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Spatiotemporal variations in hydrological regimes within Central Africa during the XXth century

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Abstract

Using several statistical tests, we divided into homogeneous segments the XXth century long discharges data series and the rainfall data series of the Congo River and of several of its right bank sub-catchments. These tests revealed that the River Congo at Brazzaville experienced a phase of so called stable discharge from the beginning of the XXth century until 1960, a phase of surplus discharge during the 1960s, testimony to its centennial flooding, and then from 1971 onwards, two successive phases of lower discharge. The second one, stretching from 1980 up to now, being the most accentuated with a 10% drop in the total series' interannual discharge (40 600 $m^3 s^{-1}$). It has only been very recently, in 1990 that the river dropped to its lowest level of the century. The dates at which hydrological discontinuities appear, are observed to be globally similar within practically all of the tributaries studied, the most significant being that of 1970, already well known in West Africa. During the second half of the century, these discontinuities occur roughly every ten years at the beginning of the 1960s, 1970s, and 1980s. Rainfall discontinuities are not as numerous as discharges ones. They separate homogeneous phases whose variations between them are less pronounced than that of those separated by discharges discontinuities. This underlines the major importance of the geographical location and of the physiographical characteristics of river basins on hydrological spatiotemporal variations. Lastly, we show that the effects of the recent drought are more visible and pronounced in the northern areas of this vast basin than in the southern ones.

Keywords: Central Africa; Congo river; Oubangui river; Discharges; Rainfall; Climatic discontinuities

1. Introduction

Rainfall, runoff and groundwater variability over West and Central Africa have been the subject of many works such as that of Nicholson (1979), Lamb (1985), Sircoulon (1987), Nicholson et al. (1988), Hubert et al. (1989), Janicot (1992), Fontaine and Bigot (1993), Hubert and Carbonnel (1993), Mahé (1993), Olivry et al. (1993), Nicholson and Palao (1993), Mahé and Olivry (1995), Aka et al. (1996), Wesselink et al. (1996), Bricquet et al. (1996, 1997), Servat et al. (1997), Paturel et al. (1998), Mahé and Olivry (1999), Nicholson et al. (2000) and Mahé et al. (2001). The reduction of amplitude in hydrological regimes which has been the century's most significant hydrological event since 1970, due to its duration and intensity, has attracted the attention of numerous

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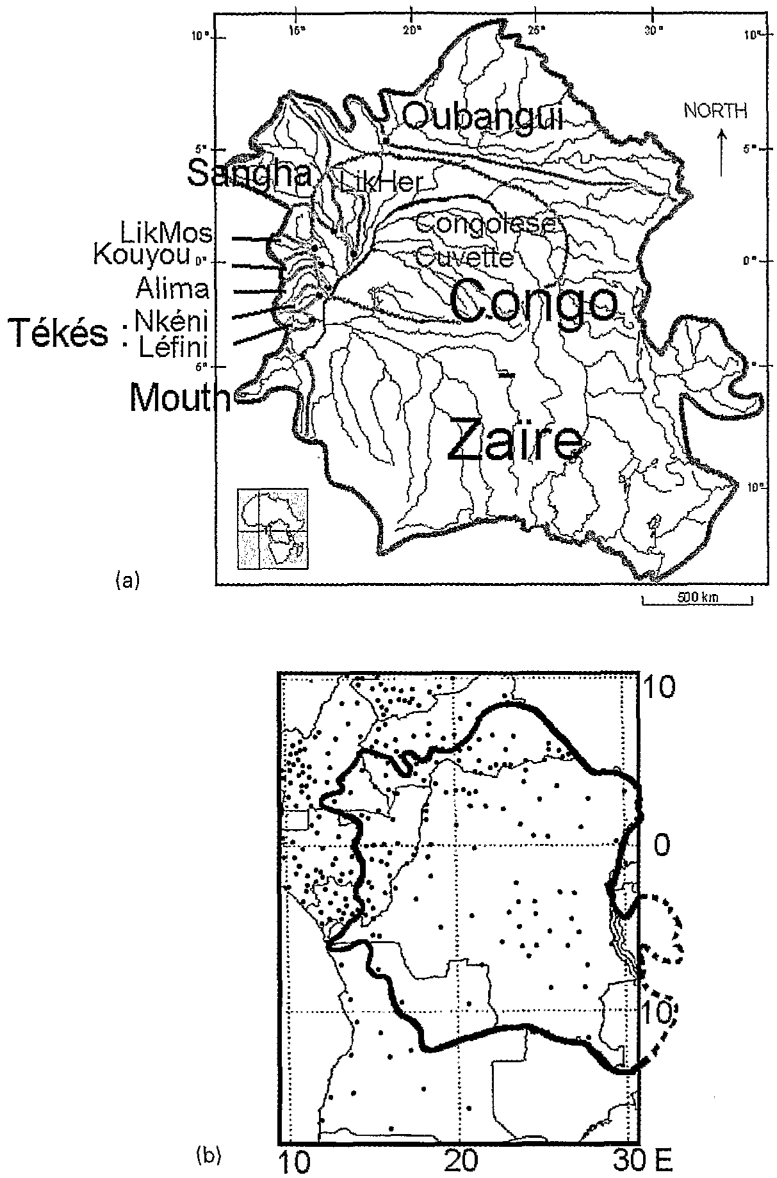

Fig. 1. (a) Presentation of the Congo basin and of the studied area, contours of the sub-basins of the Congo River. (LikHer: Likouala aux Herbes; LikMos: Likouala Mossaka) and (b) The raingauge network used in this study (Congo basin: bold outlined).

authors who have notably tried to link this to variations in sea surface temperatures of the south Atlantic Ocean (Anthony et al., 1983; Mahé and Citeau, 1993; Moron et al., 1995; Bigot and Moron, 1997). However, there are less works on Central Africa. A number of them study the relationship between seasonal variations in the Zaïre basin's water balance and the atmospheric vapor flow (Matsuyama et al., 1994), or propose climatic variations over the Zaïre basin's left bank being related to solar activity (Kazadi and Kaoru,1996). Others link the effects of climatic changes to the advancement of the drying up of water rivers and groundwater reserves (Mahé et al., 2000, Mahé et al., 2001; Orange et al., 1997).

Table 1
Statistical segmentation (Hubbert test) of annual rainfall and hydrological series of the River Congo's right bank sub-basins (taken from Larque and Maziezoula, 1995). The indicated discontinuities are the significant results of all the tests carried out using the software KHRONOSTAT

Basins	River gauging stations	Area covered (km^2)	Interannual discharge (m^3 s^{-1})	Segmentation of rainfall (mm) and variations (%)		Segmentation of discharges (mm) and variations (%)	
Oubangui	Bangui	488 500	3800	1951–1960: 1482		1936–1959: 272	
			(1936–93: 3900)	1961–1992: 1434	−3.2%	1960–1970: 315	+16%
						1971–1982: 315	−27%
						1983–1993: 174	−25%
Sangha	Ouesso	158 300	1600	1951–1973: 1604		1948–1970: 359	
				1974–1993: 1511	−5.8%	1971–1993: 287	−20%
Likouala-aux-Herbes	Botouali	24 800	280	1951–1981: 1750		1949–1959: 289	
				1982–1993: 1622	−7.3%	1960–1970: 459	+58.8%
						1971–1993: 336	−26.8%
Likouala Mossaka	Makoua	14 100	220	1951–1993: 1689		1953–1981: 503	
						1982–1993: 420	−16%
Kouyou	Owando	10 100	215	1951–1969: 1725		1952–1993: 575	
				1970–1985: 1654	−4.1%		
				1986–1993: 1566	−5.3%		
Alima	Tchikapika	20 070	590	1951–1957: 1762		1952–1960: 859	
				1958–1969: 1803	−2.3%	1961–1971: 976	+13.6%
				1970–1993: 1709	−5.2%	1972–1993: 914	−6.3%
Nkéni	Gamboma	6200	200	1951–1957: 1731		1952–1993: 965	
				1958–1969: 1802	+4.1%		
				1970–1993: 1662	−7.8%		
Léfini	Bwembé	13 500	420	1951–1993: 1616		1952–1993: 871	
Congo–Zaïre	Brazzaville	3 500 000	40 600	1951–1969: 1 600		1902–1959: 357	
			(1936–93: 40 300)	1970–1989: 1528	−4.5%	1960–1970: 433	+21%
						1971–1981: 373	−14%
						1982–1993: 335	−10%

On the basis of the evolution of the regimes of major West and Central African rivers, certain authors such as Olivry et al. (1993); Mahé and Olivry (1995, 1999) have noticed that the discharges' decreasing during the last decades is stronger in tropical Sahelo–Sudanian areas than in humid Equatorial areas. Laraque et al. (1998) calculated discharges for small regions within the Congo basin, for several periods of homogeneous discharges, statistically determined within a century-long data base.

Using a regional study, this work will aim to compare spatiotemporal variations in discharge and rainfall within the sub-basins of this equatorial hydrosystem's right bank in order to deepen the understanding of its hydroclimatic processes over the course of the century.

We used four statistical discontinuity detection tests onto each of the data series of the sub-basins of the River Congo's right bank, in order to find out homogeneous time series segments. We next took the hydrological segmentations of the Congo and the Oubangui as a reference in order to draw a comparison between sub-basins discharges variations. Their analysis enabled us to define which zones of the entire basin are most sensitive to changes in surface discharge. Finally, we discuss the origin of the homogeneous segmentations encountered, as well as the role that basin physiography plays in the basin's response to climatic changes in terms of discharge. Then, a comparison will be established with the hydroclimatic modifications of Western and Austral Africa.

2. Overview

The 4700 km long Congo River lies in a large curve that crosses the equator twice (Fig. 1a). Its basin, which occupies the middle of Central Africa between the parallels of 9°N and 14°S and the meridians of 11°E and 31°W, covers a total area of 3.7 million km^2. It represents the largest hydrological system in Central Africa and provides half of all river water supplies from the African continent to the Atlantic Ocean.

We investigated the right bank tributaries of the Congo River between the towns of Liranga and Brazzaville in the Congo Republic (Fig. 1a). This zone stretches over almost 1 million km^2 of which 73% is monitored by river gauging stations (Table 1). The rivers studied flow from north to south, crossing three very different physiographical areas.

The first is that of the Oubangui basin: a vast ferruginous cuirassed peneplain covered from north to south by steppe, by bushy/wooded savannah followed by dense forest lying under a transitional tropical, humid climate (1600–1800 mm yr^{-1}) (Bultot, 1971; Callède et al., 2001).

The Sangha's upstream basin provides a transition with the western part of the Congelese 'Cuvette' that lies further to the south: a vast depression dominated by dense, humid and shady forest that is partly flooded during the high flows season. The geology of this region, which has an equatorial climate and through which flows the Likouala-aux-Herbes and the Likouala–Mossaka rivers, is constituted of sandy or clayey quaternary fluvial alluvia.

Even further south lies the Kouyou basin which borders the sandy sandstone formations of the 'Batéké Plateaux', through which flow the Alima, the Nkéni and the Léfini rivers. This well-watered massif (1800–2000 mm yr^{-1}) of 700–800 m altitude is nevertheless covered by only a bushy savannah.

Those sub-basins of the Congo that are studied here, cover areas varying between 6000 and 500 000 km^2 with annual average discharges varying between 200 and 4000 m^3 s^{-1} (Table 1), to their main gauging stations.

3. Data and methodology

The data from approximately 250 raingauging stations (160 within the basin) covering the whole of the Congo basin and its close contours (Fig. 1b) were used for the reconstruction of annual missing data by using the 'Méthode du Vecteur Régional' (MVR) (Wotling et al., 1995; Mahé et al., 2001). Of course, the quality of the reconstruction of missing annual rainfall data series depends on the quality of information collected, and to a large extent, on the climatic representativeness of those geographic units chosen for the homogenization between stations. Finally, using an automatic processing chain (Mahé et al., 1994) we calculate the amount of annual rainfall between 1951 and 1993 within the sub-basins studied, except for the whole of the Congo basin whose

Table 2
Comparison of discontinuity years in discharges series, from three statistical tests: Hubert, Pettitt, Lee and Heghinian

River basins	Segmentation of discharges Hubert test year of discontinuity	Pettitt test year of discontinuity	Bayesian method of Lee et Heghinian year of discontinuity
Oubangui	1936–1959		
	1960–1970		
	1960–1970	1970	1970
	1971–1982		
	1983–1993		
Sangha	1948–1970	1970	1970
	1971–1993	1970	1970
Likouala-aux-Herbes	1949–1959	NO	1959
	1960–1970		
	1971–1993		
LikoualaMossaka	1953–1981	1981	
	1982–1993		
Kouyou	1952–1993	NO	NO
Alima	1952–1960	1960	1960
	1961–1971		
	1972–1993		
Nkéni	1952–1993	NO	NO
Léfini	1952–1993	NO	NO
Congo–Zaïre	1902–1959		
	1960–1970		
	1971–1981	1979	1981
	1982–1993		

available data terminates in 1989. The reconstruction of missing data is necessary in order to homogenize the series over the same period of time before calculations, but it artificially increases the importance of the actual average and it generates a lower variability. We can assume that gaps occurred randomly over the area up to 1989, which minimize the risk of under estimation of the variability, but after 1989 over Zaïre the lack of data could generate a bias in the calculation of area average rainfall over our area at its border with the Zaïre basin.

The number of raingauge stations as well as the percentage of observed data are higher over the area covered by the Congo right bank's basins which are studied than over Angola and Zaïre which form the main part of the Congo–Zaïre basin. Thus the average value of available data for the whole Congo basin is about 62%, and there are 38% of reconstructed data in the final database. For the whole area, data are more abundant during the 1950s and the 1960s (76 and 72%), than during the 1970s and the 1980s (64 and 40%). These percentages are much higher over the right bank's basins area (81, 83, 76, and 56%, for the four decades). For the 1990s, the percentage is only of 21% in regard of the total number of stations used for the four previous decades. But we did not homogenize the whole data set, but only a limited number of stations over a smaller area (two-third of the number of stations within the area of the right bank's basins).

The longest existing hydrological data series are those of the Congo River at Brazzaville–Kinshasa, and of its second tributary, the Oubangui River at Bangui, the data of which date back to 1903 and 1936 respectively (Laraque and Maziezoula, 1995). Due to a lack of hydrological data for the river's left tributaries, we concentrated our efforts on tributaries of the River Congo's right bank (Fig. 1a) whose main river gauging stations provide data series dating back to around 1950 (Laraque and Maziezoula, 1995), the time at which hydrometeorological networks were opening.

After taking into account the results presented by Lubes-Niel et al. (1998), four statistical discontinuity detection tests were systematically applied to each of these basin's chronological series. A 'discontinuity' can be defined by a change in the probability law of a chronological series at a given moment. We were only

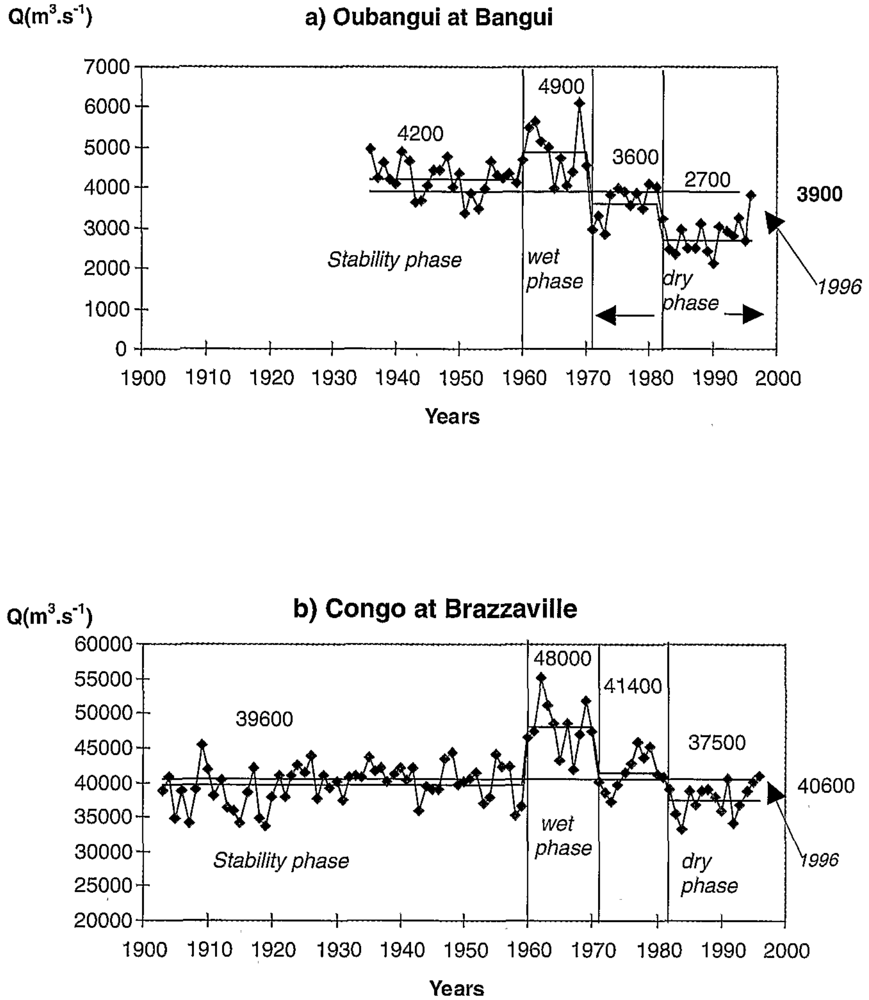

Fig. 2. Phases of homogeneous flows of the Oubangui (top) and the Congo rivers (bottom) during the XXth century.

interested in discontinuities affecting the average value, the non-stationarity of chronological series is defined by the existence of a singularity translated by a change in average (Aka et al., 1996), for all of the methods used: Pettitt's test (1979), Buishand's U statistic (1982, 1984) and Lee and Heghinian's Bayesian procedure (1977), and the Hubert segmentation test (Hubert et al., 1989; Hubert et al., 1998). Each of these mathematical tools are reliable for detecting average discontinuities and they also have their specificities: the 'Buishand and Ellipse de Bois' (Bois, 1986) tests provide a qualitative evaluation of the existence of a discontinuity, that of 'Pettitt' searches for an eventual discontinuity and situates it within the reading, 'Lee–Heghinian's Bayesian' method is based on the hypothesis that a discontinuity exists and determines the probability of its position within time, and 'Hubert's segmentation', looks for different discontinuities and in this way divides the reading into homogeneous periods. These methods are based on the hypothesis that the data series' variance is unchanging.

Next, rather than using a comparison based on fixed decades, we have chosen to use a comparative approach based on homogeneous periods according to discontinuity tests results.

4. Spatiotemporal variations in hydropluviometric data series during the XXth century

A synthesis of the results of the statistical tests used can be found in Table 1, where the average amount of runoff and rainfall for each of the basin's homogeneous periods is noted, as well as their variation in percentage from one period to the previous one.

With the exception of the group of basins that make up the Batékés Plateaux (Kouyou, Alima, Nkéni and Léfini), it can be observed that assumed discontinuities in the hydrological series are more frequent than those found in the rainfall series.

The discontinuity years in the Table 1 result from the Hubert test, and the Buishand test and the 'Ellipse de Bois' confirm the existence of a discontinuity in the series. The Pettitt and Lee and Heghinian tests (Table 2) confirm the major year of discontinuity chosen after the Hubert test.

4.1. Detection of discontinuities within rainfall series

Although most of the rainfall data series of the basins studied are divided into two temporal segmentations, those of the Batékés Plateaux are divided into three sections. The reason for this greater number of divisions must be linked to the region's location, which is more meridional, the fact that it is a massif of higher altitude and its proximity to the ocean.

The first rainfall discontinuity to occur in any of the right bank's sub-basins appeared in the Oubanguian basin in 1960, separating two homogeneous periods (1951–1959 and 1960–1992) with a reduction of 3% in rainfall between the first and the second period.

For all the other basins, the discontinuities occur 10 or even 20 yr later, with rainfall drops varying between 2 and 8%. For the whole Congo basin, rainfall dropped of 4.5% between the periods of 1951–1969 (1600 mm yr^{-1}) and 1970–1989 (1530 mm yr^{-1}).

4.2. Detection of discontinuities within discharges series

The dates at which discontinuities appear in the hydrological data series are similar for both of the main rivers studied, the Oubangui and the Congo rivers, whose data series are the longest ones.

Between 1936 and 1994, the Oubangui River experienced four phases of discharge that contrasted more sharply than those already recorded by Hubert and Carbonnel (1993) in the Congo's century-old data series (Table 2 and Fig. 2).

For each of these series, these phases are divided into two large periods comprising of a 'stable' and an 'unstable' period. The interannual discharges for the two rivers were respectively 4200 and 39 600 $m^3 s^{-1}$ during the so called stable first half of the century, whilst during the second unstable half of the century, discharges series show stationarity segmentations that occur at roughly ten year intervals. A humid subperiod can be observed between 1960 and 1970 with the occurrence of centennial flooding, when increases of respectively 16 and 21% can be seen (4900 and 48 000 $m^3 s^{-1}$ for the Oubangui and the Congo rivers, respectively) (Table 1).

Between 1971 and 1981, the Congo River then experienced a return to the average with 41 400 $m^3 s^{-1}$ (i.e. a drop of −14%), and from 1982 experienced a truly deficient phase during which the lowest discharges were reached. During this last episode, discharges were 10% inferior to those of the precedent, registering only 37 500 $m^3 s^{-1}$ (Table 1). On the other hand, the River Oubangui's 'dry' period started abruptly after the humid period of 1960–1970 when its interannual discharge dropped by −27%. This became much more pronounced as from 1982 when it experienced another drop of −25% compared to the previous period. In comparison with the initial period of 1936–1959, the regime from 1982 therefore dropped by almost −36% (Orange et al., 1997), whilst the comparison for the Congo for the same periods registers a drop of only −5%.

In order to facilitate comparisons between the basins, we will henceforth present the results following the period of common discharges data, i.e. between 1951 and 1993. It should be noted that the 1951–1993s average is similar to that of the homogeneous periods, 1902–1959 for the Congo River and 1936–1959 for the Oubangui River.

The hydraulicity, (ratio of the annual discharge by the interannual average discharge), for the studied period (in this case, 1951–1993) allows for an easy comparison of discharges variations between different rivers independently of the river basin surface or discharge amount. The variations in hydraulicity for

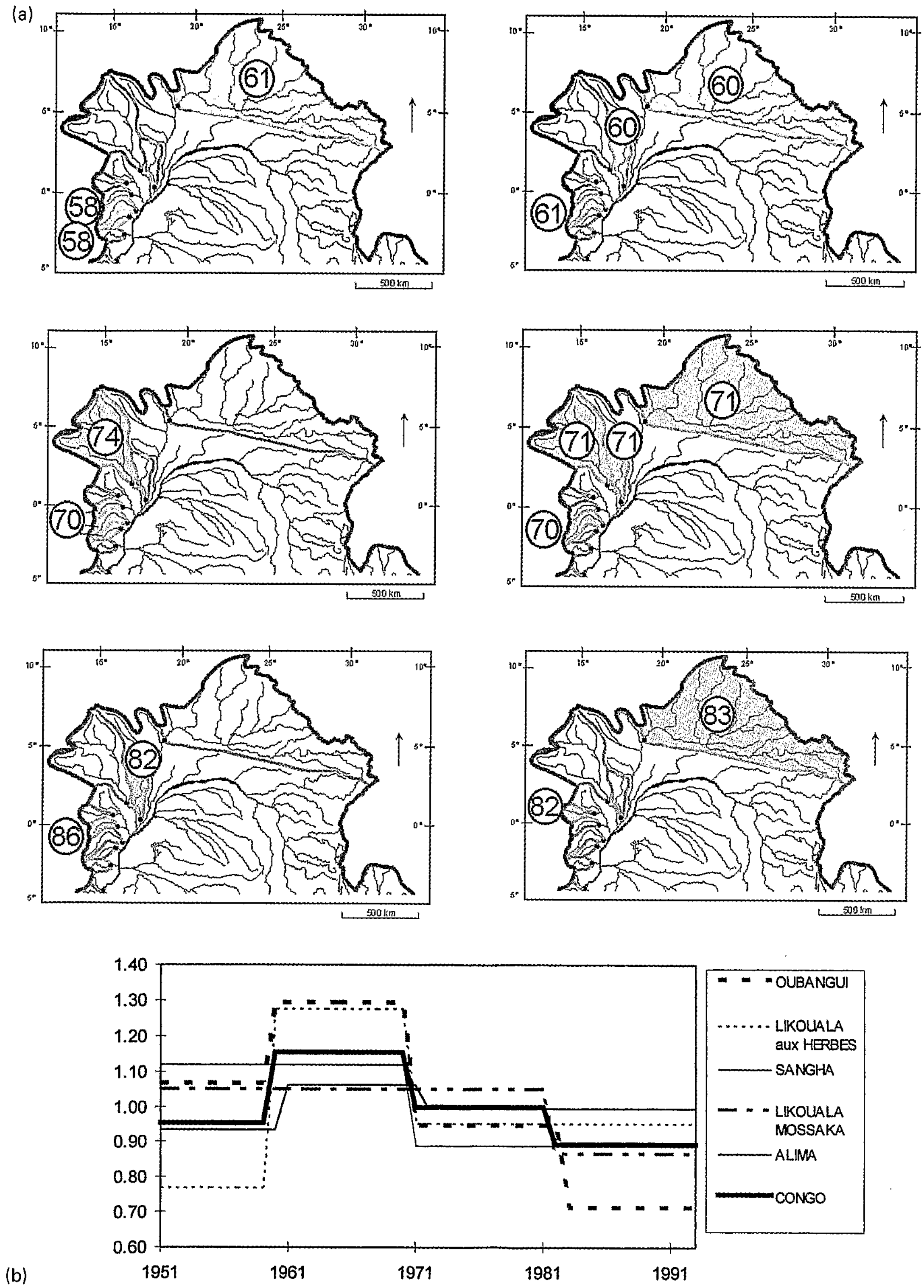

Fig. 3. (a) Segmentation of the rainfall and discharges series, according to the Hubert test. Top: before 1970, Center: between 1970 and 1980, Bottom: after 1980. (Rainfall: no discontinuity for LikMos and Léfini; Discharges: no discontinuity for Kouyou, Nkéni and Léfini) and (b) Segmentation of the hydraulicities of some characteristic tributaries of the River Congo's right bank.

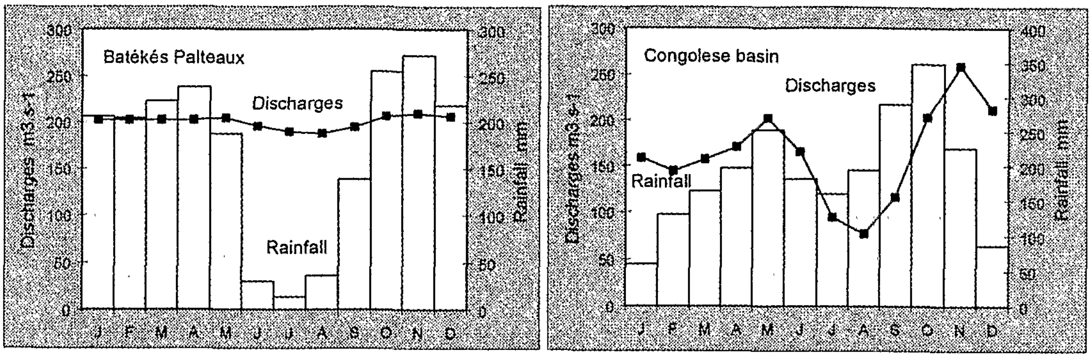

Fig. 4. Typical mean rainfall charts and hydrological regimes of the Batékés Plateaux (Djambala station:1969–92) (Nkéni at Gamboma:1953–93), and of the Congolese basin (Ouesso station:1966–94) (Likouala Mossaka à Makoua:1953–93).

each homogeneous discharge periods of five right bank's tributaries, that are representative of the different physiographic regions studied (Laraque and Pandi, 1996), depend on the physiographical regions through which these rivers flow, with the occurrence of a gradual 'roughly 10 yr step' decline since 1960 (Fig. 3a). During the second half of the century, the decade of 1970 marks a 'hinge period' with hydraulicities close to the unit, between two decades of symmetrically opposed hydraulicities: the 1960s 'wetter' period with values ranging from 1.04 to 1.3 and the 'drier' period between years 1982 and 1993 with values falling to −0.72.

From 1970, hydraulicities become inferior to the unit in practically all rivers (Table 1 and Fig. 3b). Exceptions to the rule are the Likouala–Mossaka, whose sole discontinuity fell in 1981, and the rivers of the Batékés Plateaux, for which either no discontinuity is statistically discernible or variations are only slightly ones. This latter case is illustrated by the Alima, whose values for the periods of 1951–1960, 1961–1971 and 1972–1993 are, respectively, 0.9, 1.1 and 1 (Fig. 3b). This remarkable, and also intra-annual, regulation of the Batékés Plateaux' regimes, which are seen to be practically 'insensitive' to the two rainfall discontinuities affecting them in 1957 and 1969, is due to the presence of a powerful sandy-sandstone aquifer in the plateau (Olivry, 1967; Laraque and Pandi, 1996). Contrary to the other basins studied, a smaller number of stationary segmentations are therefore observed within the series of discharge than within the series of rainfall. The thickness of this aquifer reaches about 400 m and it covers a surface of about 45 000 km^2 over the Congo country (Laraque and Pandi, 1996). Concerning the Batékés Plateaux, the weak average seasonal variations of the discharges, can only be explained by a great capacity for storage and consequently for flow regulation of the sandy-sandstone aquifer. Infiltration of the rainfall is very important in this thickness aquifer, which mitigates the peak flood and help minimize the drought. This is also the reason why it is in this region that some of the most regular rivers of the planet are encountered. The Batéké rivers hydrological regimes are practically independent of the regional rainfall regime (Fig. 4) (Laraque et al., 1998b).

Concerning the Congolese basin, the lower permeability of the soils, the interception of rainfall, the evapo-transpiration of the forest cover, and the direct evaporation on the floodable areas as well as the swamps, lead to an important water deficit. As there is no important aquifer as in the Batéké Plateaux, the hydrological regime is more similar to the regional rainfall rhythm (Fig. 4).

4.3. Analysis of hydroclimatic fluctuations

In order to draw a comparison between all of the tributaries studied, we adopted the previously defined main hydrological segmentations of the Congo and the Oubangui rivers as the reference period, bearing in mind that these were representative of all the regional variations within the smaller geographical units (Table 3).

In comparison with the 1951–1993 reference period in this study, the wet period of 1960–1970

Table 3
Mean annual rainfall (in mm yr^{-1}) and discharge (in $m^3 s^{-1}$) and their variation ratios by homogeneous hydrological periods over the 1951–1993 data series from the north (the Oubangui basin) to the south (the Léfini basin). Study period for the Congo rainfall: 1951–1989. Legends: LikHer—Likouala aux Herbes, LikMos—Likouala Mossaka, Oub—Oubangui. Example: ratio of rainfall or discharges for the Xi periods, say: [((Xi)− (51_93))/(51_93)] × 100

		North					South			
			Congolese cuvette			Batékés plateaux				
	Periods	Oub	Sangha	LikHer	LikMos	Kouyou	Alima	Nkeni	Lefini	Congo*
Rainfall (mm yr^{-1})	1951_93	1445	1561	1714	1689	1669	1744	1712	1616	1563
	1951_59	1476	1613	1777	1696	1702	1754	1723	1596	1576
	1960_70	1484	1617	1748	1737	1753	1834	1838	1689	1609
	1971_81	1428	1530	1730	1666	1644	1702	1667	1584	1511
	1982_93	1399	1497	1622	1661	1591	1692	1631	1594	1558
	51_59/51_93	2.1	3.35	3.68	0.43	2.0	0.58	0.63	−1.25	0.8
Inter-period ratios (%)	60_70/51_93	2.7	3.63	1.94	2.82	5.0	5.14	7.34	4.51	2.9
	71_81/51_93	−1.2	−1.93	0.91	−1.36	−1.5	−2.40	−2.66	−1.99	−3.4
	82_93/5193	−3.2	−4.08	−5.38	−1.66	−4.7	−2.95	−4.76	−1.37	−0.3
	71_93/51_93	−4.4	−6.00	−4.47	−3.02	−6.2	−5.35	−7.42	−3.36	−3.7
Average discharges ($m^3 s^{-1}$)	1951_93	3800	1615	281	216	215	584	200	416	41 600
	1951_59	4040	1739	217	206	194	546	192	425	39 700
	1960_70	4900	1873	359	246	258	615	209	433	48 000
	1971_81	3600	1477	277	224	211	584	199	413	41 500
	1982_93	2700	1393	260	188	187	582	198	395	37 400
	51_59/51_93	6.3	7.72	−22.72	−5.01	−9.6	−6.59	−4.09	2.10	−4.6
Inter-period ratios (%)	60_70/51_93	29.0	15.99	27.69	13.71	20.2	5.26	4.42	4.06	15.4
	71_81/51_93	−5.3	−8.56	−1.43	3.38	−1.7	0.00	−0.28	−0.72	−0.2
	82_93/51_93	−29.0	−13.74	−7.67	−13.24	−13.0	−0.43	−1.09	−4.94	−10.1
	71_93/51_93	−16.9	−11.50	−4.55	−5.37	−7.6	−0.22	−0.72	−2.73	−5.7

thus revealed increases ranging from +29% for the Oubangui to +5% for the whole of the Batékés Plateaux rivers. On the other side, using the same reference period, the driest period of 1982–1993 was accentuated by drops of −29% for the Oubangui River, −14% for the Sangha River, and −13% for both the Likouala–Mossaka and the Kouyou rivers; these drops then disappear from the entire Batéké Plateaux rivers, their average falling from 0 to −5%.

Compared to the same reference period, the Congo's interannual discharges during these two periods underwent intermediate hydraulicity variations of respectively +15 and −10% (Table 3). The Congo discharges show a composite variability, which is due to the sum of its tributaries.

5. Discussion

For the whole Congo basin during the second half of the century, the most significant absolute amplitude of discharge variation was that of the wet period 1960–1970, followed by that of the dry period 1982–1993 with a variation of −10%. Even when the whole of the twentieth century is studied, i.e. from 1903 to now, these two periods stand out with a variation of +18 and −8% respectively for the Congo's century-old hydrological data series.

However, the most marking event of the century is indeed the duration of this persistent actual phase of poor discharge recorded from 1970 and accentuated from 1982. On the scale of the Congo basin, the Oubangui River shows the largest amplitude of variation with −29% and 14 yr of dry period duration. This represents the main 'hydroclimatic discontinuity' of this century, followed by that of the 1960s 'wet phase', the amplitude of which reached +25%, in regard to the 1936–1993s average. Since 1993, this 'hydroclimatic drought' seems to progressively be coming to a halt, with the Congo and the Oubangui rivers recently having returned to 'normal' discharge when only in 1996 did they return to their interannual discharges after an almost regular increase since, respectively, 1990 and 1992 (Fig. 2).

But within this very last context that indicates a resumption of discharge, the right bank's second tributary, the Sangha River, shows a discrepancy with a year of very low discharge recorded in 1996, its 1250 $m^3 s^{-1}$ twenty years return period discharge being the second lowest discharge value after 1983. This clearly shows the spatial heterogeneity of hydroclimatic phenomenon at the scale of a so large river basin such as that of the Congo River.

By means of example we can compare the drops in precipitation and in discharge during the whole of this last dry period of 1971–1993 in regard to the interannual 1951–1993 average. It is noted that these vary simultaneously but non proportionally from north to south, with, respectively, −4 and −34% for the Oubangui basin, −6 and −22% for the Sangha basin, then −5 and −0% for the Alima basin (Table 3). The Congo basin integrates such spatial disparities with respectively −4 and −13% for the same periods. Table 3 also shows that, in regard to the same reference period (1951–1993), the magnitude of the discharge's variations are higher than that of the rainfall. The pattern is different for the Batéké rivers. For example, during the relatively wet period of the 1960s, the precipitation deviation from the interannual mean (+5.1%) in the Alima basin was practically equal to that in discharge (+5.3%). During the dry period (1971–1993), the precipitation deviation (−5.3%) was 26 times greater than that in discharge (−0.2%). In comparison with the other basins, these subdued responses of discharge to local rainfall variations illustrate remarkably well the dominant regulating role played by the powerful Batéké aquifer (Laraque et al., 1998b).

The origins of the spatiotemporal heterogeneity of variations in discharge must therefore be studied not only using a finer characterization of rainfall studied on a seasonal, monthly and daily scale (number of days of rain, length and intensity of dry and rainy seasons, etc.), but also bearing in mind the basins' variable physiography.

Another point to consider when looking at the Congo basin during the first half of the century, is the relative stability in discharge that preceded a period of contrasted variability, that occurred during the second half of the century. This can be linked to the climatic fluctuations (temperature, rainfall) noted in left bank of the Congo basin during the last thirty years by Kazadi and Kaoru (1996). In Austral Africa, Van Langenhove et al. (1998) showed similar stationary segmentations for hydroclimatic data series of the Zambezi River (1908–1997), with the beginning of the actual dry period in 1982, similarly to that of the Congo River. The hydroclimatic events in the Austral part of the Congo basin (and especially over the Kassai basin) might have a major role in the making of the average signal founded in the Congo River discharges data series to Brazzaville.

Other comparisons between segmentations were carried out by Hubert and Carbonnel (1993), using the same statistical tools, for the series of discharges within West African rivers such as the Senegal and the Niger rivers, and those of the Congo River. The segmentations are different between Western and Central African rivers. The former show a wet period occurring almost ten years earlier and of almost twice the length of those observed in the majority of Central African rivers. However, this spatiotemporal slide of ten years from West to Central Africa does not occurs during the dry discontinuity that appeared simultaneously around 1970. Since 1970, for the first time, the rivers of these two regions experienced altogether two discontinuities of stationary, albeit less pronounced in Central Africa, indicating successive drops in their discharge. This 'hinge' period, which is now well-known throughout West Africa, corresponds to a major hydroclimatic 'break' of the century which occurs almost simultaneously within the rainfall and discharges series of these two regions of the continent.

Furthermore, although the global rainfall drop in Sudano–Sahelian Africa reached 30% since the 1970s (Carbonnel and Hubert, 1985) and cause heavy falls in the hydrological regimes such as 50%, for example, for the Senegal River during the 1980s (Mahé and Olivry, 1995), a similar but less intense phenomenon occurred in Central Africa. For this same period, much smaller rainfall fluctuations of between 2 and 8% resulted in drops in discharge of close to 30% (Table 1); the ratio between variations in discharge to variations in precipitation varies between 2 and 4 times. The Oubangui River, however, stands out with drops in discharge that are almost nine times greater than those in precipitation (Table 3), meaning it the basin that is the most sensitive to climatic fluctuations in all of the right bank and probably in the whole of the Congo basin.

By reconstructing the discharge data series, not from principal gauging stations but by basin outlets, Laraque and Olivry (1996) and Laraque et al. (1998) have already shown how the Oubangui River is alone responsible for over three quarters of the recent reduction in the right bank's supplies to the Congo River, as much due to the amount of its supply (more than half) as due to the drop in its discharge (−29%). This represents 35% of the last drop in discharge experienced by the Congo River at Brazzaville, despite the fact that the area covered by the Oubangui basin corresponds to not even a fifth of that covered by the Congo basin.

6. Conclusions

This first systematic statistical categorization of the rainfall and discharges data series observed during the XXth century within the Congo basin and their comparative spatiotemporal study reveals similar stationary hydrological segmentations in the majority of the sub-basins studied, i.e. right bank's tributaries of the Congo River. Four segments were recorded during the second half of the century in the River Congo's century old data series at Brazzaville. The great interannual regularity in discharge of this latter river that has been observed from the beginning of the century until the 1960s leads one to think that the same must be true of its tributaries. The discharges data series of the Oubangui River, which began in 1936, seems to confirm this.

Concerning the Congo River, the fall in discharge that followed the period of exceedingly heavy discharge during the 1960s was in fact simply a return to the average over the century. It was only at the beginning of the 1980s that its regime experienced a significant drop and this has continued right up until the present day with a drop in its interannual discharge of 10%.

The Oubangui River, a tributary having the greatest range of hydroclimatic variation that discharges over a fifth of the total Congo's basin area, plays a leading role in the variations in hydraulicity within the Congo River to Brazzaville. However the vast expanse of the Congo basin and the complementary source of its water supplies from both the northern and southern hemispheres are responsible for the great hydrological inertia of this basin.

If a concordance exists between the dates of occurrence of hydrological discontinuities and rainfall discontinuities, there is no apparent spatiotemporal relationship between their amplitudes of variation. Indeed, depending on the basin, feeble rainfall variations can very well be translated by significant hydrological fluctuations and vice versa, because of the non linearity relationship between rainfall and discharges. With the exception of the basins of the Batékés Plateaux, rainfall discontinuities are generally not as numerous nor as pronounced (2–8%) as hydrological discontinuities which can reach 30%. This latter case reveals the complexity of the reaction process of discharge to precipitation, which, in function of the basins' physiography, integrates a memorization effect of the previous climatic variations, which can last several years.

The hydrological discontinuity of the 1970s, that was experienced by almost all of the basins, marks the start of the 'climatic drought' in Central Africa, a region also known as 'wet Africa'. This corresponds to that observed in the Sahel as well as in non sahelian West Africa where much greater rainfall drops of 20–25% as well as drops in discharge reaching 45–60% were observed (Paturel et al., 1997). By forecasting a dry climatic period, the discontinuity experienced during the 1970s therefore represents the most significant hydroclimatic incident within the whole of the Atlantic side of the African continent.

Even if catastrophic scenarios (drought, desertification, famine,...) such as those evoked by various authors including Kazadi and Kaoru (1996) do not appear to constitute a threat to the Congo basin in general, the hydroclimatic evolution of its northern margins are nevertheless worrying. The regional study of large fluvial basins therefore remains important, particularly as the disparities in the functioning of their hydroclimatic sub-units are masked by global integrating responses in outlet discharge.

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