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RAINFALL VARIABILITY AND DROUGHT INFERENCE IN SUDANO-SAHELIAN REGION OF NIGERIA

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ABSTRACT

Rainfall variability in Sudano-Sahelian regions of Nigeria (SSRN) over the 20th century and its potential links to the Sahelian drought have been examined using daily rainfall series from seven synoptic stations in SSRN. Using the 30 year climate interval (i.e., 1940-1970 and 1970-2000), the percentage changes in mean monthly rainfall depth and number of rain days, ranges between 4 and 33% for the core season and between 3 and 70% in the marginal periods. The standardized rainfall index (SRI) and normalized rain day index (NRI), two statistical descriptors, are defined and used in this study to highlight the variability in rainfall and infer drought occurrence in SSRN. Both indices reveal that the temporal variability in the amount and distribution of rainfall and number of rain days observed within the region have to a large extent contributed to the 1973 and 1984 drought occurrences in the region. Similarly, the relatively low NRI values observed within the region for the recent years may also be an indication that the drought conditions since the early 1970s might be reoccurring.

Keywords: Rainfall variability, rain days, drought inference, Sahelian region

INTRODUCTION

Rainfall is a crucial climate element in all the dry regions of the world. The variability of its spread and magnitude often leads to extreme and well-pronounced hydrological events, such as droughts, floods, erosions and other environmental hazards. The impacts of these consequent adverse events on human and natural systems in the arid and Sahelian regions, and the need to have a better understanding of this varying aspect of weather, have led to series of research studies in the past (Nicholson and Palao, 1993; L'hote et *al.,* 2002; Druyan and Koster, 1989; Dennett et *al.,* 1985; Dalezios and Bartzokas, 1995). This study therefore intends to use some defined statistical descriptors to describe the nature of the observed rainfall variability in Sudano-Sahelian Regions of Nigeria (SSRN) and infer the occurrences of drought in this specific region. The analysis and characterization of these rainfall extremes and their variability provide very useful site specific information needed in the design, development, operation and management of agricultural and water resource systems that are usually required to ameliorate such impacts.

MATERIALS AND METHODS

Study area

SSRN is a semi-arid region and lies between latitudes 10° N – 14°N and longitudes 3° and 14.5° E as shown in Figure 1. Its climate results from the influence of two main wind systems: the moist, relatively cool, monsoon wind which blows from the Atlantic Ocean towards the country and brings rainfall; and the hot, dry, dust-laden Harmattan wind which blows from the north-east across the Sahara desert. The mean temperature in SSRN is generally between 25 and 35 °C (Otun, 2005).

Rainfall data used in the study

Daily rainfall records used in this study are from seven well-spatially distributed synoptic stations shown in Figure 1. Detail information on each of these stations is shown in Table 1. These stations were managed by the Nigerian Meteorological Agency and each has continuous long term rainfall records. The available rainfall data for each meteorological station in SSRN was checked for consistency using the double mass curve analysis. Stations having wide ranges of gaps and missing records and inconsistency their records were excluded in the study. A list of years with missing records that were exempted in the analysis for each station under study is also included in Table 1.

Rainfall variability analysis

Variability is defined as the deviation of a hydrological time series over its mean. A dimensionless measure of variability that is widely used in hydrology is the statistical coefficient of variation (CV) according to Todorov (1985). Two similar statistical descriptive measure of variability defined in Equations (1) and (2) by Otun (2005) are the Standardized Rainfall Index (SRI) and Normalized Rainday index (NRI). Equations (1) and (2) are used in this study for the rainfall variability analysis.

$$SRI_i = \frac{R_i - \bar{R}}{\sqrt{CV_R}} \quad (1)$$

$$NRI_i = \frac{ND_i - \bar{ND}}{\sqrt{CV_{ND}}} \quad (2)$$

where: R_i is rainfall amount for period/season i, ND_i is the number of rain days for period/season i, CV_R and CV_{ND} are coefficient of variation of the rainfall amount and rain-days series respectively. CV_R and CV_{ND} are also defined in Equations (3) and (4), respectively. SRI_i and NRI_i are standardized rainfall index and normalized rain day index for the period/season i

$$CV_R = \left[\frac{1}{n-1} \sum_{i=1}^{n} \left(R_i - \bar{R} \right)^2 \right] \quad (3)$$

$$CV_{ND} = \left[\frac{1}{n-1} \sum_{i=1}^{n} \left(ND_i - \bar{ND} \right)^2 \right] \quad (4)$$

$\bar{R}$ and $\bar{ND}$ are mean rainfall amount and mean number of rain-days, respectively, and n is total no of data elements in rainfall depth or number of rainy days series.

A negative "difference" term in the numerator of Equations (1) and (2) gives rise to negative SRI and NRI values, which is a useful measure of rainfall-deficiency for the particular period or season and location. Negative NRI or SRI values can therefore be employed to describe the relative severity of rainfall deficits, and in turn used in describing or identifying historical drought occurrences. As seen in their formulations in Equations (1) and (2), both NRI and SRI have the advantage of suppressing the effect of local factors which causes strong variation of rainfall pattern over time and space.

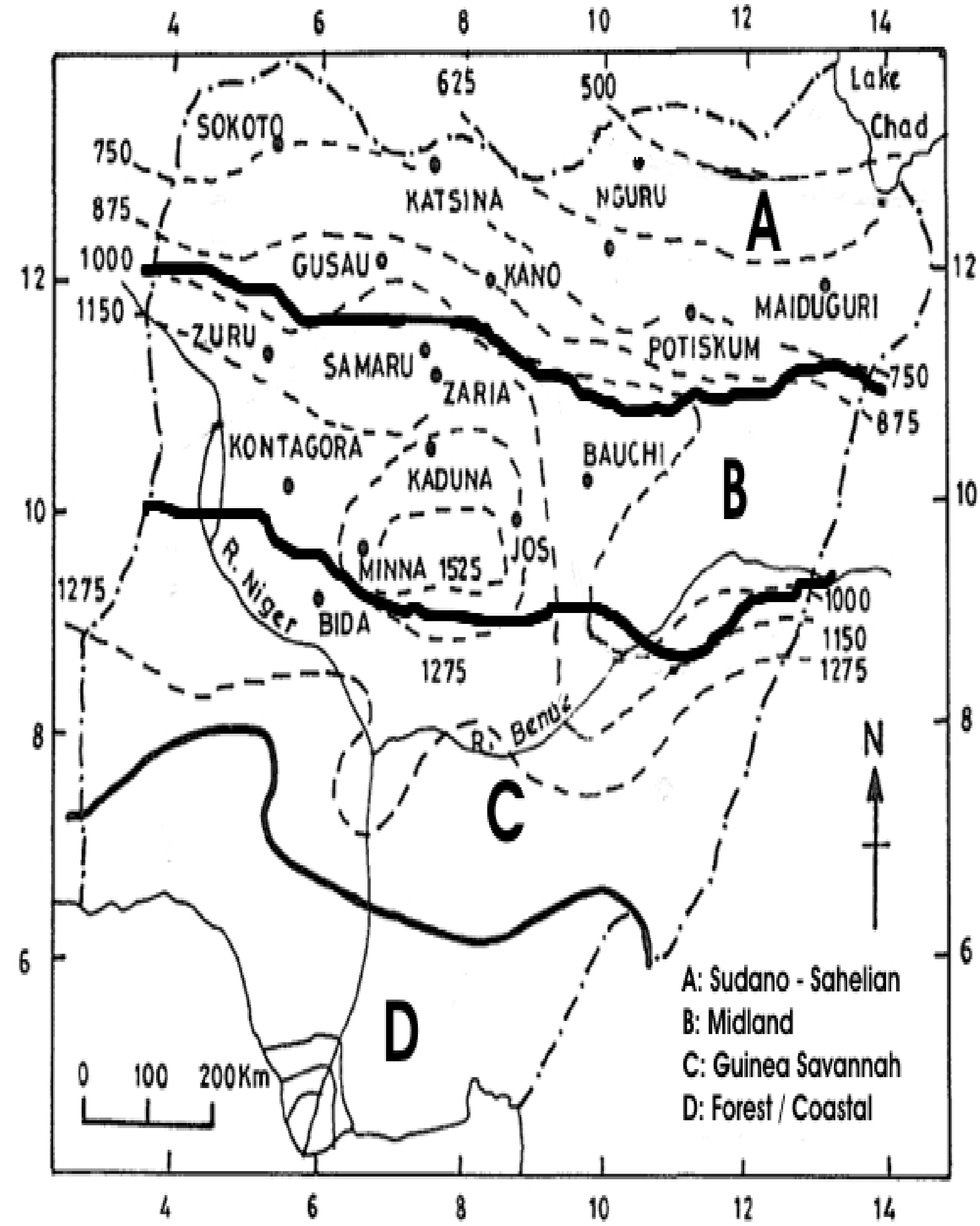


Figure 1: Map of Nigeria Showing the Sudano-Sahelian Region and the Synoptic Stations Used in the Study

Table 1: Information on the Meteorological Stations Used in the Study

S/No	Station	Period of Record Used		Latitude	Longitude	Altitude (m)	Years with Missing Records (Exempted in the Analysis)
1	Gusau	1942-	2002	12o 10' N	06o 42' E	461	1995,1996,1997,1998,2000
2	Kano	1916-	2003	12o 03' N	08o 32' E	469	Nil
3	Katsina	1922-	2003	13o 10' N	07o 41' E	514	1925,32,43,44,45,46,47,48, 1966,67,68,95,97
4	Maiduguri	1945-	2003	11o 51' N	13o 05' E	351	1949,1972,1981,1997
5	Nguru	1942-	2001	12o 53' N	10o 28' E	341	1961,1965,1986,1994, 1996
6	Potiskum	1936-	2003	11o 22' N	11o 02' E	412	1940,66,67,68,70,87,91,93
7	Sokoto	1952-	2003	13o 10' N	05o 11' E	348	1995

Table 2: Periodic Variations in Mean Monthly Depth of Rainfall

Location	Period	Mean Monthly Depth of Rainfall (mm)							
		April	May	June	July	August	September	October	Annual
Gusau	1940-1970a	21.6	79.7	138.2	209.7	303.8	198.4	26.5	986.8
	1970-2000	20.9	76.4	132.1	204.4	282.3	204.0	28.4	951.5
	% Change	3	4	4	3	7	-3	-7	4
Kano	1940-1970	9.5	66.3	123.1	203.1	301.0	123.0	11.0	839.3
	1970-2000	12.9	47.8	112.7	218.8	284.2	126.1	14.4	818.2
	% Change	-36	28	9	-8	6	-3	-31	3
Katsina	1940-1970	2.8	40.5	81.3	210.1	256.9	108.8	7.6	708.8
	1970-2000	3.2	23.9	62.9	150.0	168.1	90.0	10.4	509.2
	% Change	-12	41	23	29	35	17	-37	28
Maiduguri	1940-1970 b	8.6	29.2	77.3	185.0	254.6	94.0	20.3	670.1
	1970-2000	5.4	26.6	63.0	157.9	173.8	98.5	10.6	536.4
	% Change	37	9	18	15	32	-5	48	20
Nguru	1940-1970 a	3.9	28.7	55.9	134.7	218.3	92.0	8.2	542.7
	1970-2000	3.0	11.7	37.3	133.1	152.2	55.4	7.3	400.7
	% Change	23	59	33	1	30	40	11	26
Potiskum	1940-1970	8.8	40.5	95.6	198.3	264.0	125.3	20.5	753.6
	1970-2000	7.1	31.9	78.6	193.8	209.0	100.9	24.4	645.9
	% Change	19	21	18	2	21	19	-19	14
Sokoto	1940-1970d	11.6	40.9	99.5	192.6	240.5	132.2	21.1	739.2
	1970-2000	3.5	40.0	80.8	165.6	202.9	108.6	14.0	617.3
	% Change	70	2	19	14	16	18	33	16

Note: [a] the average for 1942-1970 was used; [b] the average for 1945-1970 was used, [c] the average for 1952-1970 was used

Specifically, some of the studies that have reported on rainfall variability and their associated anomalies in Nigeria include Adefolalu (1986), Anyadike (1993), Ati and Iguisi (2007), Hess *et al.* (1995), Oladipo and Salahu (1993), Olaniran and Summer (1990), Olaniran (2002) and Tarhule and Woo (1998). In comparison with other methods (e.g., percent of rainfall anomaly, and variations over normalized thresholds approaches), Otun (2005) showed that the main advantage of employing SRI and NRI lies in their ability to conjunctively describe both rainfall variability as well as define a drought index that forms an integral part of the decision support systems required for effective drought monitoring and management in any place.

RESULTS AND DISCUSSION

The available rainfall records between 1918 and 2004, for seven stations in SSRN, namely Gusau, Kano, Katsina, Maiduguri, Nguru, Potiskum and Sokoto were checked for consistency, using the double mass curve analysis, before being employed for the variability analysis in this study.

Rainfall variability

Table 2 shows the percentage change between the mean monthly and annual rainfall depth for the two recent 30-year climate intervals, the 1940-1970 and the 1970-2000. It clearly shows that there is an annual decrease of over 14% for at least 70% of the stations under study. There is also a general decreasing trend for most of the monthly rainfall depth variations. The incremental changes observed in some months are few and did not significantly change the downward trend in the 30-years mean monthly rainfall for all the stations under study in the SSRN.

On monthly basis, Tables 3 and 4, respectively, show the mean monthly variation in the rain days and rain depths for all the stations studied. As expected, the dry months starting from November to about April of sequent years are still notably reflected. The Tables also show the two distinct subperiods of the rainy months, namely the "core" period consisting of July and August with heavy rainfall, and the "marginal" periods, with relatively marginal rainfall, occurring in the months of May-June and September-October.

As also observed by Ati and Iguisi (2007), the core season is characterized by greater number of rainy days than for the marginal periods. It can also be deduced that the intra -seasonal variability on monthly scale is greater during the marginal periods than during the core period. Similarly, it can be seen in Tables 3 and 4 that over 70% of the total annual rains fall in the core season for all the stations under study.

Using the 30-year climate interval, i.e., (1940-1970 and 1970-2000), it is shown in Tables 2 and 5, that the percentage changes in mean monthly rainfall depth and number of rain days, ranges between 4 and 33% for the core season and between 3 and 70% in the marginal periods.

In both Tables 2 and 5 and for most months, the monthly values for 1940-1970 periods are higher than the corresponding values for 1970-2000 periods. These declining variations observed in the amount of rainfall depth and number of rain-days in SSRN between 1940 and 2000 have to a great extent a strong connection that can be used to infer the occurrences of drought conditions prevailing in SSRN. However, there is a marginal difference in the magni-

Table 3: Monthly Variation in Mean Number of Raindays for Stations Studied in SSRN

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gusau	0	0	0	2	7	11	13	17	13	2	0	0
Kano	0	0	0	1	5	8	13	17	10	1	0	0
Katsina	0	0	0	0	4	7	12	15	9	1	0	0
Maiduguri	0	0	0	0	4	7	12	15	8	1	0	0
Nguru	0	0	0	0	2	5	10	12	6	1	0	0
Potiskum	0	0	0	1	4	7	12	15	9	2	0	0
Sokoto	0	0	0	0	3	7	11	14	9	1	0	0

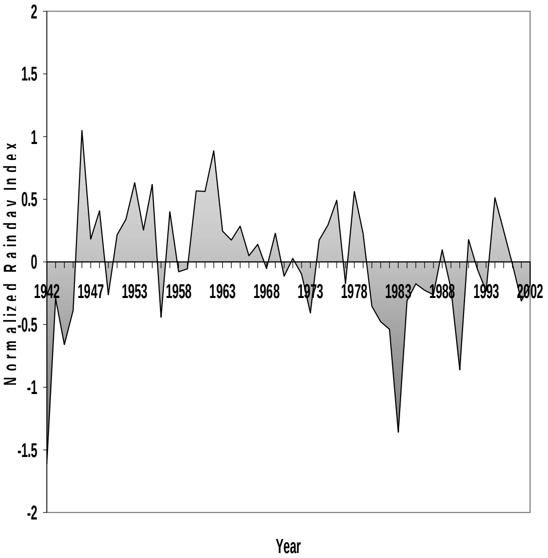
Table 4: Monthly Variation in Mean Rainfall Depths for Stations Studied in SSRN

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gusau	0.1	0.6	4.1	19.1	68.9	119.7	181.4	255.8	173.2	26.4	0.4	0.3
Kano	0.0	0.3	1.3	11.1	57.8	120.3	222.2	306.6	135.0	13.9	0.0	0.0
Katsina	0.1	0.0	0.4	3.4	34.8	68.7	144.7	192.9	89.2	8.2	0.2	0.0
Maiduguri	0.0	0.0	0.4	7.0	25.4	67.5	158.9	196.8	92.1	12.1	0.2	0.0
Nguru	0.0	0.0	0.3	3.0	18.6	43.3	122.9	170.3	67.5	7.3	0.6	0.0
Potiskum	0.0	0.0	0.1	7.5	33.1	76.6	173.2	210.0	102.8	19.8	0.1	0.0
Sokoto	0.1	0.1	1.2	7.4	38.9	85.2	178.9	211.5	115.3	16.5	0.2	0.0

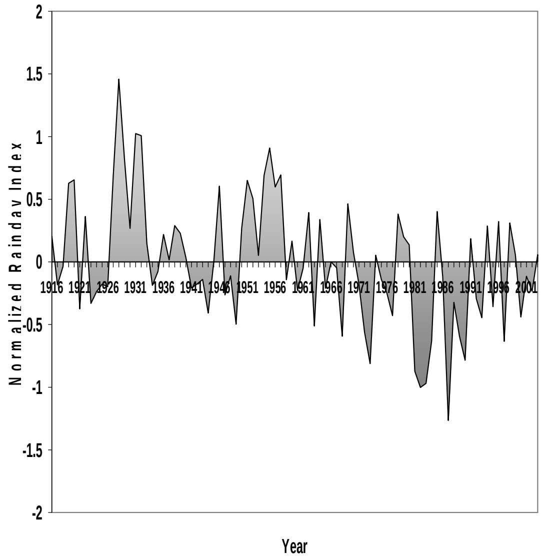
Table 5: Periodic Variations in Number of Rain Days

Location	Period	Monthly Total Rain Days							
		Apr	May	Jun	Jul	Aug	Sep	Oct	Total
	1940-1970a	28	74	106	130	169	138	27	681
Gusau	1970-2000	15	58	90	113	145	105	24	553
	% Change	46	22	15	13	14	24	11	19
	1940-1970	12	51	93	140	177	111	16	602
Kano	1970-2000	11	50	78	134	153	83	15	526
	% Change	8	2	16	4	14	25	6	13
	1940-1970	4	35	57	98	120	77	11	403
Katsina	1970-2000	5	32	61	107	128	73	10	417
	% Change	-25	9	-7	-9	-7	5	9	-3
	1940-1970 b	9	40	76	114	147	83	16	488
Maiduguri	1970-2000	8	37	55	101	116	68	14	401
	% Change	15	8	28	11	21	18	13	18
	1940-1970 a	3	29	57	103	131	78	11	414
Nguru	1970-2000	4	20	37	83	100	47	9	301
	% Change	-33	31	35	19	24	40	18	27
	1940-1970	10	48	73	108	155	91	23	510
Potiskum	1970-2000	8	37	56	108	126	74	20	429
	% Change	20	23	23	0	19	19	13	16
	1940-1970d	14	42	75	123	161	101	17	535
Sokoto	1970-2000	6	34	63	108	130	81	14	438
	% Change	57	19	16	12	19	20	18	18

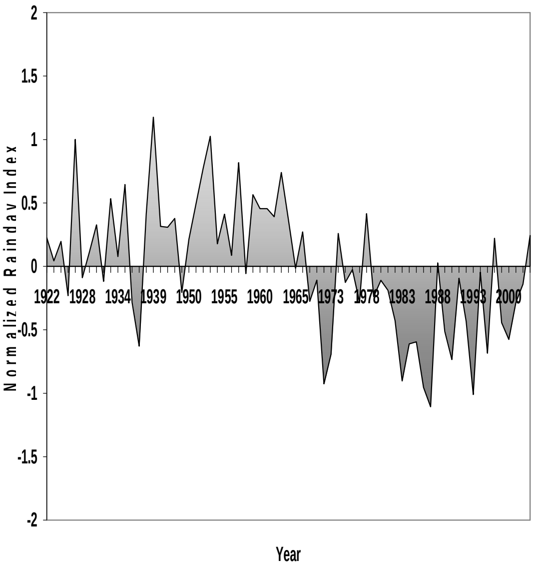
Note: Using available data: [a] the average for 1942-1970; [b] the average for 1945-1970 or [c] the average for 1952-1970 was used



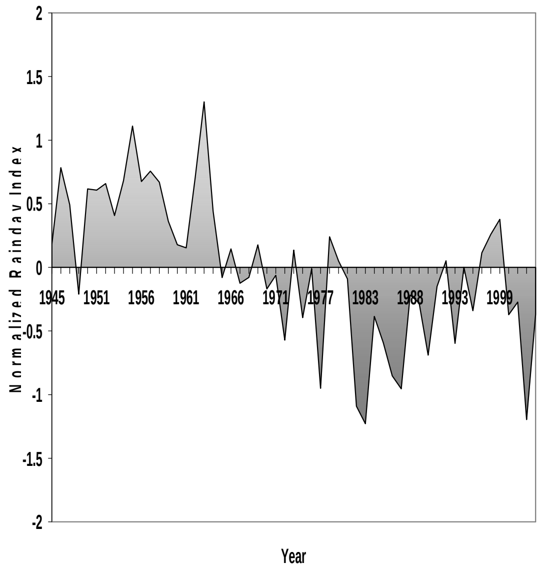
2(a): Mean Seasonal NRI Values at Gusau



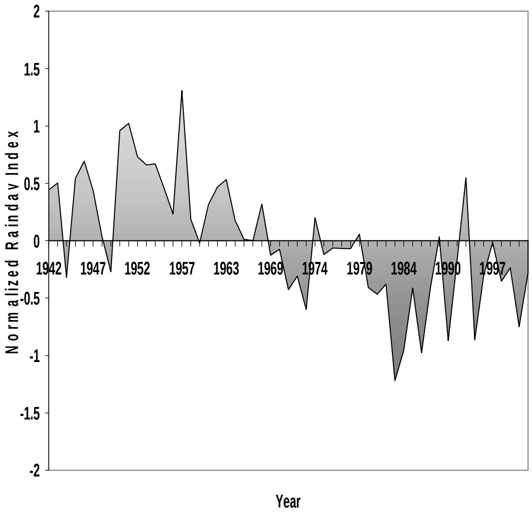
2(b): Mean Seasonal NRI Values at Kano



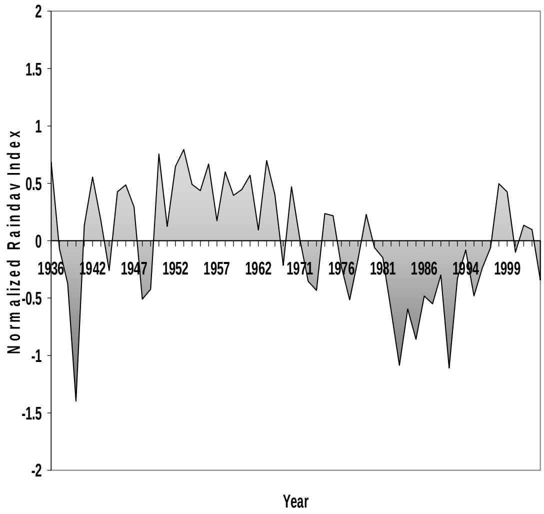
2(c): Mean Seasonal NRI Values at Katsina



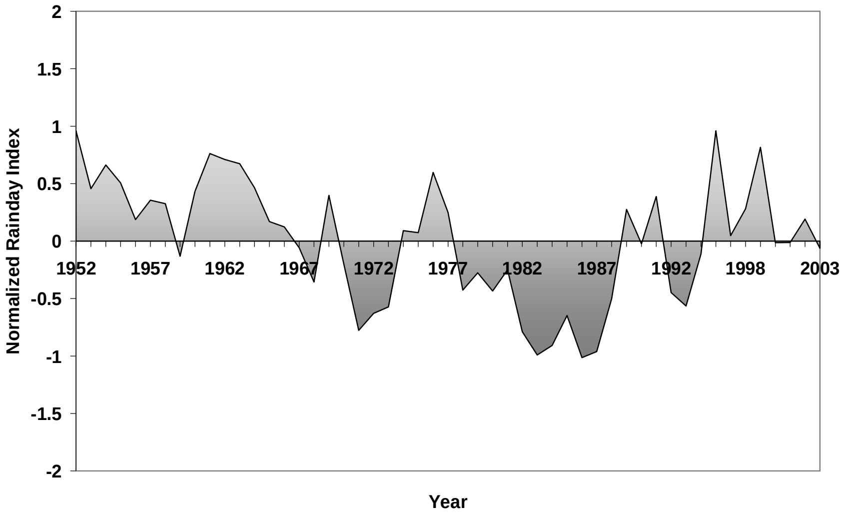
2(d): Mean Seasonal NRI Values at Maiduguri



2(e): Mean Seasonal NRI Values at Nguru

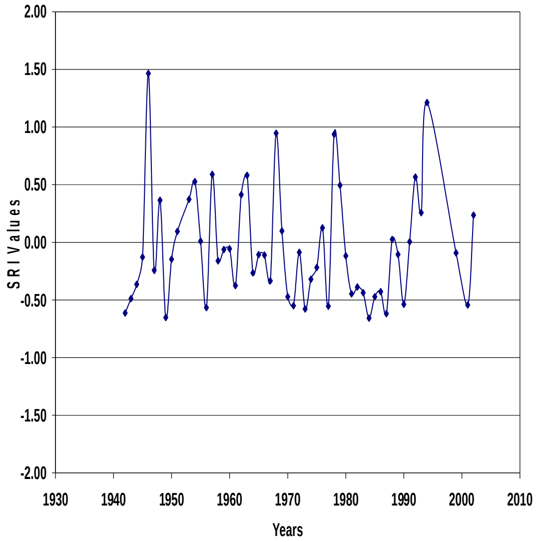


2(f): Mean Seasonal NRI Values at Potiskum

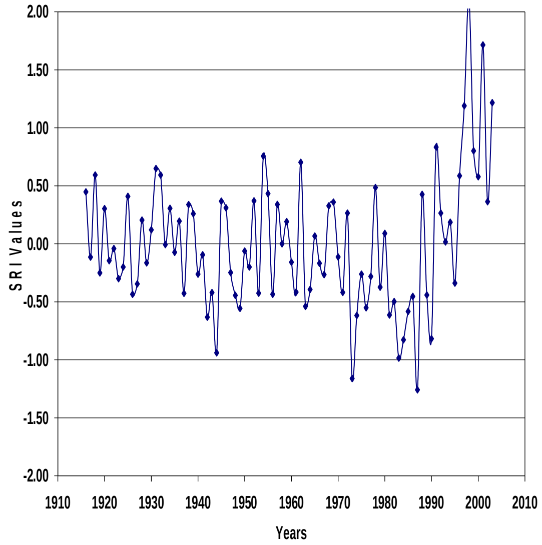


2(g): Mean Seasonal NRI Values at Sokoto

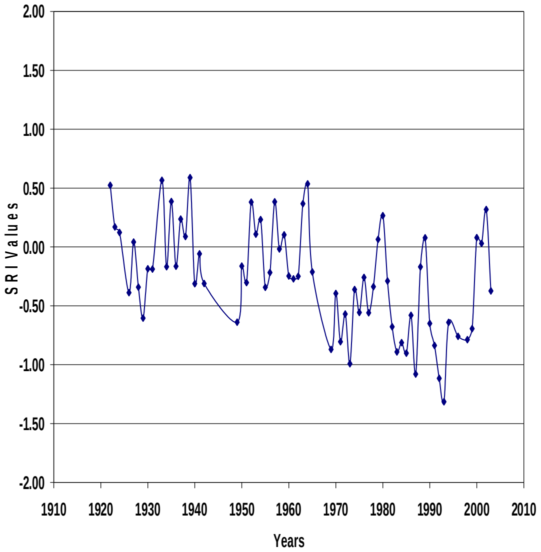
Figure 2: Distribution of Seasonal NRI Values at Gusau, Kano, Katsina, Maiduguri, Nguru, Potiskum and Sokoto Stations



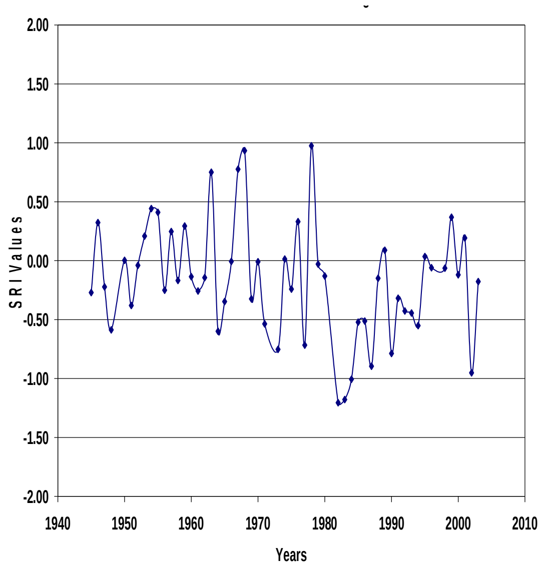
3(a): Seasonal SRI Values at Gusau



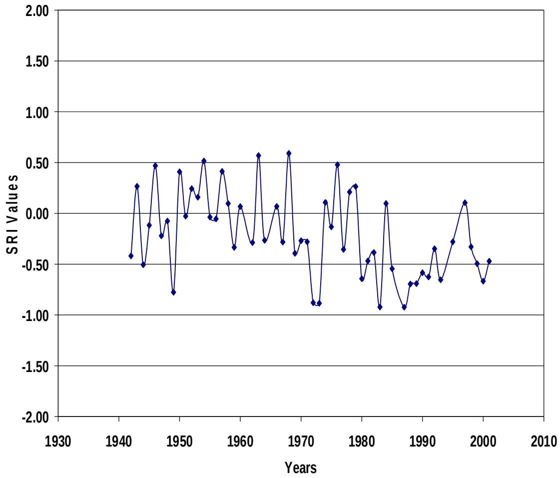
3(b): Seasonal SRI Values at Kano



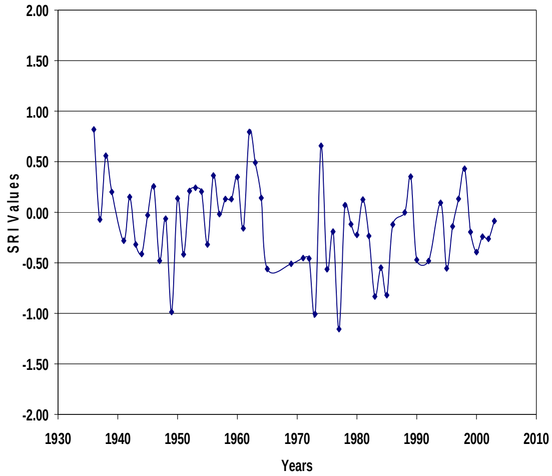
3(c): Seasonal SRI Values at Katsina



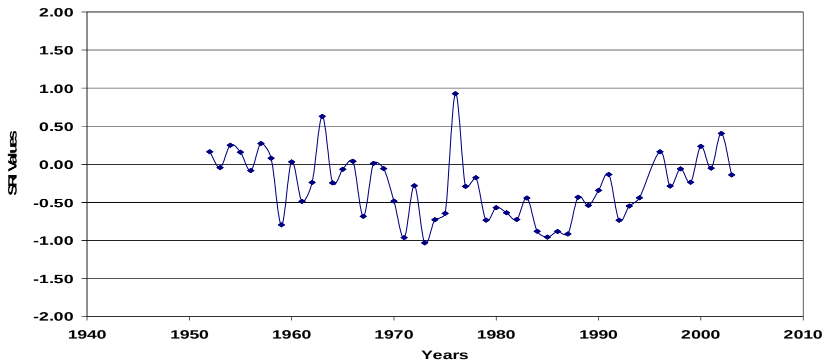
3(d): Seasonal SRI Values at Maiduguri



3(e): Seasonal SRI Values at Nguru



3(f): Seasonal SRI Values at Potiskum



3(g): Seasonal SRI Values at Sokoto

Figure 3: Distribution of Seasonal SRI Values for Gusau, Kano, Katsina, Maiduguri, Nguru, Potiskum and Sokoto Stations

tude of the percentage change in the 30 years mean of the rain days and rainfall depth values obtained for Maiduguri, Nguru, Potiskum and Sokoto.

Drought inference from rainfall variability analysis

A significant observation from these analyses is the occurrence of extended periods with much less than "normal" precipitation amount (or no of rain days) in variance with the seasonal rainfall means, which are usually used to infer or define drought occurrence. The severity of such drought occurrences is strongly expressed by the values of SRI and NRI variability indices obtained and plotted for all the stations in Figures 2 and 3.

Both SRI and NRI values also show the inter-seasonal rainfall variability within the SSRN. There is also an indication that both SRI and NRI values vary along the western-eastern geographical line divide of SSRN. Specifically, NRI values plotted in Figure 2 showed consistent downward trends in their values for all the stations under study. Spatially, Kano and Gusau, located within the central region of the SSRN, can be inferred to have mild drought incidence with average NRI > -1.2, Nguru and Maiduguri, at the extreme right of the SSRN, are worst stricken with average NRI < -1.2).

The historical drought years experienced in the SSRN between the 1970-1972 and 1983 -1984 are also well revealed in all the NRI plots for each of the stations under study. Varying low NRI values observed in the late 1990s and early 2000 in some of the stations under study might also be an indication that the drought conditions of the early '70s are reoccurring.

The SRI values plotted in Figure 3 also revealed the inter-annual rainfall variability in SSRN and clearly earmarked the pseudo-periodic dry years, with the drought spell of 1972-1974 and 1983-1984. However, unlike the NRI series, a persistent downward trend is not noticeable in the SRI values. It shows an upward trend in some cases (e.g., Kano, Sokoto) after an initial decline and also indicated some fluctuations and unstableness in its trend for most of the stations under study.

It is therefore clear from this study that the salient aspect of drought characterization that would have been lumped, if not entirely omitted or hidden with the use of SRI drought index, has been better revealed or earmarked by NRI. Sequent, NRI is particularly a good drought index that can be employed in decision support systems for effective drought monitoring and management in SSRN.

CONCLUSION

This study examines the observed rainfall variability in Sudano-Sahel regions of Nigeria in the context of their historical evidence and drought inference. It reveals that the temporal variability in the amount and distribution of rainfall and number of raindays observed within the region has to a large extent contributed to the 1973 and 1984 drought occurrences in the region. Similarly, the varying low NRI values observed in SSRN up till the early 2000 within the region might also be an indication that the drought conditions of early seventies are reoccurring. A better understanding of these seasonal rainfall variations in these regions is certainly important to the planning of many drought amelioration programmes in agriculture, water supply, transportation, commerce and insurance, etc.

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