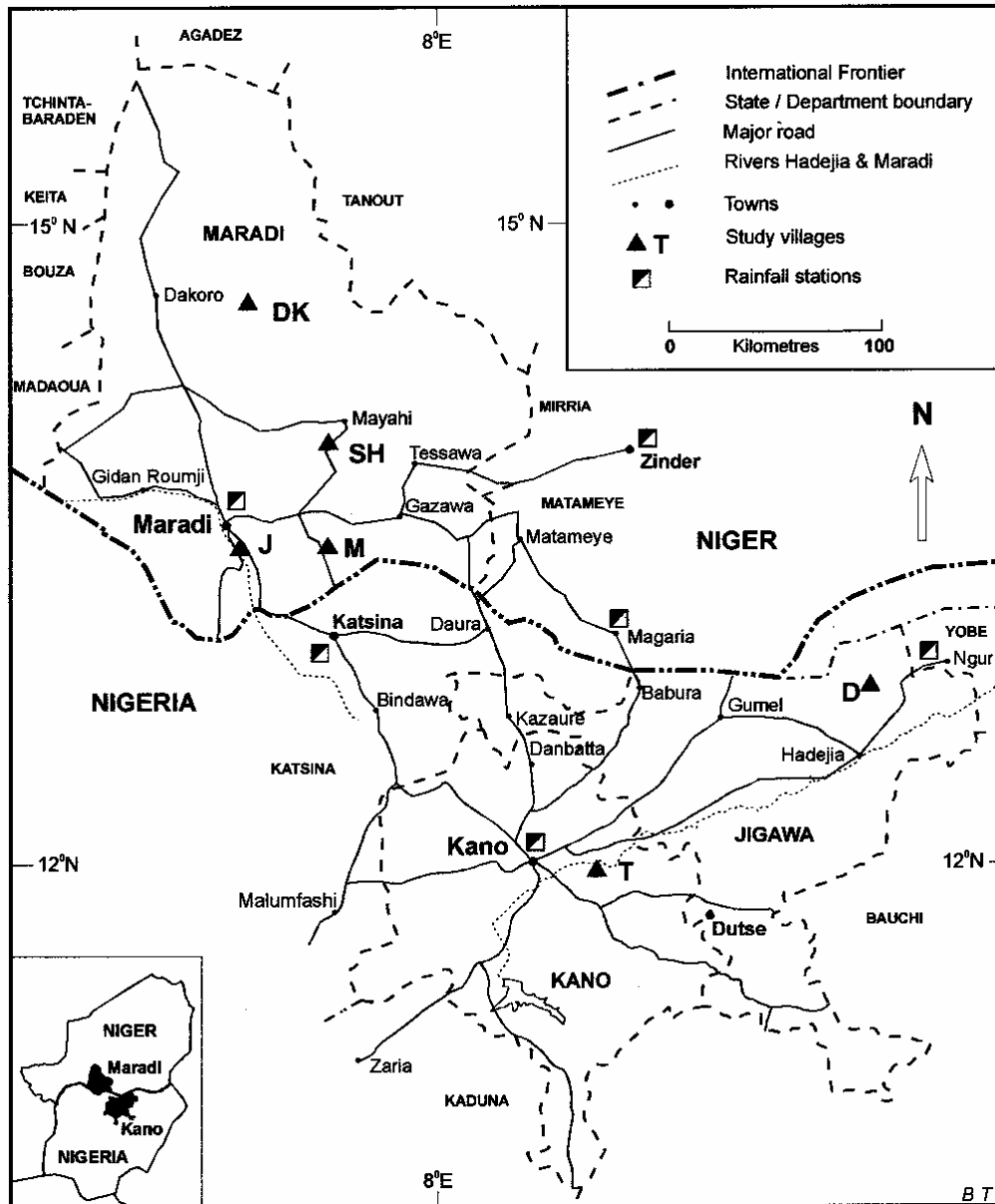
Email:
mikemortimore@compuserve.com
mary@marytiff.demon.co.uk

Website:
www.drylandsresearch.org.uk

Dr. J. Ayodele Ariyo
Kwara State College of Education
PMB 309
Oro
Kwara State
Nigeria

Email:
ariyodele@yahoo.com

Preface map



Abstract

Rainfall data from five stations (Kano, Magaria, Maradi, Nguru and Zinder) are analysed for the period 1931-1999, to show long-term trends, seasonal changes, and the incidence and severity of droughts. The first of these analyses shows that long-term trends were spatially persistent and that the record is dominated by a long downward trend from the 1950s to the 1970s, two severe troughs in the early 1970s and early 1980s separated by a short recovery, and followed by divergent trends (rising in Kano and persistently low in Zinder) during the 1990s. The long-term trends provide no reliable basis for predicting future rainfall. The second analysis shows that inter-annual variability and long-term decline differ from month to month, with the steepest decline in August and the greatest variability in May and June. The third analysis shows that all the five stations are equally affected, though not to the same degree every year, by drought (defined in terms of standard precipitation indexes based on deviation from mean annual rainfall). The success of rural households in adapting to the challenge of climate change can be evaluated against these measures.

Résumé

Les données pluviométriques de cinq stations (Kano, Magaria, Maradi, Nguru et Zinder) ont été analysées pour la période 1931-1999, afin de montrer l'évolution à long terme, les changements saisonniers, et la fréquence et la sévérité des sécheresses. La première de ces analyses indique que l'évolution à long terme est persistante sur le plan spatial. Les données montrent qu'elle est marquée par une tendance régulière à la baisse des années 1950 aux années 1970, deux périodes de sécheresses sévères au début des années 1970 et 1980 séparées par une courte période de reprise, et suivies par des tendances divergentes (hausse à Kano et faiblesse persistante à Zinder) durant les années 1990. L'évolution à long terme de la pluviométrie ne fournit pas d'indications suffisamment sûres pour pouvoir faire des prédictions quant à l'avenir. La seconde analyse indique que la variabilité inter-saisonnière et le déclin à long terme varient selon les mois, avec la plus forte baisse en août et la plus grande variabilité pendant les mois de mai et de juin. La troisième analyse montre que les cinq stations sont affectées par la sécheresse (définie par des indices de précipitation standard obtenus en calculant la différence avec la moyenne pluviométrique annuelle) bien qu'elles ne le soient pas toutes au même degré. La manière dont les ménages paysans ont réussi à s'adapter au challenge présenté par ces changements climatiques peut être évalué en tenant compte de ces mesures.

CONTENTS

1	INTRODUCTION.....	1
2	SAHELIAN RAINFALL IN LONG-TERM PERSPECTIVE	1
3	ANALYSING THE CHANGES	3
	3.1 Desiccation.....	3
	3.2 Changes in seasonality.....	6
	3.3 Drought.....	11
4	ADAPTATION.....	13
	REFERENCES	14

Acknowledgements

Data used in this study were provided by the Climate Change Unit, University of East Anglia.

About the author

Michael Mortimore is a geographer who taught and researched at Ahmadu Bello University, Zaria, Nigeria between 1962 and 1979, and was Professor of Geography at Bayero University, Kano from 1979 to 1986. Subsequently he carried out research studies as a Senior Research Associate in the Department of Geography, Cambridge University, the Overseas Development Institute and as an Honorary Fellow of the Centre of West African Studies, University of Birmingham. His research and publications have focused on environmental management by smallholders in the drylands of Africa. In 1998 he and Mary Tiffen set up the Drylands Research Partnership.

Acronyms and abbreviations

ITC:	Inter Tropical Convergence
PI:	Precipitation Index

1 INTRODUCTION

Change and variability in the rainfall are supremely important determinants of livelihoods in the Kano-Maradi region. They determine primary production from year to year. They define the possibilities for investment, both in enhancing productivity and in conserving natural resources. In so far as they constrain primary production, they strengthen peoples' need to diversify their incomes. The rainfall has therefore been a constantly recurring theme during the four decades of this study.

The objective of this profile is to identify those aspects of rainfall which have had an impact on human activities. This analysis is based on the records of annual rainfall from the stations listed in Table 1 (see Preface map for locations).

Table 1: Rainfall stations and periods

Niger	Period	Nigeria	Period
Zinder Aero	1916-1999	Nguru	1942-1992
Magaria	1938-1999	Katsina	1931-1987
Maradi	1932-2000	Kano Aero*	1931-1994
		Kano Farm*	1916-1999

*Kano Aero series commenced in 1905. However, data for recent years after 1994 are not presently available.

2 SAHELIAN RAINFALL IN LONG-TERM PERSPECTIVE

The densely-populated farmlands and heavily grazed pastures of the Sahelo-Sudanian Zone of West Africa have experienced fluctuations in rainfall on all time-scales - from decadal (based on ten-day analytical periods) to monthly, seasonal, annual, and longer term. The longer term fluctuations are caused by the oscillations of the climatic borders of the Sahara Desert, of which there is abundant geological, archaeological and recent historical evidence (e.g., Grove and Pullan, 1964; Nicholson, 1978, Tucker *et al.*, 1991). Contemporary changes in rainfall should be evaluated, therefore, not as aberrations from a natural equilibrium, but as normal occurrences in a disequilibrium regime. A necessary condition for sustainable livelihoods in such a region is for people to adapt continuously in their farming, livestock-keeping, or other income-earning activities (Behnke *et al.*, 1994; Mortimore, 1998).

The Great Sahel Drought, whose culmination shocked the region and the world in 1972-74, created a perspective among outside observers which was at variance with these facts of life. It was seen then not only as a drought and a crisis in food production but also as a failure of farming and stock-keeping systems, of resource conservation and of economic coping strategies (Mortimore and Adams, 2000). The reactions of the international community precipitated several Sahelian countries, including Niger (but not Nigeria) into a state of chronic dependency on food aid.

Subsequently, drought was described as 'persistent' in the Sahel region (Lamb, 1982), and in 1983-4 some stations, including those in northern Nigeria, recorded even lower rainfall than in the early 1970s (Mortimore, 1989). However in some years rainfall was satisfactory for crop and livestock production, so the meaning of 'persistence' became, essentially, an increased probability of drought. Indeed, the long-term decline of average rainfall is better described as 'desiccation' than as 'drought' in order to distinguish its effects from those of annual or shorter term deficiencies in the rainfall. Such deficiencies, for practical purposes, are defined in terms of the needs of the natural ecosystems and of the crop and livestock production systems.

No matter what statistical averaging period is used, the downward trend manifests itself in long-term rainfall series (Agnew and Chappell, 1999). However, a straight-line downward-sloping trend, all too easily imposed on such data, provides no basis for forward projections, and may give a misleading description of the changes that occurred. The data may be as well described by a step-wise or 'jump transition' model, in which a significant shift occurred in the late 1960s. This event was 'an abrupt change in precipitation in the form of a more or less well defined jump in the mean, preceded by an otherwise stationary pattern of events' (Demaree and Nicolis, 1990: 221). This change resulted in a reduction of up to 30 percent in the average rainfall of tropical northern Africa between the periods 1931-60 and 1961-90 (Hulme, 1992), a change which was observed locally in an area immediately east of the Kano-Maradi region (Hess *et al.*, 1994).

Desiccation is the product of an increased frequency of drought, and given a sharply seasonal rainfall regime in which one growing season is separated from the next, this is what matters for farmers and livestock keepers. No mechanism linking the rainfall in one season with that in the next has been demonstrated. Linkages between land use or vegetation changes, as proposed in Charney's surface reflectivity model (1975), and Walker and Rowntree's soil moisture model (1977), did not receive immediate empirical confirmation (Nicholson, 1988). The rainfall in each season, therefore, is a random probability for practical purposes (though modelling of the effects of land cover and soil or surface condition on rainfall continues: Zheng and Eltahir, 1998). A random probability approach certainly accords with folk understanding in Sahelian societies.

Variability is a normal characteristic of Sahelian rainfall. The Sahel is intermediate between the desert and the subhumid zones of Africa, with average departures from the annual mean rainfall (1901-1973) of 20-40 percent (Janowiak, 1988). The key source of variation - and of drought - is the seasonal rainfall. This has a characteristically sharp peak in July or August. Rainfall in August shows a low-frequency fluctuation, which is superimposed on the general downward trend, so that August rainfall is significantly correlated with seasonal rainfall (Nicholson and Palao, 1993). Rainfall in June-July, however, fluctuates with a high frequency, that is, it is less related to seasonal rainfall or to the general trend.

It has also been shown that the number of storm events, rather than the amount of rain that they each deliver, accounts for much of the variation (D'Amato and Lebel, 1998; Agnew and Chappell, 1999). This carries the connotation that the migrations of the Inter-Tropical Convergence (ITC) - the mechanism that brings rain to the Sahel - are not the primary cause of drought. Rather, drought is the result of dynamic conditions in the weather system. Consequently, in drought years, convective rainfall fails to develop

normally, and storms often produce dust rather than rain. A study of the relationship between the position of the ITC and rainfall (during the period 1983-88), which used satellite indicators of cloud formations, showed that other than in one year (1988), there was no systematic difference between dry and wet years in the location of the ITC. Rather, differences were readily apparent in the intensity and spatial extent of convection, justifying the conclusion that '...the ITCZ appears to be displaced northward in some, but not all, wet years in the Sahel, but that no anomalous southward displacement is evident in dry years. Drought in the Sahel is then apparently more clearly linked to reduced convective activity' (Ba *et al.*, 1995: 428; Nicholson, 1981).

Defining and evaluating Sahelian rainfall anomalies, among which drought is foremost, is affected by the selection of an averaging period as a 'normal' baseline with which to compare the rainfall in a particular year, month or decade. The long-term fluctuations affect averages (Hulme, 1992; Jones and Hulme, 1996). Thus if the 30-year period 1931-60 is taken as 'normal', the subsequent years of strong negative anomalies truly suggest a crisis for land-users. When the Sahel Drought first struck in the early 1970s, the rainfall of those 30 years was large in the 'collective memory' of farmers and livestock keepers. Younger people could not remember a comparable drought. On the other hand, to use the 30-year period 1961-90 (currently used by the World Meteorological Organisation) produces a distorted picture of the previous period, and the 1950s in particular, as 'exceptionally' wet. In the analysis which follows we use a data series based on the 60 years, 1931-1999.

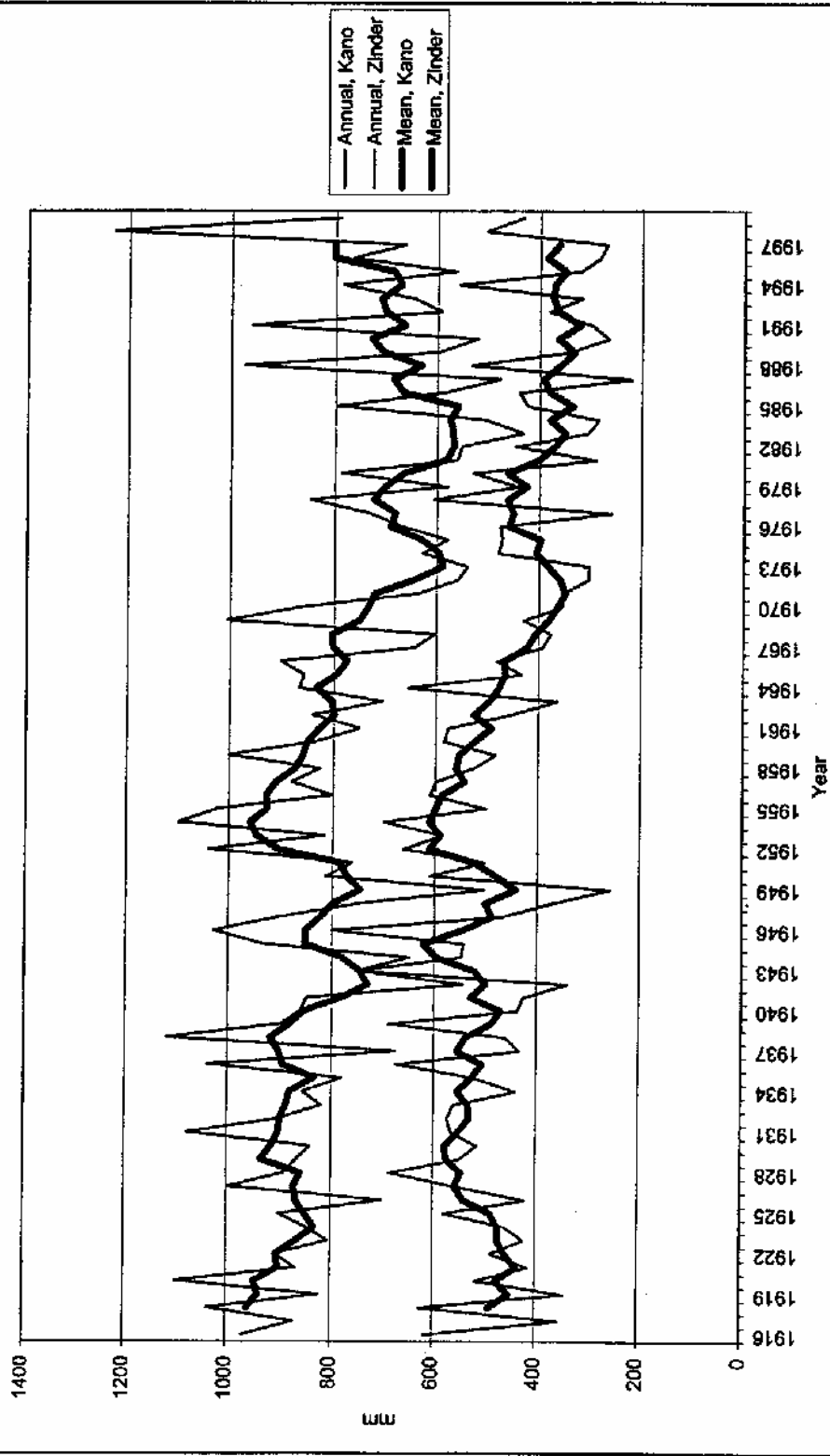
Meteorological definitions of drought, to which there is no practicable alternative, nevertheless present certain difficulties as the ecological or agronomic impact of a rainfall anomaly is affected by the seasonal distribution of rainfall, in combination with soil conditions, natural vegetation, and other factors which can be affected by management. In this profile we are concerned with the significance of climate change for such interactions. The impact of desiccation on human affairs can be graphically portrayed in maps showing the migration of rainfall isohyets, in this region southwards, as latitude is significantly correlated with rainfall (Mortimore, 1989; Sivakumar, 1992; ICRISAT, 1993; Ozer and Erpicum, 1995; Badiane, 2000, Bouzou, 2000). This simple picture is complicated by an increased variability and seasonality (Hulme, 1992), which add to the risk faced by the production systems. The question of adaptation to these risks is taken up again below.

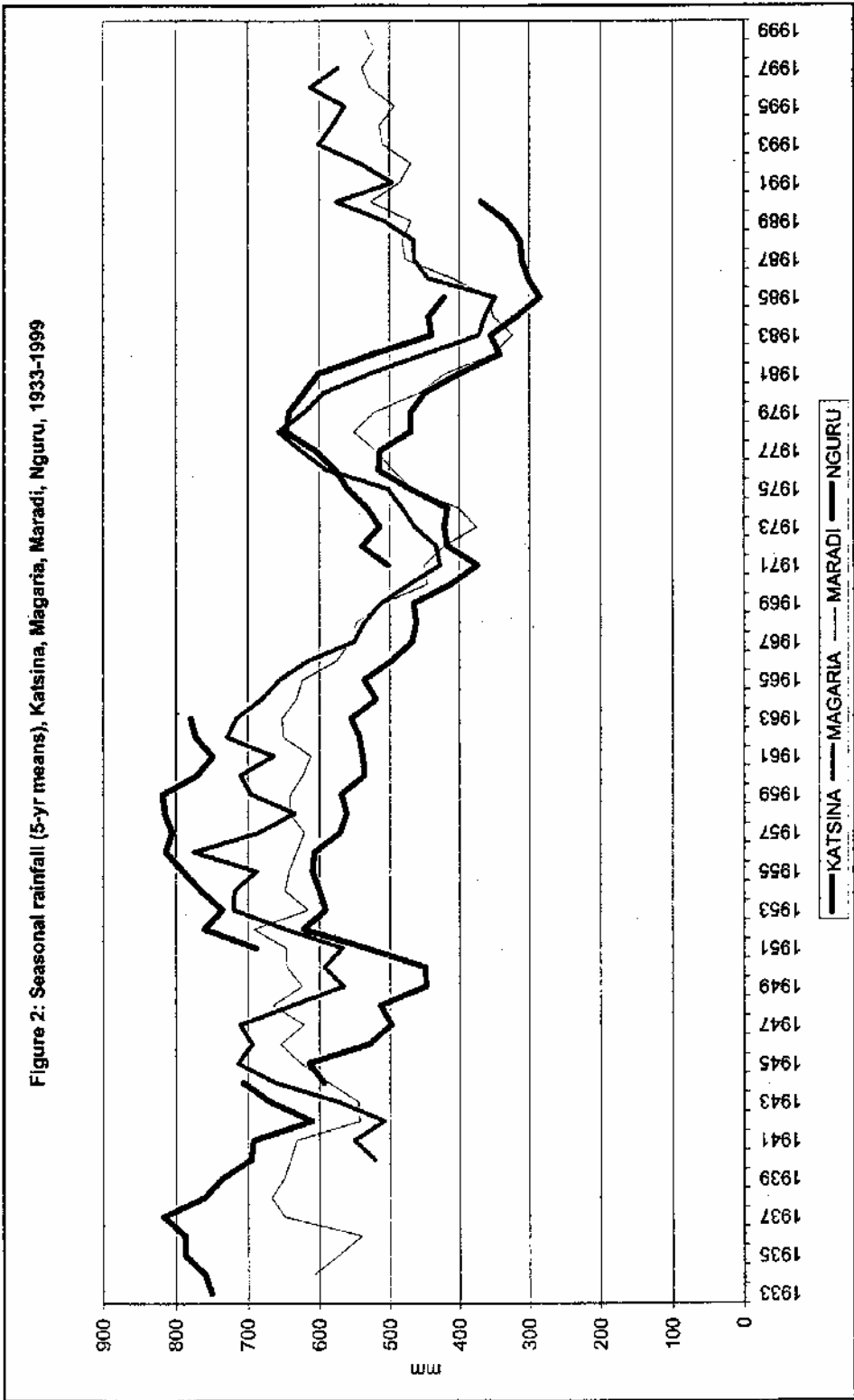
3 ANALYSING THE CHANGES

3.1 Desiccation

Figure 1 shows long-term annual rainfall series for Kano Farm (Lat. 12° N; mean annual rainfall, 796 mm) and Zinder Aero (Lat. 14°N; mean annual rainfall, 469 mm), from 1916 to 1999. The annual series show strong similarities, with low rainfall at both places in 1917, 1919, 1926, 1937, 1943, 1949, 1972-73, 1983-84, and 1987. The two series have a correlation coefficient of 0.66. The running means show similar slopes throughout, and especially from 1928 to 1949, and from 1954 to 1973 (both periods of approximately twenty years). After 1974, the next twenty years saw a short-lived rise

Figure 1: Annual Rainfall, Kano (upper) and Zinder (lower), with 5-yr mean, 1916-1999





from 1974 to 1979-80, followed by a fall to very low rainfall in 1982-86 (Kano) and 1983-86 (Zinder), and then an improvement at Kano but two very dry years in 1996 and 1997 at Zinder. The similarity between these series illustrates the strong spatial persistence of rainfall patterns (which extend across latitudes) noted by Nicholson and Palao (1993), not only in the long-term downward tendency but also in the shorter 20-year phases or low frequency fluctuations.

These long-term patterns condition the expectations of 'normal' rainfall and define the adaptive challenge that faces farmers and livestock keepers in the Kano-Maradi region. No other series of this length are available. To accommodate shorter series (Table 1), but to include two successive 30-year periods, we now focus on the period beginning in 1931.

For this period, three of the other four stations (Magaria, Maradi, Nguru) confirm the general pattern (Figure 2). The data series for Katsina is incomplete. The graphs show rainfall during the growing season only (May-September). Rainfall before this season is useless, being usually followed by drought; and amounts received in October are usually negligible, though an unexpected shower can assist late maturing crops.

3.2 Changes in seasonality

Given the similarity of rainfall patterns among the six stations, changes in seasonality are shown with 5-yr running means for an average of all six stations, arranged by month (Figure 3). Trend lines are added. Strong differences in slope suggest significant variation between months in the rate at which rainfall has declined during the period, with May and September declining most steeply and July the least. This is consistent with a shortening of the average rainy season. However, these trends disguise large differences in variability, judged by a visual inspection of the running means. Rather surprisingly, variability about the trend diminishes steadily from the beginning (May) to the end (September) of the season. In practical terms, this means that the beginning of the growing season is increasingly unpredictable, but a shortening at the end is increasingly likely. It may further be observed that each month has its own pattern of low-frequency fluctuation, though a close inspection reveals most of the key features of the annual and seasonal curves in the monthly ones. The differences are due to the small number of stations used.

Figure 3: Seasonal rainfall, average of six stations, 5-yr means for May, July, August and September, 1931-1989

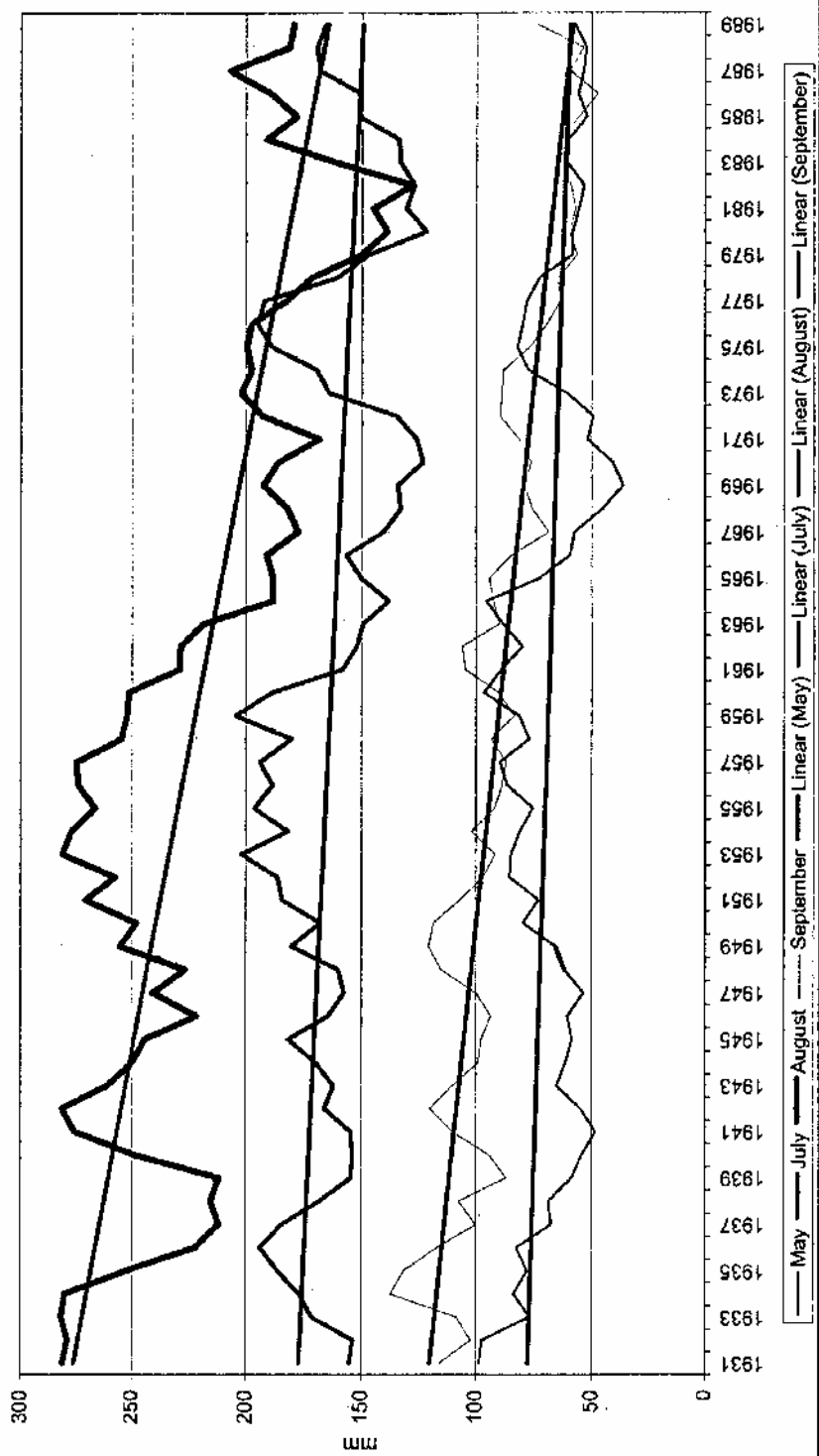


Figure 4a: Variability of seasonal rainfall (SPI), Zinder, 1931-1999

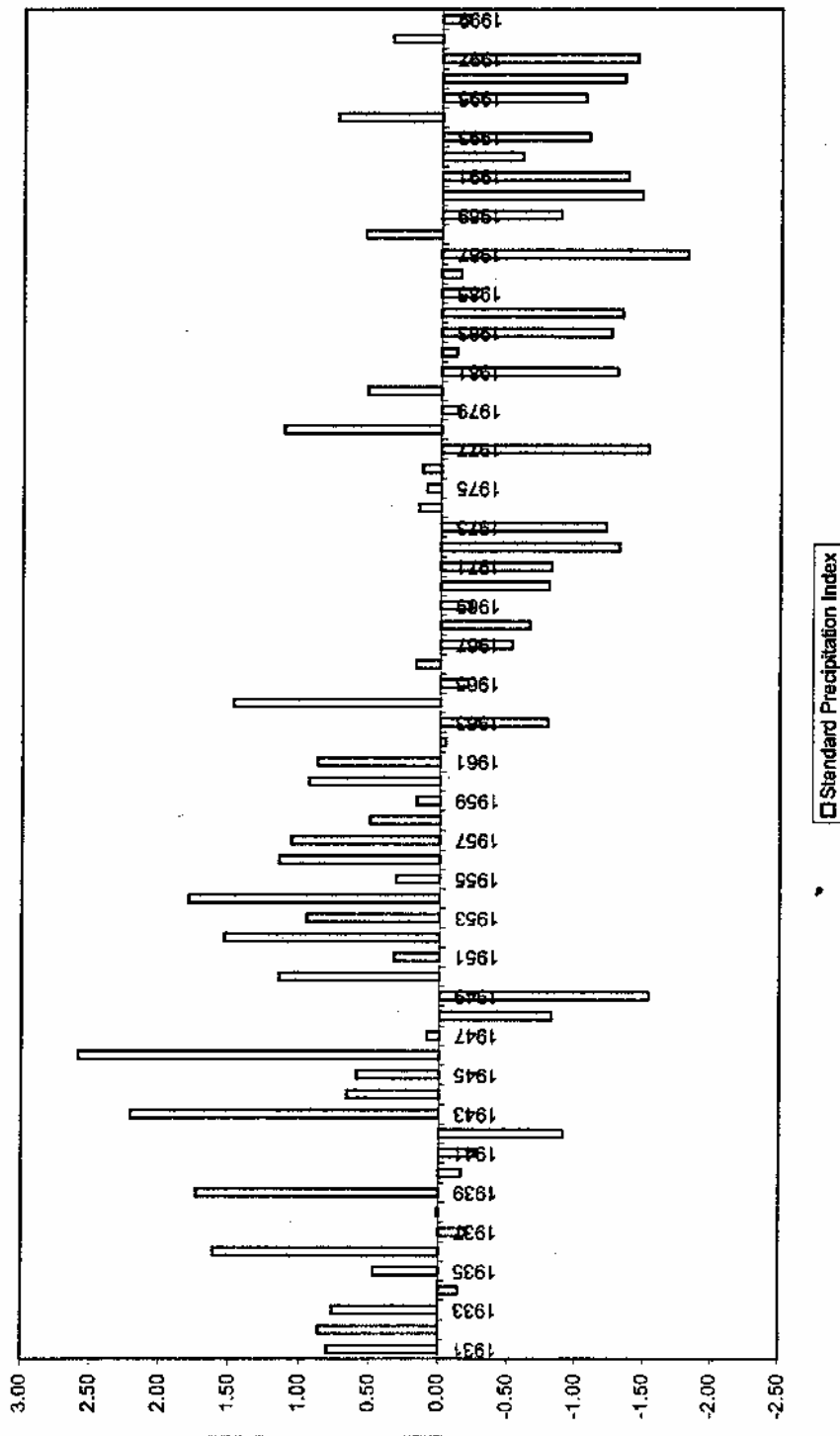
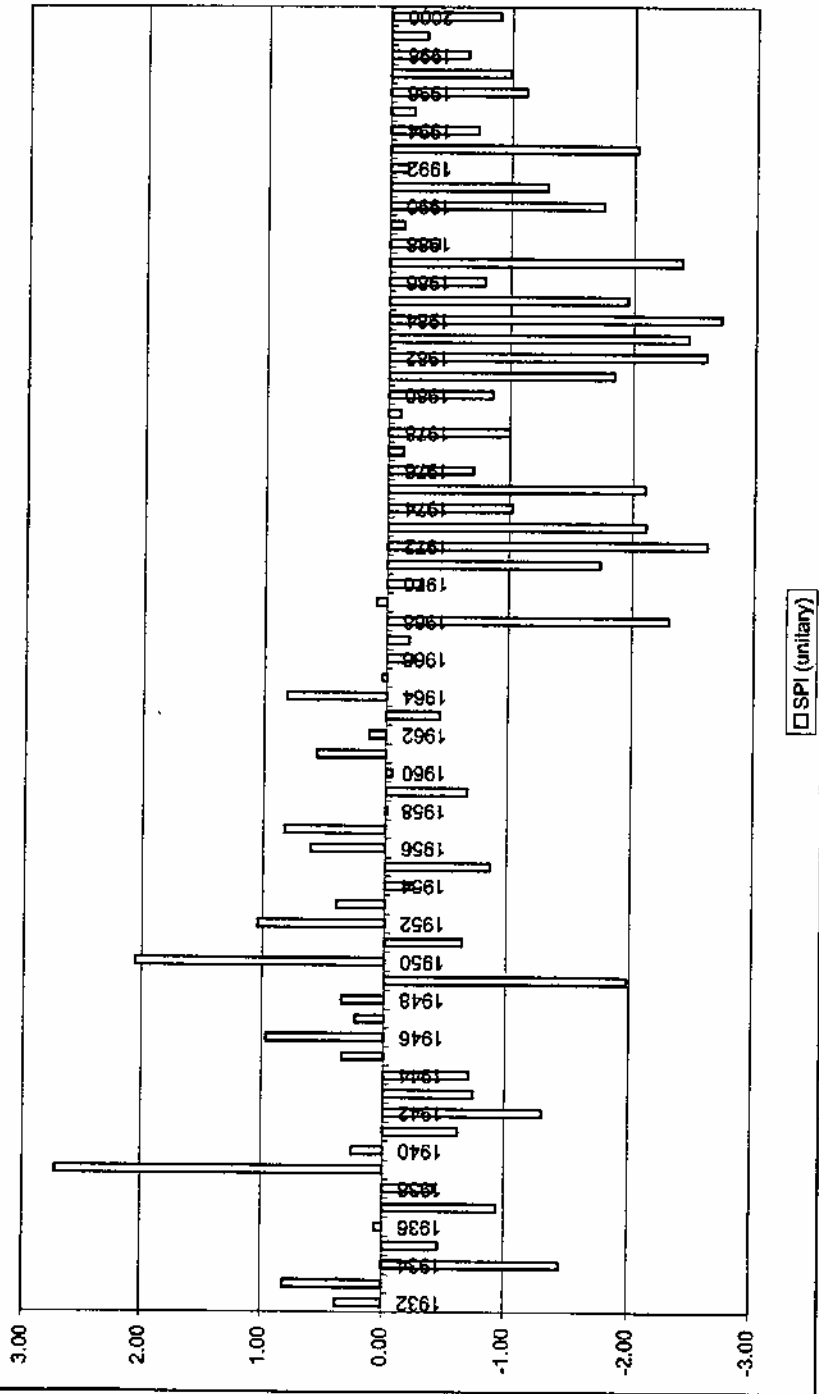
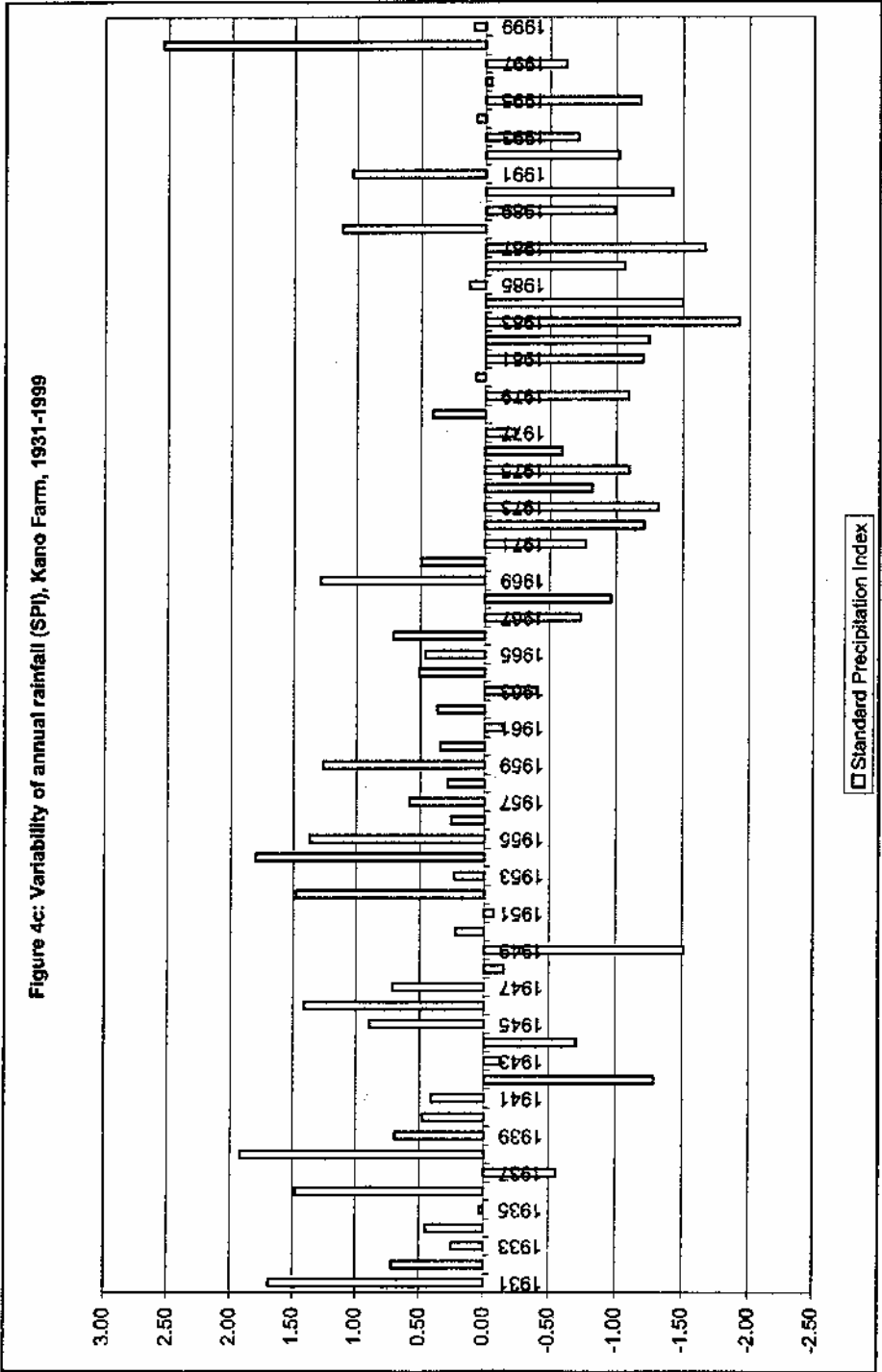


Figure 4b: Variability of seasonal rainfall (SPI), Maradi, 1932-2000





3.3 Drought

The measurement of drought depends on the selection of averaging period (Agnew and Chappell, 1999), and to avoid the distortions implicit in using either of the two 30-year periods (1931-60 and 1961-90), we employ the long-term average seasonal rainfall (May-September) for each station to compute a Precipitation Index (PI) according to the formula

$$PI = (X - \bar{X}) / SD$$

where

X = seasonal rainfall for the year and station,

\bar{X} = average seasonal rainfall (of the period specified for the station), and

SD = the seasonal standard deviation for the station

(Downing *et al.*, 1988; Mutiso *et al.*, 1990 - in a parallel study of Machakos District; Agnew, 2000).

Figure 4 shows the results of this analysis for the three stations for which we have complete records: Zinder Aero and Maradi (seasonal rainfall) and Kano Farm (annual). As this construction represents each year or season separately, in terms of departures from expectation (the long-term mean) rather than absolute amount of rainfall, it reflects the circumstances of farmers and livestock keepers more realistically than a running mean. A transition from frequent positive anomalies to negative in the early 1960s is clearly shown at all the stations. The exceptional high rainfall in 1998 confirms a rising trend during the later years of the sequence. But a straight trend line does not describe the pattern as well as a sinuous curve with a 30-40 year wavelength. If this pattern is continued into the future, it carries positive implications for both governments and land users.

Drought probability classes for the Sahel have been proposed by Agnew and Chappell (1999), using a normalised precipitation index based on standard deviations from mean rainfall. This allows rainfall anomalies to be computed for each station in relations to its own 'normal' rainfall, in a form which permits comparison with other stations irrespective of the amount of average rainfall. Using this method, the intensities of drought experienced at our six rainfall stations are shown in Table 2. Some of them were, to a varying degree, local but the major regional droughts of 1949, 1972-73, 1983-84 and 1987 are very clearly shown. From 1931 until 1942, drought was rare, and an even longer period of relative freedom from drought occurred between 1950 and 1970. But in the following 26 years there were three major regional droughts, two of them lasting for two years or longer (1972-73 and 1983-84). An important observation is the significantly greater severity of the drought of 1983-84 compared with that of 1972-73. This was most conspicuous at Maradi, where three extreme droughts occurred in consecutive years (1982-84). Indeed, drought had become such a frequent occurrence by the 1980s that the extreme event of 1987, which affected all six stations, attracted little attention outside the region.

The frequency of moderate, severe and extreme droughts at the six stations is shown in Table 3. During the 60 years, a moderate or worse drought occurred on average every 4.8 years and a severe or extreme drought every 8.1 years. However, as their distribution in time shows, the frequency of droughts increased after the early 1970s, so

such averages have little practical value. Remarkably, this table shows that the frequency of drought (moderate or worse, severe or worse), characterised by this method, does not vary significantly. It is for practical purposes equally common and equally severe at all six station, irrespective of latitude or average seasonal rainfall. This corrects a common illusion that drought becomes more frequent as rainfall diminishes towards the desert.

Table 2: Intensity of droughts at six stations, 1931-1990 (seasonal rainfall) (major regional droughts shown in bold)

Year	Zinder Aero	Magaria	Maradi	Nguru	Katsina	Kano Aero
1942	Mod	Mod				Mod
1944					Sev	Ext
1948	Mod			Ext		
1949	Sev		Sev	Sev		Sev
1963	Mod					
1968			Sev			Sev
1969					Sev	
1970	Mod					
1971	Mod		Mod		Mod	
1972	Sev	Mod	Ext	Sev	Sev	Mod
1973	Sev	Ext	Sev	Sev	Sev	Ext
1975						Sev
1976			Sev			
1977	Sev			Mod		
1978					Mod	
1981	Sev		Mod			Sev
1982		Sev	Ext		Mod	Mod
1983	Sev	Mod	Ext	Ext	Sev	Sev
1984	Sev	Sevt	Ext	Mod	Ext	Ext
1985		Mod	Sev		Ext	Mod
1986		Mod		Sev		
1987	Ext	Ext	Sev	Sev	Ext	Sev
1988				Mod	-	
1989	Mod	Mod		Mod	-	
1990	Sev	Sev	Mod		-	Mod

Extreme drought: $PI = < -1.65$

Severe drought: $PI = < -1.28$

Moderate drought: $PI = < -0.84$

- no data

Is the period of low rainfall and frequent drought observed since the 1960s soon to be reversed? Upturns in the running means in the late 1990s (at Kano) are influenced by the exceptionally high rainfall of 1998. There has also been a diminution there in the frequency of droughts. But while offering some hope of a return to higher levels, such an upturn cannot be shown to have any statistical significance.

has been maintained in tandem with rising human populations and increasing pressure on land. Integrated management of crops and livestock has increased, and there is a growing fattening industry which responds to a rising demand for meat.

- An increasing proportion of arable land has been brought under permanent cultivation (Mahamane, 2000; Turner, 1997), with organic fertilisation replacing the use of subsidised inorganic fertilisers since the 1980s. There is evidence that fertility can be sustainable under such management, provided that animal manure is available in sufficient quantities (Harris, 2000; Mahaman, 2000).
- Stable and well-managed tree populations on farms, long recognised in the Kano Close-settled Zone and other densely populated areas of Nigeria, are now increasingly common in areas with lower but rising densities where arable land is rapidly replacing natural woodland (Awaiss, 2000).
- Not only because of the risk to agricultural activities, but also in response to a need for employment, monetary incomes, funds for consumption and investment capital, household incomes have been diversified further, through migration in search for opportunities (Tiffen, 2000).

These trends, which are selectively mentioned here, show that while a majority of rural households are poor in both the Maradi and the Kano regions, climate change has not undermined the basis of economic life. Positive trends in soil fertility and tree management, in a context of intensifying drought stress, are remarkable in such circumstances.

REFERENCES

- Agnew, C. (2000) 'Using the SPI to identify drought', *Drought Network News*, 12: 6-12.
- Agnew, C.T. and Chappell, A. (1999) 'Drought in the Sahel', *GeoJournal*, 48: 299-311.
- Agnew, C.T. (1995) 'Desertification, drought and development in the Sahel', in Binns, T. (ed.), *People and environment in Africa*: 137-151. John Wiley, Chichester.
- Awaïss, Aboubacar (2000) 'Gestion des forêts et des arbres au niveau des terroirs dans la région de Maradi', *Drylands Research Working Paper* 31. Drylands Research, Crewkerne, United Kingdom.
- Ba, M.B., Frouin, R., and Nicholson, S.E. (1995) 'Satellite-derived interannual variability of West African rainfall during 1983-88', *Journal of Applied Meteorology*, 34: 411-431.
- Badiane, Aminata Niane (2000) 'Région de Diourbel : Gestion des eaux', *Drylands Research Working Paper* 14. Drylands Research, Crewkerne, United Kingdom.
- Banoin, M., Joet, A. and Jouve P., "Le defrichement ameliore: une pratique paysanne d'agroforesterie au sahel," in (ed.), Jouve, P., *Gestion des terroirs et des ressources naturelles au Sahel*. CNEARC, France.
- Behnke, R., Scoones, I. and Kerven, C. (eds.) (1993) *Range ecology in disequilibrium: New models of natural variability and pastoral adaptation in African countries*. Overseas Development Institute, London.

- Bouzou Moussa, Ibrahim (2000) 'Gestion des ressources naturelles et évolution des systèmes agraires dans la région de Maradi', *Drylands Research Working Paper* 28. Drylands Research, Crewkerne, United Kingdom.
- Charney, J.G. (1975) 'Dynamics of desert and drought in the Sahel', *Quarterly Journal of the Royal Meteorological Society*, 101:193-200.
- D'Amato, N. and Lebel, T. (1998) 'On the characteristics of the rainfall events in the Sahel with a view to the analysis of climatic variability', *International Journal of Climatology*, 18: 955-974.
- Demaree, G.R. and Nicolis, C. (1990) 'Onset of Sahelian drought viewed as a fluctuation-induced transition', *Quarterly Journal of the Royal Meteorological Society*, 116: 221-238.
- Downing, T.E., Akonga'a, J., Mungai, D.N., Munguri, H.R. and Potter, H.L. (1988) 'Introduction to the Kenya case study', in Parry, M.L., Carter, T.R., and Konijn, N.T. (eds.), *The impact of climatic variations on agriculture, Vol. 2: Assessments in semi-arid regions*: 129-148. Kluwer Academic Publishers, Dordrecht.
- Grove, A.T. and Pullan, R.A. (1964) 'Some aspects of the Pleistocene paleogeography of the Chad Basin', in Howell, E.C. and Bourlière, F. (eds.), *African ecology and human evolution*: 230-245. Methuen, London.
- Hamadou, Seyni (2000) 'Évolution à long terme des productions agricoles, du système de commercialisation et des prix des produits dans la zone de Maradi', *Drylands Research Working Paper* 32. Drylands Research, Crewkerne, United Kingdom.
- Hess, T.M., Stephens, W. and Maryah, U.M. (1994) 'Rainfall trends in the North-East Arid Zone of Nigeria 1961-90', *Agricultural and Forest Meteorology*: 74: 87-97.
- Hulme, M. (1992) 'Rainfall changes in Africa: 1931-1960 to 1961-1990', *International Journal of Climatology*, 12: 685-699.
- ICRISAT, (1993) 'Agroclimatology of West Africa: Niger', *Information Bulletin No. 5*. Patancheru/Niamey: International Crop Research Institute for the Semi-Arid Tropics/Direction de la Météorologie Nationale du Niger.
- Janowiak, J.E. (1988) 'An investigation of interannual rainfall variability in Africa', *Journal of Climate*, 1: 241-255.
- Jones, P.D. and Hulme, M. (1996) 'Calculating regional climatic time series for temperature and precipitation: methods and illustrations', *International Journal of Climatology*, 16: 361-177.
- Lamb, P.J. (1982) 'Persistence of sub-Saharan drought', *Nature*, 299: 46-47.
- Le Houérou, H.N. (1996) 'Climate change, drought, and desertification', *Journal of Arid Environments*, 34: 133-185.
- Moussa, Bouzou (2000) 'Gestion des ressources naturelles et évolution des systèmes agraires dans la région de Maradi', *Drylands Research Working Paper* 28. Drylands Research, Crewkerne, United Kingdom.
- Mahamane, Ali (2000) 'Usages des terres et évolutions végétales dans le département de Maradi', *Drylands Research Working Paper* 27. Drylands Research, Crewkerne, United Kingdom.
- Mortimore, M. and Adams, W.M. (2000) *Working the Sahel: Environment and society in northern Nigeria*. Routledge, London.
- Mortimore, M. (1989) *Adapting to drought, farmers, famines and desertification in West Africa*. Cambridge University Press.
- Mortimore, M. (1998) *Roots in the African dust: sustaining the sub-Saharan drylands*. Cambridge University Press.

- Mutiso, S.K., Mortimore, M. and Tiffen, M. (1990) 'Rainfall', in Mortimore, M. (ed.), 'Environmental change and dryland management in Machakos District, Kenya, 1930-90: environmental profile', *ODI Working Paper 53*. Overseas Development Institute, London.
- Nicholson, S.E. and Palao, I.M. (1993) 'A re-evaluation of rainfall variability in the Sahel. Part I: Characteristics of rainfall fluctuations', *International Journal of Climatology*, 13: 371-389.
- Nicholson, S.E. (1978) 'Climatic variations in the Sahel and other African regions during the past five centuries', *Journal of Arid Environments*, 1: 3-24.
- Nicholson, S.E. (1981) 'Rainfall and atmospheric circulation during drought periods and wetter years in West Africa', *Monthly Weather Review* 109: 1365-81.
- Nicholson, S.E. (1988) 'Land surface atmosphere interaction: physical processes and surface changes and their impact', *Progress in Physical Geography*, 12: 36-65.
- Ozer, P. and Erpicum, M. (1995) 'Méthodologie pour une meilleure représentation spatio-temporelle des fluctuations pluviométriques observées au Niger depuis 1905', *Sécheresse*, 6: 103-108.
- Sivakumar, M.V.K. (1992) 'Climate change and implications for agriculture in Niger', *Climate Change*, 20: 297-312.
- Tucker, C.J., Dregne, H.E. and Newcomb, W.W. (1991) 'Expansion and contraction of the Sahara Desert from 1980 to 1990', *Science*, 253: 299-301.
- Turner, B. (1997) 'Land cover change around four villages in north-east Nigeria: methodology and results', 'Soils, cultivars and livelihoods in north-east Nigeria', *Working Paper 5*. University of Cambridge and University of Kano: Departments of Geography, Kano, Nigeria.
- Walker, J. and Rowntree, P.R. (1977) 'The effect of soil moisture on circulation and rainfall in a tropical model', *Quarterly Journal of the Royal Meteorological Society*, 103: 29-46.
- World Bank (2001) *World development report, 2000/01*. World Bank, Washington DC.
- Zheng, X. and Eltahir, E.A.R. (1998) 'The role of vegetation in the dynamics of West African monsoons', *Journal of Climate* 11: 2078-96.