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Will the Sahelian drought end in 1985?

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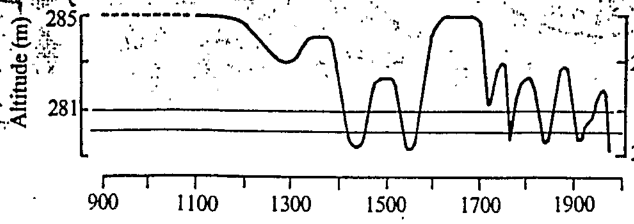

Fig. 1 Lake Chad level variations for the past 1,000 yr (from ref. 15). This curve synthesizes historical, geological and palynological data. Only the most important droughts have enough geological, historical or sociological impact to be recorded or memorized.

The great variability of rainfall in the Sahelian areas of Africa is well documented for all time scales during the Quaternary and historical periods. Since the beginning of the twentieth century the variability can be quantified from many meteorological and hydrological surveys[1–6]. The River Sénégal runoff gives a simplified view of the yearly mean rainfall over an extensive Sahelian and Sudanian area. The pattern of the annual river discharge over the nineteenth century shows short periods of drastic minimum followed by a slow return to longer periods of wet conditions with a double maximum. The mean time between the last three droughts is 31.3 yr with extreme conditions every 10.3 ± 4 yr. Extrapolating the curve of the mean annual modules suggests that the present drought should end in 1985 with full wet conditions being re-established in about 1992. If the same pattern continues, it is feared that a severe drought will occur around 2005.

In southern Sahara and northern Sahel the study of sediments, diatoms and pollens on cross-sections or cores of lacustrine deposits, has demonstrated that important environmental changes are frequent and repeated[7–12]. This variability of the climate during the past 40,000 yr is one of the main features of the Quaternary in this part of Africa[13]. On another time scale, Nicholson[14] and Maley[15] have shown that there have been alternating wet and dry periods during the past 1,000 yr. The Lake Chad level reconstitution (Fig. 1) shows how the apparent period of fluctuations depends on the method of data collection. The resolution is related to the accuracy and length of time considered. On a 10^3- and 10^4-yr time scale, only important droughts have enough geological, historical or sociological impact to merit being recorded. This is why drought recurrence seems to be more frequent in recent times. Major famines and droughts during the past 300 yr, have been correlated by Nicholson[14] who found they repeated at intervals of 72 ± 16 yr (56–86 yr between the maxima). For both the nineteenth and twentieth centuries it seems that one drought could occur during every generation. For example, a rainfall maximum was experienced around 1841 when the River Sénégal flooded into the Ferlo valley as far up as Linguère[16,17]. A minimum rainfall appeared soon after, in 1848, when the Trarza from Mauritania crossed the River Sénégal to invade the Cayor and Oualo region[18], at about this time the Lake Chad level was low[15]. The years 1870–1900 were relatively humid[14]. They could cover two periods of wet conditions because a break corresponding to a relative minimum is seen in Sénégal a short time before 1880 (ref. 14, Table 8.8).

Since the beginning of the twentieth century regular meteorological and hydrological surveys[2–6,19] have given a more quantitative and continuous set of data which illustrate the variability pattern of rainfall. The major rivers that flow through Sahel (Fig. 2), such as the Sénégal, the Niger, the Chari and partly the Nile, reflect the general annual and seasonal rainfall over a vast area of the Sahelian and Sudanian climatic zones. The annual discharges have been measured at several stations along the water course since the beginning of this century. The variation of the annual discharge shows a similar pattern for the various rivers[2] (Fig. 3): three drastic droughts clearly separated by two longer periods of humid conditions showing fluctuations

Table 1 Mean annual runoff and maximum height of the River Sénégal at Bakel

Year	Runoff (m^3s^{-1})	H_{max} (m)	Year	Runoff (m^3s^{-1})	H_{max} (m)	Year	Runoff (m^3s^{-1})	H_{max} (m)	Year	Runoff (m^3s^{-1})	H_{max} (m)
1903	631	9.49	1923	755	11.05	1943	666	9.75	1963	666	10.11
1904	735	11.15	1924	1,244	12.20	1944	330	6.95	1964	970	12.56
1905	871	10.19	1925	839	11.00	1945	945	12.26	1965	1,048	12.48
1906	1,229	13.28	1926	520	8.00	1946	745	10.85	1966	841	11.70
1907	521	8.90	1927	1,074	12.25	1947	666	10.75	1967	1,037	11.94
1908	765	10.60	1928	903	11.70	1948	572	9.90	1968	397	8.94
1909	900	11.70	1929	898	11.70	1949	467	10.10	1969	764	10.11
1910	669	10.20	1930	837	11.00	1950	1,152	12.71	1970	542	9.70
1911	537	9.55	1931	738	10.70	1951	842	11.60	1971	598	10.72
1912	563	9.50	1932	768	11.20	1952	718	11.38	1972	263	6.24
1913	271	5.20	1933	831	11.70	1953	631	10.51	1973	361	8.38
1914	443	7.25	1934	699	11.60	1954	1,068	12.32	1974	760	11.91
1915	591	9.30	1934	1,164	12.35	1955	1,049	11.54	1975	602	10.14
1916	689	10.60	1936	1,234	12.70	1956	952	12.06	1976	470	6.96
1917	646	11.30	1937	644	9.90	1957	1,029	11.82	1977	324	7.06
1918	1,142	12.60	1938	807	11.80	1958	1,037	12.89	1978	523	7.87
1919	529	9.85	1939	559	9.65	1959	788	11.68	1979	301	6.20
1920	833	11.80	1940	430	8.75	1960	621	9.84	1980		8.66
1921	430	8.90	1941	417	8.95	1961	944	12.51	1981		
1922	1,218	13.19	1942	437	9.56	1962	769	10.80	1982		

Refs are given in Fig. 4 legend. The floodheight (H_{max}) is measured, after 1950, with an error of ±1 cm. The runoff is then better than 5% accuracy. Before 1950 the error could possibly have a maximum value of 30 cm, the accuracy then fell from 5% for high values of runoff to 15% for low values (see ref. 4). From the measured maximum flood in Bakel, 8.66 m on 11 September 1980, it can be estimated that the hydrological year 1980 (ending in April 1981) will have a runoff of more than 500 m^3s^{-1}, confirming the increase of 1976 and 1977.

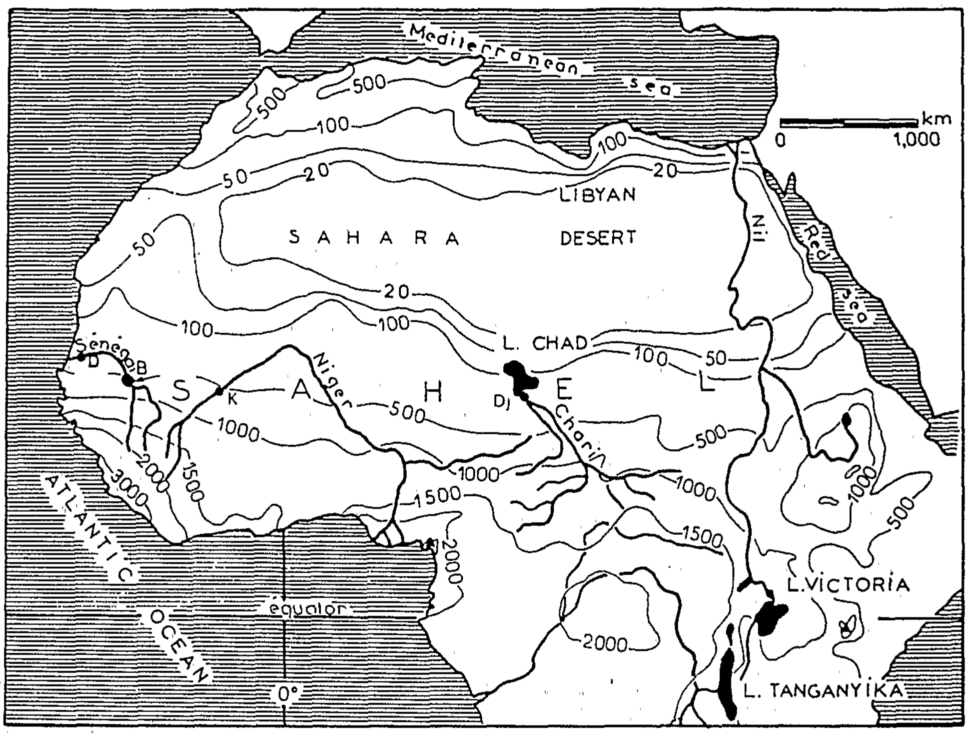

Fig. 2 Map showing the four main rivers flowing in Sahel. Isohyetes are from refs 28, 29. B, Bakel; D, Dagana; K, Koulikoro; Dj, Djamena.

mainly induced by flood plains evaporation, shape, lithology, soil, and so on. The River Sénégal has been taken as a typical example, and the Bakel hydrological station chosen because it is upstream from the main flood plains which experience great evaporation. The Bakel station (Table 1) gives a general idea of the mean rainfall over Sahelian and Sudanian zones. In both zones rainfall is a consequence of the North–South shifting of the monsoon. Meteorological data show that the annual rainfall in Sahel and Sudan fluctuates in the same direction[20,21].

To attenuate the effect of short-term variations, apparently 2 and 2.5 yr periods, curves have been constructed with various running means. We use the 7-yr running mean (Fig. 4) because the high and low points of this curve show the best coincidence with the years of maximum and minimum aridity. But similar results would be obtained with a 5-yr running mean more frequently used by hydrologists[5,19]. The curve (Fig. 4) shows several repeated characteristics. The slopes of the subvertical branches indicate that the onset of a drought is more rapid than the return to a wetter condition. Furthermore, each wet stage has a double maximum. This means that favourable conditions last ~18 yr, that is twice as long as arid periods characterized by peaks of ~8–12 yr. The drought maximum seems to recur after 31 ± 3 yr. If we consider only major events differing from the mean by more than 20%, the past 76 yr have seen seven of these extreme (maxima or minima) situations. They are separated by 8–15 yr; mean recurrence time is 10.3 yr. During the same period the solar cycle is 10.4 yr. Although the effect of solar cycles on climate is very controversial[22], indirect and complex relations could result from high atmosphere ionization[23,24] or geomagnetic field influence from solar wind[25,26].

The period of measured data (76 yr) is too short to establish a firm cyclicity in the drought appearance. Neither the nineteenth century observations, nor the records of the past 300 yr deny that a more or less dramatic drought could return at every generation, as claimed by the salt and trona producers whose livelihood depends on water table fluctuations[27]. If such a pattern continues some characteristics of the curve (Fig. 4) can be used to predict a date for the next rainfall maximum. The slope of the discharge curve during the transition to wet conditions can be used to estimate a slope between 14 and 27° for the next transition (Fig. 4). Consequently the long term average runoff should be reached at ~1985 (±2 yr) and the return to a maximum wetness at around 1992 (±4 yr). However, this favourable period will undoubtedly end and a new drought will occur towards the beginning of the next millenary; at ~2005.

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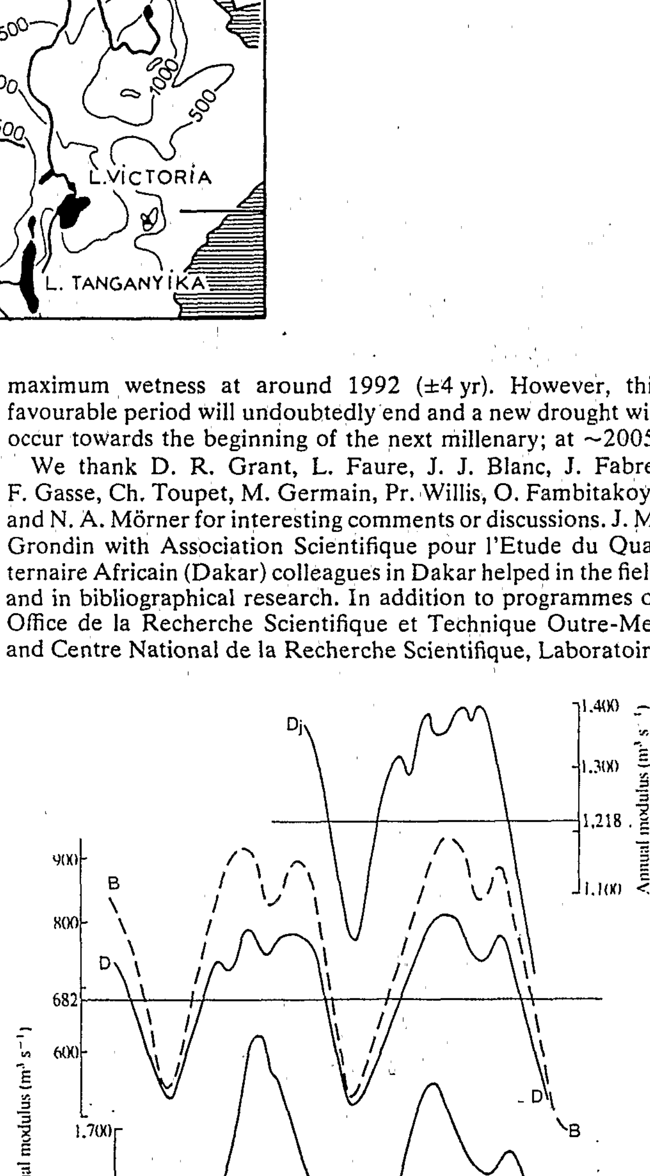

Fig. 3 Comparison of the pattern of river runoff in Sahel (7-yr running mean): Sénégal at Bakel (B) and Dagana (D), Niger at Koulikoro (K) and Chari at Djamena (Dj).

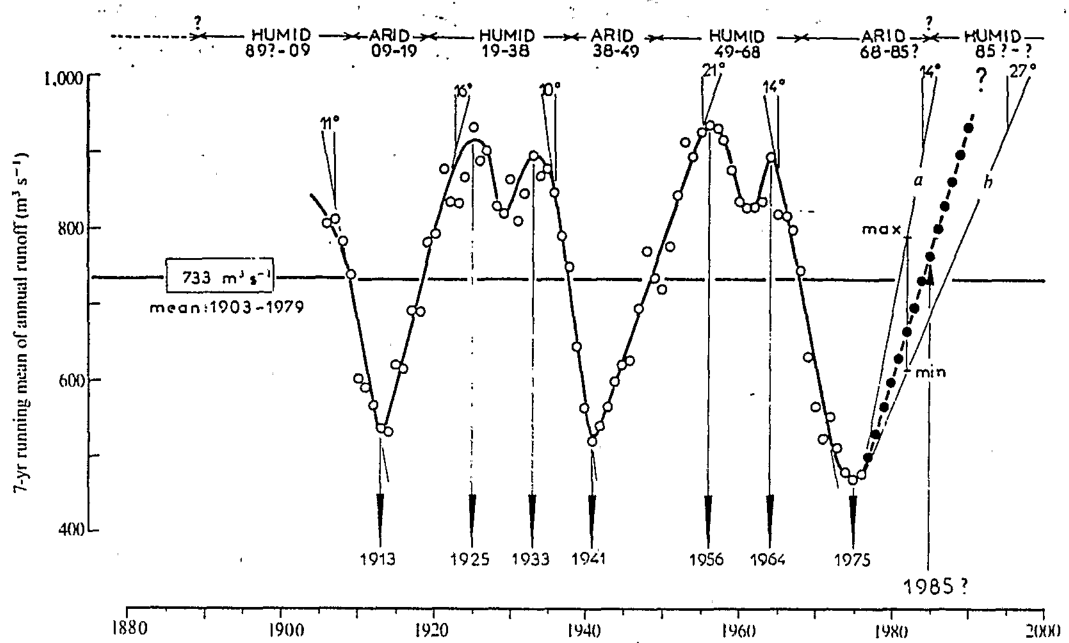

Fig. 4 Mean annual modulus of River Sénégal runoff measured at Bakel (7-yr running mean). The annual discharges have been compiled from documents of Senegal-Consult (1903–68), ORSTOM (1903–64), M. Juton (1969–71), A. Hamdinou (1971–75), ORSTOM (1975–78), Senegal Hydrological Service (1978–80). For predictive part of the curve (1977–92) a has the maximum slope (14°) of the preceding humid/arid change (the return to humid is slower than the humid/arid transition); the slope of b is given by deviation from the slopes of the two preceding fluctuations. The projected points are the mean annual modulus $D_{(year\,x)} = \frac{R_{(x-3)}+R_{(x-2)}+R_{(x-1)}+R_{(x)}+R_{(x+1)}+R_{(x+2)}+R_{(x+3)}}{7}$ where R = runoff. The ordinate indicates the mean annual modulus D.

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