MAUSAM, **51**, 2 (April 2000), 155-162

551.577.3 (61)

Trends and periodicities of rainfall over north Africa

FAWZIA I. MOURSY

Department of Natural Resources, Institute of African Research & Study,

Cairo University, Egypt.

(*Received 14 May 1999, Modified 1 December 1999*)

सार - उत्तरी अ फ्रीका के विस्तृत क्षेत्रों की वार्षिक वर्षा की प्रवृतियों और समय सारणी का अध्ययन 60 वर्षों से भी अधिक समय के 45 केन्द्रों के आँकड़ों का उपयोग करते हुए किया गया है। उत्तरी अफ्रीका के विस्तृत क्षेत्रों में वर्षा की बढ़ती हुई अथवा घटती हुई प्रवृतियाँ पाई गई है। ये प्रवृतियाँ यद्यपि इन क्षेत्रों के सभी स्थानों के लिए विशेष रूप से महत्वपूर्ण नहीं हैं, यद्यपि दूर-दूर तक फैले कुछ स्थानों के लिए ये महत्वपूर्ण हैं। जहाँ पर ये प्रवृतियाँ महत्वपूर्ण है वहाँ ये अधिक समय तक अथवा 40 वर्षों से भी अधिक समय तक प्रभावी रहती है। वर्षा की बढ़ोत्तरी अथवा घटने की प्रवृति वाले अनेक स्थानों में अर्द्धद्विवार्षिक दोलन का पता चला है। इसी प्रकार दोनों क्षेत्रों में 11 वर्षों के आवृति चक्र (सौर चक्र) का भी पता चला है। केवल छः स्थानों पर अर्द्धद्विवार्षिक दोलन और सौर चक्र दोनो का पता चला है।

ABSTRACT. Trends and periodicities in the annual rainfall of north Africa are studied using data for 45 stations having record lengths of over 60 year. Increasing or decreasing rainfall tendencies are found over large continuous areas in north Africa. These trends, however, are not significant over all the stations in the areas but only at a few places distributed at random. Wherever a trend is significant, It has persistence or a periodicity of more than 40 year. Quasi-Biennial Oscillation (QBO) is exhibited at several stations in the areas of increasing or decreasing trend. Similarly, the 11-year cycle (solar cycle) is also exhibited in both areas. The QBO and the solar cycle are both present at only six stations.

Key words – Rainfall series, Periodicities, Peaks, Trends, Moving averages.

1. Introduction

With the rapid growth of the human population and strained resources, particularly food production and water supply for people, agriculture and industry, the study of variations, trends and fluctuations of rainfall over a region is of utmost importance.

Much work has been done in various countries on trends and fluctuation of rainfall and temperature, notably by Reynolds (1953), Kraus (1960), Willett (1950), Callender (1961) and Maheras (1985), Nicholson (1979; 1980; 1993) and Hulme (1992) studied African rainfall fluctuations of the last decade.

Bunting *et al.* (1976) on studying rainfall trends in the west African Sahel have made statistical analysis of long-term rainfall records from the region. No established trends or periodicities can be detected, and the recent succession of drought years falls within statistical expectation. It has been concluded that sahelian rainfall is not clearly linked to the frequency of westerly weather over Britain. Ogallo (1979) on his study on rainfall variability in Africa, time series of annual rainfall for 69 stations in Africa were analyzed for trends and periodicities. He concluded the following points:

(a) Most of the annual rainfall series examined indicated generally an oscillatory characteristic without significant trend. Positive or negative trends observed from the smoothed graphs in the recent years were declared insignificant by a statistical test except in four stations. The four series indicated increasing rainfall tendency in the recent years. However, it was noted that the stations indicating significant trends were near those indicating no significant trends and their spatial distribution formed no particular pattern. This made it difficult to give climatological explanation for the observed trends in the annual rainfall series; hence no attempt was made to examine the general circulation parameters on which rainfall greatly depends. It is

TABLE 1

The stations used in the study of the behavior of rainfall over North Africa

Name of the station	Latitude (°N)	Longitude (°E)	Altitude (meter)	Period of data (year)
Alexandria	31 12	29 53	032	1882-1994
Agedabia	30 43	20 10	006	1924-1994
Aziza	32 33	13 20	145	1934-1994
Benina	32 05	20 16	132	1934-1994
Biskra	34 48	05 44	088	1922-1994
Cairo	30 05	31 17	026	1887-1994
Casablanca	33 34	07 40 W	-	1922-1994
Damitta	31 31	31 51	002	1913-1994
Damanhur	31 02	30 28	007	1904-1994
Derna	32 24	22 43	025	1925-1994
Dar El-Beida	36 43	03 15	023	1894-1994
El-Adem	31 51	23 55	157	1935-1994
El-Assa	32 45	11 40	-	1926-1994
El-Agilate	32 30	12 25	-	1927-1994
El-Karyate	30 23	12 35	500	1928-1994
El-Zahraa	32 30	13 30	-	1936-1994
El-Bidaa	32 38	21 30	-	1932-1994
El-Golea	30 34	02 52	398	1922-1994
Fayum	29 18	30 51	030	1910-1994
Giza	31 13	30 03	019	1902-1994
Ghadames	30 08	09 30	357	1931-1994
Galo	29 02	21 34	059	1934-1994
Gabes	33 53	10 06	005	1951-1994
Hon	29 08	15 57	261	1931-1994
Kufra	24 13	23 18	382	1933-1994
Mersa Matruh	27 13	31 20	003	1905-1994
Mansura	31 03	31 23	007	1910-1994
Misurata	32 19	15 03	032	1931-1994
Marrakech	31 37	09 34 W	462	1919-1994
Nalut	31 52	10 59	621	1931-1994
Oran	35 37	00 36 W	090	1922-1994
Port Said	32 14	31 17	001	1886-1994
Rosetta	31 24	30 25	003	1913-1994
Rakdalen	32 50	12 00	-	1923-1994
Subrata	32 30	12 25	-	1935-1994
Shahat	32 49	21 51	625	1931-1994
Sidi barrani	31 38	25 53	023	1910-1994
Salum	31 33	25 11	006	1917-1994
Suez	29 52	32 28	003	1886-1994
Sirt	31 12	16 35	013	1933-1994
Sebha	27 01	14 26	433	1931-1994
Tunis	36 50	10 14	075	1887-1994
Tripoli Air port	32 41	13 10	080	1929-1994
Zagazig	30 35	31 30	013	1926-1994
Zuara	32 55	12 05	025	1931-1994s

possible for such trends to arise from some factors, but there is a feeling that the positive trends in the recent years are part of long period oscillations, which could not be determined due to the limited data available. An overall impression is that rainfall over Africa is oscillatory in time.

(b) On assuming the generating process to be purely random, the prominent cycles in the annual rainfall were 2.0 –2.5 years and 2.7 – 3.3 years. These cycles have been detected in some past studies over certain parts of Africa. (Rodhe and Virji, 1976; Tyson *et al.*, 1975; Landsberge, 1975).

The problem of trends and periodicity in north Africa climate has always attracted and continues to attract attention of public and scientists all over the globe.

In this paper the oscillations, if any, in the annual rainfall and their nature are examined. For this purpose a network of 45 stations having long period homogeneous rainfall data are fairly distributed over north Africa,

TABLE 2

Lag-one serial correlation, r_1

Name of the station	r_1	Name of the station	r_1
Alexandria	-0.119	Gabes	+0.076
Agedabia	-0.373**	Hon	+0.049
Aziza	-0.033	Kufra	+0.050
Benina	-0.113	Mersa Matruh	+0.267*
Biskra	+0.115	Mansura	+0.045
Cairo	+0.250*	Misurata	0.805*
Casablanca	+0.104	Marrakech	-0.286**
Damitta	-0.075	Nalut	+0.034
Damanhur	+0.050	Oran	-0.220
Derna	-0.104	Port Said	-0.040
Dar El-Beida	-0.208**	Rosetta	-0.244**
El-Adem	+0.164	Rakdalen	-0.060
El-Assa	-0.062	Subrata	+0.269*
El-Agilate	-0.510**	Shahat	0.279*
El-Karyate	+0.110	Sidi Barrani	-0.117
El-Zahraa	+0.133	Salum	-0.225**
El-Bidaa	+0.325*	Suez	+0.160*
El-Golea	-0.110	Sirt	-0.019
Fayum	+0.250*	Sebha	+0.040
Giza	+0.180*	Tunis	+0.189*
Ghadames	-0.100	Tripoli Air port	-0.687**
Galo	+0.399**	Zagazig	-0.130
		Zuara	-0.003

* Significant Markov linear persistence at 95 percent.

** Significant correlation coefficient at 95 percent.

which has been selected (Table 1). The record of these stations is somewhat long and lies between 59 and 112 years.

Most of the monthly data of the stations used were obtained from the National Center of Atmospheric Research, the monthly or daily publications of the meteorological service of Morocco and Tunisia, Libya Meteorological Department, monthly climatic data for the world and official files of the authority of meteorology at Kobri El-Kobba, Cairo, Egypt. A few gaps were filled by a multiple regression analysis.

2. Data and analysis persistence

The various alternatives to randomness have the common property of low-frequency variation, which introduces positive serial correlation at small lags. To calculate the lag-one serial correlation, we used the following formula:

$$(r_1)=\frac{(N-1)\sum\limits_{i=1}^{N-1} x_i x_{i+1}-\left(\sum\limits_{i=1}^{N-1} x_i\right)\left(\sum\limits_{i=2}^{N} x_i\right)}{\left[(N-1)\sum\limits_{i=1}^{N-1} x_i^2-\left(\sum\limits_{i=1}^{N-1} x_i\right)^2\right]^{\frac{1}{2}}\left[(N-1)\sum\limits_{i=2}^{N} x_i^2-\left(\sum\limits_{i=2}^{N} x_i\right)^2\right]^{\frac{1}{2}}} \qquad (1)$$

The significance of the lag-one correlation, r_1, was tested using the one-tail 95 percent significance point of the Gaussian distribution (WMO 1966). The test value $(r_1)_t$ was computed from

$$(r_1)_t = \frac{-1+t_g\sqrt{N-2}}{N-1} \qquad (2)$$

where t_g is the value of the standard deviate in the Gaussian distribution corresponding to the desired level of significance. The r_1 values for all the stations are given in Table 2.

Gilman *et al.* (1963) have given the method of finding the persistence of the first-order, linear Markov process, which is a dominant form of trend. Accordingly, the serial correlations at lag two and lag three were compared with r_1^2 and r_1^3 respectively. When r_1 was negative, it was tested against the two-tailed value and interpreted as indicative of marked high-frequency oscillations. The significant values are presented in Table 2. They show that the sample values of r_1 were positively and significantly greater than the test value (at 95 percent) at Alexandria, Cairo, El-Dibaa, Fayum, Giza, Mersa Matruh, Subrata, Suez and Tunis with the values of r_2

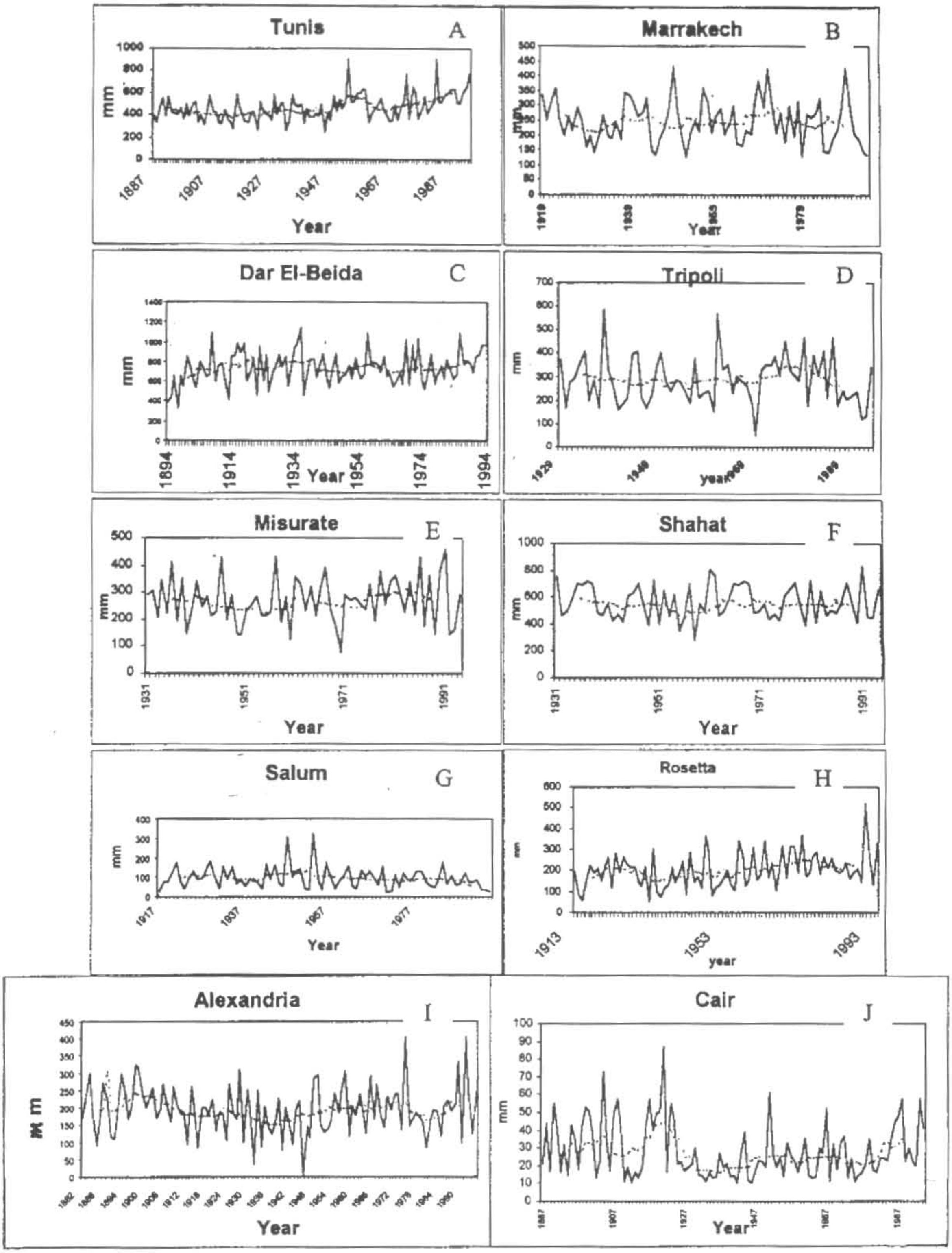

Fig. 1. Examples of filtered (10-year weighted moving average denoted curve) and unfiltered (solid curve) values of rainfall showing increasing trends (A, C, D, E, F, H), decreasing trends (B, G, J) and no significant trends (I)

TABLE 3

Mann-Kendall rank statistic

Name of the station	τ	Name of the stations	τ
Alexandria	-0.021	Gabes	+0.136
Agedabia	+0.098	Hon	-0.420*
Aziza	-0.254*	Kufra	-0.423*
Benina	-0.209*	Mersa Matruh	-0.064
Biskra	+0.048	Mansura	-0.105
Cairo	-0.114**	Misurata	+0.144**
Casablanca	+0.030	Marrakech	-0.298*
Damitta	-0.047	Nalut	+0.176*
Damanhur	-0.125**	Oran	+0.053
Derna	-0.066	Port Said	-0.089
Dar El-Beida	+0.110**	Rosetta	+0.186*
El-Adem	+0.197*	Rakdalen	+0.027*
El-Assa	+0.077	Subrata	+0.222*
El-Agilate	-0.005	Shahat	+0.141**
El-Karyate	+0.151**	Sidi Barrani	-0.055
El-Zahraa	+0.202*	Salum	-0.150**
El-Bidaa	+0.144**	Suez	-0.110**
El-Golea	-0.073	Sirt	-0.160**
Fayum	-0.181*	Sebha	-0.333*
Giza	-0.126**	Tunis	+0.175*
Ghadames	+0.150**	Tripoli Air port	+0.169**
Galo	-0.385*	Zagazig	+0.147**
		Zuara	+0.090

* Significant value at 99 percent level

** Significant value at 95 percent level

and r_3 equal to or greater than r_1^2 and r_1^3. This indicates Markov linear-type persistence at these stations. At Agedabia, El-Agilate, Galo, Misurata, Marrkech, Rosetta, Shahat, Salum and Tripolt, r_1 was significantly negative, indicating the presence of high-frequency oscillations.

3. Trend

The Mann-Kendall rank statistic has been suggested as a powerful test (Kendall and Stuart, 1961) when the most likely alternative to randomness is linear or non linear trend. The statistic τ was computed form the following equation:

$$\tau = \frac{4 \sum_{i=1}^{N-1} n_i}{N(N-1)} - 1 \qquad (3)$$

where n_i is the number of values larger than the ith value in the series subsequent to its position in the time series. The test statistic $(\tau)_t$ was :

$$(\tau)_t = \pm \quad t_g \sqrt{\frac{4N+10}{9N(N-1)}} \qquad (4)$$

where t_g is the value of t at the probability point in the Gaussian distribution appropriate to the two- tailed test. Table 3 gives the Mann-Kendall rank statistic values significant at 95 percent. A positive value indicates that the trend is one of increasing tendency while a negative value indicates a decreasing tendency. This test has been applied to all irrespective of whether or not the first test indicated a trend. A significant increasing trend was found at Dar El-Beida, El-Adam, El-Karyate, El-Zahraa, El-Bidaa, Ghadames, Misurata, Nalut, Rosetta, Rakdalen, Subrata, Tunis, Shahat, Tripoli and Zagazig, and significant decreasing trend at Azizia, Benina, Cairo, Damanhur, Fayum, Giza, Galo, Hon, Kufra, Marrakech, Salum, Suez, Sirte and Sebha. The rest of the stations do not exhibit significant trends.

4. Low pass filter

To understand the nature of this trend, the series was subjected to a "Low-pass filter" (WMO,1966), thus suppressing the high-frequency oscillations. The weight used were the nine ordinates of the Gaussian probability curve (0.01, 0.05, 0.12, 0.20, 0.24, 0.20, 0.12, 0.05, and 0.01). The response curve of the Gaussian low-pass filter has a response function that is equal to unity at infinite wavelengths; it then tails off asympototically to zero with decreasing wavelength. The response is approximately

TABLE 4

Power spectrum results

Name of the station	Class interval of significant period	Name of the stations	Class interval of significant period
Alexandria	27.8-19.6 2.4-2.2	Gabes	8.5-8.1 2.4-2.2
Agedabia	6.3-5.3	Hon	7.7-7.1 6.3-5.0
Azizia	5.8-5.1 2.4-2.2	Kufra	6.3-5.0 3.8-3.3
Benina	8.8-8.5 2.4-2.2	Mersa Matruh	14.6-10.1 2.9-2.6
Biskra	6.3-5.9 4.1-3.5	Mansura	2.8-2.2
Cairo	6.3-5.0	Misurata	4.8-4.5 2.9-2.6
Casablanca	16.1-10.6 2.9-2.6	Marrakech	17.6-13.4 2.9-2.6
Damitta	2.4-2.2	Nalut	12.0-8.8 6.3-5.0
Damanhur	2.4-2.3	Oran	12.0-7.7 2.4-2.2
Derna	7.1-7.0 2.4-2.2	Port Said	12.5-8.0 3.4-3.2
Dar El-Beida	13.7-11.2 2.4-2.2	Rosetta	14.6-10.1 4.4-4.2
El-Adem	10.7-8.0 2.6-2.2	Rakdalen	8.0-6.7 2.4-2.2
El-Assa	8.1-7.9 2.4-2.2	Subrata	4.8-4.5 2.4-2.2
El-Agilate	8.8-7.7 6.3-5.0	Shahat	7.8-7.6 2.4-2.2
El-Karyate	10.5-7.7 6.3-5.0	Sidi Barrani	26.4-18.8 2.8-2.0
El-Zahraa	8.3-8.1 6.3-5.0	Salum	13.5-11.7 2.4-2.2
El-Bidaa	4.8-4.5 2.4-2.2	Suez	17.6-12.5 6.4-6.2
El-Golea	6.3-5.0	Sirt	8.3-8.1 3.4-3.2
Fayum	6.3-5.0	Sebha	6.3-5.0 3.8-3.3
Giza	6.3-5.0	Tunis	27.9-23.4 2.4-2.2
Ghadames	6.3-5.0	Tripoli air port	14.6-12.0 2.4-2.2
Galo	24.7-18.8 6.3-5.0	Zagazig	8.8-6.9 6.3-5.0
		Zuara	13.5-11.7 3.4-3.2

$$R(f) = \exp\left[-2\Pi^2\sigma_g f^2\right] \qquad (5)$$

where σ_g was the appropriate standard deviation (*i.e.*, 6 σ_g = 10 year). The trend was not linear but oscillatory, consisting of periods of more than 10 yr in duration. A few filtered series along with the unfiltered series are depicted as examples in Fig. 1.

5. Power spectrum analysis

The time series of the mean annual rainfall for all stations has been subjected to power spectrum analysis by following the method of Blackman and Tukey (1958) as given in WMO Technical Note 79 (1966). To achieve satisfactory resolution in the spectrum, a maximum lag, m, has been chosen as large as possible but not exceeding one-third of the total number of years of the record involved in the analysis. To reduce the chances of picking up a high power, the analysis has been separately conducted with five or six different maximum lags that might have arisen due to "Aliasing effect" consistent with the above restrictions. The null hypothesis for this purpose was considered in accordance with whether or not the series revealed any persistence. If the persistence was of the Markov linear-type, the appropriate red noise spectrum and the associated 99, 95, and 90-percent limits were calculated, and the individual peaks were tested with reference to these limits. If the lag-one correlation was significantly greater in magnitude than zero but higher lag correlation did not taper off exponentially, the spectral estimate in the first half were tested with reference to the red noise spectrum and the rest against white noise. In the absence of any persistence, the spectral estimates were tested against the white noise spectrum.

Significant peaks (2.3, 2.8, 3.6 and 5 to 6 years) revealed by the spectral analysis are given in Table 4. These show low frequency oscillation at Alexandria, Casablanca, Galo, Mersa-Matruh, Marrakech and Tunis. The higher frequency oscillations tend to occur quasi-periodically on time scales of about 2.0-3.0 at Alexandria, Azizia, Benina, Damietta, Damanhur, Derna, Dar El-Beida, El-Adem, El-Assa, El-Bidaa, Gabes, Mersa Matruh, Mansura, Misurta, Marrakech, Oran, Rakdalen, Subrata, Shahat, Sidibarrani, Salum, Tunis and Tripoli.

The shorter waves 2.0-3.0 years seem to be associated with quasi-biennial oscillation. This connection has been mentioned by other researchers (Angell *et al.*, 1996; and Lamb, 1972). Lamb (1972) noted that a quasi-biennial oscillation is related to the southern oscillation, which is the strength of subtropical high belt in both northern and southern hemisphere. Also studies have shown that there may be two fundamental time scales in the interannual variability of the monsoon–ocean-atmosphere system, *i.e.*, a quasi-two year cycle associated with tropical biennial oscillation (TBO) and a 4-6 years cycle associated with El-Nino southern oscillation (ENSO). Also minor peaks at periods in the range 3-5 years appear to be associated with the southern oscillation (Folland *et al.* 1986). Nicholson (1989) found that waves of about 2.3-3.5 year, and 5 year are apparent in equatorial and southern Africa. He explained that these same time scales characterize many other meteorological phenomena in the tropics, such as the quasi-biennial oscillation, sea surface temperature and El-Nino southern oscillation (ENSO) and they are apparent in rainfall series throughout the tropics. Cycles of nearly 11 years are seen at Casablanca, Dar El-Beida, El-Adem, El-Karyate, Mersa Matruh, Nalut, Oran, Port Said, Rosetta, Salum, Suez, Tripoli and Zuara. It is important to note that of all the stations having nearly 11 year cycles, only Dar El-Beida, El-Adem, Merasa Matruh, Oran, Salum and Tripoli have exhibited QBO (Table 4). QBO, it may be pointed out, is often considered as apart of the solar cycle (nearly 11 year) which in turn is intimately related to the ultraviolet emission (Shapiro and Ward, 1962, Staley, 1963).

6. Conclusion

This study shows that the areas having increasing and decreasing trend in the annual rainfall are practically contiguous. However, this trend is not significant over all the stations in the area but only at a few places, distributed at random. QBO is exhibited at several stations in the areas of increasing and decreasing trend. Similarly, the 11-year cycle (solar cycle) is also exhibited in both these areas. However, both the QBO and 11-year cycle are present at six stations only. This is an important feature that has to be seriously considered when we seek a physical explanation for the QBO in the rainfall.

References

Angell, J.K., Kroshover, J. and Carpenter, T.H.,1966, "Note concerning the period of the quasi-biennial oscillation" , *Mon. Wea. Rev.*, **95,** 319-323.

Blackman, R. B. and Tukey, J. W., 1958, "The measurement of power spectra", Dover Publication, New York, U.S.A., 190 p.

Bunting, A. H., Dennett, M. D., Elston, J., and Milford, J. R., 1976, "Rainfall trends in the west African Sahel", *Q. J. Roy. Met. Soc.*, **102**, 59-64.

Callender, G. S., 1961, "Temperature fluctuations and trends over the earth", *Q. J. Roy. Met.. Soc.*, **87**, 1-12.

Folland, C. K., Parker, D. E. and Palmer, T. N., 1986, "Sahel rainfall and Worldwide sea temperatures 1901-85, Observation, Modelling and Simulation studies", *Nature*, **320**, 602-607.

Gilman, D. L., Fuglister, F. J. and Mitchell, J. M. Jr., 1963, "On the Power Spectrum of Red noise", *J. of Atm. Sci.*, **20**, 182-184.

Hulme, M., 1992, "Rainfall changes in Africa: 1931-60 to 1961-90", *International Journal of Climatology*, **132**, 685-699.

Kendall, M. G. and Stuart, A., 1961, "The advanced theory of statistics", Hafner publishing Company, New York, N. Y. 2, 676 p.

Kraus, E. B., 1960, "Synoptic and dynamic aspect of climatic change", *Quarterly Journal of the Royal Meteorological Society*, London, England, **86 (367)**, 1-15.

Lamb, H. H., 1972 "Climate: Present, past and future fundamentals and climate now", Methuen, London, **1**, 240-250.

Landsberg, H. E., 1975, "Sahel drought: Change or part of climate?", *Arch. Met. Geophys.*, **B 23**, 193-200.

Maheras, P., 1985, "A factorial analysis of mediterranean precipitation", *Arch. Met. Geoph. Biocl. Ser.*, **B 36**, 1-14.

Nicholson, S. E., 1979, "Revised rainfall series for the west African subtropical region", *Mon. Wea. Rev.*, **107**, 620-623.

Nicholson, S. E., 1980, "The nature of rainfall fluctuations in subtropical west Africa", *Mon. Wea. Rev.*, **108**, 473-487.

Nicholson, S. E., 1989, "Long-term changes in African rainfall", *Mon. Wea. Rev.*, **44**, 46-56.

Nicholson, S. E., 1993, "An overview of African rainfall fluctuation of the last decade", *Journal of Climate*, **6**, 1463-1466.

Ogallo, L. T., 1979, "Rainfall variability in Africa", *Mon. Wea. Rev.*, **107**, 1133-1139.

Rodhe, H. and Virji, H., 1976, "Trends and periodicities in east Africa rainfall data", *Mon.Wea.Rev.*, **104**, 307-315.

Reynolds, G., 1953, "Rainfall at Bidston, 1867-1951", *Quarterly Journal of the Royal Meteorological Society*, **79(390)** , 137-149, London, England.

Shapiro, Ralph and Ward, Fred, 1962, "A Neglected cycle in sunspot Numbers?", *J. of Atm. Sci.*, **19**, 506-508.

Staley, D. O., 1963, "A Partial Theory of the 26-month Oscillation of the Zonal Wind in the Equatorial Stratosphere", *J. of the Atm. Sci.*, **20(6)**, 506-515.

Tyson, P. D., Dyer, T. G. J. and Mametse, M. N., 1975, "Secular changes in South African rainfall", *Quart. J. Roy. Met. Soc.*, **101**, 817-833.

Willett, H. C., 1950, "Temperature Trends of the past Century", Centenary Proceedings of the Royal Meteorological Society, London, England, March – April, 195-206.

World Meteorological Organization, 1966, "Climatic change", WMO, Technical Note No. 79, WMONo. 195. Tp. – 100, Geneva, Switzerland, 80 p.