May 2000

Using the SPI to Identify Drought

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Agnew, C. T., "Using the SPI to Identify Drought" (2000). *Drought Network News (1994-2001)*. 1.
https://digitalcommons.unl.edu/droughtnetnews/1

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This article was written in response to the recent analysis of drought in Turkey by Komuscu (1999). The study showed the relationship between drought duration, drought frequency, and drought time scale using the Standardized Precipitation Index (SPI):

$$SPI = \frac{(X_{ik} - \overline{X}_i)}{\acute{o}_i}$$

where

$\acute{o}_i$ = standardized deviation for the ith station
X_{ik} = precipitation for the ith station and kth observation
$\overline{X}_i$ = mean precipitation for the ith station

The index has the advantages of being easily calculated, having modest data requirements, and being independent of the magnitude of mean rainfall and hence comparable over a range of climatic zones. It does, however, assume the data are normally distributed, and this can introduce complications for shorter time periods. Komuscu claims that the SPI has not been widely applied or tested and employs the drought classes suggested by McKee et al. (1995), reproduced here in Table 1.

The SPI is of course the same as the Standardized Rainfall Anomaly, defined by Jones and Hulme (1996) and widely used in the analysis of desiccation in drylands. Figure 1 shows a typical example of such use, depicting the widely reported downward trend in Sahelian rainfalls (only continental Sahelian stations are employed after the suggestions of Ba et al. [1995], Janicot et al. [1998], and Nicholson and Palao [1993] that other parts of West Africa belong to a different climate regime). Komuscu's assertion that the SPI is underused for drought assessment appears to be correct, in that it is the persistence of the negative anomalies that receives most attention rather than an examination of their intensity or impact (for example, see Hulme, 1992). That is, rainfall anomalies are used to investigate desiccation rather than drought (see Agnew, 1995, for further discussion). The purpose of this paper is then to question the values assigned to the SPI for drought classes and to suggest alternative, more rational thresholds. The effect of using different drought classes is investigated using annual rainfalls from the Sahelian region of West Africa, and the

SPI	Probability of occurrence	Komuscu (1999) and McKee et al. (1995) drought classes	Proposed new drought classes
Less than -2.00	0.023	Extreme drought	
Less than -1.65	0.050		Extreme drought
Less than -1.50	0.067	Severe drought	
Less than -1.28	0.100		Severe drought
Less than -1.00	0.159	Moderate drought	
Less than -0.84	0.201		Moderate drought
Less than -0.50	0.309		No drought
Less than 0.00	0.500	Mild drought	No drought

Table 1. Probabilities for different standardized rainfall anomalies.

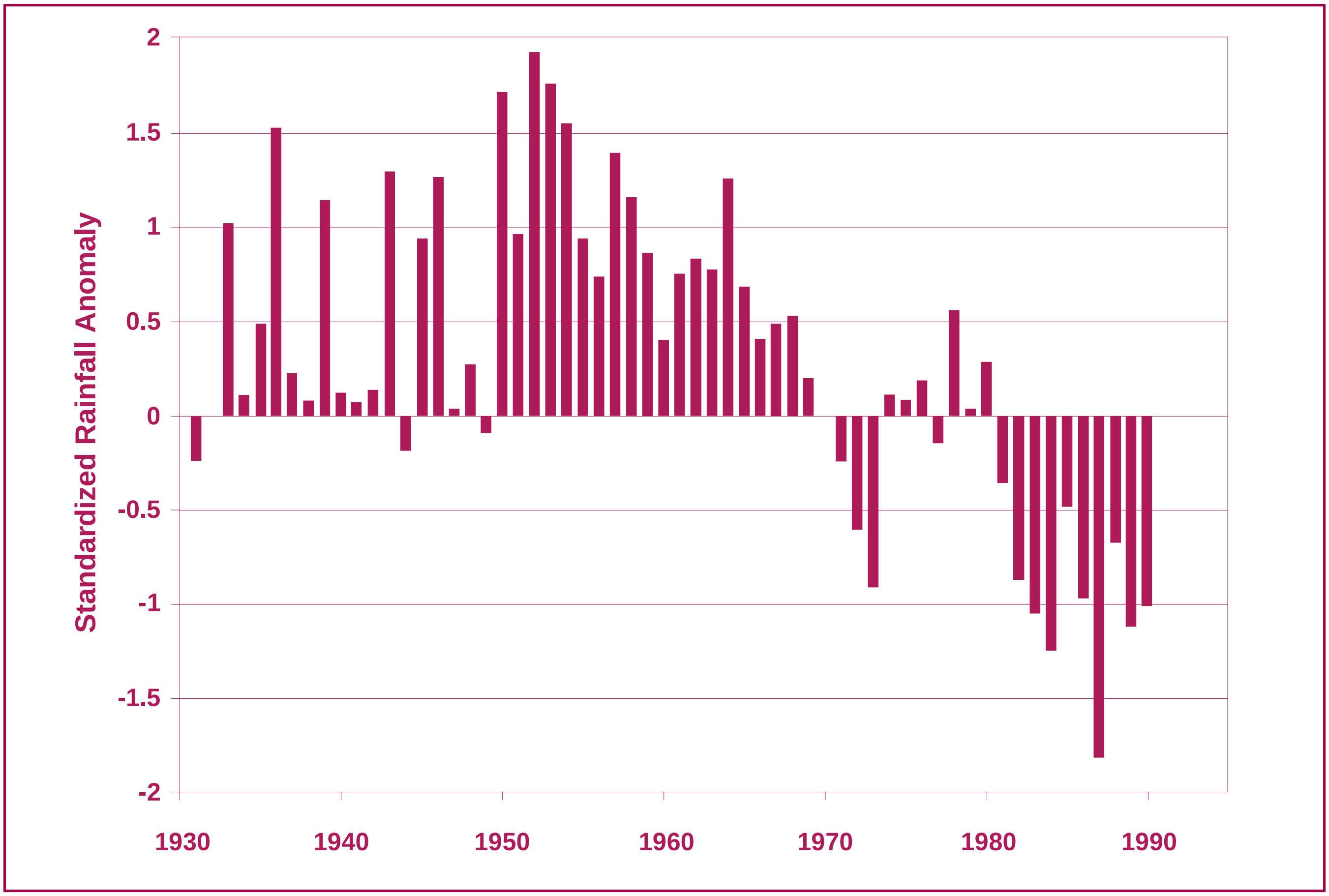

Figure 1. Standardized annual precipitation anomalies for the continental Sahel (Burkina Faso, Mali, and Niger), using the 1961–90 base period.

problem of changing the base averaging periods is presented.

What is Meteorological Drought?

This question has been addressed time and again (Agnew and Anderson, 1992; Wilhite, 1993), and it has often been stated that no universal definition of drought exists. There is little to be gained by reproducing a long list of conflicting definitions that merely illustrate the diverse interests of those who investigate drought. Most definitions anyway can be resolved into a generic statement that drought is caused by an imbalance between water supply and demand. Hence drought can be defined in terms of both supply reduction and demand increase, and there are numerous definitions of hydrological, agricultural, ecological, and economic drought that demonstrate this. Many, however, agree with Palmer (1965) and Beran and Rodier (1985) that drought is essentially a meteorological phenomenon. The analysis below adopts this perspective—that examining the occurrence of meteorological drought is the most fundamental requirement of any investigation.

The second premise of this account is that drought is an abnormal occurrence. This is an equally important point and it is the reason why it is suggested that Table 1 should not be used without modification for drought analysis. In McKee's classification (McKee et al., 1995), all negative indexes (SPI) are taken to indicate the occurrence of drought; this means for 50% of the time, drought is occurring. This is clearly nonsense! It also raises the notion of "persistent drought," which confuses drought with desiccation.

Based on Warren and Khogali (1992), drought can be distinguished from desiccation as follows:

- Drought occurs when moisture supply is abnormally below average for periods of up to 2 years.
- Desiccation is a period of aridization brought about by climate change lasting decades. Thus drought requires short-term relief, whereas desiccation requires longer-term measures such as resettlement and land use change.

When desiccation takes place, one can expect an increase in drought frequency, but a definition of drought that assumes any precipitation below the mean constitutes a drought will lead to exaggerated claims for climate change. Better that drought is defined as an abnormal event and that a significant change in climate is required for drought to become persistent.

New SPI Intensity Classes

The occurrence of drought has been widely reported for southern England in the 1990s, giving rise to concerns about low flows in the rivers of the region (Marsh et al., 1994; Acreman and Adams, 1998):

> The Environment Agency reported today that groundwater levels are so low in South East England that the environment and water supplies will be at risk next year if the weather remains drier than average this winter. *(Env. Agency Press Release 04/11/1997:113/97)*

Approaches to the definition of low flows can be divided into those that examine flow statistics, those that model hydrological processes, and those that employ biological/habitat conditions. Procedures for low flow estimation in gauged and ungauged catchments have been produced for the United Kingdom by the Institute of Hydrology (Gustard et al.,

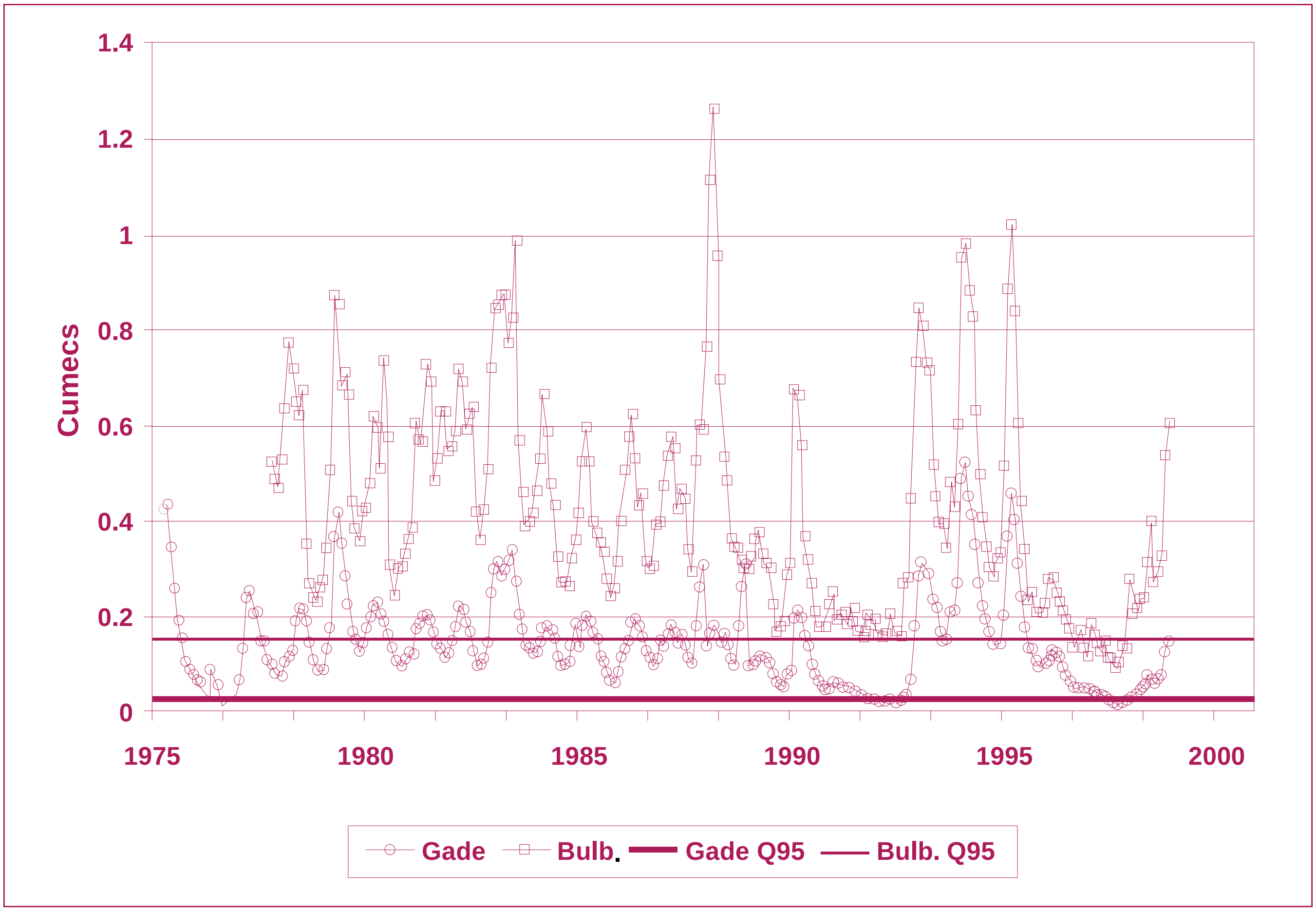

Figure 2. Daily flows for the Bulbourne and Gade rivers in Hertfordshire, with low flow thresholds Q95 plotted.

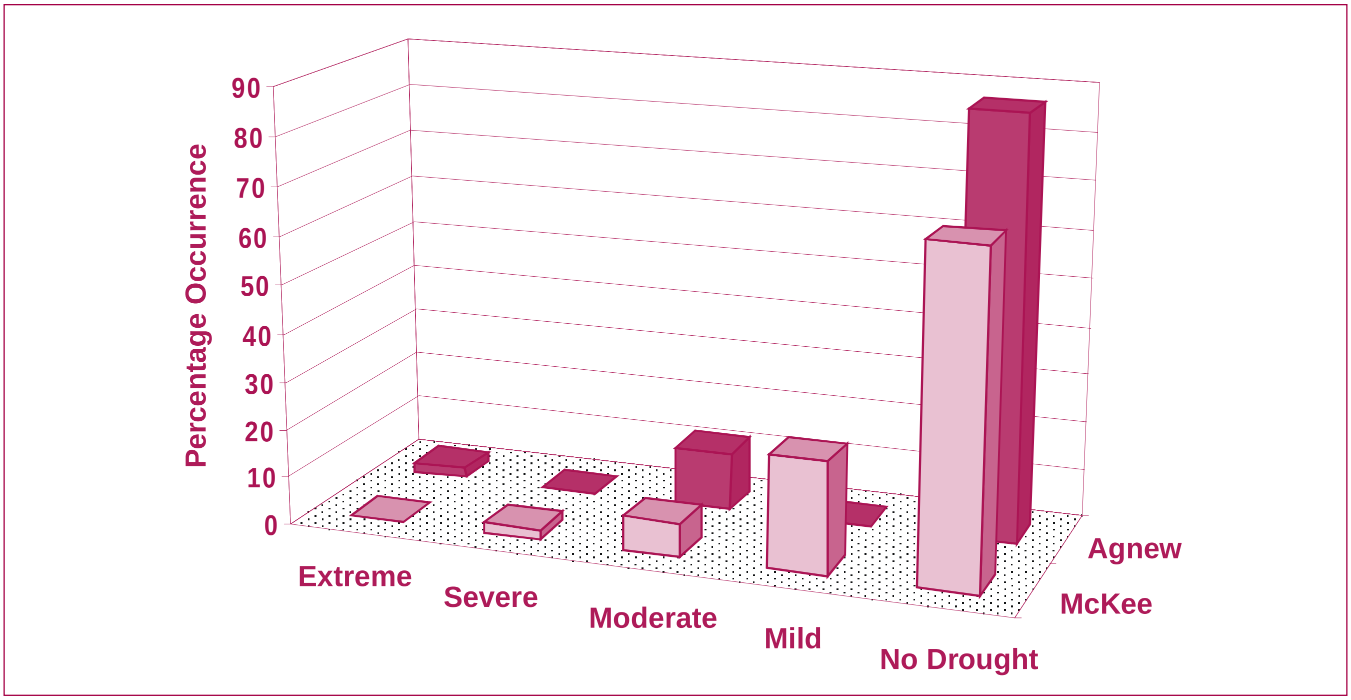

Figure 3. Drought classes (McKee et al., 1995, and author) for annual rainfalls in the continental Sahel region between 1931 and 1990, based on the 1961–90 averaging period.

1992). Claussen (1995) summarized the statistical approaches for low flow determination in gauged catchments:

- 7-day minimum (annual and 10-year minimum)
- 1-day minimum (median annual)
- 90% and 95% percentile exceedance
- Base flow index (ratio of baseflow to total flow)

The Q95(1) (the 95 percentile from the 1-day flow duration curve) is commonly used and is calculated here for two drought-prone rivers, the Gade and the Bulbourne, which flow in catchments some 40 km north of London. The Environment Agency (1997, p. 54) described conditions in this region:

> The cause of low flows in rivers is attributable to a combination of factors, which include lack of rainfall . . . seasonal fluctuations in the chalk water table, and water abstraction . . . Over the period October 1996 to September 1997, rainfall and groundwater recharge in the East Chilterns [were] 88% and 51% of the long-term average respectively.

Figure 2 shows the 1990s increase in low flows in these rivers and the use of the Q95 threshold to demarcate abnormal deficits (curiously, annual rainfalls have been increasing in this region during the 20th century, but the winter to summer rainfall ratio has also increased, as low rainfalls in summer are now more frequent). It is suggested that climatologists should learn from their hydrologist colleagues and employ a threshold similar to Q95 for defining meteorological drought.

The SPI drought thresholds recommended here therefore correspond to 5%, 10%, and 20% probabilities. Hence drought is only expected 2 years in 10 and extreme drought only 1 year in 20. This, it is believed, is a more realistic drought frequency than that used by Komuscu, and it corresponds to the employment of the term *abnormal occurrence*, as used in other branches of environmental science.

The impacts of changing the drought class boundaries are exemplified in Figure 3, based on the data used to draw Figure 1. It is evident that little change is made for extreme drought conditions, but the most important effect is to reduce the incidence of mild meteorological droughts. It may seem curious that there are a large number of no-drought years (68% or 86% for McKee et al. [1995] or the author's classes, respectively) given the widespread reports of drought

Drought class	**McKee et al. (1995)**	**1961–90 base period**	**1931–60 base period**	**Agnew**	**1961–90 base period**	**1931–60 base period**
	SPI value	McKee	McKee	SPI value	Agnew	Agnew
Extreme	<-2	0	1	<-1.65	1	3
Severe	<-1.5	1	5	<-1.28	0	6
Moderate	<-1.0	4	5	<-0.84	7	6
Mild	<0	14	30			
None	>0	41	19	>-0.84	52	45
Total		60	60		60	60

Table 2. The probability of different drought intensity classes based on the SPI, over the period 1931–60 for the continental Sahel.

in the Sahelian region (e.g., Nicholson and Palao, 1993, p. 371): “The Sahelian region of West Africa is well known for the extreme droughts it experiences. The current one has prevailed since the late 1960’s.” D’Amato and Lebel (1998, p. 956) note the “prolonged drought that has struck the Sahel for 25 years now.”

Table 2 provides an explanation. The standard period for computing climatological averages has recently been changed by the WMO from 1931–60 to 1961–90 (Hulme, 1992). Because the 1940s and 1950s were wetter than normal in the Sahel, using a base period of 1931 to 1960 to calculate the SPI produces a higher average and hence a greater incidence of drought. Thus there are 41 no-drought years between 1931 and 1990, using McKee’s classes (McKee et al., 1995) for the 1961–90 base period, but this drops to only 19 no-drought years using the 1931–60 base period. There is much less change using the author’s suggested drought classes because shifting the base period largely affects drought classes that are closest to the mean rainfall. Thus the drought classes suggested by McKee are highly sensitive to the base averaging period. Nevertheless, no matter which drought classes are used, there is some impact in changing to the new 1961–90 averaging period, and in a recent analysis (Agnew and Chappell, 1999) it was found that more than 40 years of data were required to compute the mean rainfall in the Sahel that was independent of the base averaging period.

A final point concerning the use of the SPI as employed here is that it was used to compute average conditions across the region known as the continental Sahel. Thirty-five stations were used from Burkina Faso, Mali, and Niger. Figure 4 shows the standardized rainfall anomalies from Figure 1, but with the maximum and minimum anomalies from individual stations superimposed. The huge variations, both negative and positive, suggest that care needs to be exercised when using the SPI as a spatially averaged index and that it would be better to compute the occurrence for each station rather than the approach employed above of averaging anomalies.

Conclusions

A new classification for drought intensity has been proposed based on the Standardized Precipitation Index (SPI). This uses probability classes rather than magnitudes of the SPI for classification and is therefore suggested as a more rational approach. The effect is most noticeable at the demarcation of mild and moderate droughts. There are, however, significant flaws in this approach. First, it is based on a designation of what is abnormal. In drylands it is difficult to calculate precipitation averages with any certainty and it has been suggested that the use of the 1961–90 thirty-year averaging period is questionable.

The approach also takes no account of impacts. If the resilience of people or the ecosystem has been diminished, then even a moderate drought can have an impact. Downing (1992) has referred to this as “vulnerability,” and this changes between parts of the community (e.g., children compared to adults) and

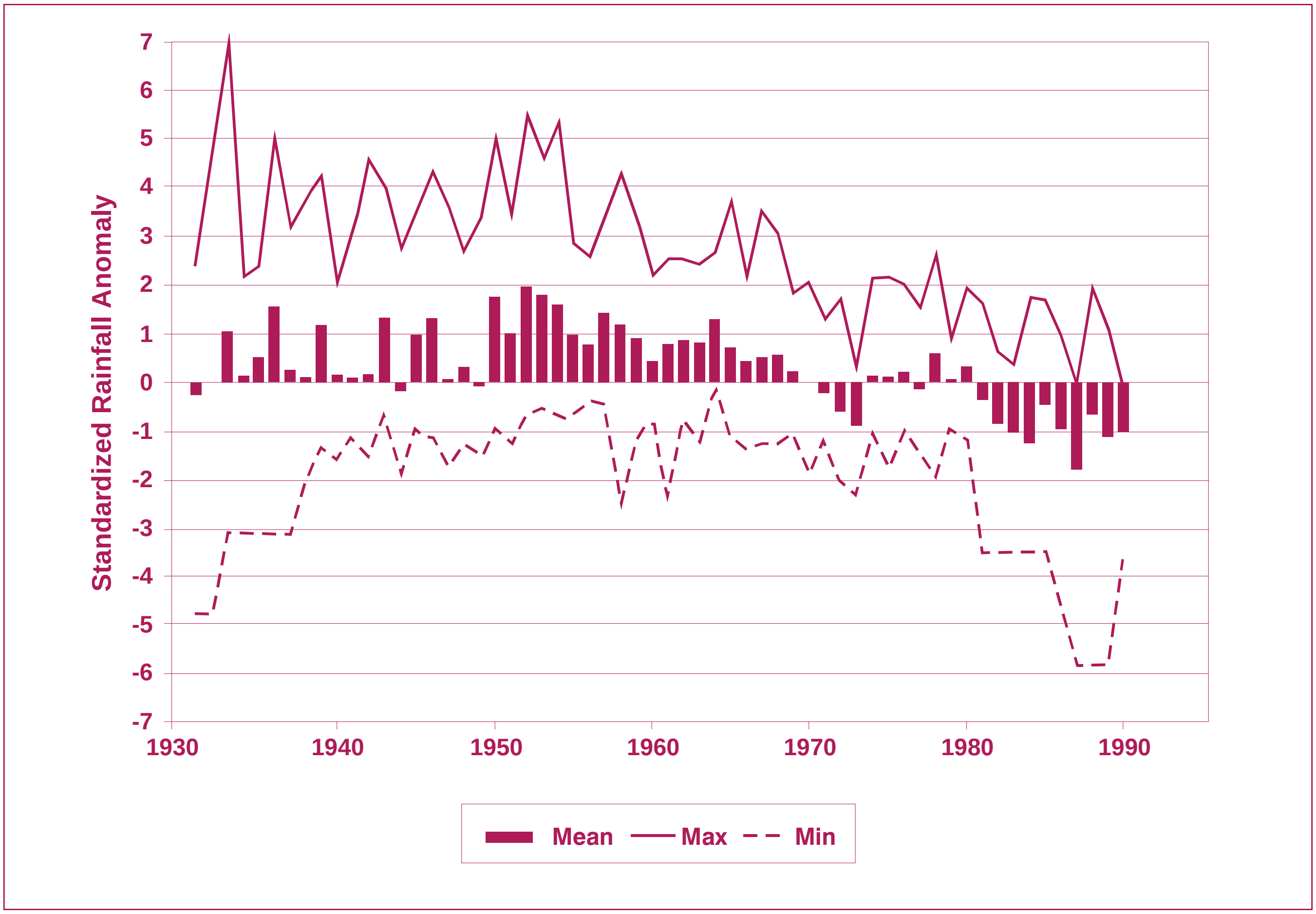

Figure 4. Average standardized precipitation anomalies for the continental Sahel using the 1961–90 base averaging period and the maximum and minimum anomalies observed at individual stations.

through time. Hence purely statistical definitions of meteorological drought should be treated with caution. Perhaps of equal significance is the omission within the SPI of any assessment of persistence. It is rare that drought in any one year causes major hardship. It is the sequence of low rainfalls that creates difficulties. For example, in England the drought of 1976 was really caused by the low rainfalls in the preceding year, while the drought of 1992 was the result of the low rainfalls from 1988. The SPI therefore needs to be developed from merely classifying intensities to include drought sequences, and the selection of appropriate averaging periods needs more attention.

Acknowledgments

The annual rainfall totals were generously provided by the Climate Research Unit at the University of East Anglia. The river flow data was provided by the Environment Agency, United Kingdom.

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