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GEOFIZIKA VOL. 25 No. 1 2008

Short communication
UDC 551.577.3

Analysis of rainfall records (1923–2004) in Atar-Mauritania

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Received 15 May 2007, in final form 28 January 2008

The shortage of water resources in Adrar region, especially in Atar (Capital city of Adrar prefecture) and the surrounding villages along Seguelli watershed has been taken the concern of the policy maker and populations of this region since long time. This area had been suffering from recurrent droughts and faced water crises many times. Several attempts have been made to overcome these problems. Meanwhile the risk is still endangering the life and agricultural activities in one of the most important oasis areas. This study analyzed Atar rainfall time series periodicity, trends, and its relationship with Sea Surface Temperature (SST). The nonparametric Spearman test was used for trend analysis and the serial autocorrelation for persistency. Also, power spectrum and Fourier fit were deployed for analysis of frequency and periodicity. The tendency of Atar rainfall time series shows rainy periods in 1920's and 1950's and decreased rainfall since the late of 1950s. On the other hand, the prolonged drought periods appeared during 1970's in contemporaneous with the Sahelian drought. The persistency analysis indicated the presence of biennial components in the annual and bimonthly rainfall in last three decades. SSTs of Atlantic, Indian and Pacific Ocean were modulating Atar rainfall during 1923–1992 period.

Keywords: Atar-Mauritania, frequency, persistence, rainfall, SST, trend.

1. Introduction

Atar is located in Adrar region in the southern Sahara zone of the northern Mauritania. In this area water shortage, salinity and drought are the main environmental problems. About 80% of the wells drilled »between 1950s to 2000s« to solve the problems of water supply in Atar city (Figure 1) have been abandoned and more than 10% were negative (dry). On the other hand, the use of motorized pumps; in the recent decades, instead of manual extraction

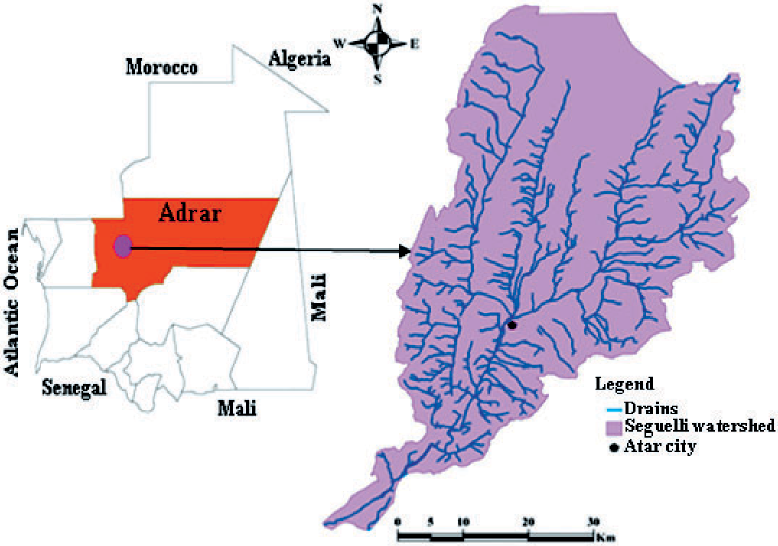

Figure 1. Map of Mauritania and geographical location of Adrar prefecture, Atar city and Seguelli watershed drainage networks.

method and the increasing demand on water have complicated the problems of water resources.

The rain in Sahel and southern Sahara mostly comes from humid air masses carried by the Atlantic Ocean and monsoonal winds. The pole ward movement of the Inter-Tropical Convergence Zone (ITCZ) controls monsoonal rain over the continent. The meeting of maritime flow (northeasterly), continental flow and monsoonal flow, during the northern hemisphere summer season; develop the ITCZ over Mauritania and western Africa in general.

Several studies have investigated the influences of Sea Surface Temperature (SST) on the precipitations over the Western Africa (Landsea and Gray, 1992; Biasutti et al., 2004 and Hunt, 2000). Large-scale changes in SST patterns are thought to be the major driving forces, which promote changes in atmospheric circulations (Herrmann and Hutchinson, 2005). Warm conditions over global oceans, especially in the Atlantic and Indian Oceans, tend to promote more dry conditions over the continent as a whole (Nicholson, 2001). Also, modeling studies confirmed statistical association between observed Sahel precipitation variability and tropical Atlantic SST, in the mid 1980s (Giannini et al., 2005). Therefore, large scales to regional SST were assumed in several researches to have an impact or influence on the Sahel and more general African precipitation regimes. Here we aim to study the characteristics of Atar rainfall; as it represent the oldest record in the region, in attempt to participate in the efforts to solve the water resources problems in that areas.

2. Data and methods

The longest rainfall record in the region was found for Atar city expanding from 1923 to 2004 as a complete monthly span. Daily precipitation data set was collected from Nouakchott regional Agro-Hydro-Meteorological Center (AGRIMET) and the complete daily span was limited to 1931–1992 period. On the other hand, monthly rainfall time series (1923–2004) was obtained from ASECNA (Agence pour la Securite De La Navigation Aerienne en Afrique et a Madagascar).

Time series set of monthly Global Sea-Ice and Sea Surface Temperature version 2.2 (GISST2.2) every one degree all over the world (1921–1992) obtained from BADC (the British Atmospheric Data Center) was also used in this study.

The non-parametric Spearman rank correlation test was used for trends analysis of rainfall time series. The Spearman correlation rank was computed as by Ogallo (1979) and Kendall and Stuart (1968):

$$r_s = 1 - \frac{6\sum_{i=1}^{N} di^2}{N(N^2-1)} \tag{1}$$

where, $di = k_i - i$, k_i is the rank of series X_i and N the total number of observations.

The approximate significance of r_2 for $N > 8$ and $df = N - 2$ is calculated by computing t statistic and comparing it with Student's t-distribution.

$$t = r_s\left(\frac{df}{1-r_s^2}\right)^{1/2} \tag{2}$$

The autocorrelation coefficient was used for persistence analysis as used by Mirza et al. (1998).

$$r_k = \frac{\sum_{i=1}^{N-k}(x_i - m)(x_{i+1} - m)}{\sum_{i=1}^{N}(x_i - m)^2} \tag{3}$$

where m is the mean value of the time series X_i, N number of observations and k is the time lag.

Negative value of r_1 can be interpreted as indication of high-frequency oscillations in the rainfall time series, however significant positive value of r_1 is indication of Markov linear-type persistence if r_2 and r_3 equal to or greater than $r_1{}^2$ and $r_1{}^3$ (Jagannathan and Parthasarathy, 1973).

The significance of r_1 can be estimated using the one-tail 95% significance of the Guassian distribution (WMO 1966).

$$r_1 = \frac{-1+t_g\sqrt{N-2}}{N-1} \tag{4}$$

where t_g is the value of standard deviation in the Guassian distribution table.

Following Salas et al. (1980) the significance of r_k can be estimated at two-tailed 95% confidence level by:

$$r_k(95\%) = \frac{-1 \pm 1.96\sqrt{N-k-1}}{N-k-1} \tag{5}$$

The Maximum Entropy Method (MEM) was applied to detect the dominant periods of precipitation time series. For that purpose monthly and annually time series were normalized to remove the seasonal fluctuation.

$$R = (r - m) / Sm \tag{6}$$

where R: normalized rainfall, r: original rainfall (mm), m: monthly mean value and Sm: monthly standard deviation.

The periods of highest spectrum values were selected and applied to Fourier series to check their fitness to the original time series. Also, three months moving average of rainfall and SST were used for rainfall and SST smoothing.

$$\mathrm{Y}_{i+1/2(n-1)} = 1/n\sum_{i=1}^{n} Xi \tag{7}$$

where: $\mathrm{Y}_{i+1/2(n-1)}$ moving average, Xi: monthly average of rainfall and n: moving average order.

Finally, the cross correlations between August and September rainfall and SST were obtained using rainfall span from 1923 to 1994 and SST span of 1922 to 1994 to find out the oceanic areas that are influencing rainfall during this period.

3. Results and discussions

3.1. Rainfall anomalies and trends

The analysis of annual, monthly rainfall and the coefficient of variation between 1923 and 2004 (Table 1) showed a dry season with average blow five mm extend from November to June and a relatively rainy season from July to October with maximum in August and September. The coefficient of variation shows lowest values for August and September which can be interpreted as they are the most reliable month for rainfall occurrences. The average of annual precipitation during 1923–2004 was around 91 mm and the annual rain-

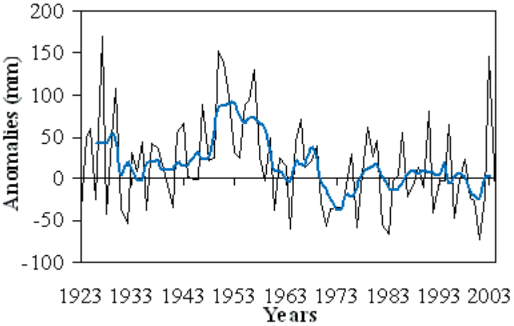

Figure 2. Anomalies of annual rainfall (back line) and 5 years moving average (blue line) compared to WMO 1961–1990 period.

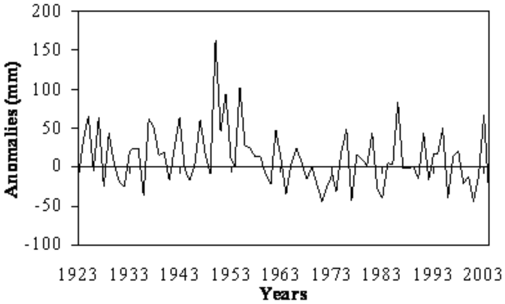

Figure 3. Anomalies of August-September rainfall compared to WMO 1961–1990 period.

fall varied considerably during this 82 years span, having both high and low values compared to the world meteorological organization (WMO) normal period (1961–1990). The most obvious droughts occurred during the 1970's, which was below the average of 1961–1990 (73.6 mm) in several years as indicted by Figure 2 (anomalies graphs and moving average). On the other hand, during 1920's and 1950's periods, rainfall anomalies were above the average. The anomalies of the August–September rainfall (Figure 3) reveal the general trend of annual rainfall. Therefore these two months could modulate the annual rainfall time series.

Table 1. Monthly average rainfall (R) and coefficient of variation (C_v) – 1923–2004.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
R (mm)	1.6	2.1	1.0	0.3	0.93	4.2	6.8	27.1	29.7	9.1	4.50	3.6
C_v	2.48	2.85	3.13	3.56	3.18	3.06	1.62	0.84	0.91	2.53	2.40	3.20

The seasonal precipitation tendency in the study area is marked by two clear periods expanding from November to May and from June to October for the dry season and the rainy season, respectively. The maximum precipitation occurs in August and September with a low variability, which led us to consider that these two months precipitation occurrence are more reliable and of high importance

Atar annual rainfall time series was characterized by large interannual fluctuations. Thus, during the period of 1920's and 1950's remarkable wet periods were observed with a maximum of 244.1mm in 1927 and 225.0 mm in 1950. In 1930s and 1940s rainfall showed positive anomalies, less important than priory and late periods. The deficient years having below average (90.9 mm/year) amounts are representing 34 years and mostly during the period of 1970's up to 1990's. In general we can consider that 1920's and 1950's were wet periods while since 1958 a remarkable decrease in rainfall amount was observed. Also, in the early 1970's a prolonged drought period has been appeared simultaneously with the Sahelian drought, which was the most devastating drought in the region during the last three decades of the 20th century. It was among the largest climatic changes anywhere (Trenberth et al., 2007). However, during 1960s the rainfall condition in the southern Sahara or Sahara margin was not wet as in the Sahel. The persistency of droughts is apparent since 1970s (Figure 2). Therefore, to investigate the trends and persistency of rainfall we used the Spearman rank test and autocorrelation coefficients for different periods during 1923–2004 as illustrated in Table 2 and 3.

Table 2. Spearman' test for annual and August-September rainfall.

	Period	1923–2004	1923–1960	1930–1959	1950–1983	1950–2004	1957–1983	1958–2004
	df	80	36	28	32	53	25	45
Annual	r_s	–0.23	0.28	0.35	–0.55	–0.38	–0.26	–0.10
Rainfall	t	–2.14[b]	1.80[c]	1.99[c]	–3.71[a]	–2.99[a]	–1.38	–0.69
August	r_s	–0.22	0.12	0.28	–0.45	–0.26	–0.20	–0.01
-September	t	–2.03[b]	0.75	1.58	–2.86[a]	–1.98[c]	–1.02	–0.08

[a] Trends statistically significant at $p<0.01$.
[b] Trends statistically significant at $p<0.05$
[c] Trends statistically significant at $p<0.10$.

The Spearman test showed a significant decreasing trends for the annual and August-September (bimonthly) rainfall for the whole period (1923–2004) and significant increasing trends during 1923–1960 for annual rainfall only. However, during 1930–1959 the trend was significant for both time series; therefore the wet period during 1920s can be attributed to an increase in the rainfall during other months (out of August–September period). On the other hand, the highly significant decreasing trends in 1950–1983 and 1950–2004 for the annual rainfall were followed by significant decrease in August–September rainfall, which confirm the influence of these two months on the annual rainfall. However, during 1958–2004 the decreasing trend of both time series was insignificant, which can be interpreted as a sign for persistency of rainfall in the recent decades. The degree of persistency was determined by performing autocorrelations (for up to three period lags) on bimonthly (August–September) and annually rainfall time series as illustrated in Table 3.

Table 3. Autocorrelation coefficients of annual and bimonthly rainfall.

	Period	r_1	r_2	r_3
Annual rainfall	1923–1957	0.46*	0.02	0.21
	1958–2004	–0.05	–0.18	–0.05
August and September rainfall	1923–1957	–0.07	0.02	0.09
	1958–2004	–0.05	–0.18	–0.05

*Statistically significant at $P<0.05$.

The annual rainfall during 1923–1957 showed significant ($P < 0.05$) positive lag 1 autocorrelation (Table 3). Yet, the condition r_2 and r_3 equal to or greater than r_1^2 and r_1^3 was not satisfied for lag 2 (r_2). Therefore, the time series are not free of Markov linear type persistence. However, during 1958–2004 the rainfall was characterized by insignificant negative r_1, which indicate the presence of biennial component. On the other hand, bimonthly rainfall during 1958–2004 and 1923–1957 periods showed insignificant negative autocorrelations coefficients, signifying that biennial component and high frequencies are inherent in August and September rainfall. Contrary, Nicholson and Palao (1993) reported that low frequency mode was dominant in Sahelian August-September rainfall.

The trends analysis showed that the decreasing trends of annual rainfall during 1923–2004 was followed by a decrease in bimonthly rainfall also the persistency analysis indicated the absence (presence) of biennial components in the annual (bimonthly) rainfall during 1923–1957. Therefore, the rainy period conditions before 1960s may not be caused by bimonthly rainfall amount only. However, since 1950s the decreasing trends of annual rainfall were followed by decreased bimonthly rainfall trends.

3.2. Frequency and periodicity

The analysis of continuous drought days and rainfall events of Atar time series for the complete span of 1930–1992 are illustrated in Figure 4. The top twenty continuous dry days and top 20 rainfall event values are presented in the Figure 5, which is showing concentrated continuous dry days especially during the period of 1980's. On the other hand, rainfall events occurrence is

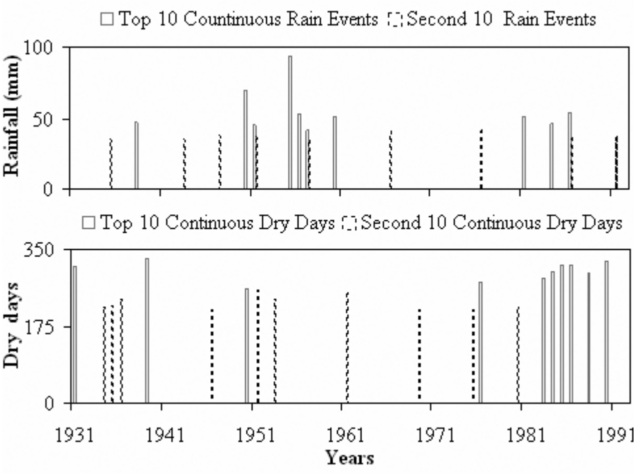

Figure 4. Distribution of top 20 continuous dry days and rainfall events (1930-1992).

more apparent during 1950's and 2, 4 and 10 years patterns are present in the patterns of dry days and rainfall events series.

The results of periodicity analysis confirm the presence of high frequency and biennial components declared previously. The presence of 11-year cycle usually attributed to sunspot number, which in turn influence the global climate.

3.3. Rainfall and SST relationship analysis

Figure 6 is showing the area of significant correlations between three months moving average of SST and rainfall of August and September. The cross-correlation was computed from lag 0 month to 12 months. The positive

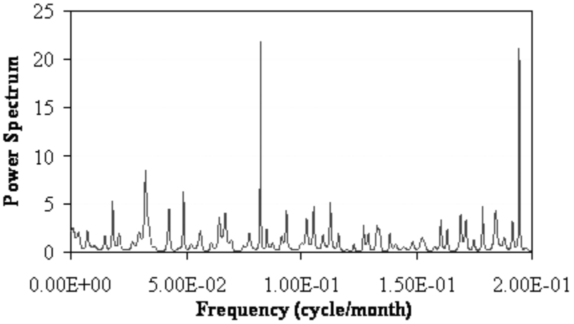

Figure 5. MEM power spectrum Atar rainfall (1923-2004).

Table 4. Frequencies obtained by spectral analysis.

f (cycle/month)	T(month)	T(year)
0.0820	12.20	1.02
0.0324	30.86	2.57
0.0488	20.49	1.71
0.0181	55.25	4.60
0.0426	23.47	1.96
0.067	14.93	1.24
0.0939	10.65	0.89
0.1692	5.91	0.49
0.0075	133.33	11.11
0.0034	294.12	24.5

Table 5. Combination of Atar rainfall (1923–2004) frequencies.

f	0.1692	0.0820	0.0426	0.0324	0.0181	0.0075	0.0034
T	0.5	1	2.0	2.5	4.6	11.1	24.5

f(cycle/month) T(year)

significant correlations regions are recognized at the northern hemisphere with a four lags (i.e. 1 to 4 for August and 2 to 5 for September). On the other hand, the negative values are mostly located around the equator and southern hemisphere. The common regions of significant correlation between rainfall and SST are mainly during 6 months lags and are:

- North Atlantic Ocean: with a positive correlation during four months lag (April to July).
- Indian Ocean: with a negative correlation during 6 months lag (February to July).
- Pacific Ocean: with both positive in the north and south and negative around the equator.

Both inter-annual and decadal variability of Sahel rainfall results from the response of the African summer monsoon to oceanic forcing amplified by land-atmosphere interaction (Trenberth et al., 2007). Rainfall over the Sahel and southern Sahara is controlled by the summer northern hemisphere immigration to the ITCZ (Nicholson, 1993). However, simultaneous SST changes in the Indian and Atlantic Oceans can »mimic« a shift of the ITZC over West Africa in summer (Bader and Latif, 2007). Hunt (2000) found that Pacific North America (PNA) oscillation influence the Sahelian rainfall via its impact on the North Atlantic Oscillation (NAO). Therefore, these two ecological zones are supposed to be under the influence of same climatic factors. Several studies reported that El Niño Southern Oscillation (ENSO) has indirect influence on Sahelian precipitation, by exciting SST in the Atlantic and Indian oceans. Also SST play important role in the annual cycle of air temperature and precipitation over the Atlantic Ocean. As a result, the theoretical basis of SSTs influence on rainfall in the Sahel and its northern borders (southern Sahera) is strong. Therefore, the changes in SSTs patterns, which are attributed to the climate changes, could be the main cause of the drastic changes of Atar rainfall.

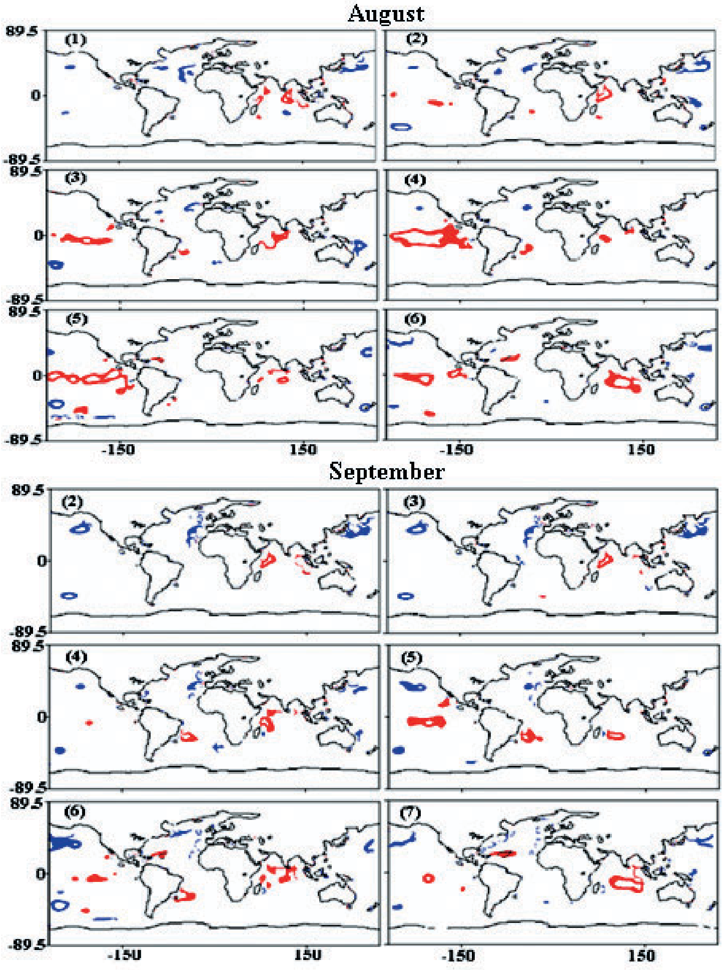

Figure 6. Cross-correlation between SST and rainfall of August and September: Blue color indicates the areas of significant positive correlation, red color indicates the areas of significant negative correlation and the numbers inside the parentheses represent lags values.

4. Conclusion

Atar rainfall time series is characterized by a succession of rainy months from July to October and dry ones from November to June. The rainfall trend was characterized by a high interannual variability with wet periods in 1920's and 1950's. On the other hand, the prolonged drought appeared in late1960's; after a significant decreasing trend of rainfall during the late 1950s, was concurrent with the Sahelian devastating drought. Therefore, the change in Atar rainfall patterns could be attributed to the climatic changes, which affected the Sahel and Saharan margin environment.

The cycles of Atar rainfall can be divided in short period from half year to five and longer than five; up to around 25 years. Atar rainfall had experienced a remarkable change since the late 1950s, which caused changes in the characteristics of the serial-autocorrelations coefficients and rainfall trends. Thus, during the last four decades biennial components persistence was present and the rainfall time series was free of Markov type in contrast with the early period.

The North Atlantic, Indian and Pacific Oceans influenced Atar rainfall during 1923–1992 and SSTs changes, which is affected by global warming; could be the main cause of the drought appearance and persistency in Atar area.

Acknowledgments – The authors are grateful to the ASECNA, AGRYMTH and BADC for providing the rainfall and SST data. Also, we gratefully acknowledge the Monbusho (the Ministry of Education, Science and Culture, Japan).

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SAŽETAK

Analiza oborine (1923-2004) u Ataru-Mauretaniji

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U području Adrara, posebno u Ataru (glavnom gradu pokrajine Adrar) i okolnim selima duž Seguelli sliva proučavao se manjak vodenih resursa u odnosu na političke odnose i stanovništvo tog područja kroz duže vrijeme. To je područje karakterizirano čestim periodičnim sušama i nedostacima vode. Usprkos pokušajima da se taj problem prebrodi, život i poljoprivreda su i dalje ugroženi u jednoj od najvažnijih oaza u tom području. Ova studija analizira periodičnost vremenskog niza oborine u Ataru, trendove niza i njegov međuodnos s površinskom temperaturom mora. Pri analizi trenda koristio se neparametarski Spearman-ov test, dok je perzistencija analizirana putem autokorelacije. Također se koristio i spektar snage i harmonijska analiza za određivanje frekvencija i periodičnosti. Tendencija vremenskog niza oborina u Ataru pokazuje kišne periode u dvadesetim i pedesetim godinama 20. stoljeća i smanjenje oborine od kasnih pedesetih godina 20. stoljeća. Dugotrajni periodi suše pojavljuju se tijekom 70-tih istovremeno sa sušom u Sahelu. Analiza perzistencije ukazala je na postojanje dvogodišnjih komponenti u godišnjoj i dvomjesečnoj oborini u zadnje tri dekade. Površinske temperature mora Atlantika, Indijskog i Pacifičkog oceana utjecale su na količinu oborine u Ataru u razdoblju od 1923. do 1992. godine.

Ključne riječi: Atar-Mauretanija, frekvencija, perzistencija, oborina, površinska temperature mora, trend

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