Drylands Programme

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Rainfall in the Sahel

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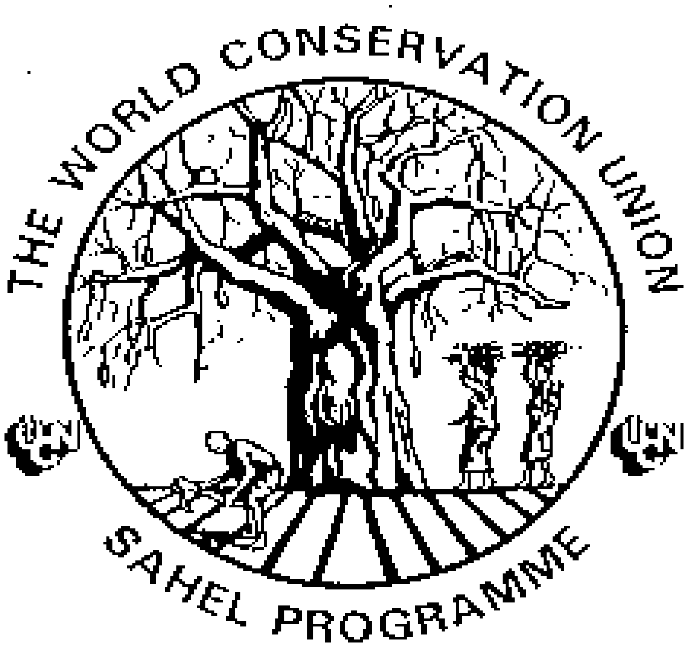

The IUCN - the World Conservation Union - has published the IUCN Sahel Studies 1989, as part of its Sahel Programme. Running to 152 pages, the Sahel Studies includes sections on Rainfall, Population, Food and agricultural production, Conservation areas, Agricultural prices and natural resource management, Sustainable development, Supply and provision of firewood, and Pastoral land tenure. The report provides reviews of recent research on sustainable development issues by leading experts in the various fields.

Under an agreement between IUCN and IIED, Haramata is publishing four edited papers from the Sahel Studies in the Issues Envelope series - two in each of the September and December 1989 editions. In this Issues Envelope are included papers on Food and Agricultural Production and on Sahelian Rainfall. The original version of the Agriculture and Food paper was written by Dr. M. Norton-Griffiths formerly of IUCN, Nairobi and that on rainfall by Dr. G. Farmer of the Climatic Research Unit, University of East Anglia, UK. Haramata has been responsible for the editing of the original text.

Copies of the full IUCN Sahel Studies 1989 are available in English and French and can be obtained from the IUCN Publications Unit, 219c Huntingdon Road, Cambridge CB3 0DL, UK (price UKstg.12.50 or US$25).

RAINFALL IN THE SAHEL

1. Introduction

This issues paper is concerned with rainfall variations in ten sub-Saharan countries that can be classed as lying within the Sahelian region. The ten countries are Senegal, Mauritania, Mali, Burkina Faso, Niger, Chad, Sudan, Ethiopia, Djibouti and Somalia.

The Sahel region of Africa, the semi-arid area to the south of the Sahara, has experienced a very pronounced climate anomaly over the last twenty years with widespread, below-normal rainfall. In the western half of the latitude band, every seasonal rainfall total since 1968 has been below normal. In such a case it is difficult, as will be shown below, to know just what 'normal' is. For the purpose of this paper, however, we are using as a reference period the international standard 30-year period, 1931-60, or the similar length 1941-70.

Given the marginal nature of the region in terms of its rainfall amounts and consequent agriculture and pastoralism, any deficit in the primary resource of water has immediate and potentially disastrous effects.

For example, 22 African countries experienced food shortages or shortfalls as of October 1984, shortfalls that are clearly related to the extreme drought of 1984. An estimated 250 million people were affected at that time. All of the Sahelian band of countries under study here, in common with other semi-arid regions, were affected by this climate anomaly.

2. Temporal Variations at the Regional Scale

2.1. Data sources

Much work has been carried out on historical and earlier (i.e. palaeo-climatological) records of rainfall in the Sahel. This is reviewed by Farmer and Wigley (1985). The present paper is concerned with the period of instrumental rainfall measurements. The monthly rainfall data used here come from four main sources compiled regionally and internationally (1).

2.2 Data reliability

With a diverse set of sources, one must first consider the questions of data reliability and the homogeneity of individual rainfall series.

Almost all data banks contain examples of different kinds of error. Unfortunately, it is virtually impossible to detect and correct these errors, except in the most extreme (and therefore most important) cases. It may be asked then if any confidence can be placed on results from analysis of these data. The answer to this question is 'yes'. Since the errors tend to be random in sign and to occur randomly in space and time, spatial averaging, as used here, will minimise the effects of such errors.

2.3 Method of analysis

A description is given here of how the time series graphs are derived. Having defined a particular area and a particular season, say May to October, the seasonal rainfall series for each station in the area is first normalised (3). Having normalised each station with respect to the same reference period, a spatial mean rainfall anomaly is found by averaging the values for all stations with data.

2.4 Western and Central Sahel

Regional time series have been derived for western (Figure 1) and central Sahel (Figure 2). The rainfall season chosen runs from May to October; while the geographical boundaries are between 10 N and 15 N latitude for both regions, and 20 W to 10 E for the western Sahel and 10 E to 40 E for the central Sahel. Those parts of Ethiopia, Somalia and Djibouti which lie east of 40 E cannot be grouped with the central Sahel region because of the different timings of their rainy seasons.

Taking the western Sahel first (Figure 1), the run of deficit years since 1968 is readily apparent. It should also be noted that the 1950s were generally wetter that the 1941-70 average. This was also a period of increase for both human and livestock populations. The early twentieth century was also a relatively dry period, with only 1906 and 1909 being above normal in a 21-year period. This dry event is almost comparable with the period since 1968.

A visual inspection of Figure 1 shows what appear to be quasi-periodic fluctuations in the western Sahel in a time scale of around 50 years. However, a 40-60 year periodicity in a data series that is only 67 years long, while it is a real characteristic of this particular set of numbers, has absolutely no practical significance or value. To use a periodicity for predictive purposes we would need at least five or six complete

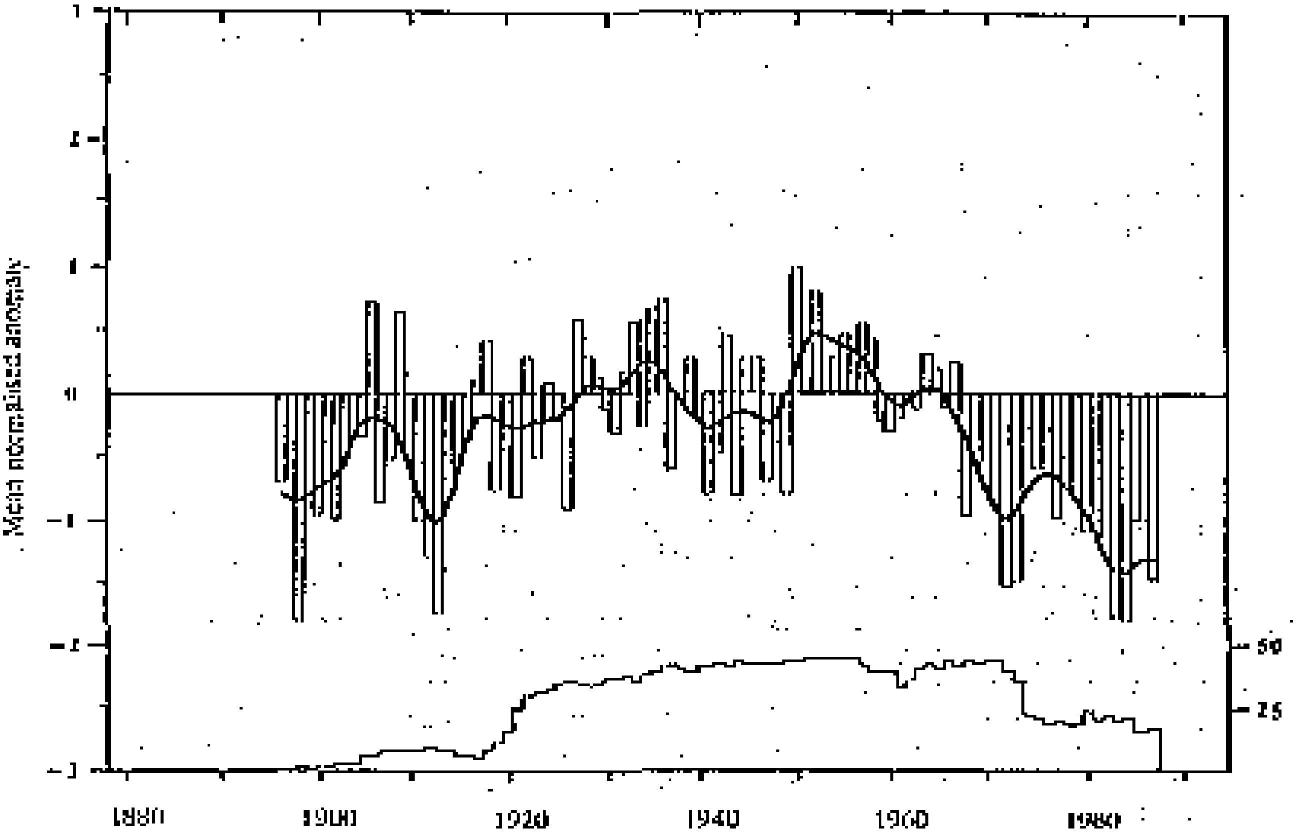

Fig. 1: Regional time series for the western Sahel; for geographical limits see text. The smooth line shows the course of the slower, background variations (obtained using a nine-term, padded binomial filter). The bar chart at the base shows the number of stations included in the average for each year.

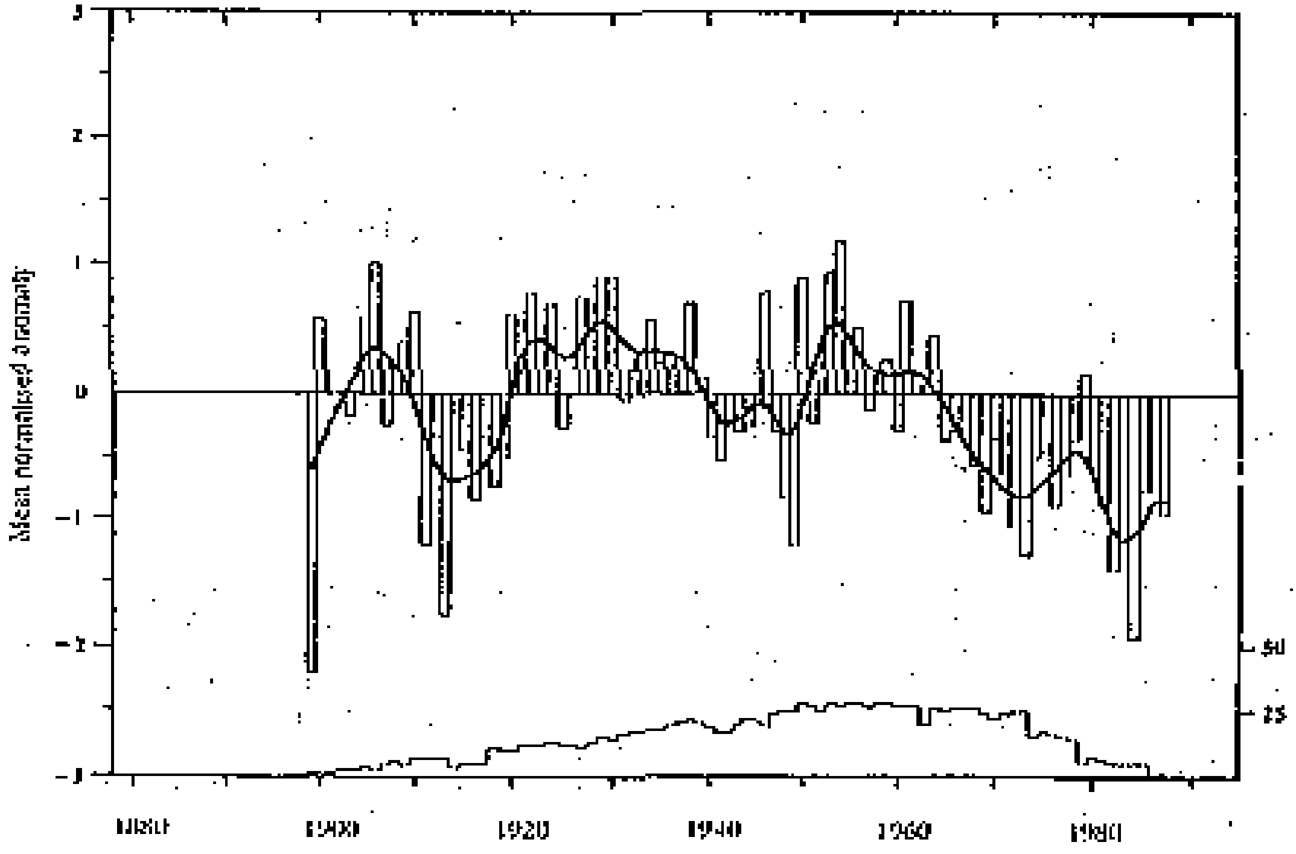

Fig. 2: As for Figure 1, but for the central Sahel up to roughly the Ethiopian border.

cycles before we could be certain that it was not merely an ephemeral feature.

The central Sahel (Figure 2) also shows dryness in the early twentieth century centred around 1913, but for a much shorter period than in the western Sahel. (Note that the drought of the 1910s was a very real and quite widespread event). The 1950s a not as wet as in the west. The recent dryness in this region started earlier, in 1965, but is not as severe as in the wester case.

2.5 Choice of mean period

The graphs in Figures 1 and 2 use 1941-70 as the base or reference period for normalising. The analytical method used, however, can take any time period as its base. What the graphs represent are relative differences from year to year and these would be virtually the same whatever base period was used. It i informative, however, to recalculate using a more recent, drier period as the base. Figure 3 uses a shorter base period of 196 to 1987, the driest period. With the drier 1968-87 base period, there are more values above the zero line. The extreme drought periods around 1913, 1972 and the 1980s are more clearly highlighted.

Although the choice of a base period does not affect the actual rainfall amounts, it can, as is shown here, make a great difference to how a particular anomalous period is perceived.

3. Within Season and Region Rainfall Variations

We now reduce the spatial and temporal scales. There are marke spatial variations in the pattern of rainfall variability, investigated here by the use of national rainfall series.

In reducing the temporal scale, it is well known that the decli in the seasonal (May to October) totals has been concentrated i certain months, though here too there are spatial variations. combination of these spatial and temporal fluctuations also presents us with more detailed information about the possible impacts of the variations in rainfall.

3.1 National series

Of the six most westerly countries of the region (Senegal to Chad), it is Senegal that shows the greatest deficits in recent years (with the recent deficit period beginning around the end o the 1960s). A similar start date can be seen in the data for Mauritania. Burkina Faso and Niger show large deficits around 1913, equal in magnitude to their recent deficits. Deficit yea that start earlier in the 1960s can be seen in the series for Mali. The Sudan series shows much the same pattern as those

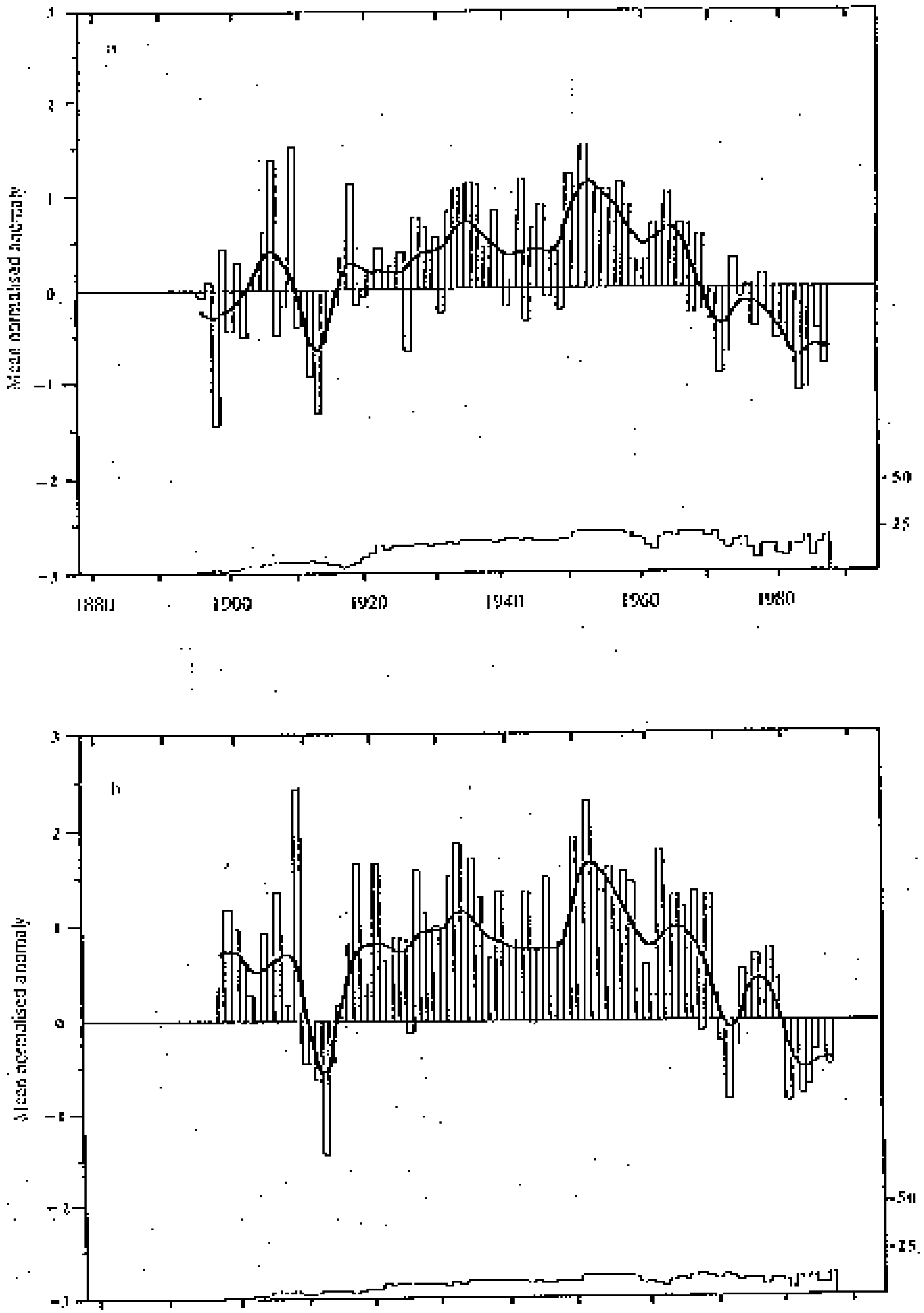

Fig. 3 : The effect of changing the base period in the calculation of long-term averages for the Western Sahel. While virtually reducing the effect of the deficits in recent years, the period 1920 to 1970 becomes anomalously wet.

countries further west.

In the two series for Ethiopia, the early, Belg, rains are in contrast with the main season, Kiremt, rains in recent years. While the Kiremt totals have shown something of a subdued 'Sahel picture' of deficits, since the mid-1960s the Belg rains have been favourable in the 1980s. For Somalia, neither of the rainfall seasons shows the persistent deficits in recent years common further west.

3.2 Analysis of individual months

It has been shown, mainly for the western Sahel, that the deficit in the seasonal totals has not been spread evenly over the rainy season. August, the wettest month, has seen the greatest percentage decline, with September also showing a marked decline. In Gambia, it was August and then July that showed the greatest relative deficits. Using regional series which extended back to 1900, Farmer and Wigley (1985) showed that, in the earlier droughts of the 1910s and 1940s, the decline in June and July was much more marked than is the case with the recent deficits.

The spatial variations of the recent deficits were analysed and a considerable degree of spatial variation in the results is apparent. The western part of the area shows a pattern of declines in all four months, while eastern areas only show marked and widespread declines in August and September. Overall, there are greater decreases in August than in the other months. In the extreme west there is a coherent region in which strong deficits in August are ubiquitous.

4. Implications of Intra-Seasonal Changes

After a run of twenty years all with rainfall amounts below the so-called 'normal' value (i.e. the 1931-60 averages), the meaning of the term 'normal' becomes questionable. The persistently low rainfall amounts have led some authors to discuss whether we are experiencing a true climatic change or merely an unusually protracted anomaly which is merely part of the natural variability. If 'change' is defined to mean a statistically significant difference in the average values of two periods, then we certainly have witnessed a climatic change. If the mean of the 1931-60 period is compared to the mean of the 1968-87 period for the western and central Sahel (Figures 1 and 2), the differences are statistically significant in each case.

The implications of this change are not insignificant. In the planning process, use is made of mean statistics for factors such as climate. Using means for 1931-60 would paint too optimistic a picture of Sahelian rainfall. In planning for the future, it would be more prudent to use means based on the last twenty years rather than the wetter earlier period.

To illustrate the effect of using a wetter or drier base period, we consider the FAO computation of the length of the growing period (LGP). The LGP is an important factor in the concept of agroecological zones (AEZ), which in turn form part of the basis for the estimation of potential (human) population supporting capacities. The FAO definition of LGP is the duration (in days) when the precipitation is greater than half the potential evapotranspiration (PET), with about 20 days added on at the end of the season to allow for additional evapotranspiration of stored soil moisture. The rainfall means on which the LGP calculations for the AEZ study are based are for 1931-60.

There is no doubt that an agriculturally-based classification such as the AEZ approach of the FAO is of major practical value. However, a base period of 1931-60 will clearly give an over-optimistic picture of carrying capacity for many parts of the Sahel.

In the calculation of the potential population supporting capacity, one of the first steps is to use the LGP to establish what crop can be grown. An over-optimistic LGP (compared to the recent period) may suggest a presently non-viable crop, leading to a totally erroneous population estimate. Given that the study area here is marginal semi-arid, a reduction in the LGP may even remove some areas out of the zone potentially able to support crop agriculture.

Thus, while the approach and methodology of AEZ work is in essence very valuable, one should be most cautious in accepting any implications based on 1931-60 data.

There is great potential for research work on the agricultural significance of the changing patterns of rainfall in recent years. Factors, easily amenable to analysis, include the number of rainy days within a season, the mean amount of rain per rainy day, and the frequencies and lengths of wet and dry spells within the rainy season.

5. Causes of the Rainfall Deficits

Many hypotheses have been put forward to explain the recent prolonged spell of dry years. However, none of these has been conclusively proven. Obviously, the immediate reason is a rainfall deficit, but this may be due to one or more of many factors; an absence of available moisture in the atmosphere; large-scale subsidence (which suppresses convective activity); divergent air-flow in the lower troposphere; a decline in atmospheric stability; and an absence of rain-bearing systems. Changes in such factors involve changes in weather systems on many spatial scales, from local to global. Figure 4 provides a schematic flowchart to guide us through some of the possible mechanisms. We will discuss them here, using as a framework, an increasing spatial scale.

Postulated local causes for the persistent drought conditions focus on changes in either the albedo (reflectivity) of the ground surface or in the soil moisture or both, with such changes hypothesized as resulting from vegetation loss due to overgrazing and removal of woody vegetation. These are thought to be biogeophysical feedback mechanisms, i.e. once they start they feed back on themselves to perpetuate the drought conditions.

In the case of albedo, removal of vegetation increases the albedo. This, in turn, changes the heat balance of the surface-atmosphere system. The large-scale changes in heat sources and sinks result in increased divergence in the lower atmosphere and reduced uplift in the higher albedo region. Less uplift means less rain, which means less vegetation, and so the cycle goes on.

A similar case exists for soil moisture. Less soil moisture gives less evaporation. The resultant change in the partitioning of latent and sensible heat contributions to the surface energy balance causes a net reduction in upward motion, reducing convective activity. This leads to less rainfall which further reduces the soil moisture levels and reinforces the initial cause.

The mechanisms for the albedo and soil moisture hypotheses are interrelated since they both operate through changes in the radiation budget of the surface. Both of these hypotheses have been tested many times with computer models.

In these model experiments, changes in the albedo or the soil moisture are imposed externally, and the resulting changes in rainfall are monitored. While these experiments do produce rainfall changes in the right direction, the imposed stimulus is generally much larger than has been observed in reality.

Thus, while the physical reality of the albedo and soil moisture mechanisms has been established, the exact nature of their role in the persistent drought is not so definite.

Remote forcing mechanisms have also been proposed. The two most important are deforestation and sea surface temperature changes. Deforestation on the Guinea Coast (which is occurring at one of the highest percentage rates in the world) has been proposed as a mechanism for reinforcing drought in the Sahel. When rain falls on a forest, a percentage of the moisture is returned to the atmosphere by evapotranspiration. In West Africa, the summer monsoonal airflow would transport this moisture further north.

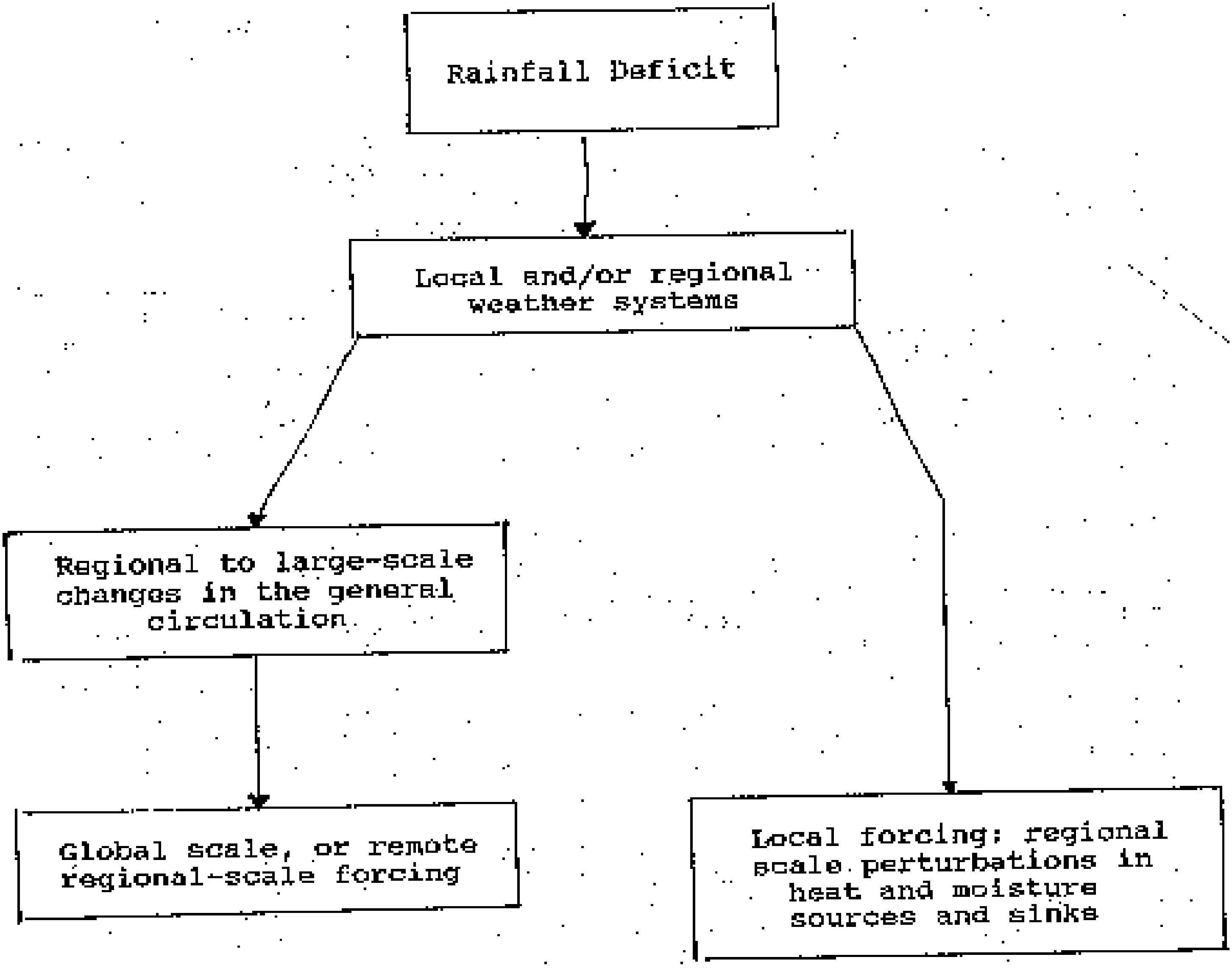

Fig. 4: Schematic diagram to illustrate possible causes of rainfall deficit in the Sahel (Farmer and Wigley, 1985).

This process may take place several times before the net remaining moisture reaches the Sahel. If forest is removed,

there would be a reduction in the amount of moisture returned to the atmosphere and carried northward. This hypothesis is one that could, and should, be tested using a transect analysis of rainfall isotopes from the Atlantic to the Sahel.

As we extend the spatial scale, the next area of possible causes lies in the Atlantic Ocean. In general terms, the southern Atlantic has been consistently and anomalously warmer than the northern Atlantic since around 1970. Various workers have used statistical techniques to relate Atlantic sea surface termperatures (SSTs) to variations in Sahel rainfall. While the statistical linkages are strong, the physical mechanism is more elusive.

The link between Atlantic SSTs and Sahel rainfall may be through a zonal circulation over the Atlantic. Alternatively, changes in the flow of the ocean currents may be weakening the summer monsoonal flow. Yet another possibility is that the reduced temperature gradient between the Sahara and the (warmer than before) Gulf of Guinea may influence the position of the African Easterly Jet and the consequent tracking of squall lines. So even though we can see relationships between variations in Atlantic SSTs and Sahel rainfall, we still have some way to go before we fully understand the reasons why.

Another possible cause for rainfall deficits in the Sahel is the quasi-periodic El Nino/Southern Oscillation (ENSO) phenomenon. Although ENSO itself is confined to the Pacific Ocean, extreme ENSO events, such as that in 1982/83, have been linked to climate anomalies in many parts of the globe.

The largest spatial scale for effects on Sahel rainfall is the globe. A candidate cause here would be changing global climates due to increasing levels of carbon dioxide and other greenhouse gases. These levels have been increasing steadily since the Industrial Revolution, while global-scale temperatures have also been increasing steadily. However, an undeniable statistical demonstration that the global warming is a greenhouse effect has not yet been made, largely because of natural long term fluctuations and the problem of picking out the greenhouse effect 'signal' from the natural 'noise'. Thus, demonstration of a regional-scale greenhouse effect (i.e. on Sahel rainfall) is impossible at present. Nevertheless, one would certainly expect the greenhouse effect to influence Sahel rainfall in the future (just as it will influence climatic conditions worldwide), and it is clearly important to study this process further.

Footnotes:

(1) The first source is the World Weather Records (WWR) data bank compiled and updated by the National Center for Atmospheric Research (NCAR), USA. The WWR data have global coverage, but for Africa the network has been greatly enhanced by the work of S E Nicholson. The main sources are within the Sahelian region. They are the CILSS Agrhymet centre in Niamey and the individual national meteorological agencies who have kindly provided data for updating the other series.

(2) Each value has the long-term seasonal mean taken away and the difference is then divided by the long-term seasonal standard deviation. The long-term period on which the mean and standard deviation are based here is 1941 to 1970, a period chosen because it is the most recent period with a wide geographical spread of available data points. Normalising gives a set of data series that are more readily comparable as each series will then have a mean close to zero and a standard deviation close to one.

__Reference__: Farmer, G. and Wigley, T. M. L. (1985). Climatic trends for tropical Africa. ODA Research Report. Climatic Research Unit, Norwich, UK.