THE GLOBAL ENVIRONMENT MONITORING SYSTEM

GEMS
SAHEL SERIES
NUMBER 2

NAIROBI
1988

Inventory and Monitoring of Sahelian Pastoral Ecosystem

ANNEX 2:
RAINFALL IN THE FERLO (SAHELIAN REGION OF NORTH SENEGAL) SINCE 1919

UNITED NATIONS ENVIRONMENT PROGRAMME
OD AND AGRICULTURAL ORGANISATION
GOVERNMENT OF SENEGAL

SAHEL SERIES

1. Introduction to Sahelian Pastoral Ecosystems Project
2. Rainfall in the Ferlo (Sahelian Region of North Senegal) since 1919
3. Use of Light Aircraft in the Inventory and Monitoring of Sahelian Pastoral Ecosystems
4. Sampling the Sahel
5. Monitoring Pasture Production by Remote Sensing
6. Inventory of Water Resources in the Ferlo
7. Woody Vegetation in the Sahel

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Executive Summary:

The GEMS Sahel Series is a product of the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems. This project was set up to demonstrate and assess the GEMS methodology for ecological monitoring in a West African pastoral ecosystem.

The present document, the second in the series, describes the climatic context of the rainfall in the test region, presents the long-term rainfall data of the area, and examines these data with the aid of computer programs which are presented in Appendices. It describes and quantifies the variability inherent in the rainfall and seeks to detect patterns in the rainfall grouped into periods of months and years. Correlations between stations are examined. Rainfall probabilities at certain stations are calculated and annual isohyets mapped for four years over the test zone.

Global Environment Monitoring System Program Activity Centre
SAHEL Series No 2

Title:
Rainfall in the Ferlo (Sahelian region of north Senegal) since 1919

Author: M. Sharman

Target audiences: Government of Senegal
Other Governments in Sahel
Development agencies
Range managers
Data analysts for ecological monitoring projects

Objectives:

(1) To provide data on the rainfall in the Ferlo, north Senegal, for use by government and development agencies
(2) To present techniques for the analysis of rainfall data in the Sahel, including computer programs which can be adapted for the analysis of other time series data
(3) To make recommendations for the correct interpretation of long-term rainfall data

Frontispiece: The sahelian zone

Source: Van Chi-Bonnardel R. (1973)
L'Atlas de l'Afrique. IGN, Paris.
Editions Jeune Afrique. Paris

Preface

From the available data it seems probable that the numbers of domestic stock in the Sahel have reached levels equal to those of the decade before the catastrophic drought of 1968-72. At the same time the condition of the rangeland has improved only slightly, if at all, from its degraded state immediately after the drought. Furthermore, in parts of Africa, extension of agriculture has meant that pastoralists no longer have access to some of their former pastures. If the future of pastoral peoples is to be assured, the condition of rangelands must be preserved and if possible improved. Unfortunately the protection of the pastures poses well-nigh intractable social and complex ecological problems. The ecological problems alone cannot be solved unless the dynamics of the ecosystem are understood, and understanding can only be achieved by approaching the ecosystem as a functioning whole. To this end, the United Nations Environment Programme's Global Environment Monitoring System (GEMS) set up the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems, which was executed by FAO as part of the global network of GEMS monitoring projects.

Objectives of the sahelian monitoring project

There were two major objectives. Firstly, the project was to adapt the standard GEMS ecological monitoring methods to the inventory and monitoring of sahelian pastoral ecosystems. Thus data were to be collected from observations made at three levels (on the ground, from the air, and from satellites), using methods designed to encourage a systems approach in their presentation and use. Secondly, the project was to collect data which would improve understanding of the renewable resources in the world's arid lands.

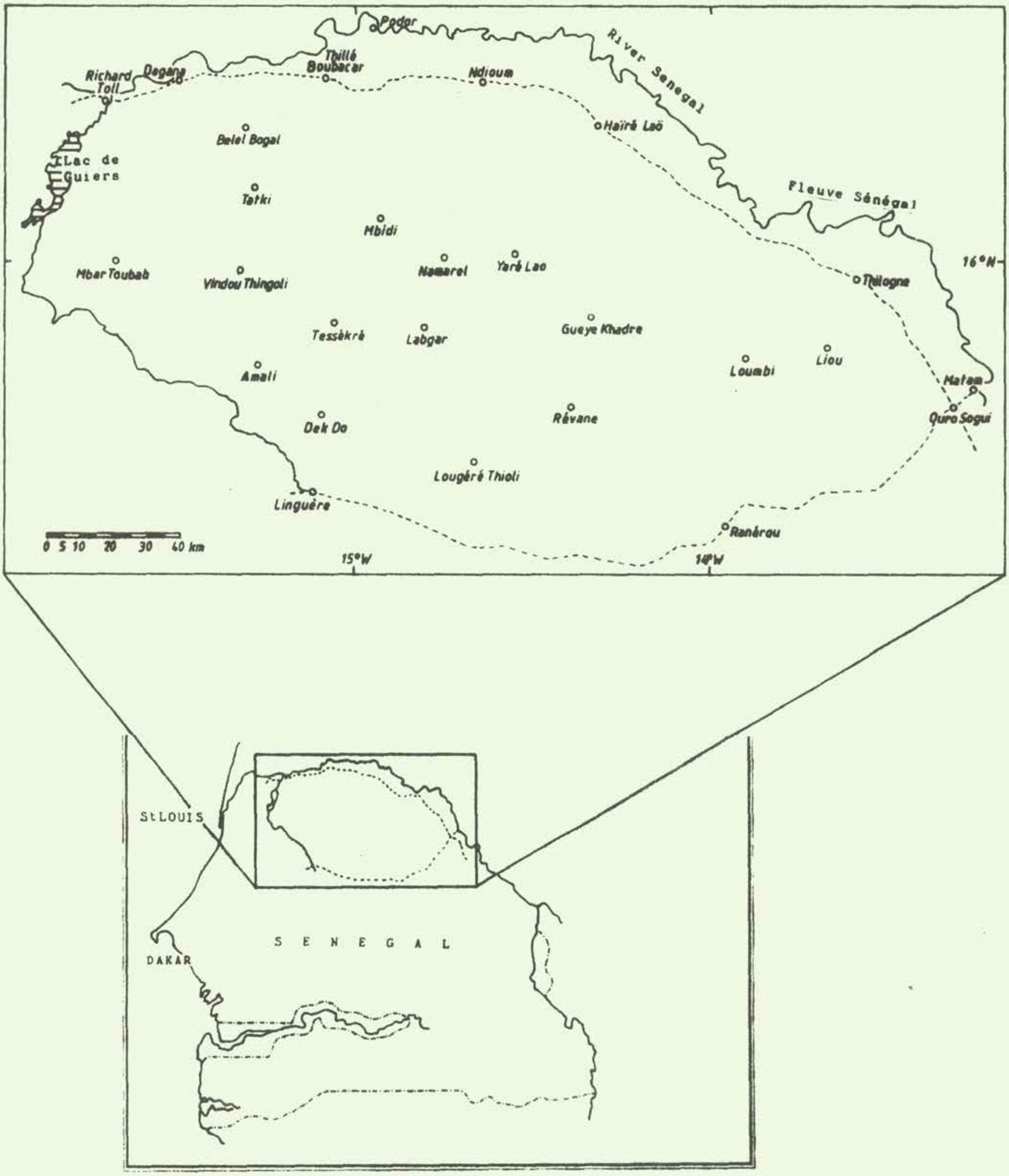
Choice of test zone

The ecology and economy of the north of Senegal is typically sahelian, and the area faces many of the ecological problems that confront the Sahel elsewhere. The zone chosen as a test area for the project, some 30,000 sq km of low-lying pastoral land (Figure 1), is bordered to the west by the shallow Lac de Guiers, to the north and east by the River Senegal, to the southwest by the fossil valley of the Ferlo, ending at Linguère, and to the south by the road between Linguère and Matam (on the River Senegal). This area corresponds roughly with that known traditionally as the Ferlo du nord, or north Ferlo. In the GEMS Sahel Series the test zone is known simply as the Ferlo.

Objectives of this document

(1) To provide data on the rainfall in the Ferlo, north Senegal, for use by government and development agencies
(2) To present techniques for the analysis of rainfall data in the Sahel, including computer programs which can be adapted for the analysis of other time series data
(3) To make recommendations for the correct interpretation of long-term rainfall data

Figure 1: Location of Pilot Zone of Pastoral Ecosystems Project



Rainfall in the Ferlo (Sahelian region of north Senegal) since 1919

Table of contents:

1 Introduction
  1.1 Air movements in the region
  1.2 Mechanism of Rainfall in the Ferlo
2 Methods
  2.1 Data available
  2.2 Treatment of the data
  2.3 Data storage
3 Results
  3.1 Statistical distribution of rainfall in the region
  3.2 Long-term rainfall in the Ferlo - status
  3.3 Long-term rainfall in the Ferlo - trend
    3.3.1 Caveat
  3.4 Oscillations about the trend line
  3.5 Correlation in the data
    3.5.1 Correlation between monthly totals at a given station
    3.5.2 Correlation between stations
  3.6 Rainfall probabilities
  3.7 Drawing isohyets: automatic generalisation of data from points
    3.7.1 Criteria for the algorithm
    3.7.2 Algorithm used
    3.7.3 Annual isohyets in the Ferlo 1980-1984
4 Discussion and conclusions
5 Bibliography

Table 1: Format of data files for stations with long-term rainfall data
Table 2: Regression of annual rainfall with time since the start of observations
Table 3: Regression of annual rainfall with time before and after 1949
Table 4: Statistically significant regressions (p<=0.01) of monthly rainfall with time since the start of observations
Table 5: Correlations of rainfall totals between stations
Table 6: Classification of rainfall probabilities
Table 7: Classified monthly rainfall at four stations in the Ferlo
Table 8: Comparison of observed rainfall data with expected

Frontispiece: The sahelian zone
Figure 1: Location of Pilot Zone of Pastoral Ecosystems Project
Figure 2: The three anticyclones (Azores, StHelens and Saharan) which control the movement of air masses in West Africa
Figure 3: Location of rainfall stations in the north Ferlo
Figure 4: Frequency distributions of annual rainfall at four stations in the Ferlo
Figure 5: Medians and mean monthly rainfall at four stations in the Ferlo
Figure 6: Long-term isohyets of median rainfall in the Ferlo (After Bellocq 1983)
Figure 7: Annual rainfall records from the start of records to 1984
Figure 8: Autocorrelation of annual rainfall at four stations in the Ferlo
Figure 9: Daily rainfall at selected stations in the Ferlo
Figure 10: Gamma curves for the calculation of annual rainfall probabilities at four stations in the Ferlo
Figure 11: Gamma curves for the calculation of monthly rainfall probabilities at four stations in the Ferlo
Figure 12: Annual isohyets in the Ferlo 1980-1984

Appendix 1: Rainfall data for thirty-five stations in the Ferlo 1980-1984
Appendix 2: Rainfall data for four stations in the Ferlo 1919-1984
Appendix 3: Summary statistics for rainfall data at four stations in the Ferlo
Appendix 4: Monthly rainfall data for four stations in the Ferlo 1980-1984
Appendix 5: Programs used to produce results presented in text

5.1 PROGRAM 1: Summary statistics
5.1.1 SAMPLE OF RESULTS OF PROGRAM 1

5.2 PROGRAM 2: Calculate least-squares regression, calculate and store residuals, and plot transformed data on line printer
5.2.1 SAMPLE OF RESULTS OF PROGRAM 2

5.3 PROGRAM 3: Autocorrelation of time series
5.3.1 SAMPLE OF RESULTS OF PROGRAM 3

5.4 PROGRAM 4: Correlation of rainfall at two sites
5.4.1 SAMPLE RESULT OF PROGRAM 4

5.5 PROGRAM 5: Rainfall probabilities by Gamma function
5.5.1 SAMPLE RESULT OF PROGRAM 5

5.6 PROGRAM 6: Generalise from point data to regular grid
5.6.1 SAMPLE RESULT OF PROGRAM 6 (only the left-hand part of the page output by the computer is represented)

1 Introduction

The data discussed here were collected in the Ferlo, the sahelian northern region of Senegal (Figure 1). For a general introduction to the Ferlo see Le Houérou (1986a).

Major ecological changes have taken place in the Ferlo since the beginning of the century (Barral 1982). These changes include, amongst others, the replacement of perennial grass species characteristic of the sahelo-sudan zone by annual species typical of the Sahel, of more mesophytic woody species by xerophytic ones, by the almost total disappearance of mammamian and reptillian game species, and by a replacement of sahelo-sudanian bird species by sahelian ones (Morel and Morel 1983).

Part of this ecological regression may be an example of the now-classic changes due to overgrazing, expecially since much of the change has taken place since the increase in livestock numbers pastured permanently in the area following the installation in 1949 of the first boreholes in the Ferlo (Barral 1982). However, part of the change may be due to a decrease in the rainfall in north Senegal since the early 1950s, of the sort reported by Nicholson (1983) for wide areas south of the Sahara.

This document therefore sets out to put the rainfall data for the region in their climatic context, and to examine these data for any systematic elements which could be used for the prediction of rainfall from year to year at a given site or from place to place in a single year.

GEMS is not of the opinion expresed in Stern and Dale (1983) that given the wide availability of commercial statistical packages "the era of writing programs for ... statistical analysis is now over". Many projects will continue to find themselves faced with the analysis of data for which they possess no pre-packaged software. The task of the person responsible for data analysis, who in such circumstances is often not a trained programmer or statistician, may be greatly eased by finding listings of working programs which he or she can adapt to the project's needs. For this reason computer programs used in the analyses presented here are given in Appendices.

1.1 Air movements in the region

Three subtropical anticyclones govern the movement of the winds in the Ferlo, as they do for the rest of West Africa. These three centres of high pressure (Figure 2) move seasonally, altering the position of the Intertropical Convergence Front, which influences the climate between Senegal and Chad. Well to the south of Senegal between November and May, the Front moves north in June, July and August, and back south in September and October. The three anticyclones are:

(1) the Azores anticyclone, which moves the Front south in January and February, and which produces a wind blowing from the north known as the Alizee.

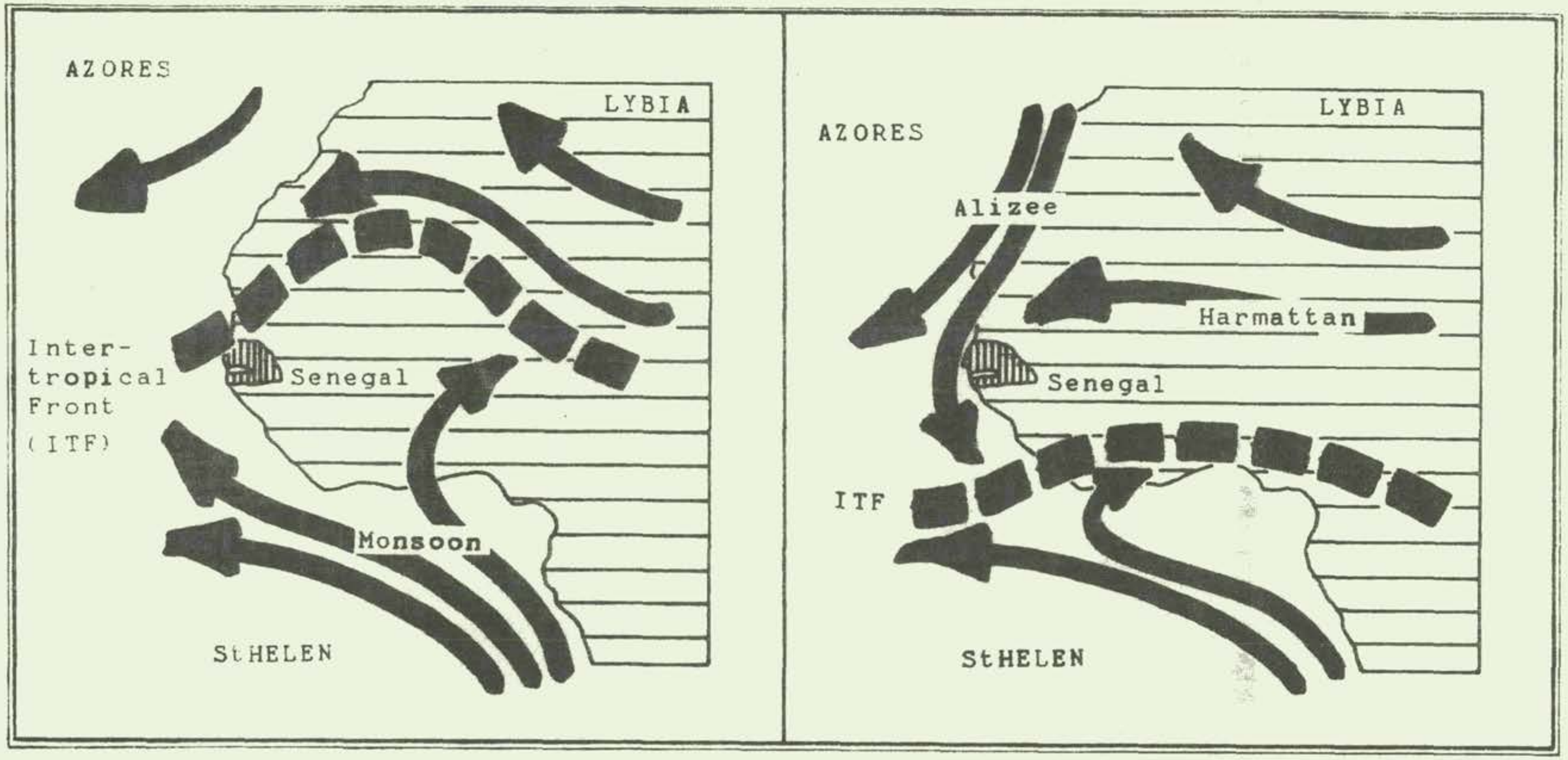


Figure 2: The three anticyclones (Azores, StHelens and Saharan) which control the movement of air masses in West Africa

(2) the St. Helen anticyclone, centred over the Bay of Benin, starts to move north in June, bringing the moist southerly monsoon, and returns to its southern location in September. Near the west coast, the Alizee slows the northward movement of this anticyclone, so that Senegal feels the southerly monsoon later than does the rest of West Africa.

This moist wind is essential to the lives of the plants in the Ferlo. Even before the first rains, the monsoon reduces the saturation deficit of the air so much that woody plants start to flush and to bud (Giffard 1974).

(3) the Saharan anticyclone brings the hot dry Harmattan, which blows over Senegal from the northeast from March until the onset of the rains. This wind increases the potential evapotranspiration, so that all plant species that grow in the Ferlo must be adapted against dessication. Occasionally reaching high speeds on the ground, the Harmattan provokes wind erosion in the northeast of the Ferlo and in other areas devoid of vegetation. Windborne sand can injure leaves and new shoots. The dust carried by the Harmattan and deposited in the Atlantic, sometimes reaching the Carribean, amounts to several tens of millions of tonnes each year (Carlson et Prospero 1972).

1.2 Mechanism of Rainfall in the Ferlo

The sheet of air forming the monsoon becomes thinner as it moves northwards. By the time it reaches the north of Senegal it is only 1000-2000m thick, normally insufficient to support convection rainfall. At the start of the rainy season, the Harmattan, coming from the northeast, meets the southerly Monsoon along the Intertropical Front and raises it to high altitudes, where it cools. Sometimes this cold wet mass of air drops abruptly through the Harmattan, reaching the ground in a violent windstorm which raises a curtain of sand and dust. The resulting sandy squalls can tear leaves, uproot trees, and destroy huts. Thus in the Ferlo rainfall is characterised by brief downpours which start violently, with rain typically falling at a rate of between 27 and 62 millimetres per hour, and then gradually peter out (Giffard 1974).

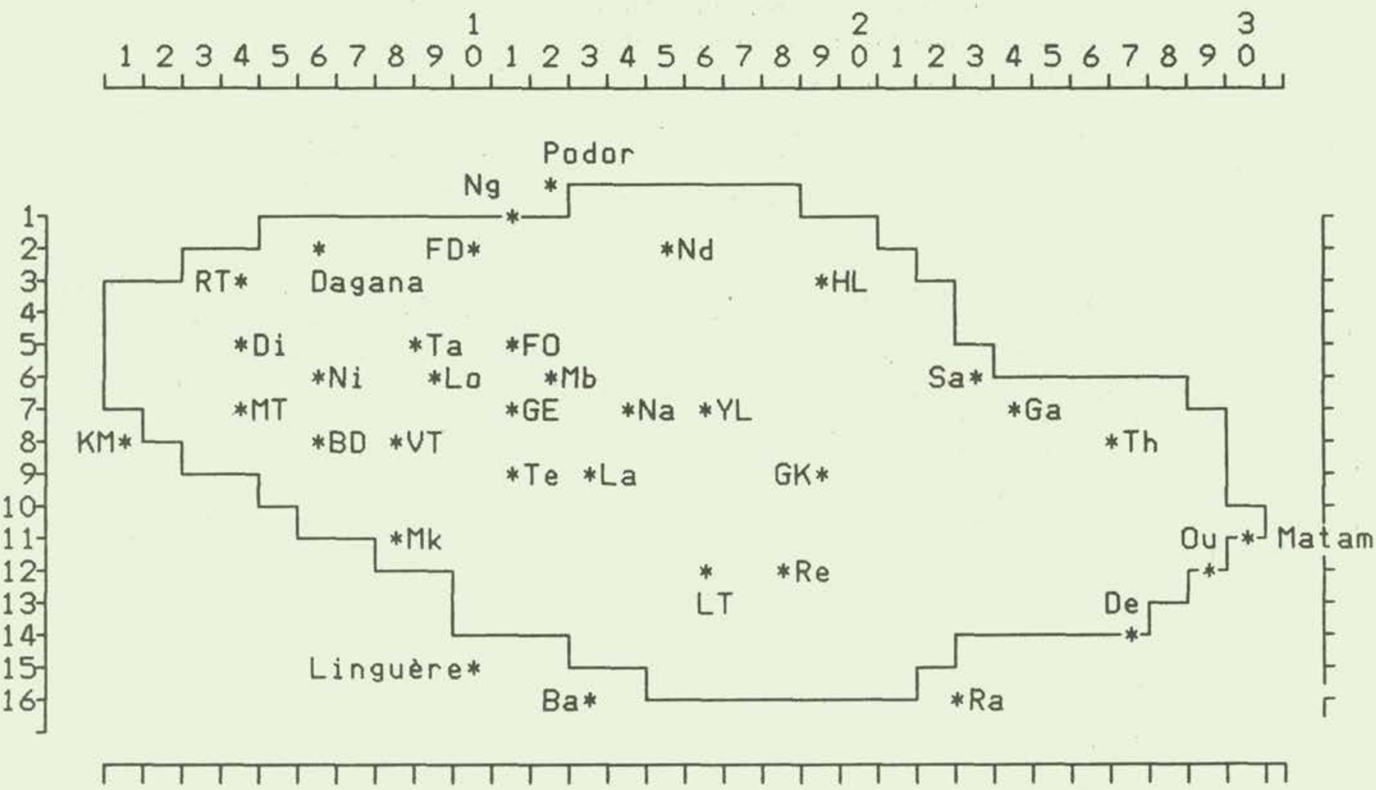
As the Intertropical Front moves north the sheet of air forming the monsoon becomes thicker over northern Senegal, and intense heating of the ground and lower layers of the atmosphere may occasionally give rise to more gentle convection rainstorms.

2 Methods

2.1 Data available

Figure 3 is a schematic map showing the four stations in the Ferlo which have been monitoring rainfall for more than 50 years (Dagana, Matam and Podor since 1919; Linguère, since 1933). These data are available at the Direction de la Météorologie Nationale, at Yoff Airport, Dakar. Although three of these stations are in the valley of the River Senegal, the project considers them as being climatically representative of the

Figure 3: Location of rainfall stations in the north Ferlo



KEY to rainfall stations

- Ba Barkedji
- BD Boki Divé
- De Dendoudi
- Di Diaglé
- FD Fanaye Diéri
- FO Fété Ole
- Ga Galoyal
- GE Ganine Erogne
- GK Guèye Kadar
- HL Haïré Laö
- KM Keur Momar Saar
- La Labgar
- Lo Lodé
- LT Lougéré Thiolly
- MT Mbar Toubab
- Mk Mbeuleukhé
- Mb Mbidi
- Na Namarel
- Nd Ndioum
- Ng Nianga
- Ni Niassanté
- Ou Ourrosogui
- Ra Ranerou
- Re Revane
- RT Richard-Toll
- Sa Saldé
- Ta Tatki
- Te Tessékré
- Th Thilogne
- VT Vindou Thingoli
- YL Yaré Laö

Tick-marks are 10 km apart, and correspond with the local UTM grid.

region. While these data are not always complete, they provide a valuable record which can be examined for trends both before and after the installation of the first boreholes. Figure 3 also shows the network of rainfall stations monitored by the project in 1980-1984. The number of stations varied from year to year (1980:21 stations; 1981,27; 1982,29; 1983,28; 1984,28).

The project shared the view expressed by Bellocq (1983), that for its purposes the object of the study of rainfall in the Sahel is functional ecology and not abstract climatology. As a consequence, all the available data were used in the following analyses, with the result that the observations depend on a variable number of years. The raw data are to be found in Appendices 1 and 2.

2.2 Treatment of the data

Although daily rainfall totals are available for some stations, the temporal distribution of rainfall is highly irregular (Figure 9) and its analysis lies outside the scope of this report. The project nevertheless recognises the need for research into the relationship between temporal distribution of rainfall and plant growth, especially since sahelian grasses are adapted so that not all of the seeds germinate when conditions are suitable for germination. This means that successive rainstorms two or three weeks apart may provoke successive waves of germination, between which the seedlings shrivel and die. Since different species have different germination strategies, under these conditions the seedstock will become poorer and poorer in the opportunistic early-germinating species. Successive years in which rain is poorly distributed may therefore act not only to reduce the primary production of the pastures through the general reduction of seedstock, but also to change their species composition. The species composition of a pasture is a major contributor to its quality, and hence to its secondary productivity.

For some ecological monitoring purposes, it is therefore desirable to consider daily rainfall totals or data grouped into short periods, such as ten-day totals. Active research on the effects on productivity of the short-term distribution of rainfall is being carried out in the Ferlo by the host organisation of the project (eg see Dieye 1983). An excellent review of the analysis of daily rainfall is given in Stern and Dale (1983). The present document seeks to detect patterns in rainfall grouped into longer periods, that is, months and years.

In the historical data some of the monthly totals for some stations were missing (see Appendix 1) and the following algorithm was used to estimate them. For every missing month's data, the previous 5 year's data and the following 5 year's data were searched for non-missing values of rainfall for the relevant month. The mean of the resulting sum was found and taken to be the estimate of the missing month's data. Yearly rainfall totals were taken to be the total of rain recorded (or estimated) for the months of May through October, that is, the months of the growing season. The rain that falls during these six months normally makes up more than 95% of the total, and rain that falls outside these months is of little ecological consequence.

2.3 Data storage

Data were filed on disk in tabular format, with a separate file for each of the four stations with long-term data. Part of the data for one station is shown in Table 1. The first column contains the date. The second and subsequent columns contain the rainfall total for May to October of that year. Missing data are flagged by a -1.

3 Results

3.1 Statistical distribution of rainfall in the region

Basic statistical data on the distribution of rainfall within months and year by year were calculated using Program 1 in Annex 4. Summary statistics on annual and monthly rainfall data collected at four stations over fifty years are given in Appendix 3.

Although the years of the Great Sahelian Drought from 1968 to 1974 were particularly dry, the dryest years on record at each of the four stations with long-term data were either 1983 (Dagana, Matam and Podor) or 1984 (Linguère).

The ecological aridity of a site depends not only on the mean or median annual rainfall, but more particularly on its variability. Erratic and unpredictable rainfall has the ecological effect of making it impossible for some plant species to survive in an area where the long-term mean annual rainfall would seem adequate.

The data presented in Appendix 3 show that at any one site in the Ferlo annual rainfall can vary greatly between years. This is readily apparent in the typically large range of values of rainfall by comparison with the measures of central tendency, both for annual totals and monthly rainfall. In the Ferlo the standard deviation of the annual rainfall is usually between 30% and 45% of the mean. This and other measures commonly used by climatologists to describe the variability of the rainfall at arid and semi-arid sites are given in Table 2. These values correspond closely with those given by Le Houérou (1986b) for other stations in the Sahel with equivalent long-term mean rainfall. He points out in this paper that by comparison with other arid and semi-arid regions of the world, the variability in the rainfall in the Sahel is moderate. However, by comparison with temperate areas, variability is nevertheless high.

In some sites in the Sahel, not only does the rainfall at a given site vary greatly between years, but its statistical distribution is often asymmetric, as a result of a few years having unusually high rainfall and more than half of the years having less than the mean annual rainfall. This is not true of the long-term records at four sites in the Ferlo (Figure 4), where the median is sometimes below and sometimes above the mean annual rainfall. However, rainfall in any given month is below the long-term mean for that month more frequently than it is above

Table 1: Format of data files for stations with long-term rainfall data

Year	May	June	July	Aug	Sept	Oct
1919	-1.0	-1.0	127.5	214.8	60.8	-1.0
1920	-1.0	-1.0	135.4	116.0	114.5	43.5
1921	-1.0	29.5	30.0	-1.0	25.2	-1.0
.	.	.	.	.	.	.
.	.	.	.	.	.	.
1982	0.1	13.2	79.0	135.0	45.0	8.0
1983	10.0	30.2	22.3	143.3	8.0	0.0
1984	0.6	28.3	49.7	30.1	38.1	0.0

Table 2a: Measures of the variability of the annual rainfall in the Ferlo

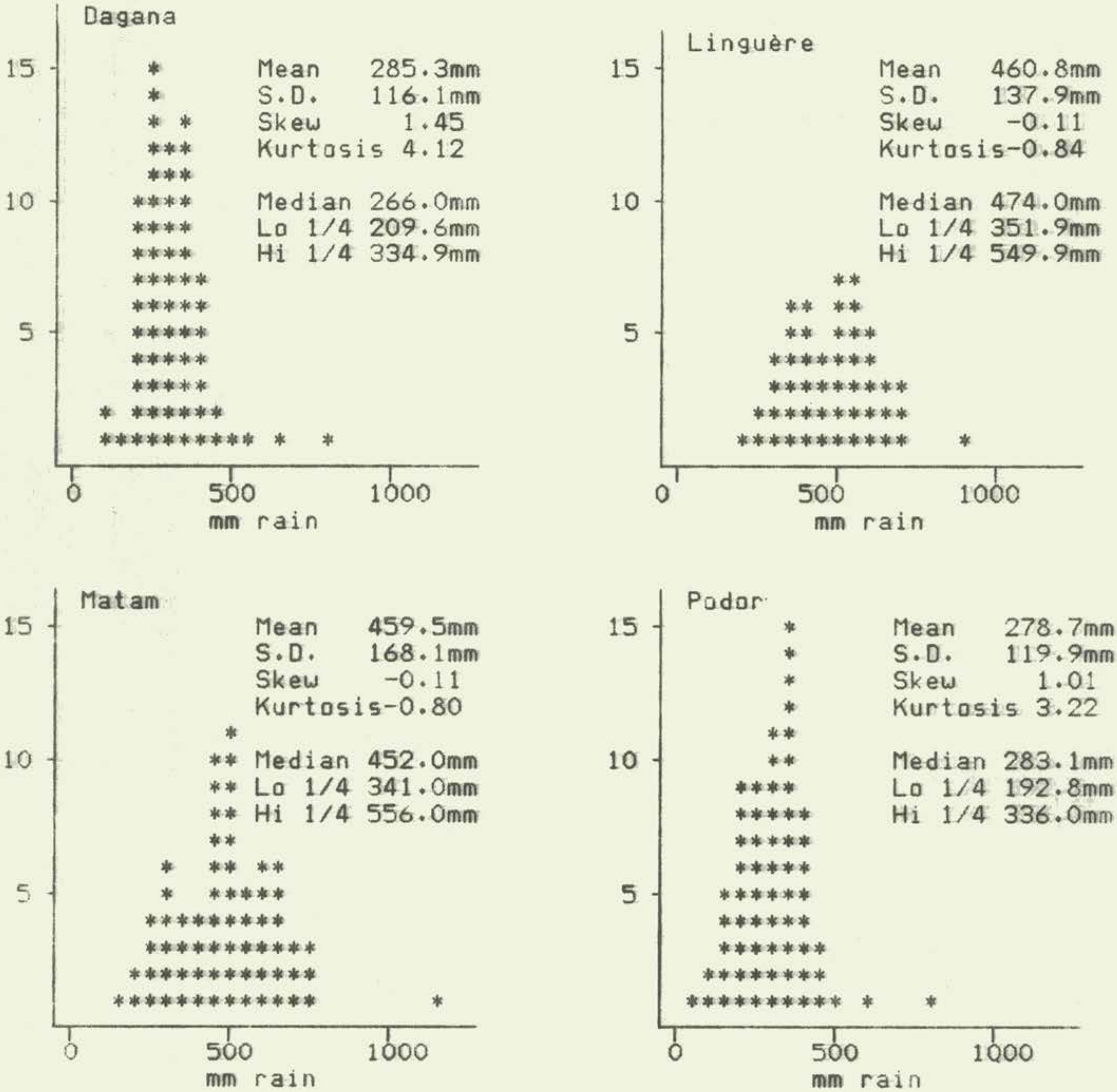
Annual	SD/Mean	Range/Median	(90p-10p)/Median	DepRain(f0.8/Mean)
Dagana	0.406	2.76	0.903	0.691
Linguère	0.299	1.40	0.755	0.713
Matam	0.366	2.13	0.978	0.638
Podor	0.430	2.69	0.942	0.626

Table 2b: Measures of the variability of the monthly rainfall in the Ferlo

Monthly	SD/Mean	Range/Median	(90p-10p)/Median	DepRain(f0.8/Mean)
Dagana				
May	3.252	-	-	0.000
June	1.388	15.81	7.063	0.000
July	0.775	4.83	2.021	0.307
August	0.578	3.38	1.455	0.482
September	0.600	3.31	1.926	0.490
October	1.492	21.72	9.583	0.000
Linguère				
May	2.355	-	-	0.000
June	1.082	8.70	4.105	0.164
July	0.497	3.01	1.394	0.570
August	0.467	2.11	1.332	0.596
September	0.493	2.71	1.424	0.603
October	1.169	8.98	4.862	0.106
Matam				
May	3.026	-	-	0.000
June	0.923	5.55	2.803	0.186
July	0.503	2.39	1.283	0.518
August	0.481	2.75	1.398	0.612
September	0.579	3.09	1.605	0.457
October	1.201	8.73	4.492	0.000
Podor				
May	2.925	-	-	0.000
June	1.290	12.42	6.997	0.000
July	0.879	4.91	2.537	0.231
August	0.610	3.18	1.568	0.438
September	0.718	4.34	1.929	0.370
October	1.604	28.65	7.203	0.000

SD/Mean = Standard deviation / Mean
Range/Median = Range of values / Median
(90p-10p)/Median = Difference between 90th and 10th percentile / Median
DepRain(f0.8/Mean) = dependable rains, or 20th percentile / Mean

Figure 4: Frequency distributions of annual rainfall at four stations in the Ferlo



Note: Lo 1/4 is lower interquartile
Hi 1/4 is upper interquartile

The various shapes of the frequency distribution of annual rainfall at the four stations results in the median sometimes being above and sometimes below the mean.

it. Statistically speaking, the monthly rainfall distributions are positively skewed (see Appendix 6 for method used to calculate skewness), especially in months of low mean rainfall (Appendix 3). Thus the means of monthly rainfall totals are consistently higher than the medians (Figure 5). The ecological significance of this is that predictions based on the mean are normally too optimistic.

For the above reasons, in most arid and semi-arid areas the long-term mean rainfall is not a good index of probable rainfall, and should not be used as the basis of planning decisions, for which the median is preferable. At stations in the Sahel, however, the means and medians of annual rainfall are equally useful except in the extreme north, near the 100mm isohyet. The Project recommends the use of the median where values are to be compared with annual rainfall data collected in other arid areas, and where a measure of central tendency of monthly rainfall is needed.

Unfortunately, the median tends to be more sensitive than the mean on the addition of new data values to the list of those used to derive central tendancy. This sensitivity arises because the median shifts half-way between neighbouring central values every time a new item is added to the list, irrespective of the magnitude of the new value. The mean, however, tends to change by a smaller and smaller fraction as new items are added. In many areas, isohyets drawn on the basis of median annual rainfall thus depend to a greater extent than those drawn on the basis of mean annual rainfall on the set of years used to establish the map.

3.2 Long-term rainfall in the Ferlo - status

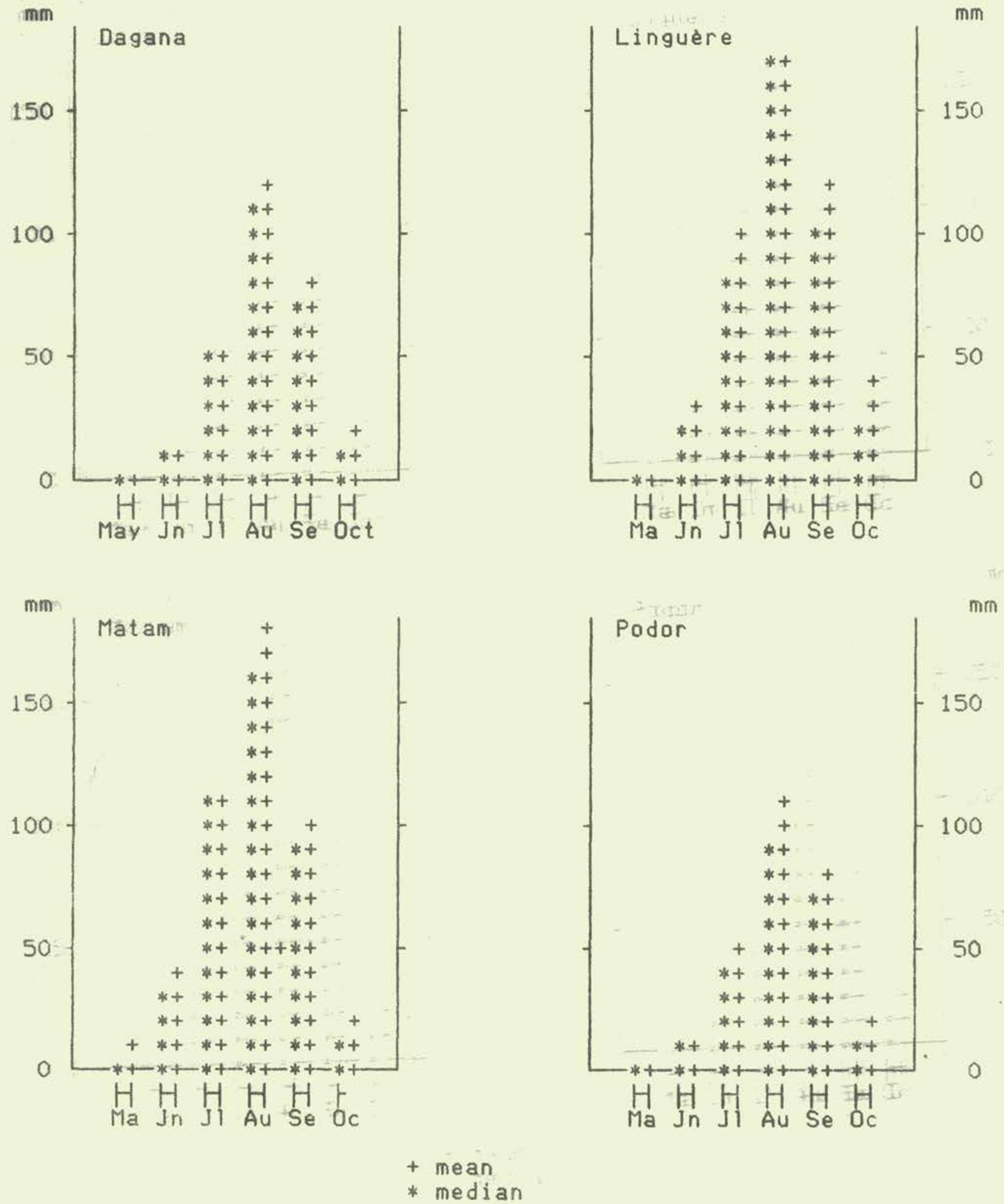
The two southerly stations (Linguère and Matam) normally receive more rain (long-term annual medians of 474 and 452 mm respectively) than do the two northerly stations (Dagana and Podor) (266 and 283 mm). August is the wettest month of the year in about two years out of three, with both July and September occasionally being wetter.

Figure 6 (redrawn from maps in Bellocq 1983) shows the approximate isohyets of the median long-term rainfall. In general the Ferlo lies between the 250mm isohyet in the north and the 450mm isohyet in the south. This places it clearly in the Sahel as defined by rainfall criteria alone (see Le Houérou and Grenot 1986 for definitions of the Sahel).

3.3 Long-term rainfall in the Ferlo - trend

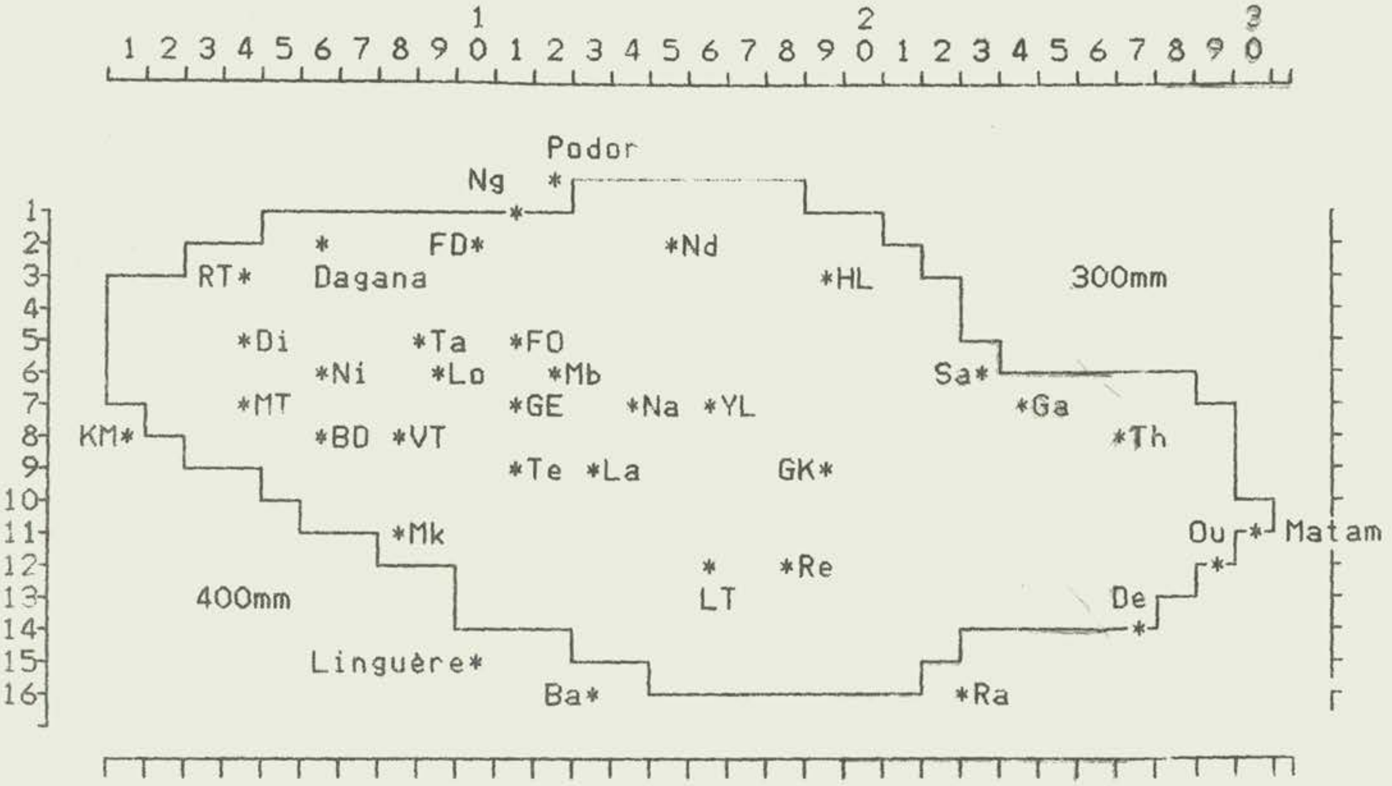
It is possible that repetitive patterns of rainfall exist, and for reasons given above, knowledge of such patterns would be of great benefit to planners. In searching for pattern in any time-series the first step is to examine the data for trend (Kendall 1984). The data may then be expressed as residual values about the trend line, and the resulting series further examined for regularities in the data.

Figure 5: Medians and mean monthly rainfall at four stations in the Ferlo



Means are consistently higher than the medians.

Figure 6: Long-term isohyets of median rainfall in the Ferlo (after Bellocq 1983)



KEY to rainfall stations

Ba Barkedji
BD Boki Divé
De Dendoudi
Di Diaglé
FD Fanaye Diéri
FO Fété Ole
Ga Galoyal
GE Ganine Erogne
GK Guèye Kadar
HL Haïré Laö
KM Keur Momar Saar
La Labgar
Lo Lodé
LT Lougéré Thiolly
MT Mbar Toubab
Mk Mbeuleukhé
Mb Mbidi
Na Namarel
Nd Ndioum
Ng Nianga
Ni Niassanté
Ou Ourrosogui
Ra Ranerou
Re Revane
RT Richard-Toll
Sa Saldé
Ta Tatki
Te Tessékré
Th Thilogne
VT Vindou Thingoli
YL Yaré Laö

Data from Dagana, Matam, Podor and Linguère were examined for linear trend by least-squares regression analysis, both for rainfall data summed by month and for annual totals (Program 2 in Appendix 4). The annual data (Figure 7) were examined over the entire span of historical records (Table 3), and reexamined for the periods preceding and following the installation of the first boreholes in 1949 (Table 4).

The mean annual decrease in rainfall is more marked the greater the long-term median rainfall at the station. Since the start of observations Linguère and Matam have experienced a drop of about 0.8% per year relative to the long-term median, while the rainfall at Dagana and Podor has diminished by about 0.6% per year relative to the long-term median.

There is no linear trend in rainfall totals in the set of data from the beginning of observations to 1949 (Table 4); that is, the yearly rainfall totals oscillated in some undetermined way about the mean. From 1949 to 1984, however, the annual rainfall total diminished sharply at all four stations, with Matam receiving on average 11mm less each year than it did the year before, a decrease of 2.5% per year relative to the long-term median. Corresponding figures for the other stations are: Dagana 2.1%, Linguère 1.7%, Podor 2.6%. This reduction in annual rainfall since 1949 is therefore largely responsible for the long-term linear trend detected in Table 3.

Only five of the 24 regressions of monthly rainfall with time were significant at a probability of $p <= 0.01$ (Table 5). The general trend to diminished annual rainfall is largely a result of diminished rainfall in the wettest months of the year, notably August.

3.3.1 Caveat

It is improbable that a trend in past rainfall can be used to help predict future rainfall, and, given our present knowledge of the dynamics of the atmosphere, it is also unlikely that past trends can be used to help construct a model of the mechanism which results in a given annual rainfall total.

The trend towards diminished rainfall over the past three decades therefore needs careful interpretation. It certainly cannot be taken to mean that rainfall will continue to be poor, or continue to decrease. However, in view of our ignorance of the driving mechanism, it would be prudent to make plans and provisions for the future on the assumption that some long-term depression of rainfall totals is likely. With this in mind, long-term medians, like long-term means, should be regarded as being optimistic.

3.4 Oscillations about the trend line

It is possible that the pattern of observations may be periodic, that is, that one or more wet years tend to be followed, after a lapse of time, by another series of wet years. By comparing the sequence with

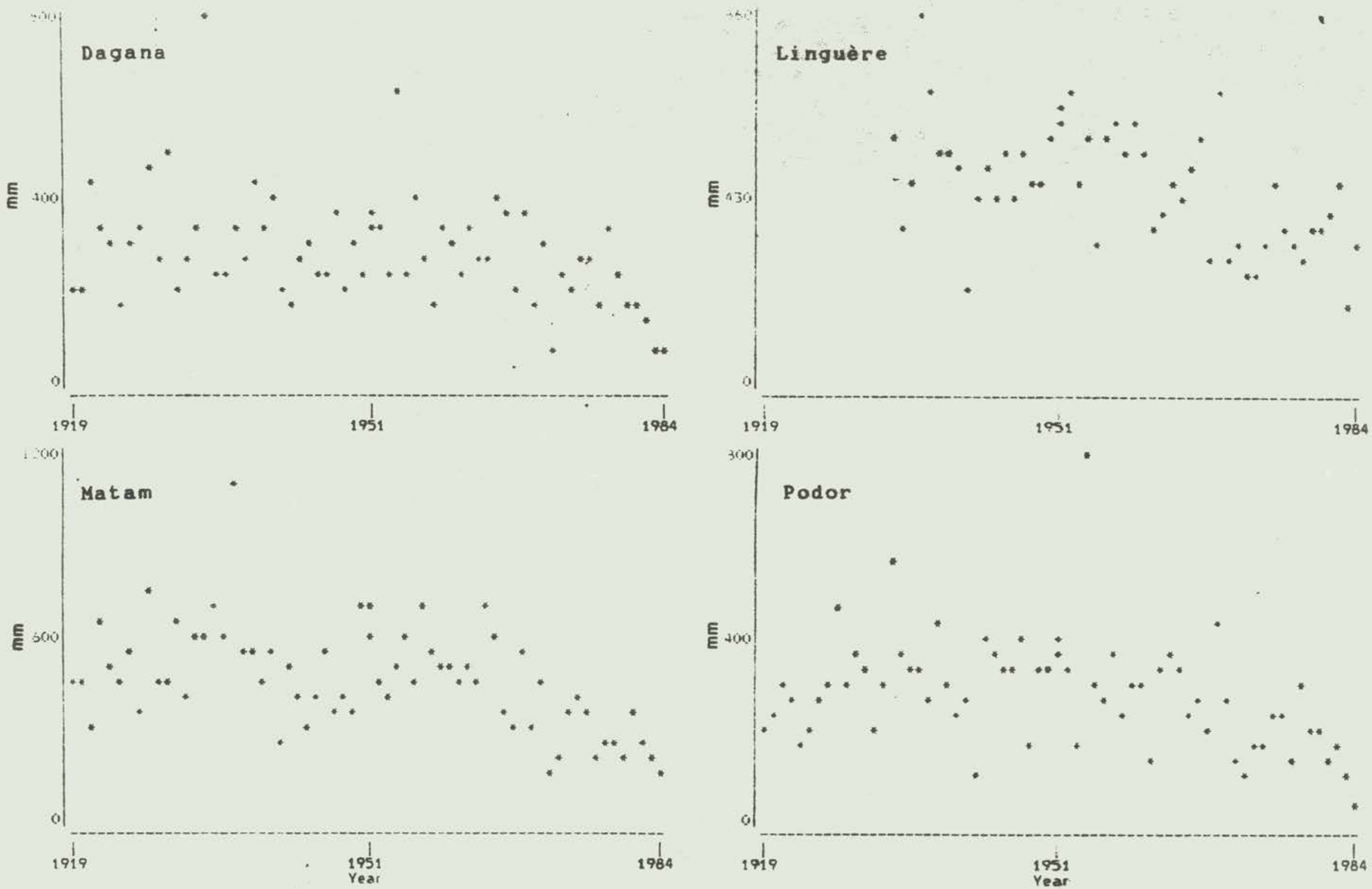


Figure 7: Annual rainfall records from the start of records to 1984
(Note varying vertical scales)

Table 3: Regression of annual rainfall with time since the start of observations.

Station	Data since	Equation (slope intcpt)	F (df)	probability	%variance explained
Dagana	1919	Year x (-2.09)+4359	8.3(1,64)	<0.01	11.5
Linguère	1933	Year x (-4.50)+9269	16.2(1,50)	<0.001	24.4
Matam	1919	Year x (-4.11)+8496	18.1(1,64)	<0.001	22.1
Podor	1919	Year x (-2.05)+4271	7.7(1,64)	<0.01	10.7

Table 4: Regression of annual rainfall with time before and after 1949

Station	Before 1949		After 1949	
	Equation (slope intcpt)	probability	Equation (slope intcpt)	probability
Dagana	Year x (-1.13)+ 2495	n.s.	Year x (-5.56)+11190	<0.001
Linguère	Year x (-7.19)+14450	n.s.	Year x (-8.19)+16560	<0.001
Matam	Year x (-2.24)+ 4840	n.s.	Year x (-11.2)+22520	<0.001
Podor	Year x (+1.84)- 3252	n.s.	Year x (-7.41)+14820	<0.001

Table 5: Statistically significant regressions (p<=0.01) of monthly rainfall with time since the start of observations

Station	Month	Equation (slope intcpt)	F (df)	probability	%variance explained
Dagana	August	Year x (-1.31)+2671	9.5(1,63)	<0.005	13.1
Linguère	August	Year x (-2.77)+5591	17.6(1,50)	<0.001	26.3
Matam	June	Year x (-0.71)+1428	9.3(1,61)	<0.005	13.2
Matam	August	Year x (-2.21)+4492	20.1(1,63)	<0.001	24.2
Podor	August	Year x (-1.11)+2277	7.1(1,32)	=0.01	10.2

itself at successive points, such a pattern may be detected and measured. The process of self-comparison is most conveniently carried out by computing the autocorrelation function, defined as the linear correlation between the series and the same series at a later time. The equation of the autocorrelation of a time series at lag L is given in Kendall (1984) and in Davis (1973), and Program 3 (Appendix 4) was used to establish the autocorrelation functions of monthly and yearly rainfall totals for the four stations for which long-term data are available.

At Matam there is a statistically significant tendency for the total rainfall for any given year to resemble that of the preceding year (lag of 1 year) and that of the last-but-one year (Figure 8). This tendency is not repeated in monthly totals, and there is otherwise no apparent periodic oscillation in rainfall at these four stations; that is, successive annual rainfall totals are independent of all previous rainfall totals. Thus, even if generally low rainfall can prudently be expected, there should be intermittent relief with years of high rainfall.

That there is no strict cyclicity in the rainfall data is brought out by the negative results of Fourier analysis. Although this analysis was carried out on these data, the results and the program are not presented here, being of limited interest for ecological data.

3.5 Correlation in the data

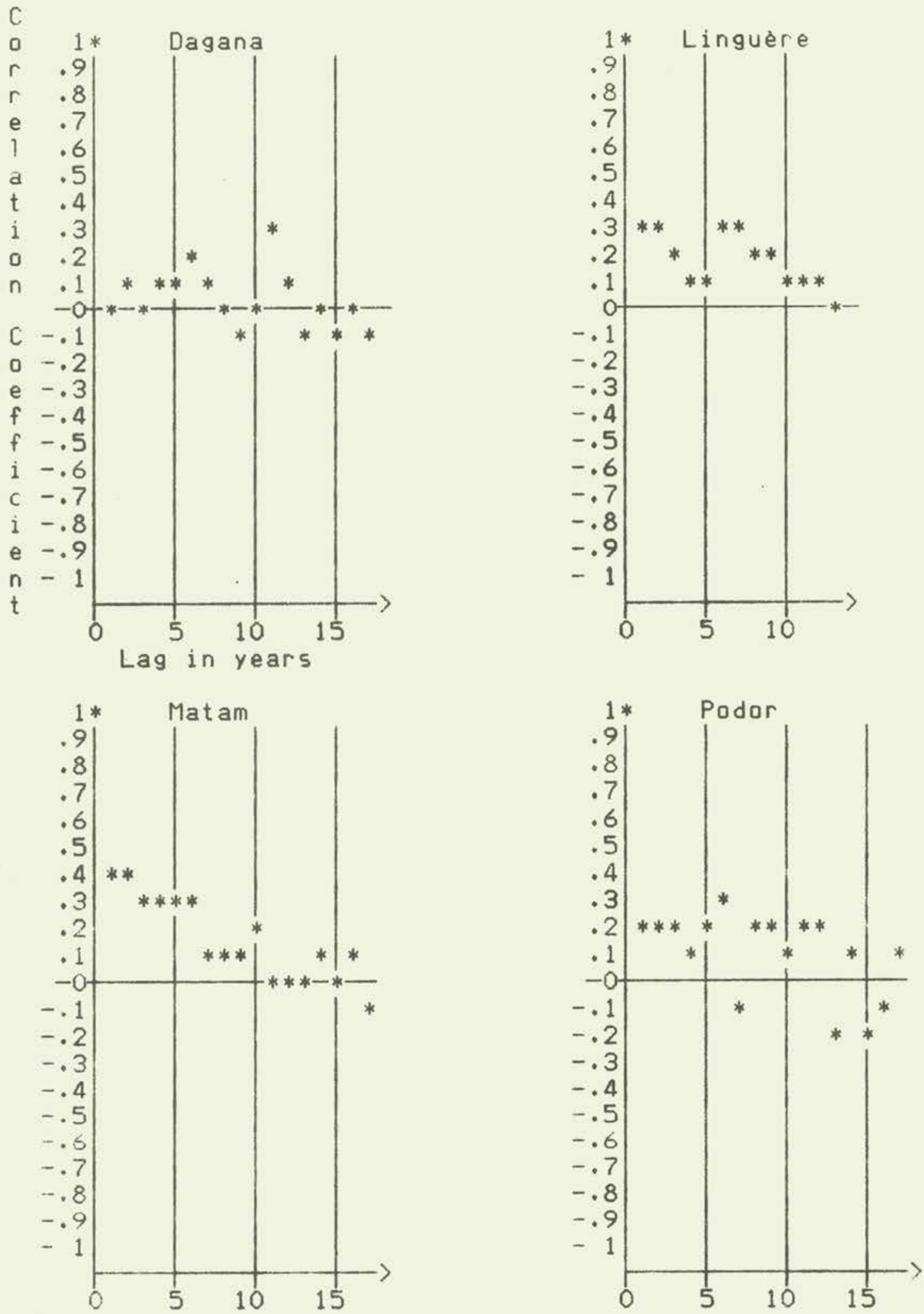
3.5.1 Correlation between monthly totals at a given station

If the rainfall in a given month were to some extent dependent on the rainfall of the previous month, limited short-term predictions could be made which might be of considerable use to planners. The data from successive months were therefore correlated for the four stations with long-term data. However, of the 20 tests carried out, only 7 were significant at $p < 0.05$, and for all practical purposes the rainfall in any given month may be considered independent of that of preceding and subsequent months.

3.5.2 Correlation between stations

Adjacent areas may have widely differing annual rainfall totals in any given year. Thus in the Ferlo, for the years 1980-84, with rainfall measured at 35 stations (mean distance apart 22km), the median difference in rainfall at neighbouring stations was 43.5mm (interquartile range 4.9-77.3mm). The median rainfall at all the stations was 203.1mm (interquartile range 118.3-297.9mm), so that the median difference in rainfall between neighbouring stations was 21% of the median rainfall. However, there is some spatial continuity in rainfall at this scale; rainfall measured at nearest-neighbour stations tends to differ by a smaller margin than that measured at stations that are not nearest neighbours (Kolmogorov-Smirnov one-sample test, D=0.25,

Figure 8: Autocorrelation of annual rainfall at four stations in the Ferlo



These plots show the extent to which the rainfall in any given year at the site is correlated with that of the subsequent year (a lag of 1), and with that two years later (a lag of 2), three years later, and so on. If, for example, years of high rainfall tended to occur at 11-year intervals, the plots would show a high correlation at a lag of 11. Since this is not the case, we conclude that there is no detectable pattern in the way in which the rainfall in any given year may be related to that in a later year.

Table 6: Correlations of rainfall totals between stations

Station 1	Station 2	r	df	t	p	m	St1=0	St2=0
Dagana	Linguère	0.492	48	3.917	<0.001	1.32	91.6	-69.6
Dagana	Matam	0.330	32	2.681	<0.01	2.62	-294.4	112.2
Dagana	Podor	0.736	62	7.355	<0.001	1.02	-11.6	11.3
Linguère	Matam	0.673	48	6.304	<0.001	1.46	-225.0	153.8
Linguère	Podor	0.516	48	4.178	<0.001	0.87	-118.1	136.4
Matam	Podor	0.413	62	3.427	<0.01	0.46	70.0	152.1

Key to column headings:

r	Pearson's product-moment correlation coefficient
df	degrees of freedom
t	value of t statistic for this level of r
p	probability
m	slope of the principal axis through the data pairs; number of mm at station 2 for each mm at station 1
St1=0	theoretical value at station 2 when no rain falls at station 1
St2=0	theoretical value at station 1 when no rain falls at station 2

N=73, $p < 0.01$). The practical result of this is that rainfall maps using isohyets have climatological meaning, especially when based on a reasonably dense network of rainfall stations such as that used by the project in the Ferlo.

This conclusion is further supported by analysis of the data from the four stations at which long-term observations have been made. In general, annual rainfall totals are highly correlated between stations (Table 6).

In Table 6, the columns marked "m", "St1=0" and "St2=0" describe the equation of the major axis through the scatter of points in the correlation (Sokal and Rohlf 1969). "m" indicates the mean multiplication factor to convert rainfall totals at station 1 to rainfall totals at station 2. "St1=0" shows the theoretical total predicted at station 2 when no rain falls at station 1, and "St2=0" shows that at station 1 when no rain falls at station 2. These are therefore the intercepts on the station 2 and station 1 axes respectively. These values were calculated by Program 4 in Appendix 4.

3.6 Rainfall probabilities

Unfortunately, the erratic inter-annual variability of the rainfall and the decrease in annual rainfall over the last three decades render any simple measure of central tendency, such as mean or median, of doubtful value for range managers and those responsible for making ecologically sound decisions in the Sahel. The task of these persons is made more difficult by the ecological importance of the temporal distribution of the rain in the course of a single rainy season. By way of illustratio of the erratic distribution of rainfall in time, Figure 9 shows daily rainfall at selected stations.

For most of the 34 rainfall stations there are insufficient data to provide estimations of rainfall probabilities in detail over the Ferlo. At the four stations for which there are sufficient data (Dagana, Linguère, Matam and Podor) the frequency distribution for the monthly rainfall is well modelled by the so-called "incomplete Gamma curve". This curve describes a frequency distribution which can never be less than zero (although there may be many observations of zero), and which is asymmetric, tailing off gradually at high values. For a more detailed description of this curve and its application, see Thom (1966) or Gommes (1983). The logarithmic Normal curve is also frequently used to describe asymmetric rainfall distributions (Brunet Moret 1975). Bot theoretical distributions assume that each year's rain, or each succeding month's rain, is independent of that which precedes it. As w have seen, this is apparently the case for the Ferlo.

Program 5 in Appendix 4 calculates the parameters of the Gamma curve from rainfall data and prints out the values of the computed curve at the required intervals. By adjusting the parameters of the Gamma curve to the annual or monthly data collected for many years at a rain statio it becomes possible to calculate the probability that any given amount of rainfall will fall during the year or in any selected month. This

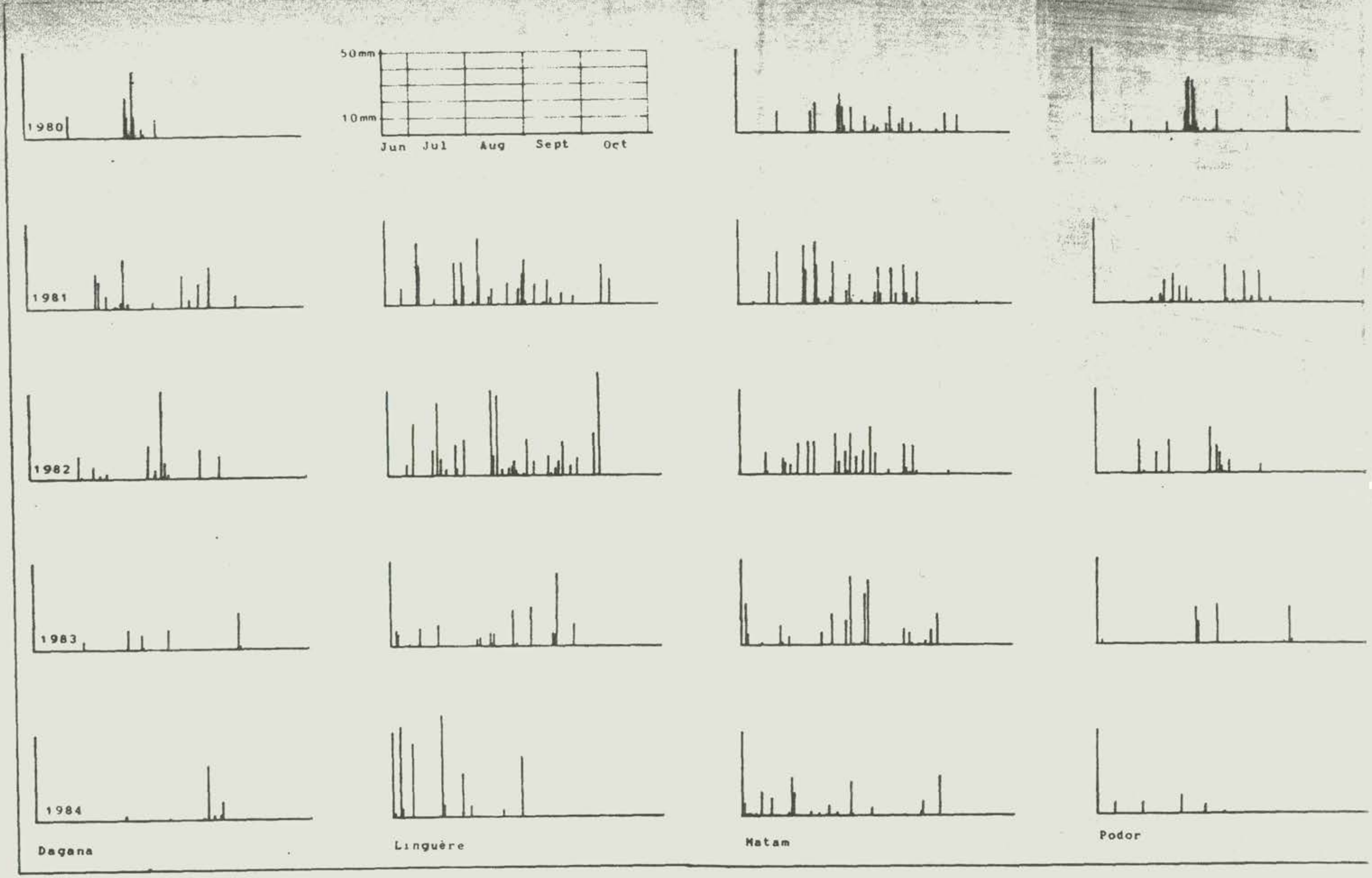


Figure 9: Daily rainfall at selected stations in the Ferlo

technique has been applied to the data collected at the four stations in the Ferlo with long-term observations (Figure 10). Thus for example an annual total of 320mm or less may be expected 14 years out of 100 at Linguère, and 63 years out of 100 at Dagana. In the long term, Matam can expect to receive less than 110mm of rain in July in one year in two. In the same month Podor, 1 degree further north than Matam, will receive less than 45mm with the same probability (Figure 11).

By using the threshholds that are frequently used in statistics, it is possible to express these monthly or annual rainfall probabilities in 6 classes (Table 7).

For example, 146.2mm fell at Matam in 1984, which, by reference to Figure 10, means that this year was "exceptionally dry" relative to the long-term expectation at the station. The same year could be classified as "dry" at Linguère, where 372.8mm fell.

The rainy-season months of 1980-1984, classified using this system, were demonstrably unusually dry (Table 8).

The monthly rainfall data from which these tables were constructed are given in Appendix 4.

Since there is no correlation between the rainfall of successive months, it is possible to calculate the number of months in a sample as large as this which would fall into the various classes, assuming that the rainfall for those months were representative of the monthly rainfall distribution in the long-term data (Table 9). There is little point in subjecting data as extreme as these to statistical test (Kolmogorov-Smirnov One-Sample or Chi-squared would be appropriate tests).

3.7 Drawing isohyets: automatic generalisation of data from points

Both for the presentation of data and for modelling, maps of rainfall distribution must be prepared. The isohyets on the map are necessarily generalisations, based on point data, whose accuracy increases as the density of the network of stations increases. The exact placement of the isohyets between any pair of stations will depend on the judgement of the cartographer, and no two cartographers will align the isohyets in exactly the same way.

The advantage of using a program to calculate the alignment of the isohyets is that the algorithm has to be specified exactly, and the alignement of isohyets can therefore be reproduced exactly by another program using the same algorithm. Furthermore, the effect of altering parameters in the algorithm is easily examined, in a process which is sometimes called sensitivity testing.

3.7.1 Criteria for the algorithm

While the algorithm itself is explicit and repeatable, the criteria for judging the results can seldom be objective. The analyist would

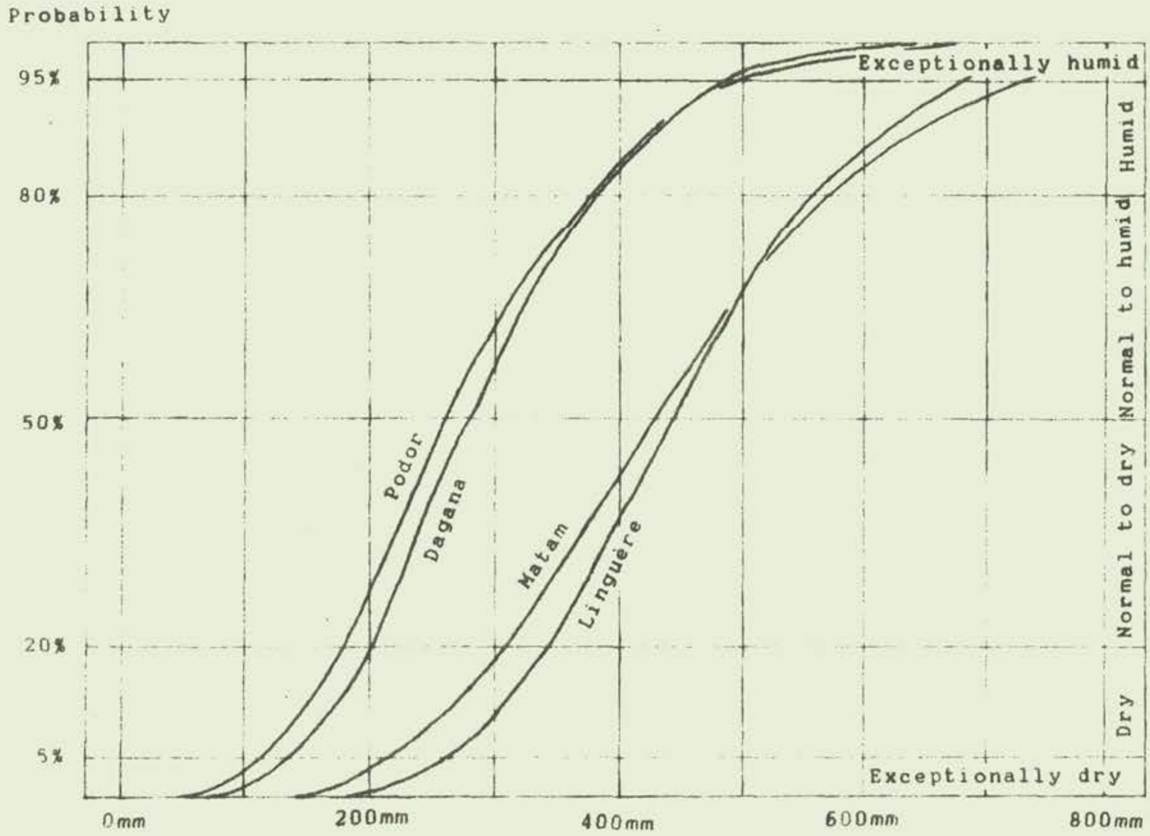


Figure 10: Gamma curves for the calculation of annual rainfall probabilities at four stations in the Ferlo

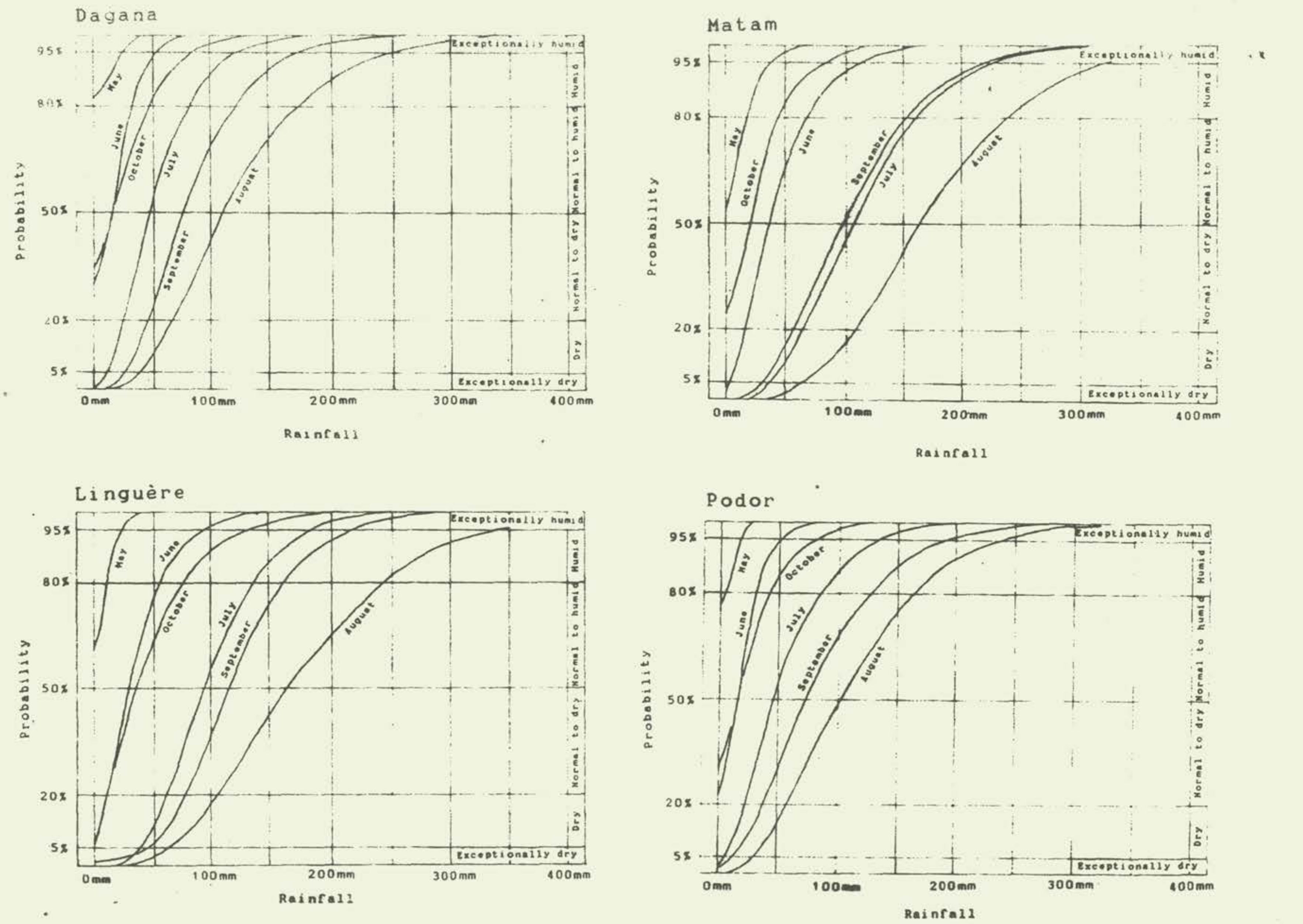


Figure 11: Gamma curves for the calculation of monthly rainfall probabilities at four stations in the Ferlo

Table 7: Classification of rainfall probabilities

Class	Probability that a year will fall into this class	Cumulative probability
A: exceptionally humid	5%	5%
B: humid	15%	20%
C: normal to humid	30%	50%
D: normal to dry	30%	80%
E: dry	15%	95%
F: exceptionally dry	5%	100%

Table 8: Classified monthly rainfall at four stations in the Ferlo

	Dagana					Linguère				
Month	1980	1981	1982	1983	1984	1980	1981	1982	1983	1984
June	D	D	D	D	?	D	D	C	D	A
July	E	D	E	F	?	D	C	C	F	C
Aug	D	E	D	F	?	C	D	D	E	F
Sept	D	D	E	E	?	D	F	E	E	F
Oct	D	D	D	D	?	E	C	B	F	F

	Matam					Podor				
Month	1980	1981	1982	1983	1984	1980	1981	1982	1983	1984
June	E	E	D	D	D	E	E	E	C	D
July	E	B	D	F	E	E	C	C	F	E
Aug	E	D	D	D	F	B	E	D	D	F
Sept	E	D	E	F	E	E	D	F	E	F
Oct	C	D	D	D	D	E	E	E	E	E

Table 9: Comparison of observed rainfall data with expected

Class	Observed	Expected
A	1	4,75
B	3	14,25
C	10	28,5
D	36	28,5
E	30	14,25
F	15	4,75

normally aim to produce a map which reproduces closely that which would be drawn by a good cartographer, and refinement of the algorithm will usually depend upon his intuitive assessment of the similarity between its product and the map he expected to see. A contour map of rainfall distribution should presumably possess the following features:

1. Mapped values at rainfall stations should be identical to the observed rainfall at those stations.
2. Gradients between rainfall stations should be smooth, and there should be no discontinuities in the contoured surface.
3. Although rainfall stations with observations atypical of those of surrounding stations will necessarily be at a peak or sink in the resulting map, there should be no evidence of a trend surface from which nearly all rainfall stations stand out as peaks and sinks.
4. There should be no tendency for values at cells with rainfall stations to be consistently higher or lower than the values of cells without rainfall stations.

Many algorithms exist for drawing contours such as isohyets automatically. The first, and in the present application, the only, step in contouring usually is to derive values from the data for a regular grid of control points. These values may be estimated in many ways, ranging from estimates equal to that of the nearest observation to estimates derived from trend surfaces constructed using all the observations. The latter method is normally unsatisfactory for rainfall contouring, since in general few if any of the original measurements will lie on the surface. Commonly, the values are calculated from observations recorded at nearby stations, the contribution of those stations being weighted by some function of their distance from the cell concerned (Creutin and Obled 1982).

The finer the grid used to establish the control points, the smoother the resulting contour lines will be, but the longer the program will take to calculate the values at the control points. Isohyets were plotted for the Ferlo by choosing a grid cell size to correspond to the 10x10km cell size used for the systematic reconnaissance flights (see GEMS PAC Information Series Number 3 "Use of Light Aircraft in the Inventory and Monitoring of Sahelian Pastoral Ecosystems"). This allowed rainfall estimates to be used in subsequent analyses of other project data. The test zone was therefore divided into just over 300 grid squares, of which 29 contained a rainfall station. Six of the rainfall stations shown in Figure 1 were outside the test zone, but their data were also used in estimating rainfall in neighbouring grid cells.

3.7.2 Algorithm used

The project tested several algorithms and found that the following method would produce satisfactory results. The rainfall calculated for any cell containing a rainfall station was equal to the observation at that station. The rainfall estimated at all other cells depended on the rainfall observed at all stations within 100km, weighted by the inverse of the fourth power of the distance between the station and the cell. Program 6 was used to calculate the estimated values.

3.7.3 Annual isohyets in the Ferlo 1980-1984

The resulting maps are shown in Figure 12. The disastrous rains of 1984 stand out in clear contrast to the poor rains of 1982 and 1983 and moderate rains of 1980 and 1981.

In 1980 the extreme north-west of the Ferlo recieved less rain than normal, the extreme south-east being particularly dry. Although in 1981 the north was dryer than normal, the rest of the Ferlo received a reasonably good rainfall. Nevertheless, according to the livestock herders the rains were poor. This biassed perception of what constitutes good rains has been recorded by many researchers in many parts of the world. In 1982 the north-south gradient became steeper, and the whole of the Ferlo received nearly 100mm less than normal. In 1983 the situation was even less satisfactory, with every region of the Ferlo receiving nearly 200mm less than normal. The 1984 rains provided nearly 300mm less than normal in the north, and a steep rainfall gradient was recorded from north to south. In this series of maps the reader will note the alarming southerly movement of the 100mm isohyet, the symbolic limit of the desert.

Given the irregular and highly localised rainfall, it is not surprising to see that the annual isohyets are not as smooth as those of the long term median. Frequently, northerly stations recieved more rain than did more southerly ones. The criterion that mapped values at rainfall stations should be identical to the observed rainfall at those stations means that isohyets are sometimes clearly influenced by some individual stations. An obvious case in point is the bullseye around Fété Olé in 1980. If there is any reason to believe that the data collected at a given rainfall station are incorrect, they should be discarded.

4 Discussion and conclusions

Several authors (eg Nicholson 1983, Hare 1984) have remarked on the relatively good rains in the Sahel in the 1950s and early 1960s. The data from the four stations in the Ferlo do not support this observation - annual rainfall at these stations was in no way outstanding by comparison with the preceding years.

The long-term trend in rainfall since the beginning of the 1950s at these four stations (and by implication, elsewhere in the Ferlo) gives cause for concern. From 1949 onwards the Ferlo has suffered two major constraints on productivity: the decrease in the rainfall and the increase in livestock numbers. Since in the Ferlo livestock depend almost entirely on aquifers for drinking water, and not on rainfall, the primordial role of rainfall in the Ferlo is in its effect on plants. In this the Ferlo is not typical of all areas of the Sahel, especially those in which livestock depend on surface waters. In years characterised by rainfall which is poor or badly distributed, and therefore by a reduced productivity, the grazing pressure exerted by the livestock exceeds the carrying capacity of the pastures. The natural

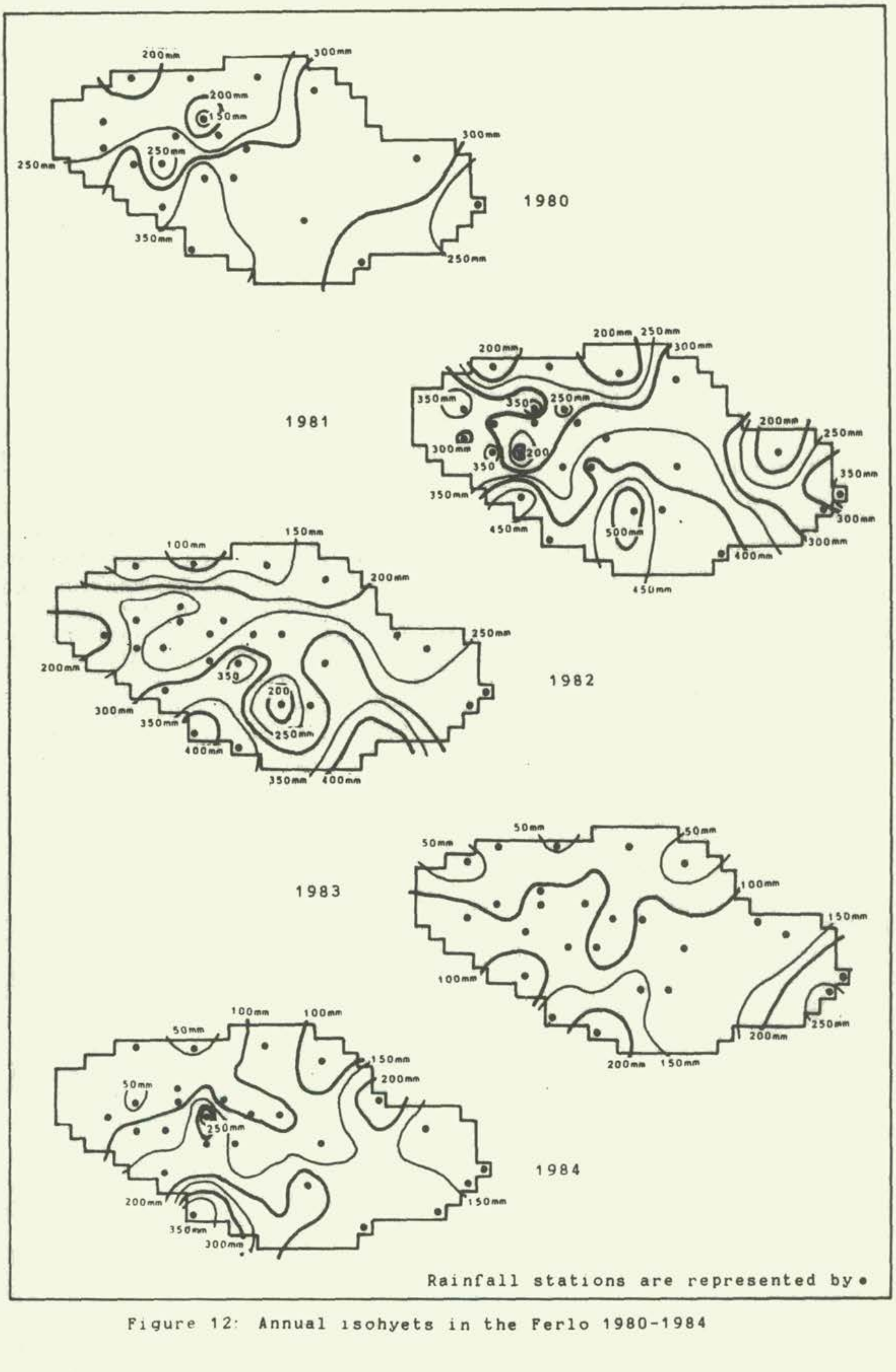


Figure 12: Annual isohyets in the Ferlo 1980-1984

consequence for the pastures is a long-term reduction in their capacity to provide for the animals which depend on it. The natural consequence for the livestock - and sometimes for the pastoralists - is famine.

In the Great Drought of 1968-1972 the pastoralists responded to disastrous primary production by massive migration to the south, where some of them stayed as the rainfall improved and the pastures started to recover in the late 1970s. Between 1972 and 1981 the numbers of livestock in the Ferlo increased without any limit imposed from outside. In 1983 and 1984 the poor rains triggered another massive migration to the south.

At present, therefore, the system is regulated by (1) the inability of the ecosystem to provide for the numbers of animals it is asked to support, and (2) the exportation of its excess animal population to the south, where agricultural lands suffer an increased demand on their capacity. This unhealthy system provokes the kind of ills that too many pastoral and rural areas now suffer.

Weather forecasting in the Sahel would be most useful if it could be shown that there was some predictable relationship between the rainfall in one year and that in some subsequent year. Despite many attempts to detect patterns in annual totals (see for example Jagannatha and Parthasarathy (1973) and Rodhe and Virji (1976)), most authors find no evidence of periodicity in rainfall anywhere in the world. By contrast, trends have been detected in many locations. Indeed, the trend towards decreased rainfall in the Ferlo since the late '40s and early '50s is apparently part of a widespread reduction in rainfall everywhere in the Sahel (Nicholson 1983). The mechanism of this reduction remains unknown.

Although the ability to forecast from month to month within the same rainy season would be of more limited use to planners than would the ability to forecast from year to year, it would nevertheless be highly advantageous. However, from the work reported here on data in the Ferlo, and from other work on Sahelian climates, there seems little hope that any short-term pattern will be detected. Rainfall in one month is apparently independent of that in previous months, and there seems to be no persistence in rainfall patterns.

Despite this erratic and unpredictable rainfall, planners are not faced with a hopelessly random situation. Indeed, because of the independence between rainfall totals, it is possible for them to work in the knowledge that a given rainfall total will be exceeded in a given number of years out of a hundred, in the long term. Thus they can base their decisions on probabilities rather than on forecasting. Their ability to make sound decisions is improved as the quality and quantity of the data improves. In the case of rainfall, the density and the distribution of raingauges plays the most important part in determining the quality of the data available. Although the network of raingauges in the Ferlo from 1980-1984 was considerably more dense than that found elsewhere in the Sahel, it is clear from the annual isohyets that a still denser network would result in a more accurate map of rainfall. This is brought out from the increased complexity in the shapes of the isohyets in the west of the area, in which the network was at its most dense. A full discussion of the types of station and criteria for raingauge distribution is given in Clarke (1986) and in WMO (1983).

In general, the manager or planner is not interested in rainfall in itself, but rather in its relationship to primary production. Models which attempt to predict productivity on the basis of the temporal distribution of rainfall (eg Bellocq 1983, Cornet 1983, Dieye 1983, Penning de Vries et al 1982) tend to be complex, containing many variables whose values must be known, and are therefore closely linked to the local conditions. The more sophisticated models are probably of little general use for most ecological monitoring programs.

However, there is some hope that a simple model linking total rain with productivity may be of use in an ecological monitoring program. Firstly, rainfall that is poorly distributed through the season is presumably more likely in years of low total rainfall, and hence years of low rainfall will in general be years of poor productivity. Secondly, in most of the Sahel, if the rain were to be perfectly distributed from the point of view of plant growth throughout the season, productivity would then be limited by total rainfall. Thus the annual rainfall can be used as a rough guide to the primary production of the pastures. Empirical support for this hypothesis was given by Le Houérou and Hoste (1977), who pointed out that in the pastures of the mediterranean basin and the sahelo-sudanian zone roughly 2 to 3 kilogrammes per hectare of dry matter are produced for each millimeter of annual rainfall. Further supporting evidence is presented in GEMS (1986), where rainfall is shown to be highly correlated with an index of chlorophyll activity, and hence of standing green biomass, calculated from satellite data.

In the extreme south of the Sahel primary production is limited not by rainfall but by soil fertility, according to Penning de Vries et al (1982). A close link between rainfall and production should not be expected in these areas.

It is inevitable that sooner or later we shall be forced to reconsider the politics of the exploitation of the Ferlo. Ideally a system would be set up in which the numbers and distribution of livestock are controlled in such a way as to be adapted to the physical and vegetal conditions currently experienced by the area. In the future, animal numbers ought to be controlled by consensus, and not by catastrophe.

Appendix 1: Rainfall data for thirty-five stations in the Ferlo 1980-1984. Measurements are in millimetres.

Station	1980	1981	1982	1983	1984	Lat De	Lat Mi	Long De	Long Mi
Barkedji	-	-	358.1	215.5	-	15	43	15	20
Boki Divé	361.9	354.2	259.0	-	118.4	15	57	15	29
Dagana	190.2	176.3	141.9	68.8	56.9	16	30	15	30
Dendoudi	-	-	-	-	184.0	15	23	13	32
Diaglé	229.3	372.0	-	-	-	16	12	15	42
Fanaye Diéri	222.3	236.3	89.2	49.0	43.1	16	32	15	14
Fété Ole	144.0	249.0	-	-	-	16	13	15	08
Galoyal	-	-	186.4	-	267.1	16	04	13	52
Ganine Erogne	-	361.3	340.4	128.6	127.5	16	04	15	07
Gueye Kadar	-	-	229.0	100.0	-	15	52	14	28
Haïré Lao	322.1	333.2	177.8	43.7	83.6	16	24	14	19
Keur Momar Sarr	-	309.9	192.2	108.6	-	15	55	15	58
Labgar	346.1	405.7	377.1	92.4	131.2	15	50	14	47
Linguère	380.9	399.6	475.7	190.4	372.8	15	23	15	07
Lodé	284.4	290.3	246.5	113.2	90.9	15	18	16	10
Lougéré Thiolly	-	541.0	183.5	161.0	-	15	34	14	36
Matam	217.5	370.8	275.9	240.7	147.2	15	40	13	15
Mbar Toubab	244.8	298.0	192.8	119.4	77.2	16	01	15	40
Mbeuleukhé	348.8	464.6	311.8	78.8	180.7	15	38	15	20
Mbidi	210.4	317.0	231.8	141.4	83.7	16	08	14	56
Namarel	303.6	349.5	271.4	57.8	93.2	16	00	14	47
Ndioum	220.5	155.9	141.7	59.2	140.3	16	31	14	38
Nianga	-	-	-	77.6	48.5	14	55	16	31
Niassanté	-	297.7	267.2	51.8	40.1	16	10	15	33
Ourrosogui	-	286.4	286.1	255.6	134.4	15	37	13	19
Podor	219.6	139.5	129.7	93.5	31.4	16	39	14	58
Ranerou	281.5	403.6	416.9	-	199.4	15	18	13	57
Revane	349.0	433.0	297.0	117.5	207.0	15	37	14	24
Richard Toll	-	-	-	29.0	-	16	28	15	42
Saldé	-	-	-	-	221.0	16	10	13	53
Tatki	-	351.2	277.5	100.0	92.0	16	14	15	17
Tessekré	382.0	303.9	299.8	118.1	171.2	15	51	14	04
Thilogne	321.4	193.0	238.1	117.5	136.8	15	58	13	35
Vindou Thingoli	206.8	192.6	196.0	120.5	116.8	16	00	15	20
Yaré Lao	-	-	258.4	102.8	97.3	16	02	14	33

Appendix 2: Rainfall data for four stations in the Ferlo 1919-1984. Measurements are in millimetres.

Year	Dagana	Lguère	Matam	Podor
1919	194.0k		464.4l	227.7j
1920	212.0b		443.8k	244.8g
1921	421.0		306.1m	284.8
1922	335.2		640.9h	253.1
1923	307.5		480.5	180.2
1924	181.0		459.1	197.0d
1925	292.0		556.0	280.9c
1926	340.5		333.8	307.9e
1927	496.2		739.2	475.7
1928	262.5		452.0	315.2e
1929	519.9		429.0	381.0d
1930	196.9		451.0	347.5n
1931	259.3e		411.3j	200.4
1932	325.0		591.0e	291.8
1933	795.0	598.4i	640.3	633.2
1934	232.0	362.6	746.2	361.4
1935	237.5	477.8	630.3a	338.8
1936	348.5	853.1	1111.9	338.8
1937	264.5	680.5	550.7	272.2
1938	422.3	576.2	537.7	466.4
1939	329.2	532.3	474.7	316.2
1940	393.0	517.8	562.7	233.5
1941	216.5	204.7	255.2	269.0
1942	189.2	437.2	515.7	97.9
1943	280.4	529.2	455.8	430.6
1944	316.9	452.9	295.9	374.4
1945	240.3	526.5	419.2	332.0
1946	240.5	434.5	554.9	321.2
1947	353.4	575.5	379.6	388.3
1948	225.0	460.3	314.4	186.9
1949	296.0	476.6	388.9	329.0
1950	241.6	575.9	713.8	339.3
1951	361.3	678.1	681.2	398.3
1952	366.9	619.4	603.1	367.2
1953	334.9	670.3	470.5	337.4
1954	259.3	470.5	479.5	198.8
1955	630.0	586.0	517.5	793.4
1956	276.2	333.2	583.4	333.8
1957	390.1	585.1	452.4	279.0
1958	275.6	595.8	688.9	375.3
1959	151.6	538.0	537.7	223.4
1960	342.3	611.9	484.8	309.9
1961	315.3	523.5	478.7	308.8
1962	225.1	341.3	444.7	124.8
1963	330.7	399.6	486.3	329.2
1964	278.3	482.6	506.6	351.0
1965	291.2	426.2	700.6	341.9
1966	403.0	518.5	623.7	247.3
1967	366.6	556.7	341.0	271.0
1968	220.6	301.7	308.0	209.8
1969	374.3	679.0	534.0	431.4
1970	174.7	297.1	281.0	255.1
1971	314.9	328.3	431.0	136.7
1972	79.5	245.4	175.0	109.7
1973	222.8	255.4	219.5	153.0
1974	205.8	330.0	327.5	150.9
1975	263.9	478.9	407.5	225.5
1976	293.1	478.7	392.5	264.0
1977	155.7	340.0	194.0	132.4
1978	328.5	316.0	318.7	303.9
1979	267.5	393.3	259.0	226.6
1980	190.2	380.9	217.5	219.6
1981	176.3f	399.6	370.8	139.5
1982	141.9	475.7	275.9	129.7
1983	68.8	190.4	240.7	93.5
1984	56.9	372.8	147.2	31.4

Key to small letters beside data (in general, indicate missing data*)

Letter	missing month(s)*	Letter	missing month(s)*	Letter	missing month(s)*
a	June	f	Feb-June	k	Jan-June,Nov-Dec
b	July	g	Jan-June	l	Jan-June,Oct-Dec
c	Sept	h	Jan-May,Dec	m	Jan-May,Aug,Oct-Dec
d	Oct	i	Jan-July	n	Whole year
e	Oct-Dec	j	Jan-Apr,Oct-Dec		

*The original data for some months are incomplete. For these months the rainfall was estimated by taking the means for 10 adjacent years.

Appendix 3: Summary statistics for rainfall data at four stations in the Ferlo

Yearly rainfall (including estimated data where monthly totals missing):

	Min	<-Interquartiles-> lower	Median	upper	Max	Range	Mean	S.D.	Skew	Kurtos	n
Dag	56.9	209.6	266.0	334.9	791.0	734.1	285.3	116.1	1.453	4.122	66
Lin	190.2	351.8	474.0	549.9	853.1	662.9	460.8	137.9	-0.109	-0.843	52
Mat	146.8	341.0	452.0	556.0	1109.0	962.2	459.5	168.1	-0.110	-0.801	66
Pod	31.4	192.8	283.1	336.0	791.6	760.2	278.7	119.9	1.006	3.215	66

Monthly rainfall:

	Min	<-Interquartiles-> lower	Median	upper	Max	Range	Mean	S.D.	Skew	Kurtos	n
May											
Dag	0.0	0.0	0.0	0.0	38.0	38.0	2.2	7.1	3.902	15.759	63
Lin	0.0	0.0	0.0	2.0	31.5	31.5	2.8	6.7	2.942	8.175	51
Mat	0.0	0.0	0.0	2.0	100.0	100.0	5.4	16.4	4.218	17.536	62
Pod	0.0	0.0	0.0	0.0	27.5	27.5	1.7	5.0	3.756	14.015	64
June											
Dag	0.0	0.0	5.2	18.5	82.2	82.2	13.4	18.6	2.052	4.627	63
Lin	0.0	6.6	17.5	46.0	152.2	152.2	29.6	32.0	1.144	0.379	51
Mat	0.0	13.2	30.3	52.0	168.0	168.0	39.5	36.5	1.654	2.731	63
Pod	0.0	1.2	6.5	20.4	80.7	80.7	14.1	18.2	1.572	1.706	64
July											
Dag	1.2	21.2	45.3	68.6	220.0	218.8	50.2	38.9	0.689	0.107	64
Lin	10.3	66.6	81.8	119.8	256.1	245.8	96.4	47.9	0.478	-0.254	51
Mat	11.0	66.6	109.1	157.0	272.2	261.2	111.6	56.1	0.209	-0.651	66
Pod	0.0	20.0	42.9	67.9	210.5	210.5	51.0	44.8	1.317	2.375	64
August											
Dag	16.5	67.0	108.3	146.3	383.0	366.5	118.4	68.4	1.251	2.487	65
Lin	39.6	120.6	168.7	249.5	395.3	355.7	174.9	81.8	0.404	-0.463	52
Mat	30.1	115.8	161.0	227.0	472.6	442.5	177.2	85.2	0.401	-0.486	65
Pod	12.5	58.6	93.8	157.5	310.3	297.8	109.3	66.7	0.821	0.485	64
September											
Dag	7.3	51.2	67.3	107.0	230.0	222.7	81.4	48.8	0.884	0.499	65
Lin	0.0	74.5	102.9	146.4	278.9	278.9	115.4	56.9	0.967	1.154	52
Mat	8.0	56.9	93.1	137.3	295.2	287.2	102.6	59.4	0.963	0.925	66
Pod	0.0	35.0	72.6	112.1	314.8	314.8	80.8	58.0	0.611	-0.388	63
October											
Dag	0.0	0.0	7.1	31.5	153.1	153.1	22.0	32.9	2.312	6.137	64
Lin	0.0	6.2	23.7	52.7	212.9	212.9	41.2	48.2	1.574	2.279	52
Mat	0.0	0.1	13.5	33.3	117.9	117.9	23.2	27.9	1.403	1.783	62
Pod	0.0	0.0	6.9	34.5	197.7	197.7	20.3	32.6	1.588	2.062	60

Appendix 4: Monthly rainfall data for four stations in the Ferlo 1980-1984. Measurements are in millimetres.

Month	Dagana 1980	1981	1982	1983	1984*	Linguère 1980	1981	1982	1983	1984
May	0.0	?	0.0	0.0	?	0.0	2.0	0.4	12.0	23.2
June	0.0	?	0.0	0.0	?	12.5	11.7	38.7	16.2	152.2
July	13.4	43.4	23.7	5.9	?	83.1	118.8	120.4	23.9	107.8
Aug	102.2	55.0	88.0	35.4	?	189.0	151.1	162.4	71.4	39.6
Sept	56.1	64.7	30.2	25.2	?	80.2	52.7	66.6	66.7	0.0
Oct	0.0	7.6	0.0	0.0	?	9.1	40.3	91.3	0.0	0.0

Month	Matam 1980	1981	1982	1983	1984	Podor 1980	1981	1982	1983	1984
May	0.0	0.0	0.1	10.0	0.6	4.4	0.3	0.2	0.0	0.0
June	0.0	1.7	13.0	30.3	28.3	0.0	0.0	0.0	11.0	6.5
July	43.7	175.8	79.0	22.3	49.7	14.8	42.2	55.5	0.0	7.1
Aug	95.6	112.4	135.0	143.3	30.1	169.1	48.1	69.1	58.7	17.8
Sept	46.5	80.0	45.0	8.0	38.1	25.3	44.8	5.1	23.8	0.0
Oct	22.7	0.9	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*At the time of writing the annual total for Dagana was available but the project had been unable to obtain the monthly totals at the station.

Appendix 5: Programs used to produce results presented in text

PROGRAM 1: Summary statistics

```
1000 REM Statistics
1010 ' Sort data by Shellsort
1020 ' Calculate mean, standard deviation, skewness and kurtosis
1030 ' Calculate range, median, interquartile range
1040 ' Plot histogram
1050 '
1060 GOSUB 1180 ' Initialisation
1070 GOSUB 1340 ' input data
1080 FOR MONTH%=1 TO C%-1
1090  GOSUB 1420 ' ReInitialise
1100  GOSUB 1500 ' select variable to sort
1110  GOSUB 1570 ' sort
1120  GOSUB 1750 ' summary statistics
1130 NEXT MONTH%
1140 GOSUB 3180 ' file sorted data
1150 GOSUB 3290 ' close files
1160 STOP
1170 '
1180 REM initialisation
1190 C%=7 : CLS$=CHR$(12) : TRUE%=-1 : FALSE%=0
1200 FOR I%=1 TO C%
1210  READ COLHEAD$(I%)
1220 NEXT I%
1230 DATA Year,May,June,July,August,September,October
1240 PRINT CLS$ : INPUT"Name of station";NOM$
1250 PRINT : F$=NOM$+"MONTH"
1260 OPEN "i",#1,F$
1270 R%=0
1280 WHILE NOT EOF(1) : LINE INPUT #1, DUMMY$ : R%=R%+1 : WEND
1290 CLOSE
1300 OPEN "i",#1,F$
1310 DIM RAIN(R%,C%),THRESH(13)
1320 RETURN
1330 '
1340 REM Input data
1350 FOR ROW%=1 TO R%
1360  FOR COL%=1 TO C%
1370   INPUT #1,RAIN(ROW%,COL%)
1380  NEXT COL%
1390 NEXT ROW%
1400 RETURN
1410 '
1420 REM ReInitialise
1430 DIM PLUIE%(13),HIST%(25)
1440 H%=1
1450 FIRST%=-1 : MINI=32767 : MAXI=-32767 : P%=0 : TOT%=0 : WET%=0
1460 SUMN=0 : SUMSQ=0 : TOT%=0
1470 H1#=0 : H2#=0 : H3#=0 : H4#=0
1480 RETURN
1490 '
1500 REM Select variable to sort
1510 PRINT CHR$(12)
1520 VAR%=MONTH%+1
1530 PRINT CLS$;
1540 PRINT"Sorting data for the month of ";COLHEAD$(VAR%);" at ";NOM$
1550 RETURN
```

```
1560 '
1570 REM Shellsort
1580 WHILE H%<=R%
1590  H%=H%*3+1
1600 WEND
1610 WHILE H%<>1
1620  H%=INT(H%/3)
1630  FOR I%=H%+1 TO R%
1640   V=RAIN(I%, VAR%) : J%=I%
1650   WHILE RAIN(J%-H%,VAR%) > V
1660    RAIN(J%,VAR%)=RAIN(J%-H%,VAR%)
1670    J%=J%-H%
1680    IF J%<=H% THEN GOTO 1700
1690   WEND
1700   RAIN(J%,VAR%)=V
1710  NEXT I%
1720 WEND
1730 RETURN
1740 '
1750 REM Summary statistics
1760 GOSUB 1850 ' Find max, min, sum, sum squared
1770 GOSUB 2090 ' Cast into classes
1780 GOSUB 2270 ' Calculate skewness and kurtosis
1790 GOSUB 2450 ' Calculate standard deviation
1800 GOSUB 2560 ' Calculate median and interquartile ranges
1810 GOSUB 2710 ' Print on screen
1820 GOSUB 2880 ' Send results to printer
1830 RETURN
1840 '
1850 REM  Find max, min, sum, sum squared
1860 ERC%=DEFLPRINT("(SPL)")      (See note at end of Program 2)
1870 PRINT CHR$(12)
1880 PRINT "The following sorted data are from file ";F$;
1890 PRINT " for the month of ";COLHEAD$(VAR%)
1900 LPRINT TAB(5);"The following sorted data are from file ";F$;
1910 LPRINT TAB(5);" for the month of ";COLHEAD$(VAR%)
1920 LPRINT : LPRINT TAB(5);
1930 FOR I%=1 TO R%
1940  N=RAIN(I%,VAR%)
1950  PRINT N;
1960  WHILE N<>-1
1970   LPRINT USING "###.# ";N;
1980   P%=P%+1:IF P%=10 THEN LPRINT TAB(5);:P%=0
1990   IF FIRST% THEN FIRST%=0 : OFFSET%=I%
2000   IF N>MAXI THEN MAXI=N
2010   IF N<MINI THEN MINI=N
2020   SUMN=SUMN+N : SUMSQ=SUMSQ+N^2
2030   TOT%=TOT%+1
2040   N=-1
2050  WEND
2060 NEXT I%
2070 RETURN
2080 '
2090 REM Cast into classes
2100 RANGE=MAXI-MINI : DX=RANGE/13 : THRESH(0)=MINI
2110 FOR I%=1 TO 13
2120  THRESH(I%)=THRESH(I%-1)+DX
2130 NEXT I%
2140 FOR I%=1 TO R%
2150  N=RAIN(I%,VAR%)
```

```
2160  WHILE N<>-1
2170  C%=INT((24.9+N)/25) : HIST%(C%)=HIST%(C%)+1
2180  IF C%>WET% THEN WET%=C%
2190  FOR J%=1 TO 13
2200   IF N<THRESH(J%) THEN PLUIE%(J%)=PLUIE%(J%)+1 : GOTO 2240
2210  NEXT J%
2220  N=-1
2230  WEND
2240 NEXT I%
2250 RETURN
2260 '
2270 REM Calculate skewness and kurtosis
2280 FOR I%=1 TO 13
2290  C=(I%-5)
2300  P=PLUIE%(I%)
2310  H1#=H1#+P*C : H2#=H2#+P*C^2 : H3#=H3#+P*C^3 : H4#=H4#+P*C^4
2320 NEXT I%
2330 N%=TOT% : H1=H1#/N% : H2=H2#/N% : H3=H3#/N% : H4=H4#/N%
2340 M2=H2-H1^2 : M3=H3-3*H1*H2+2*H1^3 : M4=H4-4*H1*H3+6*H1^2*H2-3*H1^4
2350 G1=M3/(M2*SQR(M2)) : G2=M4/M2^2-3
2360 SILL1=.533:SILL2=.7870001:IF N%>55 THEN SILL1=.492:SILL2=.7230001
2370 SIG1$="n.s.":IF G1>SILL1 THEN SIG1$="p<0.05"
2380 IF G1>SILL2 THEN SIG$="p<0.01"
2390 TYPE$="Negative" : IF M3>0 THEN TYPE$="Positive"
2400 SILL1=1.88 : SILL2=.9899999 :SILL3=-.8499999 : SILL4=-1.05
2410 SIG2$="n.s." : IF G2>SILL2 OR G2<SILL3 THEN SIG2$="p<0.05"
2420 IF G2>SILL1 OR G2<SILL4 THEN SIG2$="p<0.01"
2430 RETURN
2440 '
2450 REM Calculate standard deviation
2460 PRINT:PRINT
2470 LPRINT : LPRINT
2480 OFFSET%=OFFSET%-1
2490 LPRINT TAB(5);"The data include";OFFSET%;"missing values."
2500 LPRINT:LPRINT:LPRINT
2510 MEAN=SUMN/TOT%
2520 SUMXSQ=SUMSQ-(SUMN^2)/TOT%
2530 SD=SQR(SUMXSQ/(TOT%-1))
2540 RETURN
2550 '
2560 REM Calculate median and interquartile ranges
2570 ODD%=TRUE% : EVEN%=FALSE% : A%=INT(TOT%/2) : B%=OFFSET%+A%
2580 IF 2*A%=TOT% THEN EVEN%=TRUE% : ODD%=FALSE%
2590 IF ODD% THEN MEDIAN=RAIN(B%,VAR%)
2600 IF EVEN% THEN MEDIAN=(RAIN(B%,VAR%)+RAIN(B%+1,VAR%))/2
2610 NO4%=TRUE% : YES4%=FALSE%
2620 A%=CINT(TOT%/4) : B%=OFFSET%+A% : C%=TOT%-A%+OFFSET%+1
2630 IF 4*INT(TOT%/4)=TOT% THEN YES4%=TRUE% : NO4%=FALSE%
2640 IF NO4% THEN A=RAIN(B%,VAR%) : Z=RAIN(C%,VAR%)
2650 IF YES4% THEN A=(RAIN(B%,VAR%)+RAIN(B%+1,VAR%))/2
2660 IF YES4% THEN Z=(RAIN(C%,VAR%)+RAIN(C%-1,VAR%))/2
2670 LOQUAR=A
2680 HIQUAR=Z
2690 RETURN
2700 '
2710 REM print results on screen
2720 PRINT
2730 PRINT "                          n =";TOT% ;
2740 IF EVEN% THEN PRINT " (even)" ELSE PRINT " (odd)"
2750 PRINT "                        sum =";SUMN
```

```
2760 PRINT "            sum squared =";SUMSQ
2770 PRINT "                   mean =";MEAN
2780 PRINT "     standard deviation =";SD
2790 PRINT USING"      & skewness = ##.###    (&)";TYPE$;G1;SIG1$
2800 PRINT USING"              Kurtosis = ##.###    (&)";G2;SIG2$
2810 PRINT
2820 PRINT "                  range =";RANGE
2830 PRINT "                 median =";MEDIAN
2840 PRINT "    lower interquartile =";LOQUAR
2850 PRINT "    upper interquartile =";HIQUAR
2860 RETURN
2870 '
2880 REM Send to printer
2890 LPRINT TAB(10);"                  n =";TOT% ;
2900 IF EVEN% THEN LPRINT " (even)" ELSE LPRINT " (odd)"
2910 LPRINT TAB(10);"                sum =";SUMN
2920 LPRINT TAB(10);"        sum squared =";SUMSQ
2930 LPRINT TAB(10);"               mean =";MEAN
2940 LPRINT TAB(10);" standard deviation =";SD
2950 LPRINT TAB(10);
2960 LPRINT USING"  & skewness = ##.###    (&)";TYPE$;G1;SIG1$
2970 LPRINT TAB(10);
2980 LPRINT USING"          Kurtosis = ##.###    (&)";G2;SIG2$
2990 LPRINT
3000 LPRINT TAB(10);"              range =";RANGE
3010 LPRINT TAB(10);"             median =";MEDIAN
3020 LPRINT TAB(10);"lower interquartile =";LOQUAR
3030 LPRINT TAB(10);"upper interquartile =";HIQUAR
3040 FOR I%=1 TO 5:LPRINT:NEXT I%
3050 LPRINT TAB(5);NUM$
3060 LPRINT TAB(5);BAR$
3070 LPRINT TAB(5); : LPRINT USING"     0 mm &";STRING$(HIST%(0),"*")
3080 FOR I%=1 TO WET%
3090  LPRINT TAB(5);
3100  LPRINT USING"<= ### mm &";I%*25;STRING$(HIST%(I%),"*")
3110 NEXT I%
3120 LPRINT TAB(5);BAR$
3130 LPRINT TAB(5);NUM$
3140 ERC%=DEFLPRINT("(nul)")   (See note at end of Program 2)
3150 ERASE PLUIE%,HIST%
3160 RETURN
3170 '
3180 REM File sorted data
3190 CLOSE #1
3200 OPEN "O",#1,F$+".SORT"
3210 FOR ROW%=1 TO R%
3220  FOR COL%=2 TO C%-1
3230   PRINT #1,USING"###.#";RAIN(ROW%,COL%);:PRINT #1,",";
3240  NEXT COL%
3250  PRINT #1,USING"###.#";RAIN(ROW%,C%)
3260 NEXT ROW%
3270 RETURN
3280 '
3290 REM close files
3300 CLOSE
3310 PRINT"Sorted data is in file ";F$+".SORT"
3320 RETURN
```

SAMPLE OF RESULTS OF PROGRAM 1:

```
The following sorted data are from file MatamMONTH for the month of June


        0.0    1.0    1.7    2.0    2.3    2.7    3.8    4.0    4.8    5.0
        7.0    7.3    7.4    8.0   13.0   13.2   14.8   15.5   16.3   19.0
       19.5   19.7   24.0   24.5   25.0   28.0   28.3   28.5   29.0   29.5
       31.2   33.0   33.8   34.0   34.0   34.0   34.5   34.5   34.5   37.5
       37.5   44.1   45.7   46.5   46.9   50.1   51.5   52.0   52.5   53.7
       54.3   68.3   71.8   73.1   81.2   81.5   84.4   89.5  101.6  108.0
      129.7  155.5  168.0

    The data include 3 missing values.


                                    n = 63  (odd)
                                  sum = 2489
                          sum squared = 180807
                                 mean = 39.50794
                   standard deviation = 36.47175
                    Positive skewness =  1.654    (p<0.05)
                             Kurtosis =  2.731    (p<0.01)

                                range = 168
                               median = 30.3
                  lower interquartile = 13.2
                  upper interquartile = 52



                           5    10   15   20   25   30   35   40
                           |    |    |    |    |    |    |    |
                 0 mm *
            <=  25 mm ************************
            <=  50 mm ********************
            <=  75 mm *********
            <= 100 mm ****
            <= 125 mm **
            <= 150 mm *
            <= 175 mm **
                           |    |    |    |    |    |    |    |
                           5    10   15   20   25   30   35   40
```

PROGRAM 2: Calculate least-squares regression, calculate and store residuals, and plot transformed data on line printer

```
1000 REM RainReg Regression of rainfall data and storing residuals
1010 '
1020 GOSUB 1140 ' Initialisation
1030 GOSUB 1360 ' input data
1040 GOSUB 1440 ' Estimate at missing values and calculate annual totals
1050 FOR MONTH%=1 TO 7
1060  GOSUB 1700 ' Reinitialise
1070  GOSUB 1790 ' select variable to regress
1080  GOSUB 1990 ' Compile statistics
1090  GOSUB 2170 ' plot data
1100 NEXT MONTH%
1110 CLOSE
1120 STOP
1130 '
1140 REM initialisation
1150 C%=7 : TRUE%=-1 : FALSE%=0 : YEAR%=C%+1
1160 HEIGHT%=24 : ACROSS%=64
1170 CLS$=CHR$(12) : TWO$=CHR$(&HFD) : STAR$="*" : NOIDEA$="?"
1180 TITLEX$="Year"
1190 USERMES$="You are looking at data for the month of "
1200 COEF$="Coefficient of Determination, R& = #.###"
1210 EST$="At x = #### y = ###.#    (row ##)"
1220 FOR I%=1 TO C%+1
1230  READ COLHEAD$(I%)
1240 NEXT I%
1250 DATA Year,May,June,July,August,September,October,"Rainy season"
1260 PRINT CLS$ : INPUT"Name of station";NOM$ : PRINT : F$=NOM$+"MONTH"
1270 ASK%=TRUE%
1280 OPEN "i",#1,F$
1290 R%=0
1300 WHILE NOT EOF(1) : LINE INPUT #1, DUMMY$ : R%=R%+1 : WEND
1310 CLOSE
1320 OPEN "i",#1,F$
1330 DIM RAIN(R%,C%+1)
1340 RETURN
1350 '
1360 REM Input data
1370 FOR ROW%=1 TO R%
1380  FOR COL%=1 TO C%
1390   INPUT #1,RAIN(ROW%,COL%)
1400  NEXT COL%
1410 NEXT ROW%
1420 RETURN
1430 '
1440 REM Find all missing values and calculate annual totals
1450 PRINT"...filling in missing values..."
1460 FOR ROW%=1 TO R%
1470  TOTAL=0
1480  FOR COL%=2 TO C%
1490   N=RAIN(ROW%,COL%)
1500   IF N=-1 THEN GOSUB 1590
1510   PRINT USING"###.#  ";N;
1520   TOTAL=TOTAL+N
1530  NEXT COL%
1540  IF LEFT$(NOM$,1)="D" AND ROW%=R% THEN TOTAL=56.9
1550  RAIN(ROW%,YEAR%)=TOTAL : PRINT USING"####.#  ";TOTAL
```

```
1560 NEXT ROW%
1570 RETURN
1580 '
1590 REM Estimate missing values
1600 TOP%=ROW%-5 : IF TOP%<1 THEN TOP%=1
1610 BOT%=ROW%+5 : IF BOT%>R% THEN BOT%=R%
1620 SUM=0 : N%=0
1630 FOR I%=TOP% TO BOT%
1640  S=RAIN(I%,COL%)
1650  IF S<>-1 THEN SUM=SUM+S : N%=N%+1
1660 NEXT I%
1670 N=SUM/N%
1680 RETURN
1690 '
1700 REM Reinitialise (note x axis always from 1919 to last record)
1710 VAR%=MONTH%+1
1720 XMAX=RAIN(R%,1) : XMIN=1919 : YMAX=1 : YMIN=32767
1730 SUMX#=0:SUMSQX#=0:SUMY#=0:SUMSQY#=0:SUMXY#=0:N%=0
1740 TITLEY$=COLHEAD$(VAR%)+" rainfall (mm) at "+NOM$
1750 TITLEZ$="Regression of "+TITLEY$+" with time"
1760 DIM PLOT$(HEIGHT%)
1770 RETURN
1780 '
1790 REM Select variable to regress
1800 PRINT CLS$;USERMES$;COLHEAD$(VAR%);" at ";NOM$
1810 PRINT"First year of record was";RAIN(1,1)
1820 PRINT"Last year was";RAIN(R%,1)
1830 IF ASK% THEN PRINT : GOSUB 1860
1840 RETURN
1850 '
1860 REM Ask about start and end years
1870 START%=0 : QUIT%=0
1880 WHILE START%<RAIN(1,1) OR START%>RAIN(R%,1)
1890  INPUT"Analysis to start in which year - 19";S%:START%=S%+1900
1900 WEND
1910 WHILE QUIT%<START% OR QUIT%>RAIN(R%,1)
1920  INPUT"Last year of analysis - 19";S%:QUIT%=S%+1900
1930 WEND
1940 START%=START%-RAIN(1,1)+1 : QUIT%=QUIT%-RAIN(1,1)+1
1950 PRINT:INPUT"Are these values fixed for the rest of this series";R$
1960 IF R$="Y" OR R$="y" THEN ASK%=FALSE%
1970 RETURN
1980 '
1990 REM Select for compilation of statistics
2000 FOR I%=START% TO QUIT%
2010  RAIN=RAIN(I%,VAR%)
2020  IF RAIN<>-1 THEN GOSUB 2080
2030 NEXT I%
2040 IF YMIN*2<YMAX THEN YMIN=0  ' Show a zero on plot if not too far
2050 IF XMIN*2<XMAX THEN XMIN=0  ' from zero
2060 RETURN
2070 '
2080 REM Compile statistics
2090 ANNEE%=RAIN(I%,1)
2100 IF YMAX<RAIN THEN YMAX=RAIN
2110 IF RAIN<YMIN THEN YMIN=RAIN
2120 SUMX#=SUMX#+ANNEE%:SUMSQX#=SUMSQX#+ANNEE%^2
2130 SUMY#=SUMY#+RAIN:SUMSQY#=SUMSQY#+RAIN^2:SUMXY#=SUMXY#+ANNEE%*RAIN
2140 N%=N%+1
2150 RETURN
```

```
2160 '
2170 REM Subroutine to plot data
2180 GOSUB 2270 ' Print titles
2190 GOSUB 2330 ' Calculate regression statistics
2200 GOSUB 2390 ' Print regression statistics
2210 GOSUB 2570 ' Calculate and file residuals
2220 GOSUB 2680 ' Prepare plot for screen
2230 GOSUB 3140 ' Plot on screen
2240 GOSUB 3290 ' Send plot to printer
2250 RETURN
2260 '
2270 REM print titles
2280 PRINT
2290 PRINT TITLEZ$:PRINT
2300 PRINT : PRINT TAB(22);"Sample size =";N%:PRINT
2310 RETURN
2320 '
2330 REM calculate regression statistics
2340 B1=(SUMXY#-SUMX#*SUMY#/N%)/(SUMSQX#-SUMX#^2/N%)'
2350 B0=SUMY#/N%-B1*SUMX#/N%
2360 REGSS=B1^2*(SUMSQX#-SUMX#^2/N%) : TOTSS=SUMSQY#-SUMY#^2/N%
2370 RETURN
2380 '
2390 REM Print regression statistics
2400 PRINT USING"y = ###.# * x";B1;
2410 IF B0>=0 THEN PRINT"  +";
2420 PRINT USING" ####.#";B0;
2430 F= REGSS/(TOTSS-REGSS)*(N%-2)
2440 N$=STR$(N%-2) : LN%=LEN(N$)-1
2450 NCH$=MID$(N$,2,LN%)
2460 PRINT USING "      F(1,&) = ####.##";NCH$;F
2470 PRINT:PRINT TAB(15);"giving two-tailed t(";NCH$;")  = ";SQR(F)
2480 PRINT:PRINT
2490 PRINT"If the value of F is sufficiently large we can reject the
null hypothesis"
2500 PRINT"that the regression explains none of the variance in the
data;"
2510 PRINT"the regression line is significant.  (F table in Pollard: p
328)"
2520 PRINT
2530 PRINT"The proportion of the total sum of squares explained by the
regression,"
2540 PRINT"called the Coefficient of Determination, R² =";REGSS/TOTSS
2550 RETURN
2560 '
2570 REM Calculate and file residuals
2580 DIM RES(R%)
2590 OPEN "o",#3,NOM$+COLHEAD$(VAR%)+".Res"
2600 FOR I%=START% TO QUIT%
2610  RAIN=RAIN(I%,VAR%) : ANNEE%=RAIN(I%,1)
2620  IF RAIN<>-1 THEN PRINT #3,ANNEE%;RAIN;RAIN-ANNEE%*B1-B0
2630 NEXT I%
2640 CLOSE
2650 ERASE RES
2660 RETURN
2670 '
2680 REM Prepare plot for screen
2690 GOSUB 2750 ' Establish limits of data to be plotted
2700 GOSUB 2820 ' Prepare to set up text along axes
2710 GOSUB 2950 ' Scale data into plotted area
```

```
2720 GOSUB 3080 ' Copy text onto axes
2730 RETURN
2740 '
2750 REM Establish limits of data to be plotted
2760 YRANGE=YMAX-YMIN : I%=-4 : WHILE YRANGE>10^I% : I%=I%+1 : WEND
2770 YINC=10^(I%-2)
2780 TOP=YINC*(INT(YMAX/YINC)+1) : BOT=0 : GAU=1919 : DRO=XMAX
2790 MY=HEIGHT%/(TOP-BOT) : MX=ACROSS%/(DRO-GAU): CY=BOT : CX=GAU
2800 RETURN
2810 '
2820 REM Set up text along axes
2830 TY$=STR$(TOP)            : AY%=LEN(TY$) : AY1%=AY%
2840 BY$=STR$(BOT)            : BY%=LEN(BY$)
2850 CY$=STR$((TOP+BOT)/2)    : CY%=LEN(CY$)
2860 IF BY%>AY% THEN AY%=BY%
2870 IF CY%>AY% THEN AY%=CY%
2880 AX$=STR$(DRO)            : AX%=LEN(AX$)
2890 BX$=STR$(GAU)            : BX%=LEN(BX$)
2900 CX$=STR$(INT((DRO+GAU)/2))  : CX%=LEN(CX$)
2910 AY$=SPACE$(AY%) : SP$=AY$+"|"+STRING$(ACROSS%+1," ")
2920 OFFSET%=AY%+2
2930 RETURN
2940 '
2950 REM Scale data into plotted area
2960 FOR I%=0 TO HEIGHT% : PLOT$(I%)=SP$ : NEXT I%
2970 FOR I%=START% TO QUIT%
2980  X=RAIN(I%,1) : Y=RAIN(I%,VAR%) : X%=(X-CX)*MX
2990  IF Y=-1 THEN MID$(PLOT$(0),X%+OFFSET%)=NOIDEA$
3000  WHILE Y<>-1
3010   Y%=(Y-CY)*MY
3020   MID$(PLOT$(Y%),X%+OFFSET%)=STAR$
3030   Y=-1
3040  WEND
3050 NEXT I%
3060 RETURN
3070 '
3080 REM Copy text on axes
3090 MID$(PLOT$(HEIGHT%),AY%+1-AY1%)=TY$
3100 MID$(PLOT$(HEIGHT%/2),AY%+1-CY%)=CY$
3110 MID$(PLOT$(0),AY%+1-BY%)=BY$
3120 RETURN
3130 '
3140 REM plot on screen
3150 FOR H%=HEIGHT% TO 0 STEP -1
3160  PRINT PLOT$(H%)
3170 NEXT H%
3180 PRINT SPC(AY%+1);STRING$(ACROSS%+1,"-")
3190 PRINT SPC(AY%+1);
3200 PRINT"|";SPC(ACROSS%/2-1);"|";SPC(ACROSS%/2-1);"|"
3210 PRINT SPC(AY%-2);BX$;
3220 PRINT SPC((ACROSS%-BX%-CX%)/2);CX$;
3230 PRINT SPC((ACROSS%-CX%-AX%)/2);AX$
3240 A$=SPACE$(AY%+1+(ACROSS%-LEN(TITLEX$))/2)
3250 LE%=35-LEN(TITLEZ$)/2
3260 PRINT SPC(LE%);TITLEZ$
3270 RETURN
3280 '
3290 REM send plot to printer
3300 ERC%=DEFLPRINT("(SPL)")   (SEE NOTE AT END OF PROGRAM 2)
3310 LPRINT:LPRINT:LPRINT TAB(5);TITLEY$:LPRINT
```

```
3320 FOR H%=HEIGHT% TO 0 STEP -1
3330  P$=PLOT$(H%) : MID$(P$,AY%+1,1)="|"
3340  LPRINT TAB(5);P$
3350 NEXT H%
3360 LPRINT TAB(5);SPC(AY%+1);STRING$(ACROSS%+1,"-")
3370 LPRINT TAB(5);SPC(AY%+1);"|";SPC(ACROSS%/2-1);
3380 LPRINT                        "|";SPC(ACROSS%/2-1);"|"
3390 LPRINT TAB(5);       SPC(AY%-2);BX$;
3400 LPRINT SPC((ACROSS%-BX%-CX%)/2);CX$;
3410 LPRINT SPC((ACROSS%-CX%-AX%)/2);AX$
3420 A$=SPACE$(AY%+1+(ACROSS%-LEN(TITLEX$))/2)
3430 LPRINT TAB(5);A$;TITLEX$:LPRINT:LPRINT:LPRINT
3440 A$=SPACE$(AY%+1+(ACROSS%-LEN(TITLEZ$))/2)
3450 LPRINT TAB(5);A$;TITLEZ$
3460 LPRINT
3470 LPRINT TAB(19);
3480 LPRINT USING"y = ###.### * x";B1;
3490 IF B0>=0 THEN LPRINT"  +";
3500 LPRINT USING" ####.#";B0;
3510 LPRINT USING "    F(1,&) = ####.##";NCH$;F
3520 LPRINT:LPRINT TAB(31);
3530 LPRINT USING"giving two-tailed t(&)  = ##.###";NCH$;SQR(F)
3540 LPRINT:LPRINT TAB(23);:LPRINT USING COEF$;TWO$;REGSS/TOTSS
3550 ESTY1=XMIN*B1+B0 : ESTY2=XMAX*B1+B0 : LPRINT
3560 FOR I%=1 TO 5:LPRINT:NEXT I%
3570 LPRINT TAB(5);STRING$(LEN(EST$),"-")
3580 LPRINT TAB(5);:LPRINT USING EST$;XMIN;ESTY1;(ESTY1-CY)*MY
3590 LPRINT TAB(5);:LPRINT USING EST$;XMAX;ESTY2;(ESTY2-CY)*MY
3600 LPRINT TAB(5);STRING$(LEN(EST$),"-")
3610 ERC%=DEFLPRINT ("(NUL)")   (See note at end of Program)
3620 ERASE PLOT$
3630 RETURN
3640 '
```

Note: The system used to run these programs sends all LPRINT commands to the spooler. The command to initialise the spooler on this system is

    ERC%=DEFLPRINT ("(SPL)")

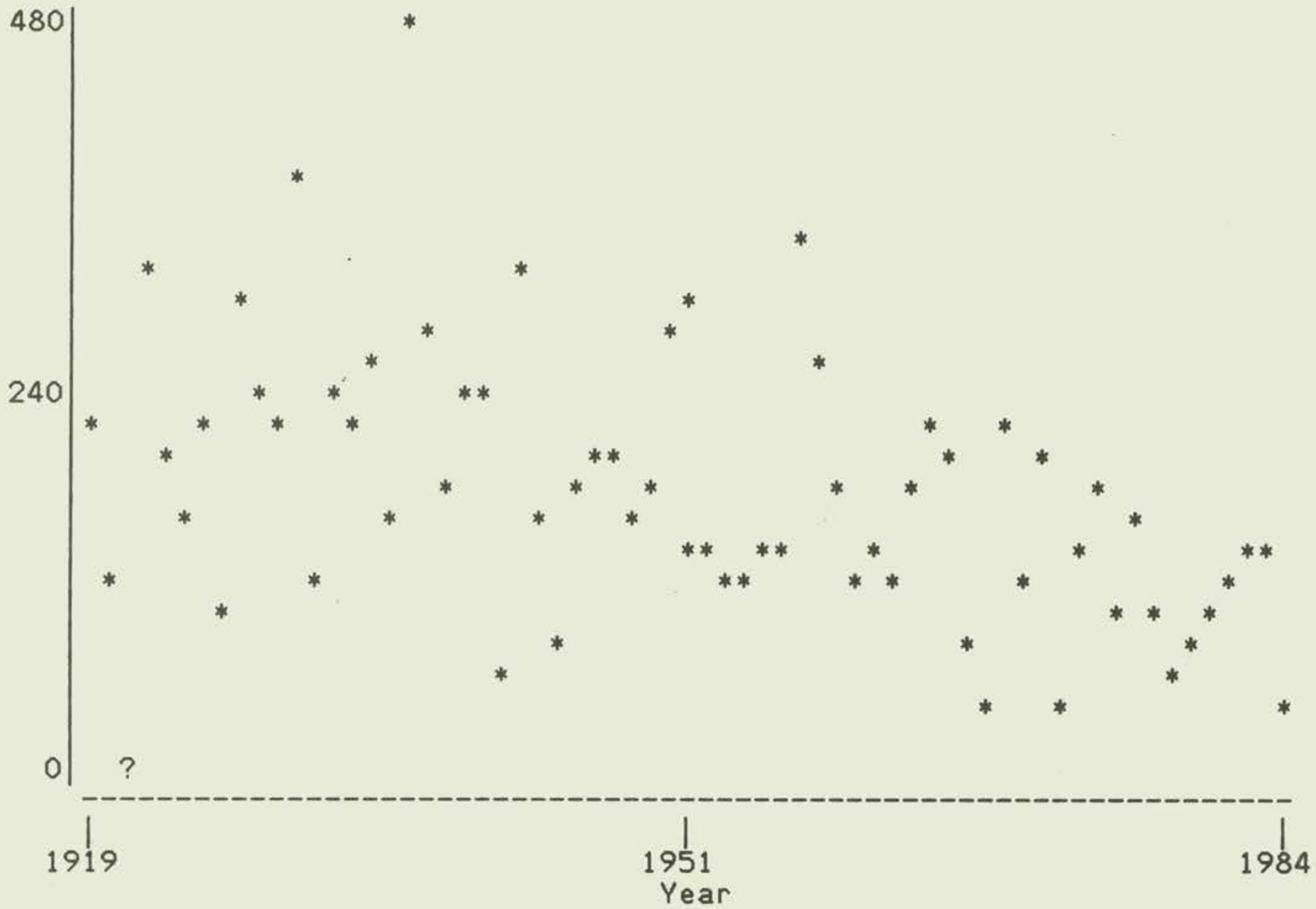
and the command to signal the end of output to the spooler is

    ERC%=DEFLPRINT ("(NUL)")

These commands should be omitted or replaced by the commands appropriate to the system used to implement the programs.

SAMPLE OF RESULTS OF PROGRAM 2

August rainfall (mm) at Matam



Regression of August rainfall (mm) at Matam with time

$y = -2.211 * x + 4492.0 \quad F(1,63) = 20.09$

giving two-tailed $t(63) = 4.483$

Coefficient of Determination, $R^2 = 0.242$

At x = 1919 y = 250.0	(row 13)	Note: this information is
At x = 1984 y = 106.4	(row 5)	included in order to help the
		analyst draw the regression line

PROGRAM 3: Autocorrelation of time series

```
1000 REM AutoRain Autocorrelation of rainfall data
1010 '
1020 GOSUB 1140 ' Initialisation
1030 GOSUB 1370 ' input data
1040 GOSUB 1480 ' Estimate at missing values and calculate annual totals
1050 FOR MONTH%=2 TO 8
1060  GOSUB 1750 ' select correct column of data
1070  GOSUB 1800 ' Calculate total variance, max and min
1080  GOSUB 1910 ' Calculate correlation for each lag (0 to r%/4)
1090  GOSUB 2180 ' plot data
1100 NEXT MONTH%
1110 CLOSE
1120 STOP
1130 '
1140 REM initialisation
1150 C%=7 : CLS$=CHR$(12) : TWO$=CHR$(&HFD) : STAR$="*"
1160 TRUE%=-1 : FALSE%=0
1170 YES$="Yy" : LP%=FALSE%
1180 M$="####    ###.#    ###.#    ###.#    "
1190 M$=M$+"###.#    ###.#    ###.#       ####.#"
1200 H$="Year      May     June     July    "
1210 H$=H$+"August  September October      Annual"
1220 T$="You are looking at rainfall data between #### and #### for the
month of "
1230 A$="Autocorrelation of & rainfall at &"
1240 FOR I%=1 TO C%+1
1250  READ COLHEAD$(I%)
1260 NEXT I%
1270 DATA Year,May,June,July,August,September,October,"Rainy season"
1280 PRINT CLS$ : INPUT"Name of station";NOM$ : PRINT : F$=NOM$+"MONTH"
1290 OPEN "i",#1,F$
1300 R%=0
1310 WHILE NOT EOF(1) : LINE INPUT #1, DUMMY$ : R%=R%+1 : WEND
1320 CLOSE
1330 OPEN "i",#1,F$
1340 DIM NU(R%,C%+1)
1350 RETURN
1360 '
1370 REM Input data
1380 PRINT"...reading the data..."
1390 FOR ROW%=1 TO R%
1400  FOR COL%=1 TO C%
1410   INPUT #1,NU(ROW%,COL%)
1420   N(COL%)=NU(ROW%,COL%)
1430  NEXT COL%
1440 NEXT ROW%
1450 SY%=1 : EY%=R% : ST%=NU(SY%,1) : EN%=NU(EY%,1)
1460 RETURN
1470 '
1480 REM Find all missing values and calculate annual totals
1490 PRINT"...filling in missing values..."
1500 YEAR%=C%+1
1510 FOR ROW%=1 TO R%
1520  TOTAL=0
1530  FOR COL%=2 TO C%
1540   N=NU(ROW%,COL%)
1550   IF N=-1 THEN GOSUB 1640
1560   PRINT USING"###.#  ";N;
```

```
1570   N(COL%)=N
1580   TOTAL=TOTAL+N
1590  NEXT COL%
1600  NU(ROW%,YEAR%)=TOTAL : PRINT USING"####.#  ";TOTAL
1610 NEXT ROW%
1620 RETURN
1630 '
1640 REM Estimate missing values
1650 TOP%=ROW%-5 : IF TOP%<1 THEN TOP%=1
1660 BOT%=ROW%+5 : IF BOT%>R% THEN BOT%=R%
1670 SUM=0 : N%=0
1680 FOR I%=TOP% TO BOT%
1690  S=NU(I%,COL%)
1700  IF S<>-1 THEN SUM=SUM+S : N%=N%+1
1710 NEXT I%
1720 N=SUM/N% : NU(ROW%,COL%)=N
1730 RETURN
1740 '
1750 REM Print title on screen
1760 PRINT CLS$: PRINT USING T$;ST%;EN%
1770 PRINT COLHEAD$(MONTH%);" at ";NOM$
1780 RETURN
1790 '
1800 REM Calculate total variance, max and min
1810 SY=0 : SYY=0 : YMAX=NU(1,MONTH%) : YMIN=NU(1,MONTH%)
1820 FOR I%=1 TO R%
1830  N=NU(I%,MONTH%)
1840  SY=SY+N: SYY=SYY+N^2
1850  IF YMAX<N THEN YMAX=N
1860  IF N<YMIN THEN YMIN=N
1870 NEXT I%
1880 VARY=(R%*SYY-SY*SY)/(R%*(R%-1))
1890 RETURN
1900 '
1910 REM Calculate correlation for each lag (0 to num%/4)
1920 ERC%=DEFLPRINT("(SPL)")   (SEE NOTE AT END OF PROGRAM 2)
1930 LPRINT TAB(10);
1940 LPRINT USING A$;COLHEAD$(MONTH%);NOM$:LPRINT
1950 QUA%=R%/4+1
1960 DIM Y(QUA%)
1970 Y(1)=1 : LPRINT
1980 LPRINT TAB(10);"Lag  d.f.  Correlation"
1990 LPRINT TAB(10);"           Coefficient":LPRINT
2000 LPRINT TAB(10);
2010 LPRINT USING"  0   ##     1.0000";R%-2
2020 FOR LAG%=2 TO QUA%
2030  SX=0 : SY=0 : SXY=0 : SERIES%=R%-LAG%+1
2040  FOR J%=1 TO SERIES%
2050   K%=J%+LAG%-1
2060   N=NU(J%,MONTH%) : M=NU(K%,MONTH%)
2070   SX=SX+N : SY=SY+M : SXY=SXY+N*M
2080  NEXT J%
2090  N=SERIES% : DF=N-2
2100  R=((N*SXY-SX*SY)/(N*(N-1)))/VARY
2110  Y(LAG%)=R
2120  L%=LAG%-1
2130  LPRINT TAB(10);
2140  LPRINT USING" ##   ##     #.####";L%;DF;R
2150 NEXT LAG%
2160 RETURN
```

```
2170 '
2180 REM Subroutine to plot data
2190 GOSUB 2260 ' Find range of values
2200 GOSUB 2330 ' Print titles
2210 GOSUB 2450 ' Prepare plot for screen
2220 GOSUB 2910 ' Plot on screen
2230 GOSUB 3060 ' Send plot to printer
2240 RETURN
2250 '
2260 REM Print range of values
2270 PRINT
2280 PRINT:PRINT"range of rainfall values:";YMIN;YMAX
2290 YMIN=-1  ' correlation coefficient has a value between
2300 YMAX=1   ' plus and minus 1
2310 RETURN
2320 '
2330 REM print titles
2340 PRINT
2350 TITLEX$="Lag"
2360 TITLEY$="Autocorrelation of "+COLHEAD$(MONTH%)+" rainfall at "+NOM$
2370 PRINT"Correlogram of rainfall at ";NOM$;" from";ST%;"to";EN%
2380 PRINT
2390 TIT$="Month of "+COLHEAD$(MONTH%)+" "
2400 IF MONTH%=8 THEN TIT$=COLHEAD$(MONTH%)+" "
2410 PRINT TIT$
2420 PRINT : PRINT TAB(22);"Length of sequence =";R%:PRINT
2430 RETURN
2440 '
2450 REM Prepare plot for screen
2460 GOSUB 2530 ' Dimension arrays
2470 GOSUB 2580 ' Establish limits of data to be plotted
2480 GOSUB 2630 ' Prepare to set up text along axes
2490 GOSUB 2720 ' Scale data into plotted area
2500 GOSUB 2810 ' Copy text onto axes
2510 RETURN
2520 '
2530 REM Dimension arrays
2540 HEIGHT%=24 : ACROSS%=64
2550 DIM PLOT$(HEIGHT%) : L%=ACROSS%
2560 RETURN
2570 '
2580 REM Establish limits of data to be plotted
2590 TOP%=1 : DRO%=QUA% : BOT%=-1 : GAU%=1
2600 MY=HEIGHT%/(TOP%-BOT%) : MX=ACROSS%/(DRO%-GAU%): CY=BOT% : CX=GAU%
2610 RETURN
2620 '
2630 REM Set up text along axes
2640 AY%=LEN(STR$(TOP%)) : AY1%=AY%
2650 BY%=LEN(STR$(BOT%))
2660 IF BY%>AY% THEN AY%=BY%
2670 CY$=STR$((TOP%+BOT%)/2) : CY%=LEN(CY$)
2680 IF CY%>AY% THEN AY%=CY%
2690 AY$=SPACE$(AY%) : SP$=AY$+"|"+STRING$(ACROSS%+1," ") : L%=AY%+2
2700 RETURN
2710 '
2720 REM Scale data into plotted area
2730 FOR I%=0 TO HEIGHT% : PLOT$(I%)=SP$ : NEXT I%
2740 PLOT$(HEIGHT%/2)=AY$+"|"+STRING$(ACROSS%+1,"-")
2750 FOR I%=1 TO QUA%
2760  X%=(I%-CX)*MX : Y%=(Y(I%)-CY)*MY
```

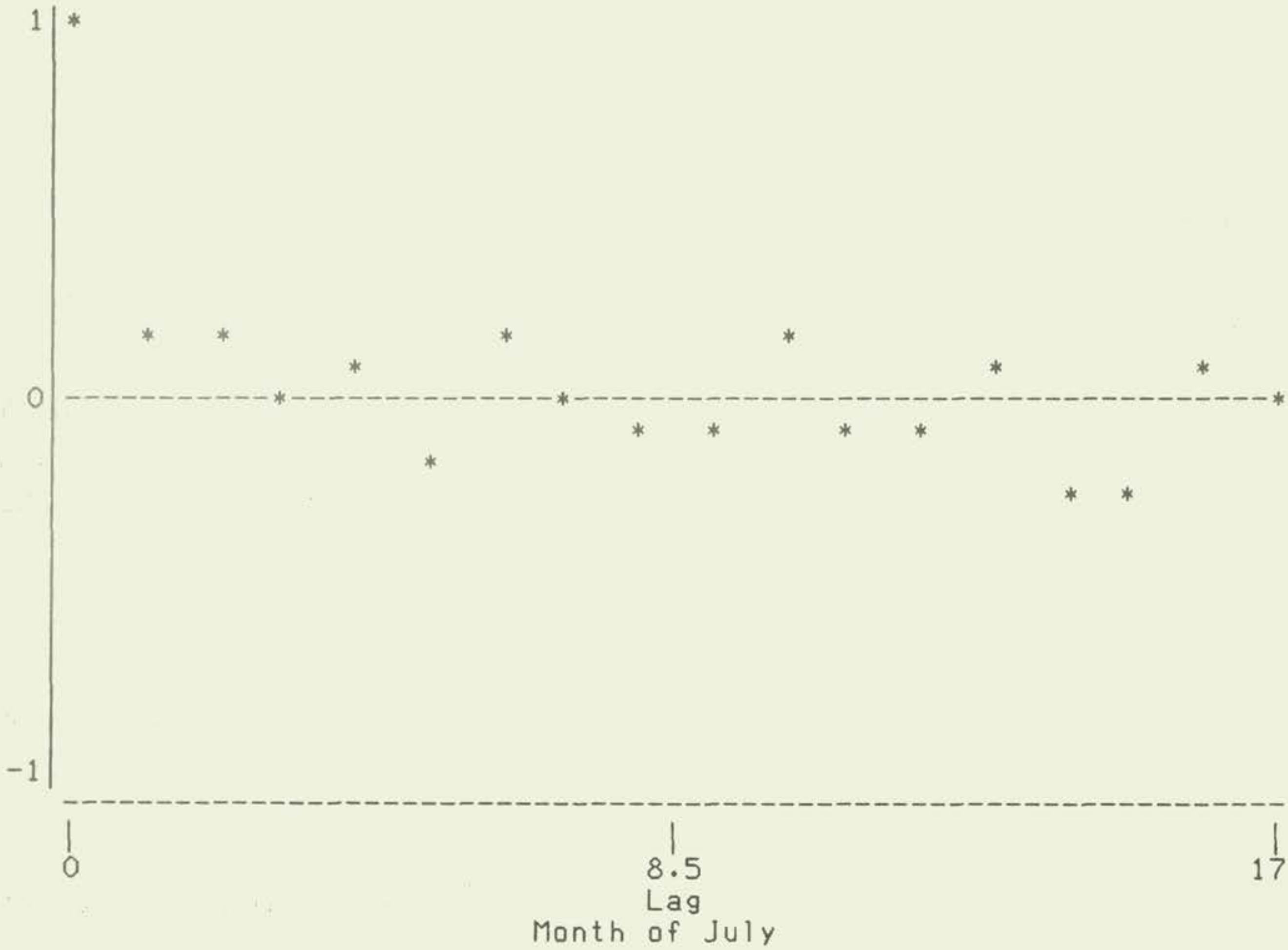
```
2770  MID$(PLOT$(Y%),X%+L%)=STAR$
2780 NEXT I%
2790 RETURN
2800 '
2810 REM Copy text on axes
2820 MID$(PLOT$(HEIGHT%),AY%+1-AY1%)=STR$(TOP%)
2830 MID$(PLOT$(HEIGHT%/2),AY%+1-CY%)=CY$
2840 MID$(PLOT$(0),AY%+1-LEN(STR$(BOT%)))=STR$(BOT%)
2850 AX$=STR$(DRO%-1) : BX$=STR$(GAU%-1)
2860 AX%=LEN(AX$)
2870 BX%=LEN(BX$)
2880 CX$=STR$((DRO%+GAU%-2)/2) : CX%=LEN(CX$)
2890 RETURN
2900 '
2910 REM plot on screen
2920 FOR H%=HEIGHT% TO 0 STEP -1
2930  PRINT PLOT$(H%)
2940 NEXT H%
2950 PRINT SPC(AY%+1);STRING$(ACROSS%+1,"-")
2960 PRINT SPC(AY%+1);
2970 PRINT"|";SPC(ACROSS%/2-1);"|";SPC(ACROSS%/2-1);"|"
2980 PRINT SPC(AY%);BX$;
2990 PRINT SPC((ACROSS%-BX%-CX%)/2);CX$;
3000 PRINT SPC((ACROSS%-CX%-AX%)/2);AX$
3010 A$=SPACE$(AY%+1+(ACROSS%-LEN(TITLEX$))/2)
3020 PRINT A$;TITLEX$:PRINT
3030 PRINT SPC(AY%+1);
3040 RETURN
3050 '
3060 REM send plot to printer
3070 LPRINT:LPRINT
3080 LPRINT TAB(5);TITLEY$;" from";ST%;"to";EN%:LPRINT
3090 FOR H%=HEIGHT% TO 0 STEP -1
3100  P$=PLOT$(H%) : MID$(P$,AY%+1,1)="|"
3110  LPRINT TAB(5);P$
3120 NEXT H%
3130 LPRINT TAB(5);SPC(AY%+1);STRING$(ACROSS%+1,"-")
3140 LPRINT TAB(5);SPC(AY%+1);"|";SPC(ACROSS%/2-1);
3150 LPRINT                   "|";SPC(ACROSS%/2-1);"|"
3160 LPRINT TAB(5);         SPC(AY%);BX$;
3170 LPRINT SPC((ACROSS%-BX%-CX%)/2);CX$;
3180 LPRINT SPC((ACROSS%-CX%-AX%)/2);AX$
3190 A$=SPACE$(AY%+1+(ACROSS%-LEN(TITLEX$))/2)
3200 LPRINT TAB(5);A$;TITLEX$:LPRINT
3210 A$=SPACE$(AY%+1+(ACROSS%-LEN(TIT$))/2)
3220 LPRINT TAB(5);A$;TIT$
3230 LPRINT
3240 ERC%=DEFLPRINT ("(NUL)")   (See note at end of Program 2)
3250 ERASE PLOT$, Y
3260 RETURN
3270 '
```

SAMPLE OF RESULTS OF PROGRAM 3:

Autocorrelation of July rainfall at Matam

Lag	df	Correlation coefficient
0	64	1.0000
1	63	0.1451
2	62	0.1486
3	61	0.0269
4	60	0.0883
5	59	-.1352
6	58	0.1493
7	57	-.0411
8	56	-.1078
9	55	-.0867
10	54	0.2027
11	53	-.0941
12	52	-.0458
13	51	0.0738
14	50	-.2180
15	49	-.2650
16	48	0.0652
17	47	-.0187

Autocorrelation of July rainfall at Matam from 1919 to 1984



PROGRAM 4: Correlation of rainfall at two sites

```
1000 REM CorAcross correlation of rainfall data at two sites
1010 '
1020 GOSUB 1230 ' Initialisation
1030 FOR F%=1 TO 2
1040  GOSUB 1430 ' find length of longest data set
1050 NEXT F%
1060 GOSUB 1510 ' Dimension arrays
1070 FOR F%=1 TO 2
1080  GOSUB 1640 ' Input data
1090  GOSUB 1840 ' Estimate at missing values and calculate totals
1100 NEXT F%
1110 FOR MONTH%=2 TO 8
1120  GOSUB 2110 ' Reinitialise
1130  GOSUB 2170 ' select correct column of data
1140  GOSUB 2260 ' Calculate max, min, sums and sums of squares
1150  GOSUB 2420 ' calculate correlation coefficient
1160  GOSUB 2460 ' calculate t corresponding to r
1170  GOSUB 4210 ' look up significance of t
1180  GOSUB 2510 'Plot data
1190 NEXT MONTH%
1200 CLOSE
1210 STOP
1220 '
1230 REM initialisation
1240 C%=7 : CLS$=CHR$(12) : TWO$=CHR$(&HFD) : STAR$="*"
1250 TRUE%=-1 : FALSE%=0
1260 YES$="Yy" : LP%=FALSE%
1270 M$="####    ###.#    ###.#    ###.#    ###.#    "
1280 M$=M$+"###.#    ###.#       ####.#"
1290 H$="Year      May      June      July   August  "
1300 H$=H$+"September October       Annual"
1310 CT$="r = ##.###   d.f. = ####   t = ###.###"
1320 FO$="     (####.## ####.##) <(### ###)>       "
1330 FO$=FO$+"(####.## ####.##) <(### ###)>"
1340 FOR I%=1 TO C%+1
1350  READ COLHEAD$(I%)
1360 NEXT I%
1370 DATA Year,May,June,July,August,September,October,"Rainy season"
1380 PRINT CLS$
1390 INPUT"Name of first station";NOM$(1) :PRINT:F$(1)=NOM$(1)+"MONTH"
1400 INPUT"Name of second station";NOM$(2) :PRINT:F$(2)=NOM$(2)+"MONTH"
1410 RETURN
1420 '
1430 REM Find length of longest data set
1440 OPEN "i",#F%,F$(F%)
1450 R%(F%)=1
1460 INPUT #F%,DATE%(F%),A%,A%,A%,A%,A%,A%
1470 WHILE NOT EOF(F%) : LINE INPUT #F%, DUMMY$ : R%(F%)=R%(F%)+1 : WEND
1480 CLOSE
1490 RETURN
1500 '
1510 REM Dimension arrays
1520 SWITCH%=1 : R%=R%(1) : IF R%<R%(2) THEN R%=R%(2)
1530 DATE%=DATE%(1) : IF DATE%(2)>DATE% THEN DATE%=DATE%(2) : SWITCH%=2
1540 DIM NU(2,R%,C%+1),NDF%(34),TTAB(34,4)
1550 FOR NUM%=1 TO 29 : NDF%(NUM%)=NUM% : NEXT NUM%
1560 FOR I%=1 TO 5 : READ NDF%(I%+29) : NEXT I%
1570 DATA 35,50,90,150,32766
```

```
1580 FOR SIG%=1 TO 4 : READ SIG$(SIG%) : NEXT SIG%
1590 DATA ns,.05,.02,.01
1600 RESTORE 4310
1610 FOR DF%=1 TO 34:FOR SI%=1 TO 4:READ TTAB(DF%,SI%):NEXT SI%:NEXT DF%
1620 RETURN
1630 '
1640 REM Input data
1650 OPEN "i",#F%,F$(F%)
1660 PRINT"...reading the data in ";F$(F%);"..." : R%=0
1670 DONTWANT%=0 : YEAR%=0 : IF F%=SWITCH% THEN YEAR%=DATE%
1680 IF R%(1)=R%(2) THEN YEAR%=DATE%
1690 WHILE YEAR%<DATE%-1
1700  LINE INPUT #F%,L$
1710  YEAR%=VAL(LEFT$(L$,4))
1720  DONTWANT%=DONTWANT%+1
1730 WEND
1740 FOR ROW%=1 TO R%(F%)-DONTWANT%
1750  R%=R%+1
1760  FOR COL%=1 TO C%
1770   INPUT #F%,NU(F%,R%,COL%)
1780   N(COL%)=NU(F%,R%,COL%)
1790  NEXT COL%
1800 NEXT ROW%
1810 SY%=1 : EY%=R% : ST%=NU(F%,SY%,1) : EN%=NU(F%,EY%,1)
1820 RETURN
1830 '
1840 REM Find all missing values and calculate annual totals
1850 PRINT"...filling in missing values..."
1860 YEAR%=C%+1
1870 FOR ROW%=1 TO R%
1880  TOTAL=0
1890  FOR COL%=2 TO C%
1900   N=NU(F%,ROW%,COL%)
1910   IF N=-1 THEN GOSUB 2000
1920   PRINT USING"###.#  ";N;
1930   N(COL%)=N
1940   TOTAL=TOTAL+N
1950  NEXT COL%
1960  NU(F%,ROW%,YEAR%)=TOTAL : PRINT USING"####.#  ";TOTAL
1970 NEXT ROW%
1980 RETURN
1990 '
2000 REM Estimate missing values
2010 TOP%=ROW%-5 : IF TOP%<1 THEN TOP%=1
2020 BOT%=ROW%+5 : IF BOT%>R% THEN BOT%=R%
2030 SUM=0 : N%=0
2040 FOR I%=TOP% TO BOT%
2050  S=NU(F%,I%,COL%)
2060  IF S<>-1 THEN SUM=SUM+S : N%=N%+1
2070 NEXT I%
2080 N=SUM/N% : NU(F%,ROW%,COL%)=N
2090 RETURN
2100 '
2110 REM reinitialise
2120 MAX=0 : N%=0
2130 XMAX=-32766 : XMIN=32760 : YMAX=-32766 : YMIN=32760
2140 SUMY#=0:SUMSQY#=0: SUMX#=0:SUMSQX#=0: SUMXY#=0
2150 RETURN
2160 '
2170 REM Print title on screen
```

```
2180 M%=MONTH%
2190 TITLEX$=COLHEAD$(M%)
2200 T$(9)="You are looking at the correlations in rainfall data "
2210 T$(10)="between #### and #### for the month of & at & and &"
2220 PRINT CLS$;T$(9)
2230 PRINT USING T$(10);ST%;EN%;TITLEX$;NOM$(1);NOM$(2)
2240 RETURN
2250 '
2260 REM Calculate max, mins, sums and sums of squares
2270 FOR I%=1 TO R%
2280   DONY=NU(2,I%,M%)  : DONX=NU(1,I%,M%)
2290   IF YMAX<DONY THEN YMAX=DONY
2300   IF YMIN>DONY THEN YMIN=DONY
2310   IF XMAX<DONX THEN XMAX=DONX
2320   IF XMIN>DONX THEN XMIN=DONX
2330   SUMX#=SUMX#+DONX:SUMSQX#=SUMSQX#+DONX^2
2340   SUMY#=SUMY#+DONY:SUMSQY#=SUMSQY#+DONY^2
2350   SUMXY#=SUMXY#+DONX*DONY
2360 NEXT I%
2370 SSX=SUMSQX#-SUMX#^2/R%
2380 SSY=SUMSQY#-SUMY#^2/R%
2390 SXY=SUMXY#-SUMX#*SUMY#/R%
2400 RETURN
2410 '
2420 REM calculate correlation coefficient r
2430 COEFF=SXY/SQR(SSX*SSY)
2440 RETURN
2450 '
2460 REM Calculate t which corresponds to r
2470 T=ABS(COEFF*SQR((R%-2)/(1-COEFF^2)))
2480 IF R%>50 THEN T=ABS(.5*LOG((1+COEFF)/(1-COEFF))*SQR(R%-3))
2490 RETURN
2500 '
2510 REM Subroutine to plot data
2520 GOSUB 2620 ' Print titles on screen
2530 GOSUB 2720 ' Dimension arrays
2540 GOSUB 2770 ' Establish limits of data to be plotted
2550 GOSUB 2950 ' Set up text along axes
2560 GOSUB 3070 ' Scale data into plotted area
2570 GOSUB 3240 ' Copy text on axes
2580 GOSUB 3300 ' Plot on screen
2590 GOSUB 3450 ' Send plot to printer
2600 RETURN
2610 '
2620 REM Print titles on screen
2630 M$=TITLEX$ : N1$=NOM$(1) : N2$=NOM$(2) : TITLEX$=N1$ : TITLEY$=N2$
2640 PRINT"Correlation of ";M$;" rainfall at ";N1$;" with that at ";N2$
2650 PRINT "Product-moment correlation coefficient"
2660 PRINT USING CT$;COEFF;R%-2;T;
2670 IF SIG$="ns" THEN PRINT "  (not significant)":GOTO 2690
2680 PRINT"   (p < 0";SIG$;")"
2690 PRINT:PRINT:PRINT
2700 RETURN
2710 '
2720 REM Dimension arrays
2730 HEIGHT%=40 : ACROSS%=60
2740 DIM PLOT$(HEIGHT%) : L%=ACROSS%
2750 RETURN
2760 '
2770 REM Establish limits of data to be plotted
```

```
2780 YRANGE=YMAX-YMIN : XRANGE=XMAX-XMIN
2790 IF YMAX*.75>YMIN THEN BOT=0
2800 IF XMAX*.75>XMIN THEN GAU=0
2810 I%=-4 : WHILE YRANGE>10^I% : I%=I%+1 : WEND
2820 YINC=10^(I%-2)
2830 I%=-4 : WHILE XRANGE>10^I% : I%=I%+1 : WEND
2840 XINC=10^(I%-2)
2850 TOP=YINC*(INT(YMAX/YINC)+1) : DRO=XINC*(INT(XMAX/XINC)+1)
2860 IF BOT<>0 THEN BOT=YINC*INT(YMIN/YINC)
2870 IF GAU<>0 THEN GAU=XINC*INT(XMIN/XINC)
2880 MY=HEIGHT%/(TOP-BOT) : MX=ACROSS%/(DRO-GAU)
2890 PRINT"Y axis runs from";BOT;"to";TOP;"in steps of";YINC
2900 PRINT"X axis runs from";GAU;"to";DRO;"in steps of";XINC
2910 PRINT"Vertical scaling factor of";MY;
2920 PRINT";  Horizontal scaling factor of";MX
2930 RETURN
2940 '
2950 REM Set up text along axes
2960 TY$=STR$(TOP)              : AY%=LEN(TY$) : AY1%=AY%
2970 BY$=STR$(BOT)              : BY%=LEN(BY$)
2980 CY$=STR$((TOP+BOT)/2)      : CY%=LEN(CY$)
2990 IF BY%>AY% THEN AY%=BY%
3000 IF CY%>AY% THEN AY%=CY%
3010 AX$=STR$(DRO)              : AX%=LEN(AX$)
3020 BX$=STR$(GAU)              : BX%=LEN(BX$)
3030 CX$=STR$((DRO+GAU)/2)      : CX%=LEN(CX$)
3040 AY$=SPACE$(AY%) : SP$=AY$+"|"+STRING$(ACROSS%+1," ") : L%=AY%+2
3050 RETURN
3060 '
3070 REM Scale data into plotted area
3080 FOR I%=0 TO HEIGHT% : PLOT$(I%)=SP$ : NEXT I%
3090 FOR I%=1 TO R%
3100  X%=NU(1,I%,M%)*MX : Y%=NU(2,I%,M%)*MY
3110  NUM$=MID$(PLOT$(Y%),X%+L%,1)
3120  IF NUM$=" " THEN REPL$="1"
3130  WHILE NUM$<>" "
3140   IF NUM$<="9" AND NUM$>"0" THEN NUM%=VAL(NUM$)+1
3150   IF NUM$>="A" THEN NUM%=ASC(NUM$)-54
3160   OFFSET%=48 : IF NUM%>=10 THEN OFFSET%=55
3170   REPL$=CHR$(NUM%+OFFSET%)
3180   NUM$=" "
3190  WEND
3200  MID$(PLOT$(Y%),X%+L%)=REPL$
3210 NEXT I%
3220 RETURN
3230 '
3240 REM Copy text on axes
3250 MID$(PLOT$(HEIGHT%),AY%+1-AY1%)=TY$
3260 MID$(PLOT$(HEIGHT%/2),AY%+1-CY%)=CY$
3270 MID$(PLOT$(0),AY%+1-BY%)=BY$
3280 RETURN
3290 '
3300 REM plot on screen
3310 FOR H%=HEIGHT% TO 0 STEP -1
3320  PRINT PLOT$(H%)
3330 NEXT H%
3340 PRINT SPC(AY%+1);STRING$(ACROSS%+1,"-")
3350 PRINT SPC(AY%+1);
3360 PRINT"|";SPC(ACROSS%/2-1);"|";SPC(ACROSS%/2-1);"|"
3370 PRINT SPC(AY%);BX$;
```

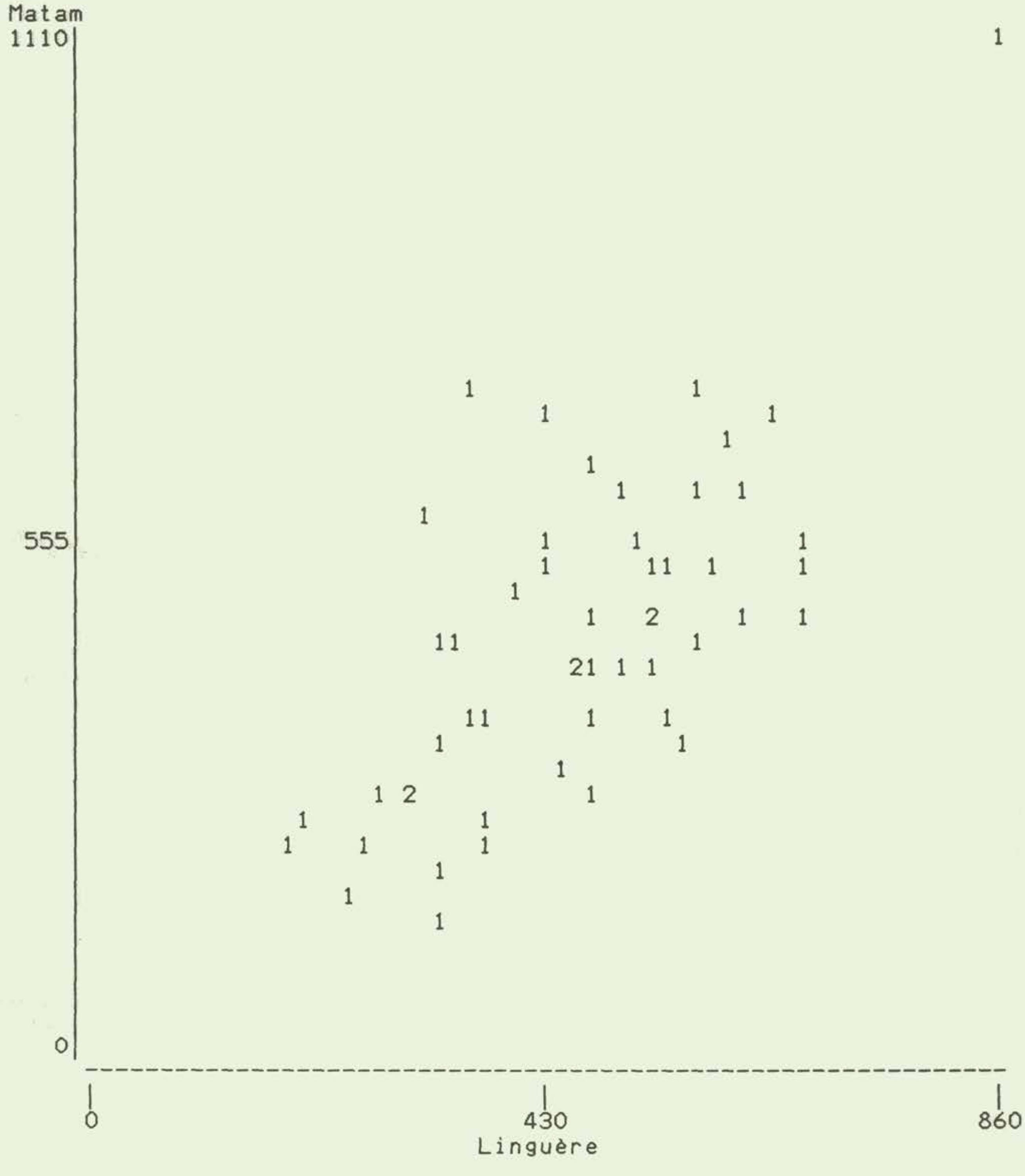
```
3380 PRINT SPC((ACROSS%-BX%-CX%)/2);CX$;
3390 PRINT SPC((ACROSS%-CX%-AX%)/2);AX$
3400 A$=SPACE$(AY%+1+(ACROSS%-LEN(TITLEX$))/2)
3410 PRINT A$;TITLEX$:PRINT
3420 PRINT SPC(AY%+1);
3430 RETURN
3440 '
3450 REM Send plot to printer
3460 ERC%=DEFLPRINT("(SPL)")    (SEE NOTE AT END OF PROGRAM 2)
3470 IF SI%>2 THEN GOSUB 3750
3480 LPRINT TAB(5);
3490 LPRINT"Correlation of ";M$;" rainfall at ";N1$;" with that at ";N2$
3500 LPRINT:LPRINT:LPRINT  TAB(5);HEAD$;TITLEY$
3510 FOR H%=HEIGHT% TO 0 STEP -1
3520  P$=PLOT$(H%) : MID$(P$,AY%+1,1)="|"
3530  LPRINT TAB(5);P$
3540 NEXT H%
3550 LPRINT TAB(5);SPC(AY%+1);STRING$(ACROSS%+1,"-")
3560 LPRINT TAB(5);SPC(AY%+1);"|";SPC(ACROSS%/2-1);
3570 LPRINT                    "|";SPC(ACROSS%/2-1);"|"
3580 LPRINT TAB(5);          SPC(AY%);BX$;
3590 LPRINT SPC((ACROSS%-BX%-CX%)/2);CX$;
3600 LPRINT SPC((ACROSS%-CX%-AX%)/2);AX$
3610 A$=SPACE$(AY%+1+(ACROSS%-LEN(TITLEX$))/2)
3620 LPRINT TAB(5);A$;TITLEX$:LPRINT
3630 A$=SPACE$(AY%+1+(ACROSS%-LEN(TIT$))/2)
3640 LPRINT TAB(5);A$;TIT$:LPRINT:LPRINT:LPRINT
3650 LPRINT TAB(5);"Product-moment correlation coefficient"
3660 LPRINT USING CT$;COEFF;R%-2;T;
3670 ME$="   (p < 0"+SIG$+")"
3680 IF SIG$="ns" THEN ME$="  (not significant)"
3690 LPRINT ME$
3700 IF SI%>2 THEN GOSUB 4070
3710 ERC%=DEFLPRINT ("(NUL)")    (See note at end of Program 2)
3720 ERASE PLOT$
3730 RETURN
3740 '
3750 REM Subroutine to plot points on boundary of confidence region
3760 SX2=SSX/(R%-1)    : SY2=SSY/(R%-1) : SYX=SXY/(R%-1)
3770 XMEAN=SUMX#/R%    : YMEAN=SUMY#/R%
3780 D=SQR((SX2+SY2)^2-4*(SX2*SY2-SYX^2))
3790 L1=(SX2+SY2+D)/2 : L2=(SX2+SY2-D)/2
3800 B1=SYX/(L1-SY2)  : B2=-1/B1
3810 ' This is where the loop would start if more than 95% cl are drawn
3820 H=3.841/((L1/L2+L2/L1-2)*R%)     ' H is apparently never used
3830 IF R%<50 THEN PRINT"I need a proper F look-up table, boss!":RETURN
3840 LPRINT TAB(5);
3850 F=3.07 : IF R%>180 THEN F=3
3860 IF R%<80 THEN F=3.15
3870 CA=L1*L2*((R%-1)/(R%-2))*2*F 'equal frequency ellipses
3880 D=SQR(CA/SY2) : E=SQR(CA/SX2)
3890 K=SQR(CA/(L2*(1+B1^2))) : Q=SQR(CA/(L1*(1+B2^2)))
3900 Y1(1)=XMEAN+D : Y2(1)=YMEAN
3910 Y1(2)=XMEAN-D : Y2(2)=YMEAN
3920 Y1(3)=XMEAN   : Y2(3)=YMEAN+E
3930 Y1(4)=XMEAN   : Y2(4)=YMEAN-E
3940 Y1(5)=XMEAN+K : Y2(5)=YMEAN+B1*(Y1(5)-XMEAN)
3950 Y1(6)=XMEAN-K : Y2(6)=YMEAN+B1*(Y1(6)-XMEAN)
3960 Y1(7)=XMEAN+Q : Y2(7)=YMEAN+B2*(Y1(7)-XMEAN)
3970 Y1(8)=XMEAN-Q : Y2(8)=YMEAN+B2*(Y1(8)-XMEAN)
```

```
3980 FOR I%=1 TO 8
3990  X%=Y1(I%)*MX : Y%=Y2(I%)*MY
4000  IF X%>DRO OR Y%>TOP THEN GOTO 4030
4010  IF X%<GAU OR Y%<BOT THEN GOTO 4030
4020  IF MID$(PLOT$(Y%),X%+L%)=" " THEN MID$(PLOT$(Y%),X%+L%)="+"
4030 NEXT I%
4040 RETURN
4050 '
4060 REM Print out equation of major axis and points
4070 LPRINT TAB(5);"Equation of major axis: y=";B1;"* x ";
4080 C=YMEAN-B1*XMEAN
4090 IF C>0 THEN LPRINT "+";
4100 IF C=0 THEN LPRINT: GOTO 4120
4110 LPRINT C
4120 LPRINT
4130 LPRINT TAB(5);"Points on boundary of 95% equal frequency ellipse:"
4140 FOR I%=1 TO 7 STEP 2
4150  Y1=Y1(I%)   : X1=CINT(Y1*MX) : Y2=Y2(I%)   : X2=CINT(Y2*MY)
4160  Y3=Y1(I%+1) : X3=CINT(Y3*MX) : Y4=Y2(I%+1) : X4=CINT(Y4*MY)
4170  LPRINT USING FO$;Y1;Y2;X1;X2;Y3;Y4;X3;X4
4180 NEXT I%
4190 RETURN
4200 '
4210 REM look up significance of t
4220 FOR I%=1 TO 34
4230  IF R%-2<=NDF%(I%) THEN DF%=I% : GOTO 4250
4240 NEXT I%
4250 FOR SI%=1 TO 4
4260  IF T<TTAB(DF%,SI%) THEN SIG$=SIG$(SI%) : GOTO 4290
4270 NEXT SI%
4280 SIG$=".001"
4290 RETURN
4300 '
4310 DATA 12.71,31.82,63.66,636.6
4320 DATA 4.303,6.965,9.925,31.60
4330 DATA 3.182,4.541,5.841,12.94
4340 DATA 2.776,3.747,4.604,8.610
4350 DATA 2.571,3.365,4.032,6.859
4360 DATA 2.447,3.143,3.707,5.959
4370 DATA 2.365,2.998,3.499,5.405
4380 DATA 2.306,2.896,3.355,5.041
4390 DATA 2.262,2.821,3.250,4.781
4400 DATA 2.228,2.764,3.169,4.587
4410 DATA 2.201,2.718,3.106,4.437
4420 DATA 2.179,2.681,3.055,4.318
4430 DATA 2.160,2.650,3.012,4.221
4440 DATA 2.145,2.624,2.977,4.140
4450 DATA 2.131,2.602,2.947,4.073
4460 DATA 2.120,2.583,2.921,4.015
4470 DATA 2.110,2.567,2.898,3.965
4480 DATA 2.101,2.552,2.878,3.922
4490 DATA 2.093,2.539,2.861,3.883
4500 DATA 2.086,2.528,2.845,3.850
4510 DATA 2.080,2.518,2.831,3.819
4520 DATA 2.074,2.508,2.819,3.792
4530 DATA 2.069,2.500,2.807,3.767
4540 DATA 2.064,2.492,2.797,3.745
4550 DATA 2.060,2.485,2.787,3.725
4560 DATA 2.056,2.479,2.779,3.707
4570 DATA 2.052,2.473,2.771,3.690
```

```
4580 DATA 2.048,2.467,2.763,3.674
4590 DATA 2.045,2.462,2.756,3.659
4600 DATA 2.042;2.457,2.750,3.646
4610 DATA 2.021,2.423,2.704,3.551
4620 DATA 2.000,2.390,2.660,3.460
4630 DATA 1.980,2.358,2.617,3.373
4640 DATA 1.960,2.326,2.576,3.291
4650 '
```

SAMPLE RESULT OF PROGRAM 4:

Correlation of Rainy season rainfall at Linguère with that at Matam




```
Product-moment correlation coefficient
r =  0.696   d.f. =   50   t =   6.015   (p < 0.001)
Equation of major axis: y= 1.441256 * x -213.8714
Points on boundary of 95% equal frequency ellipse:
     ( 711.85  450.33) <<( 50  16)>      ( 209.85  450.33) <<( 15  16)>
     ( 460.85  774.95) <<( 32  28)>      ( 460.85  125.71) <<( 32   5)>
     ( 762.80  885.52) <<( 53  32)>      ( 158.89   15.13) <<( 11   1)>
     ( 636.82  328.23) <<( 44  12)>      ( 284.87  572.43) <<( 20  21)>
```

PROGRAM 5: Rainfall probabilities by Gamma function

```
1000 REM Gamma Calculate incomplete Gamma function
1010 '
1020 GOSUB 1180 ' Initialisation
1030 GOSUB 1540 ' open file and get length of data stream
1040 GOSUB 1650 ' input data
1050 FOR MONTH%=1 TO C%
1060  GOSUB 1740 ' ReInitialise
1070  GOSUB 1790 ' pick up min and max
1080  GOSUB 1950 ' cast into classes
1090  GOSUB 2160 ' Collect other parameters
1100  GOSUB 2260 ' Calculate gamma function
1110  GOSUB 2400 ' Iteration
1120  GOSUB 2680 ' Send to printer
1130  GOSUB 2960 ' Linear interpolation at threshhold values
1140  CLOSE
1150 NEXT MONTH%
1160 STOP
1170 '
1180 REM initialisation
1190 PI#=3.14159265# : C%=6 : CLASSES%=40 : CLS$=CHR$(12)
1200 NEARENOUGH#=.0000001
1210 TRUE%=-1 : FALSE%=0
1220 PRINT CLS$
1230 PRINT"Incomplete Gamma function to be fitted to rainfall data"
1240 R$="e"
1250 WHILE R$<>"a" AND R$<>"m"
1260  PRINT:INPUT"Automatic (a) or manual (m) scaling";R$
1270 WEND
1280 AUT%=FALSE% : MAN%=TRUE% : IF R$="a" THEN AUT%=TRUE% : MAN%=FALSE%
1290 FOR I%=1 TO C%
1300  READ COLHEAD$(I%)
1310 NEXT I%
1320 DATA May,June,July,August,September,October
1330 DIM THRESH(CLASSES%),X(CLASSES%)
1340 PRINT CLS$ : INPUT"Name of station";F$ : PRINT
1350 R$="## ###.## ## &"
1360 P$="Gammacaret=####.####  Betacaret=####.####  "
1370 P$=P$+"GammaFunction=####.####"
1380 I$="   0        ###.#          #.####       #.####"
1390 J$="  ##        ###.#          #.####       #.####"
1400 B$="###.# .####  &   #.####"
1410 NOTE$="Note that value of & and y depend on classwidth (###.#mm)"
1420 PARA$="* shows value of incomplete Gamma function with &(&)=&"
1430 RAIN$="#.##                                             ###.#"
1440 DECK$(1)="Upper Gamma                          Probability "
1450 DECK$(1)=DECK$(1)+"                        Cumulative"
1460 DECK$(2)="bound funct 0.0  0.1  0.2  0.3  0.4  0.5  0.6"
1470 DECK$(2)=DECK$(2)+"  0.7  0.8  0.9   1  Observed"
1480 DECK$(3)=" (mm)          |    |    |    |    |    |    | "
1490 DECK$(3)=DECK$(3)+"   |    |    |    | Probability"
1500 SILL%(1)= 5 : SILL%(2)=20 : SILL%(3)=  50
1510 SILL%(4)=80 : SILL%(5)=95 : SILL%(6)=1000
1520 RETURN
1530 '
1540 REM Open file and dimension array for data
1550 SUFF$="MONTH.SORT"
1560 PRINT"Opening ";F$+SUFF$
1570 OPEN "i",#1,F$+SUFF$
```

```
1580 R%=0
1590 WHILE NOT EOF(1) : LINE INPUT #1, DUMMY$ : R%=R%+1 : WEND
1600 CLOSE
1610 OPEN "i",#1,F$+SUFF$
1620 DIM RAIN(R%,C%)
1630 RETURN
1640 '
1650 REM Input data
1660 PRINT"...reading data..."
1670 FOR ROW%=1 TO R%
1680  FOR COL%=1 TO C%
1690   INPUT #1,RAIN(ROW%,COL%)
1700  NEXT COL%
1710 NEXT ROW%
1720 RETURN
1730 '
1740 REM ReInitialise
1750 DIM PLUIE%(CLASSES%),CUMUL(CLASSES%),PROB(CLASSES%)
1760 SUMX#=0 : SUMLOG#=0 : ZERO%=0 : N%=0 : NONZERO%=0 : TOP%=0
1770 RETURN
1780 '
1790 REM Pick up min, max
1800 J%=1 : R=RAIN(J%,MONTH%) : MINI=0 : MAXI=RAIN(R%,MONTH%)
1810 WHILE R=-1
1820  J%=J%+1 : R=RAIN(J%,MONTH%)
1830 WEND
1840 WHILE R=0
1850  J%=J%+1 : ZERO%=ZERO%+1 : R=RAIN(J%,MONTH%)
1860 WEND
1870 IF MAN% THEN GOSUB 1900 ' Manual scaling
1880 RETURN
1890 '
1900 REM Manual scaling
1910 PRINT"Maximum rainfall recorded is";MAXI
1920 INPUT"Please give me the upper limit of the curve";MAXI
1930 RETURN
1940 '
1950 REM Cast into classes
1960 PRINT"...slotting data into classes..."
1970 RANGE=MAXI-MINI
1980 CLASSWIDTH=RANGE/CLASSES% : THRESH(0)=MINI
1990 FOR I%=1 TO CLASSES%
2000  THRESH(I%)=THRESH(I%-1)+CLASSWIDTH
2010 NEXT I%
2020 PLUIE%(0)=ZERO%
2030 FOR I%=J% TO R%
2040  N=RAIN(I%,MONTH%)
2050  C%=INT((CLASSWIDTH-.01+N)/CLASSWIDTH)
2060  IF C%<=CLASSES% THEN PLUIE%(C%)=PLUIE%(C%)+1
2070  IF C%<=CLASSES% AND C%>TOP% THEN TOP%=C%
2080 NEXT I%
2090 PRINT
2100 FOR I%=0 TO TOP%
2110  PRINT USING R$;I%;THRESH(I%);PLUIE%(I%);STRING$(PLUIE%(I%),"*")
2120 NEXT I%
2130 PRINT
2140 RETURN
2150 '
2160 REM Collect other parameters
2170 N%=ZERO%
```

```
2180 FOR I%=1 TO CLASSES%
2190  X%=PLUIE%(I%)
2200  N%=N%+X% : NONZERO%=NONZERO%+X%
2210  SUMX#=SUMX#+X%*THRESH(I%)
2220  SUMLOG#=SUMLOG#+X%*LOG(THRESH(I%))
2230 NEXT I%
2240 RETURN
2250 '
2260 REM Calculate beta and gamma
2270 PZERO=ZERO%/N%
2280 DIFLOG#=LOG(SUMX#/NONZERO%)-SUMLOG#/NONZERO%
2290 GAMMACARET#=(1+SQR(1+DIFLOG#*4/3))/(4*DIFLOG#)
2300 BETACARET#=SUMX#/NONZERO%/GAMMACARET#
2310 FUNCTION#=1-1/12/GAMMACARET#^2+1/360/GAMMACARET#^4
2320 FUNCTION#=FUNCTION#-1/1260/GAMMACARET#^6
2330 GAMMALOGGAMMA#=GAMMACARET#*(LOG(GAMMACARET#)-FUNCTION#)
2340 GAMMAFUNCTION#=EXP(GAMMALOGGAMMA#)*SQR(2*PI#/GAMMACARET#)
2350 PRINT"Probability density function"
2360 PRINT USING P$;GAMMACARET#;BETACARET#;GAMMAFUNCTION#
2370 PRINT
2380 RETURN
2390 '
2400 REM Iteration
2410 CUMUL(0)=PZERO
2420 PRINT"...Starting iteration..."
2430 PRINT"Class  Upper bound (mm)  Probability   Observed"
2440 FOR I%=0 TO TOP%
2450  IF I%<>0 THEN CUMUL(I%)=CUMUL(I%-1)+PLUIE%(I%)/N%
2460  X=THRESH(I%)
2470  WHILE X<>0
2480   U#=X/BETACARET# : OLDL#=0 : CURRENTL#=1 : STORE#=0 : ITERATION%=1
2490   INCREMENT#=1 : GAMMA#=U#^GAMMACARET#*EXP(-U#)
2500   WHILE ABS(INCREMENT#) > NEARENOUGH#
2510    MULT#=ITERATION%-GAMMACARET#-1
2520    DENOM#=(ITERATION%+U#)*CURRENTL#+(CURRENTL#-OLDL#)*MULT#
2530    NEWL#=DENOM#/ITERATION%
2540    INCREMENT#=GAMMA#/(CURRENTL#*NEWL#)
2550    STORE#=STORE#+INCREMENT#
2560    GAMMA#=GAMMA#*(ITERATION%-GAMMACARET#)/(ITERATION%+1)
2570    ITERATION%=ITERATION%+1 : OLDL#=CURRENTL# : CURRENTL#=NEWL#
2580   WEND
2590   PROB=PZERO+(1-PZERO)*(1-STORE#/GAMMAFUNCTION#)
2600   PRINT USING J$;I%;X;PROB;CUMUL(I%)
2610   X(I%)=X : PROB(I%)=PROB
2620   X=0
2630  WEND
2640 NEXT I%
2650 PROB(0)=PZERO
2660 RETURN
2670 '
2680 REM Send to printer
2690 PRINT:PRINT"...sending to spooler..."
2700 ERC%=DEFLPRINT("(SPL)")   (SEE NOTE AT END OF PROGRAM 2)
2710 LPRINT TAB(5);
2720 PRINT"Incomplete Gamma function for ";COLHEAD$(MONTH%);" at ";F$
2730 LPRINT
2740 FOR I%=1 TO 3:LPRINT TAB(5);DECK$(I%):NEXT I%
2750 FOR I%=0 TO TOP%
2760  BAR$=STRING$(51," ")
2770  FOR B%=0 TO 10 : MID$(BAR$,B%*5+1)="|" : NEXT B%
```

```
2780  MID$(BAR$,1+CINT(CUMUL(I%)*50))="+"
2790  MID$(BAR$,1+CINT(PROB(I%)*50))="*"
2800  LPRINT TAB(5);
2810  LPRINT USING B$;THRESH(I%);PROB(I%);BAR$;CUMUL(I%)
2820 NEXT I%
2830 LPRINT TAB(18);:FOR I%=0 TO 10: LPRINT "|     ";:NEXT I%:LPRINT
2840 LPRINT TAB(17);
2850 FOR I=0 TO 1 STEP .1 : LPRINT USING"#.#  ";I;:NEXT I:LPRINT" 1"
2860 CARET$=MID$(STR$(GAMMACARET#),2,6)
2870 FUNCT$=MID$(STR$(GAMMAFUNCTION#),2,6)
2880 LPRINT:LPRINT
2890 LPRINT TAB(5);"+ represents cumulative observed rainfall"
2900 LPRINT TAB(5);
2910 LPRINT USING PARA$;CHR$(226);CARET$;FUNCT$
2920 LPRINT TAB(5);
2930 LPRINT USING NOTE$;CHR$(226);CLASSWIDTH
2940 RETURN
2950 '
2960 REM Linear interpolation at threshhold probability values
2970 S%=1 : J%=0
2980 WHILE J%<=TOP%
2990  IF PROB(J%)<SILL%(S%)/100 THEN J%=J%+1 ELSE HOLD%(S%)=J%-1:S%=S%+1
3000 WEND
3010 FOR S%=1 TO 5
3020  H%=HOLD%(S%)
3030  IF H%<=0 THEN PL(1)=THRESH(0)
3040  WHILE H%>0
3050   Y1=THRESH(H%) : Y2=THRESH(H%+1) : X1=PROB(H%) : X2=PROB(H%+1)
3060   M=(Y2-Y1)/(X2-X1) : C=Y2-M*X2
3070   PL(S%)=M*SILL%(S%)/100+C
3080   H%=-1
3090  WEND
3100  IF PROB(TOP%)<SILL%(S%)/100 THEN PL(S%)=-1
3110 NEXT S%
3120 LPRINT:LPRINT TAB(5);STRING$(75,"-"):LPRINT
3130 LPRINT TAB(5);
3140 LPRINT"There is a probability of   p   ";
3150 LPRINT"that the rainfall will not excede   mm"
3160 FOR S%=1 TO 5
3170  LPRINT TAB(32);:LPRINT USING RAIN$;SILL%(S%)/100;PL(S%)
3180 NEXT S%
3190 ERC%=DEFLPRINT("(nul)")   (See note at end of Program 2)
3200 ERASE PLUIE%,PROB,CUMUL
3210 RETURN
```

SAMPLE RESULT OF PROGRAM 5:

Incomplete Gamma function for September at Linguère

```
Upper Gamma                      Probability                      Cumultd.
bound func 0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9    1 Obsrvd.
 (mm)      |    |    |    |    |    |    |    |    |    |    | Problty.
  0.0 .0192 |*   |    |    |    |    |    |    |    |    |    | 0.0192
 10.0 .0192 |*   |    |    |    |    |    |    |    |    |    | 0.0192
 20.0 .0199 |*   |    |    |    |    |    |    |    |    |    | 0.0192
 30.0 .0237 |*   |    |    |    |    |    |    |    |    |    | 0.0192
 40.0 .0355 |+*  |    |    |    |    |    |    |    |    |    | 0.0192
 50.0 .0597 |  * |    |    |    |    |    |    |    |    |    | 0.0577
 60.0 .0991 |    *    |    |    |    |    |    |    |    |    | 0.0962
 70.0 .1537 |    |  * +    |    |    |    |    |    |    |    | 0.1923
 80.0 .2215 |    |    |*   +    |    |    |    |    |    |    | 0.3077
 90.0 .2985 |    |    |    *  + |    |    |    |    |    |    | 0.3654
100.0 .3804 |    |    |    |   *|  + |    |    |    |    |    | 0.4615
110.0 .4630 |    |    |    |    |  * |  + |    |    |    |    | 0.5385
120.0 .5428 |    |    |    |    |    |  * |  + |    |    |    | 0.6346
130.0 .6170 |    |    |    |    |    |    |*  +|    |    |    | 0.6731
140.0 .6839 |    |    |    |    |    |    |   *|+   |    |    | 0.7115
150.0 .7428 |    |    |    |    |    |    |    |  * +    |    | 0.8077
160.0 .7933 |    |    |    |    |    |    |    |    *+   |    | 0.8269
170.0 .8359 |    |    |    |    |    |    |    |    | * +|    | 0.8846
180.0 .8711 |    |    |    |    |    |    |    |    |   *|    | 0.8846
190.0 .8997 |    |    |    |    |    |    |    |    |   +*    | 0.8846
200.0 .9227 |    |    |    |    |    |    |    |    |   +|*   | 0.8846
210.0 .9410 |    |    |    |    |    |    |    |    |    | *  | 0.9423
220.0 .9553 |    |    |    |    |    |    |    |    |    | +* | 0.9423
230.0 .9663 |    |    |    |    |    |    |    |    |    | +* | 0.9423
240.0 .9748 |    |    |    |    |    |    |    |    |    | + *| 0.9423
250.0 .9813 |    |    |    |    |    |    |    |    |    |  +*| 0.9615
260.0 .9862 |    |    |    |    |    |    |    |    |    |  +*| 0.9615
270.0 .9899 |    |    |    |    |    |    |    |    |    |  +*| 0.9615
280.0 .9926 |    |    |    |    |    |    |    |    |    |    * 1.0000
            |    |    |    |    |    |    |    |    |    |    |
           0.0  0.1  0.2  0.3  0.4  0.5  0.6  0.7  0.8  0.9    1

+ represents cumulative observed rainfall
* shows value of incomplete Gamma function with r(5.8072)=86.657
Note that value of r and y depend on classwidth ( 10.0mm)
---------------------------------------------------------------------
There is a probability of   p   that the rainfall will not excede   mm
                          0.05                                   46.0
                          0.20                                   76.8
                          0.50                                  114.6
                          0.80                                  161.6
                          0.95                                  216.3
```

PROGRAM 6: Generalise from point data to regular grid

```
1000 REM RainMap to create rain map of Ferlo from known data
1010 '
1020 GOSUB 1130 ' Initialise
1030 GOSUB 1270 ' Read data
1040 GOSUB 1380 ' For each cell
1050 FOR YR%=1 TO 5
1060  GOSUB 1470 ' Calculate rainfall in each cell
1070  GOSUB 1790 ' Calculate weighted rainfall and write to disk
1080  GOSUB 1930 ' Send to spooler
1090  GOSUB 2320 ' Clear arrays
1100 NEXT YR%
1110 STOP
1120 '
1130 REM Initialise
1140 M%=10
1150 DIM MAP(16,30),WT(16,30),WEST%(16),EAST%(16)
1160 DIM DIST(M%,M%)
1170 DIM NOM$(35),RAIN(35,5),X%(35),Y%(35)
1180 FOR I%=1 TO 16:READ WEST%(I%):NEXT I%
1190 DATA 13,5,3,1,1,1,1,2,3,5,6,8,10,10,13,15
1200 FOR I%=1 TO 16:READ EAST%(I%):NEXT I%
1210 DATA 18,20,21,22,22,23,28,29,29,29,30,29,28,27,22,21
1220 TRUE%=-1 : FALSE%=0
1230 F$(1)=".80" : F$(2)=".81" : F$(3)=".82" : F$(4)=".83" : F$(5)=".84"
1240 B$="     " : D$=" ###" : M$=" ###"
1250 RETURN
1260 '
1270 REM Read data
1280 PRINT"...reading data..."
1290 FOR STATION%=1 TO 35
1300   FOR YR%=1 TO 5
1310     READ RAIN(STATION%,YR%)
1320   NEXT YR%
1330   READ X%(STATION%)
1340   READ Y%(STATION%)
1350 NEXT STATION%
1360 RETURN
1370 '
1380 REM Calculate distance from central point
1390 PRINT"...calculating distances..."
1400 FOR R%=0 TO M%
1410  FOR C%=0 TO M%
1420   DIST(R%,C%)=SQR(C%^2+R%^2)
1430  NEXT C%
1440 NEXT R%
1450 RETURN
1460 '
1470 REM For each year, calculate rainfall in each cell
1480 PRINT:PRINT"...calculating rainfall for";YR%+1979;"..."
1490 FOR ST%=1 TO 35
1500  PRINT"...station";ST%;"..."
1510  RAIN=RAIN(ST%,YR%)
1520  WHILE RAIN<>-1
1530   X%=X%(ST%) : Y%=Y%(ST%)
1540   GAU%=X%-M% : TOP%=Y%-M% : IF TOP%<1 THEN TOP%=1
1550   DRO%=X%+M% : BOT%=Y%+M% : IF BOT%>16 THEN BOT%=16
1560   FOR R%=TOP% TO BOT%
1570    LEF%=GAU% : IF LEF%<WEST%(R%) THEN LEF%=WEST%(R%)
```

```
1580     RIG%=DRO% : IF RIG%>EAST%(R%) THEN RIG%=EAST%(R%)
1590     FOR C%=LEF% TO RIG%
1600      WEIGHT=1/((DIST(ABS(R%-Y%),ABS(C%-X%)))^4+1)
1610      MAP(R%,C%)=MAP(R%,C%)+RAIN*WEIGHT
1620      WT(R%,C%)=WT(R%,C%)+WEIGHT
1630     NEXT C%
1640    NEXT R%
1650    RAIN=-1
1660   WEND
1670 NEXT ST%
1680 PRINT"...winding up calculations..."
1690 FOR ST%=1 TO 35
1700  RAIN=RAIN(ST%,YR%)
1710  WHILE RAIN<>-1
1720   MAP(Y%(ST%),X%(ST%))=RAIN
1730   WT(Y%(ST%),X%(ST%))=1
1740   RAIN=-1
1750  WEND
1760 NEXT ST%
1770 RETURN
1780 '
1790 REM Calculate weighted rainfall and write to disk
1800 PRINT:PRINT"...writing map to disk file ";RAW$+F$(YR%);"..."
1810 OPEN "o",#YR%,RAW$+F$(YR%)
1820 PRINT #YR%,"Estimated rainfall for ";F$(YR%)
1830 FOR R%=1 TO 16
1840  FOR C%=WEST%(R%) TO EAST%(R%)
1850   MAP(R%,C%)=MAP(R%,C%)/WT(R%,C%)
1860   PRINT #YR%, USING"###.# ";MAP(R%,C%);
1870  NEXT C%
1880  PRINT #YR%,""
1890 NEXT R%
1900 CLOSE #YR%
1910 RETURN
1920 '
1930 REM send to printer
1940 PRINT:PRINT"...Sending map to spooler..."
1950 ERC%=DEFLPRINT("(SPL)")   (SEE NOTE AT END OF PROGRAM 2)
1960 LPRINT"Total rain for";YR%+1979 : LPRINT
1970 LPRINT CHR$(27);CHR$(15);  ' condensed chars
1980 LPRINT"      ";
1990 FOR C%=1 TO 30:LPRINT USING"##  ";C%;:NEXT C%:LPRINT
2000 FOR R%=1 TO 16
2010  LPRINT USING"## ";R%;
2020  IF WEST%(R%)=1 THEN GOTO 2040
2030  FOR C%=1 TO WEST%(R%)-1:LPRINT B$; : NEXT C%
2040  FOR C%=WEST%(R%) TO EAST%(R%)
2050   LPRINT USING M$;MAP(R%,C%);
2060  NEXT C%
2070  LPRINT
2080 NEXT R%
2090 LPRINT:LPRINT:LPRINT
2100 DIM POSIT%(16,30)
2110 FOR ST%=1 TO 35
2120  RAIN=RAIN(ST%,YR%)
2130  IF RAIN<>-1 THEN POSIT%(Y%(ST%),X%(ST%))=1
2140 NEXT ST%
2150 LPRINT"      ";
2160 FOR C%=1 TO 30:LPRINT USING"##  ";C%;:NEXT C%:LPRINT
2170 FOR R%=1 TO 16
```

```
2180  LPRINT USING"## ";R%;
2190  IF WEST%(R%)=1 THEN GOTO 2210
2200  FOR C%=1 TO WEST%(R%)-1:LPRINT B$; : NEXT C%
2210  FOR C%=WEST%(R%) TO EAST%(R%)
2220   C$=B$:IF POSIT%(R%,C%)=1 THEN C$="  * "
2230   LPRINT C$;
2240  NEXT C%
2250  LPRINT
2260 NEXT R%
2270 ERASE POSIT%
2280 LPRINT CHR$(27);CHR$(35);CHR$(65); ' Set printer back to default
2290 ERC%=DEFLPRINT("(nul)")   (See note at end of Program 2)
2300 RETURN
2310 '
2320 REM Clear arrays
2330 PRINT"...Clearing out workspace arrays..."
2340 FOR R%=1 TO 16
2350  FOR C%=WEST%(R%) TO EAST%(R%)
2360   MAP(R%,C%)=0
2370   WT(R%,C%)=0
2380  NEXT C%
2390 NEXT R%
2400 RETURN
2410 '
2420 DATA    -1,309.9,192.2,108.6,    -1, 1, 8
2430 DATA    -1,    -1,    -1, 29.0,    -1, 4, 3
2440 DATA 229.3,372.0,    -1,    -1,    -1, 4, 5
2450 DATA 244.8,298.0,192.8,119.4, 77.2, 4, 7
2460 DATA 190.2,176.3,141.9, 68.8, 56.9, 6, 2
2470 DATA    -1,297.7,267.2, 51.8, 40.1, 6, 6
2480 DATA 361.9,354.2,259.0,    -1,118.4, 6, 8
2490 DATA 206.8,192.6,196.0,120.5,116.8, 8, 8
2500 DATA 348.8,464.6,311.8, 78.8,180.7, 8,11
2510 DATA    -1,351.2,277.5,100.0, 92.0, 9, 5
2520 DATA 284.4,290.3,246.5,113.2, 90.9, 9, 6
2530 DATA 222.3,236.3, 89.2, 49.0, 43.1,10, 2
2540 DATA 380.9,399.6,475.7,190.4,372.8,10,14
2550 DATA    -1,    -1,    -1, 77.6, 48.5,11, 1
2560 DATA 144.0,249.0,    -1,    -1,    -1,11, 5
2570 DATA    -1,    -1,186.4,    -1,267.1,11, 7
2580 DATA 382.0,303.9,299.8,118.1,171.2,11, 9
2590 DATA 219.6,139.5,129.7, 93.5, 31.4,12, 0
2600 DATA 210.4,317.0,231.8,141.4, 83.7,12, 6
2610 DATA 346.1,405.7,377.1, 92.4,131.2,13, 9
2620 DATA    -1,    -1,358.1,215.5,    -1,13,15
2630 DATA 303.6,349.5,271.4, 57.8, 93.2,14, 7
2640 DATA 220.5,155.9,141.7, 59.2,140.3,15, 2
2650 DATA    -1,    -1,258.4,102.8, 97.3,16, 7
2660 DATA    -1,541.0,183.5,161.0,    -1,16,12
2670 DATA 349.0,433.0,297.0,117.5,207.0,18,12
2680 DATA 322.1,333.2,177.8, 43.7, 83.6,19, 3
2690 DATA    -1,361.3,340.4,128.6,127.5,19, 9
2700 DATA 281.5,403.6,416.9,    -1,199.4,22,15
2710 DATA    -1,    -1,    -1,    -1,221.0,23, 6
2720 DATA    -1,    -1,229.0,100.0,    -1,24, 7
2730 DATA 321.4,193.0,238.1,117.5,136.8,26, 8
2740 DATA    -1,    -1,    -1,    -1,184.0,27,14
2750 DATA    -1,286.4,286.1,255.6,134.4,29,12
2760 DATA 217.5,370.8,275.9,240.7,147.2,30,11
```

SAMPLE RESULT OF PROGRAM 6: (note that only the left-hand part of the page output by the computer is represented here)

Estimated rainfall for 1980

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1													220	221	221	224	249
2					192	190	192	209	222	222	221	218	220	221	221	223	260
3			226	218	199	193	197	215	221	218	209	201	214	222	222	227	281
4	236	232	230	229	226	218	225	240	229	183	160	173	205	229	234	246	290
5	239	235	231	229	232	245	258	271	267	189	144	182	214	255	270	273	290
6	244	241	239	239	248	280	275	276	284	244	188	210	236	292	296	292	293
7	249	247	246	245	275	336	282	237	263	266	242	233	281	304	302	300	299
8		253	251	257	325	362	284	207	230	324	357	336	328	314	308	307	309
9			267	287	336	347	290	235	264	363	382	360	346	340	326	319	325
10					324	330	329	334	332	361	374	359	346	342	334	333	341
11						336	346	349	347	351	360	354	346	341	338	343	348
12								348	351	362	364	356	347	341	341	346	349
13										379	378	370	357	346	344	346	348
14										381	380	376	364	350	344	344	346
15													366	353	344	341	339
16															346	338	331

Estimated rainfall for 1980: location of rainfall stations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1													+	+	+	+	+
2					+	■	+	+	+	■	+	+	+	+	■	+	+
3			+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5	+	+	+	■	+	+	+	+	+	+	■	+	+	+	+	+	+
6	+	+	+	+	+	+	+	+	■	+	+	■	+	+	+	+	+
7	+	+	+	■	+	+	+	+	+	+	+	+	+	■	+	+	+
8		+	+	+	+	■	+	■	+	+	+	+	+	+	+	+	+
9			+	+	+	+	+	+	+	+	■	+	■	+	+	+	+
10					+	+	+	+	+	+	+	+	+	+	+	+	+
11						+	+	■	+	+	+	+	+	+	+	+	+
12								+	+	+	+	+	+	+	+	+	+
13										+	+	+	+	+	+	+	+
14										■	+	+	+	+	+	+	+
15													+	+	+	+	+
16															+	+	+

Appendix 6: Calculation of skewness and kurtosis

The calculation of skewness and kurtosis is presented in many statistical textbooks (eg Pollard 1977, Snedecor et Cochran 1980) but is not necessarily familiar to all analysts in ecological monitoring units.

The mean is a measure of location, the variance one of the spread of the distribution. Skewness is a measure of the symmetry of the distribution about its mean, and kurtosis is a measure of its peakedness.

If x represents the N individual observations, x(1), x(2),..., x(N), then we may define

$$m1=(\Sigma x)/N$$
$$m2=(\Sigma x^2)/N$$

and in general,

$$mn=(\Sigma x^n)/N$$

If we now define

$$\mu1=m1$$
$$\mu2=m2-m1^2$$
$$\mu3=m3-3*m2*m1+2*m1^2$$
$$\mu4=m4-4*m3*m1+6*m2*m1^2-3*(m1^2)^2$$

then the:

$$\text{mean } m = \mu1$$
$$\text{variance } v = n*\mu2/(n-1)$$
$$\text{skewness } s = \sqrt{}(\mu3/(\mu2*\mu2^2))$$
$$\text{kurtosis } k = \mu4/\mu2^2$$

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