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Voortman, R.L.

published in

Physics and Chemistry of the Earth, Parts A/B/C
1997

DOI (link to publisher)

[10.1016/s0079-1946\(98\)00042-1](https://doi.org/10.1016/s0079-1946(98)00042-1)

document version

Publisher's PDF, also known as Version of record

[Link to publication in VU Research Portal](#)

citation for published version (APA)

Voortman, R. L. (1997). Recent historical climate change and its effect on land use in the eastern part of West Africa. *Physics and Chemistry of the Earth, Parts A/B/C*. [https://doi.org/10.1016/s0079-1946\(98\)00042-1](https://doi.org/10.1016/s0079-1946(98)00042-1)

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Recent Historical Climate Change and its Effect on Land Use in the Eastern Part of West Africa

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Received 25 April 1997; accepted 14 July 1997

Abstract. There are indications that low rainfall, drought periods and famine become more frequent in West Africa. This may in part be a rather early expression of the effect of global warming but it is very likely that local factors such as drastic changes in land cover due to expanded cultivated area, as required by a growing population, play an important role. Before studying the causative mechanisms of climate change, it first needs to be established that climate did indeed change significantly, and if so, its nature, extent and magnitude have to be quantified. To this effect time series of annual rainfall (1950–1992) for 42 synoptic climate stations in eastern West Africa, covering 5 countries, were analyzed. The data were subjected to several statistical tests for the entire time series and parts thereof. The outcomes were interpolated in a GIS environment to assess the spatial pattern of change. The time series and spatial analysis reveals that climate change is indeed significant in the northern part of the study area and that the degree of change shows a spatial pattern that can be related to the weather system in combination with topography. A remarkable feature is that the change in rainfall is not a gradual one, but consists of a trend break with zero trend before and after the break. This is unexpected because it might imply that causal factors have to be sought under those that do not change gradually. The year of occurrence of the break is around 1970 but varies in time, again according to a geographic pattern. The reduction of rainfall shortens the length of the growing period (LGP) and has a considerable impact on potential crop yields and their variability. The paper shows the serious implications of recent historical climate change for land use in the semi-arid region of West Africa.

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1 Introduction

Poor rainfall resulting in famine has occurred repeatedly throughout the last century in the eastern part of West Africa (e.g. Van Apeldoorn, 1981; Mainguet, 1994). These droughts were usually followed by extended periods with 'normal' rainfall. However, the drought of the early 1970's was soon followed by another in the early 1980's and in between rainfall did not revert to previous levels, at least in the Sahelian zone (Lamb, 1985). Moreover, the downturn in rainfall in the early 1970's was the most severe of the current century (Sircoulon, 1976). The reduction of rainfall amount took place concurrently with drastic changes in land use and land cover related to fast population growth and it is likely that as a consequence the hydrological cycle is affected (Savenije, 1995). The question therefore arises whether or not the frequency and the severity of the more recent droughts are an expression of a decline in rainfall that will be sustained if the current types of land use expand further, because this would have important policy implications for instance for land use planning, agricultural extension and migration.

To assess if climate has changed and what the nature and magnitude of change is, a set of statistical tests standardly used for hydrological purposes (Dahmen and Hall, 1990) has been applied to time series of rainfall that now extend up to 1992. The results for point data were further analyzed in a GIS environment to study spatial variation of climate change, for an area that extends from the Sahara desert to the Atlantic Ocean. The more humid areas are included because evidence suggests that the areas affected by drought were not limited to the Sahel only (Watts, 1987; Mortimore, 1989) and because Sahelian rainfall is naturally related to rainfall further south (Savenije and Hall, 1994; Savenije, 1995).

Data quality and the statistical tests that have been used are briefly described in section 2. In section 3 the results of time series and spatial analysis are presented. Section 4, by

means of an example, shows the impact of climate change on potential crop yields and its implications for farmer decision making, as well as policies related to land use. In section 5 the findings are summarized and the nature, magnitude and geographical extent of climate change are discussed in relation to its possible causes.

2 Data and methods

The climatic data used, consist of time series of monthly rainfall from 1950 to 1992 for 42 synoptic stations in Nigeria and its neighbouring countries (see fig.3 for their location). The available data record for a few stations goes back to around 1900. Outside Nigeria the data source was FAOCLIM (FAO, 1995). Within Nigeria the monthly data were obtained from the original monthly records of the Department of Meteorological Services at Oshodi. These data were rigorously checked, compared with other public data sources (FAO, 1995; Akintola, 1986), and for the period after 1970 with the monthly sum of daily values as digitally available from the Meteorological Department. In case of doubt the matter was referred back to the Department. For the purpose of the present analysis the monthly values have been aggregated to annual rainfall totals. Years with missing data in at least 1 month were excluded for further use. This does not seriously affect the statistical tests undertaken, unless one assumes that the missing data are outliers. Consequently, within the main part of the study area, i.e. Nigeria and Niger, only 10 percent of the stations has more than 3 missing years over a 40-year period and 50 percent has no missing years at all. Missing years are common in the south of Nigeria for the period 1966/68 due to the civil war, but this will not affect the conclusions of the study, because there was no climate change in this area, as will be shown in the following section. However, particularly in Benin and Cameroon the data record was incomplete. This has some effect on the interpolations near the western and eastern edges of the study area, but does not affect the main conclusions on the extent and severity of climate change within Nigeria and Niger.

The time series of annual precipitation were analyzed with the software for data-screening of Dahmen and Hall (1990). This software is developed for hydrological studies as a first test of rainfall data time series for stability, variously expressed as stationarity, consistence and homogeneity (Dahmen and Hall, 1990; Yevjevich and Jeng, 1969). In engineering, data should have these stable characteristics in order to be able to assess the frequency of extreme events or to allow simulation. The tests are used to detect irregularities in data sets due to extraneous influences, like for instance relocation of a station, change of measuring equipment and method, or human induced effects. In conventional hydrological studies data that show such irregularities are usually rejected for frequency

analysis. Although developed for this kind of purpose, the methods employed are also suitable as a first approximation to expose and quantify historical climate change, if the effect of extraneous influences can be ruled out.

First, the mean, standard deviation and coefficient of variation for the entire time series of each station were calculated, followed by plotting the *cumulative deviation from the mean*. The plot serves to detect breakpoints at which the characteristics of a time series change. This analysis was also applied to sub-sets before and after the breakpoint, if this occurred. Next the absence of trend was tested with *Spearman's rank-correlation* method, a distribution-free test. It was first applied to the entire time series and then to parts of it, if trends were found. In case the cumulative departure from the mean indicated a breakpoint, it was also applied to the parts before and after that point. This was followed by the application of the *F-test for stability of variance* and the *t-test for stability of mean* to split, non-overlapping, sub-sets of the time series. In both cases a normal distribution of the data is required, but this is less stringent for the t-test than for the F-test (Dahmen and Hall, 1990). These tests were standardly applied to the first and second half of the observations, followed by a comparison of the sequential decades under consideration and the periods before and after breakpoints, if these occurred. Lastly, the independence of the time series was verified by calculating the *serial correlation coefficient*.

Test results were interpolated in a Geographic Information System (GIS) in order to analyse the spatial pattern of extent and magnitude of climate change. The effect of climate change on potential crop yields was calculated on a year-to-year basis for a representative station with recently developed software following the principles of the FAO Agro-Ecological Zones Methodology (Voortman and Buurke, 1995).

3 Character, magnitude and spatial extent of historical climate change

Mean annual rainfall for the periods 1951-1960 and 1981-1990 from selected stations along a north-south gradient are presented in table 1. Visual inspection of the data learns that in the North both in absolute and relative terms rainfall was considerably lower in the more recent 10-year period. Towards the South (Kaduna) the decrease is similar in absolute terms but smaller in relative terms. Further South (Lokoja, Ibadan) we see a very slight increase in rainfall. In the coastal zone (Lagos) there are again large differences in absolute terms but relatively speaking these are much smaller than in the North.

This overall pattern is confirmed by the Spearman test results, if applied to the full length of the time series. The test shows that trends occur at spatially related stations

Table 1: Absolute and percentage change in mean annual rainfall (mm) between the periods 1951/60 and 1981/90 along a latitude gradient

Station	Latitude	Longitude	Period		Absolute change	Percentage change
			1951-'60	1981-'90		
Maradi	13.28	7.05	638	380	-258	-40.4
Sokoto	13.01	5.15	780	537	-243	-31.2
Kaduna	10.36	7.27	1363	1147	-216	-15.8
Lokoja	7.48	6.44	1138	1164	26	2.2
Ibadan	7.26	3.54	1221	1256	35	2.9
Lagos	6.27	3.24	1960	1662	-298	-15.2

and the magnitude of change varies according to a coherent spatial pattern that cuts across national boundaries and thus the effect of extraneous influences may be ruled out. Applying the test to the first and last 20 years of data for almost all stations results in absence of trend, but application to the overlapping first and last 30 years mostly indicates trends for those stations where these were also present in the entire time series. This suggests a breakpoint around 1970.

The cumulative deviation from the mean for the entire series and parts thereof was used to further pinpoint the years in which a change occurs. We take the station of Sokoto as an example for the purpose of illustration. In figure 1 the entire time series of annual rainfall is presented and figure 2 provides a plot of the cumulative deviation from the mean (expressed as a multiple of the mean). The latter confirms the findings obtained with the

Spearman test and we see a very clear breakpoint in the year 1966 with an almost consistent increase before the breakpoint and a decrease thereafter. The drought periods in the early 1940's and 1970's appear as a mere dip in a more structural trend of above average rainfall before 1968 and below average thereafter. We also note the systematically below average rainfall in the early part of this century which is in accordance with historical reports (Van Apeldoorn, 1981). All northern stations show a pattern that is similar to the example of Sokoto. However, the location in time of the breakpoint varies. At Sokoto it was early, but most commonly it falls within 3 years from 1970. For the Southern stations such evident trendbreaks are not found.

If we now apply the Spearman test to subsets before and after the breakpoint we mostly find an absence of trend. For instance in the case of Sokoto the t-value for the period

Fig.1: Annual rainfall totals for Sokoto (1907-1991)

Fig. 2: Cumulative deviation from the mean of annual rainfall in Sokoto (expressed as units of P mean)

Table 2: t-values for comparison of the mean of different periods (bold = significant)

Period	1961-'70	1971-'80	1981-'90	1971-'90
Compared with	1951-'60	1961-'70	1971-'80	1951-'70
Maradi	0.73	2.99	1.55	5.86
Sokoto	1.87	1.15	1.07	3.68
Kaduna	1.25	-0.61	2.37	1.35
Lokoja	-1.28	1.1	-0.07	0.32
Ibadan	-0.83	0.34	0.15	0.00
Lagos	-0.98	2.01	0.62	2.88

1966-1991 is only -0.550. Based on this analysis it is therefore concluded that climate changed in the northern part of the study area and that the change consists of a trendbreak around 1970 with zero-trend before and zero-trend after the year of the break.

To quantify the magnitude of climate change and to test the significance of the differences, subsequently t-tests for the stability of the mean and F-tests for stability of variance were conducted by comparing the time series before and after 1970. The same tests have been applied to 10-year periods by comparing them with the previous 10 years. A selection of results is given in table 2 (significant values in bold). The t-values obtained were interpolated with a Geographic Information System in order to analyze climate change with a time and spatial perspective. The resulting maps are presented in figure 3. Negative t-values, implying an increase in rainfall do occur (see table 2) but these are never significant (< -2). In particular for the comparison of the entire periods before and after the trendbreak negative t-values are close to zero. For the sake of simplicity of presentation the minor areas involved are mapped together with the areas with positive t-values between zero and one, implying a minor and non-significant change of rainfall.

Comparing the 1960's with the 1950's we see that the null hypothesis of equal means must be rejected in isolated parts of Niger and Chad but in most of Nigeria the t-value is below 1. If comparing the 1970's with the 1960's first of all it can be seen that there is no significant change in the areas affected in the 1960's. The changes are now located in a belt further south and in the Niger and Benue valleys. In addition there were significant changes in the coastal zone. We also note that on the windward slopes towards the Jos plateau, in the middle of the country, there is still no change. This is exactly the area that is affected in the 1980's together with an area near Lake Chad that remained hitherto rather un-affected and that is related to the former area through the direction of the south-west winds. We note a general tendency of boundaries being perpendicular to the direction of the prevailing winds in the rainy season.

We now proceed to the comparison of the periods before and after 1970, when at most northern locations a clear

trendbreak does occur. The evolving pattern of the mapped value of the t-statistic is as follows. Along the Atlantic coast significant changes did occur in some areas. More inland, differences are not significant with t-values between 1 and 0 and with very minor areas where rainfall increased slightly (not separately shown). Further north the t-value generally increases with latitude. However, this increase is less on the windward slopes towards the Jos plateau and in an eastern zone that is sloping towards mountain range on the border with Cameroon. In the latter area there is both orographic rainfall related to SW winds and rainfall originating from the Congo basin. The decrease is relatively severe in the valleys of the Niger and Benue rivers. Further north the highest t-values are found at locations that slope downwards from the Kano-Zinder Plateau towards the Chad and Niger basin. The t-values decrease near the Sahara desert, where earlier rainfall was already low. The evolving patterns lead to the conclusion that there is a relationship between the location and magnitude of climate change on the one hand and the weather system (mainly wind direction) and topography on the other.

With few exceptions the F-test showed that variance remained stable throughout the period considered. The serial correlation test was applied to all stations with a full data record. Again, with very few exceptions there was no significant serial correlation, implying that there is no autocorrelation in time and hence that in this respect the time series can be considered random.

4 Climate change and the effect on potential crop yields

To assess the effect of climate change on crop yield, the length of the growing period (LGP) and climatic yield potentials have been calculated according to the FAO Agro-Ecological Zones (AEZ) methodology (FAO, 1978; Kassam et al., 1982). The assessment is applied on a year-to-year basis for the periods before and after the trend break using the most recent FAO/SOW-VU software (Voortman and Buurke, 1995). Three cereal crop varieties with a different growth cycle (millet of 70 and 90 days and

Fig.3
Comparison of annual
rainfall means from
different periods
expressed by t-value

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Table 3: Crop yields (kg/ha) and variability of yield at Sokoto before and after trend break of 1966*

Period	1950-65	1966-91	1950-65	1966-91	1950-65	1966-91
Crop species	Millet	Millet	Millet	Millet	Sorghum	Sorghum
Growth cycle	70 days	70 days	90 days	90 days	120 days	120 days
Mean potential yield	2,890	2,781	3,935	3,546	4,177	2,613
Coefficient of variation	1	17	2	27	32	69
No. years with crop failure	0	1	0	1	1	7
No. years with reduction >50%	0	0	0	2	2	4

* Mean LGP period 1950-1965: 123.7 days (n=16), and for period 1966-1991: 104.1 days (n=26)

sorghum of 120 days) were selected and Sokoto is maintained as an example. It represents a case of significant but not severe climate change. Mean potential yields, coefficients of variation, the number of years with (near) total crop failure and those with serious yield reductions of more than 50 %, are presented in table 3.

The data show that before the break on average a 120 day Sorghum was highest yielding, though being rather risky. A 90-day Millet variety would on average produce almost the same yields with no risk at all. The 70-day millet gives a considerably lower yield because it ripens of prematurely if compared to the duration of water availability for crops. After the break, the 120 day Sorghum yields lower than both Millet varieties because its yield formation period is curtailed by the short length of growing period. In more than 25 % of the years there is no yield at all. Millet of 90 days gives on average higher yields but it is riskier than the 70-day variety. The greater security obtained with the 70-day variety is achieved at the cost of on average more than 700 kg/ha.

This analysis shows the profound effect of climate change on land use and farming systems with respect to choice of crop variety and consequently its implications for farmer behaviour in terms of risk aversion and coping mechanisms.

5 Conclusions and discussion

From the onset it may be questioned if the used tests are sufficiently powerful for the present purpose and whether the data fully meet the requirements of such statistical tests. However, the analysis has shown that the annual rainfall figures are mostly independent in time, as is usually the case (Dahmen and Hall, 1990). Moreover, most of the evidence for climate change is derived from tests that are least or not at all demanding in terms of distribution of the data. However, spatial dependence was not tested but can be assumed. The inclusion of spatial auto-correlation would certainly increase explanatory power but it is unlikely that it would affect the main conclusions of this study.

It is therefore concluded that in the northern parts of the study area climate change has occurred, that is

characterized as a trend break around 1970, separating two time series with different properties that by themselves show zero-trend. Thus, the conditions with below average rainfall persist until in the early 1990's. The analysis of change between 10-year periods shows that significant differences between such periods occurred earlier in the north and later in the south. The severity of the trendbreak generally increases with latitude and deviations from this general pattern that occur, can be related to exposition i.e. the combination of the direction of moisture bearing winds and topography. Areas where rainfall is partly of orographic origin were less and later affected than rainshadow areas and low-lying river valleys. It is further noted that boundaries of the degree of change between 10 year periods show a tendency to be perpendicular to the prevailing south-west wind direction and that severe changes between these periods occur only once in a given area. It has further been shown what the impact of historical climate change is on the decision-making environment of the farmer with regard to choice of crop variety in relation to food security and income.

With respect to the causes of climate change various hypotheses have been brought forward. Two main groups may be distinguished: those that refer to the conditions on the land and those that refer to the combined effect of phenomena occurring in the oceans and atmosphere. To the first group belong the effect of increased albedo due to lower on-site land covers related to increased cultivation (Charney, 1975), the effect that an increased area of bare soil would have on atmospheric dust (e.g. Klaus, 1981) and the effect of off-site land use changes that affect moisture re-cycling (Savenije and Hall, 1994; Savenije, 1995). The other group of hypotheses refers to the effect of ENSO phenomena in combination with sea temperature changes in the southern and northern tropical Atlantic that affect the location of the ITCZ (e.g. Houghton et al., 1996; Janicot, 1994; Lamb, 1985; Philander, 1990; Rasmussen, 1987).

Undoubtedly the moisture re-cycling mechanism is operative and it implies that rainfall in the Sahel has been recycled various times further south. Negative effects on the water balance in the south will exacerbate the situation in the north, as has been observed. However, it seems reasonable to assume that land use intensity has increased

gradually in accordance with population growth and consequently one would expect a gradually increasing effect on rainfall. This gradual change has not been observed and in fact in the 1950's and 1960's rainfall was consistently high despite a fast growing population. Moreover, in the early part of the 20th century rainfall was as low as in the recent decades, but at the time population density was very low. It is therefore difficult to accept the effect of land use on moisture re-cycling as the sole factor affecting climate change, unless it involves unknown processes where critical thresholds are at play.

If one considers rainfall in the northern zone as a whole then years of in aggregate low rainfall often but not always coincide with ENSO events or known anomalies in the tropical Atlantic. Since ENSO phenomena have become more frequent (Houghton et al., 1996), this may indeed be the reason for the observed trendbreak. However it does not explain the persistence of below average rainfall in between ENSO events, which indeed may reflect the effect of reduced moisture re-cycling. However, the evolving patterns are much more irregular if we look at individual ENSO events and anomalies in the Atlantic and try to relate these to rainfall in a spatially more explicit manner. For instance 1972 and 1976 are both considered El Niño years (Philander, 1990) but in 1972 rainfall was generally low in the north and also at the coast (Lagos), while in 1976 rainfall in the north was generally high and average at Lagos. The year 1983 was an El Niño year that was accompanied by low sea surface temperatures in the southern tropical Atlantic. In that year rainfall was low at Zinder and Maiduguri, but high at Sokoto, which is located at similar latitudes. In 1984 this was followed by a strong La Niña event (the opposite of El Niño) in combination with high sea surface temperature in the Atlantic, which equally resulted in low rainfall in most Northern stations. In both cases rainfall at the coast (Lagos) was relatively low. During the 1987 El Niño event rainfall was generally low in the north but high in Lagos. During all these events rainfall at Jos in the middle of the country remained rather unaffected. This complexity in space and time is further enhanced by the fact that El Niño events and annual rainfall statistics are of a different duration.

It is therefore concluded that the tests used in this study are appropriate to detect and quantify climate change, but that the study of cause and effect should be pursued with more powerful tools for time series analysis as used in econometrics, in combination with those developed in the field of spatial statistics (e.g. Keyzer, 1996). Such studies can make full use of spatially explicit information on land use to assess the possible effect of moisture re-cycling on rainfall in West Africa.

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