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Variability of rainfall regime in an agricultural region with a semi-arid climate: Case of Tadla irrigated perimeter (continental Morocco)

Abdelhaq BOUNDI*, Zehor AIT YACINE

Environmental Engineering, Faculty of Science and Technology -University Sultan Moulay Slimane, Béni Mellal, (Morocco)

** Corresponding author s E-mail: boundhaq@gmail.com*

ABSTRACT
The perimeter of Tadla, a strategic irrigated agricultural area in Morocco, but its rainwater resources are becoming scarcer. In fact, this work aims to study by relevant methods of rainfall variability in this perimeter, with a semi-arid climate, using 60 years (1958-2018) of data from the local network of 27 weather stations. Drought threshold is determined at 243 mm/year and the rainfall deviation index reaches -11%. Reduced centred indices provide information on equity in surplus, normal and deficit years of rainfall and that three successive periods corresponding in rainfall dominance to number: 13, 8 and 39 years; that Hanning's second order low-pass filter weighting maintains proportionalities but advances them by ten years. Mann-Kendall test also approves rainfall decrease; Sen's test gives a negative average trend slope. In addition, statistical tests for the detection of chronological rupture (Pettitt test, Lee and Heghinian bayesian method, Buishand U statistic, Hubert segmentation) detect the break in 1978 and lead to observations after rupture in reduction of 36 % in rainfall, increase in the frequency of deficit years at the expense of surplus years and mapping on a spatio-temporal distribution of precipitation of three homogeneous areas, including isohyets more displaced according to drying from west to east. Our results characterizing deep regional climate changes as rainfall are useful in programming resilience or adaptation to rainwater scarcity in such vulnerable agricultural biotopes.

Keywords: Tadla perimeter, variability, rainfall, climate changes.

INTRODUCTION
The present work aims at characterizing rainfall, necessary for crop irrigation management in the Tadla area, strategic for Moroccan country, because of its potential intensive agriculture or water resources with a tendency to become scarce. In this case, climate change in terms of rainfall manifests itself in different areas of the globe, the variation in rainfall in continental regions, which was low between years: at 1901 and at 1951, rises to the average level. Rainfall patterns are modified by a decrease in annual volumes in the western Mediterranean and non-sahelian West African areas (G.I.E.C. 2013). The Tadla perimeter is part of the Oum Er Rbia hydraulic basin, which its rainfall was decreasing between 1975 and 2009 (Jouilili *et al.* 2013). Over 1935-2004 in northern Morocco, including the study area, a rupture observed between 1972 and 1979 (Sebbar *et al.* 2011). In neighboring countries, such as the north-west of Algeria, rains have also been declining since the late 1960's (Taibi *et al.* 2013). The spatial distribution of precipitation in the study area, located in the 200-400 mm/year range (El Ajhar *et al.* 2018) and on the rainfall reduction map after chronological break is between 5% and 15% (Sebbar *et al.* 2013). The spatial and temporal variability of rainfall is highly contrasted, such as in West Africa where isohyets have moved in the direction of drying out in recent decades (Faty *et al.* 2017). So, our study aims to characterize the rainfall regime of Tadla agricultural perimeter, by appropriate methods of analysis of variability and precipitation trends and also by tests for detecting rainfall breaks, over a fairly long period of the last sixty years using data from the large local network of agro-meteorological stations, in search of regional rainfall mapping.

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MATERIALS AND METHODS

The study area

The study area, Tadla perimeter, is located between longitudes west 6° 18' 08" and 7° 04' 39" and latitudes north 32° 10' 16" to 32° 40' 10", a major part of the Tadla plain (Fig. 1). This area is located in Moroccan continental territory, 200 km south-east of Casablanca, with an area of 3600 km² and an almost flat topography with an average altitude of 400 m. This perimeter is crossed on all its length by the Oum Er Bia River, creating hence two independent sub-areas: Béni Moussa area on the left bank and the Béni Amir area on the right one (O.R.M.V.A.T 2019).

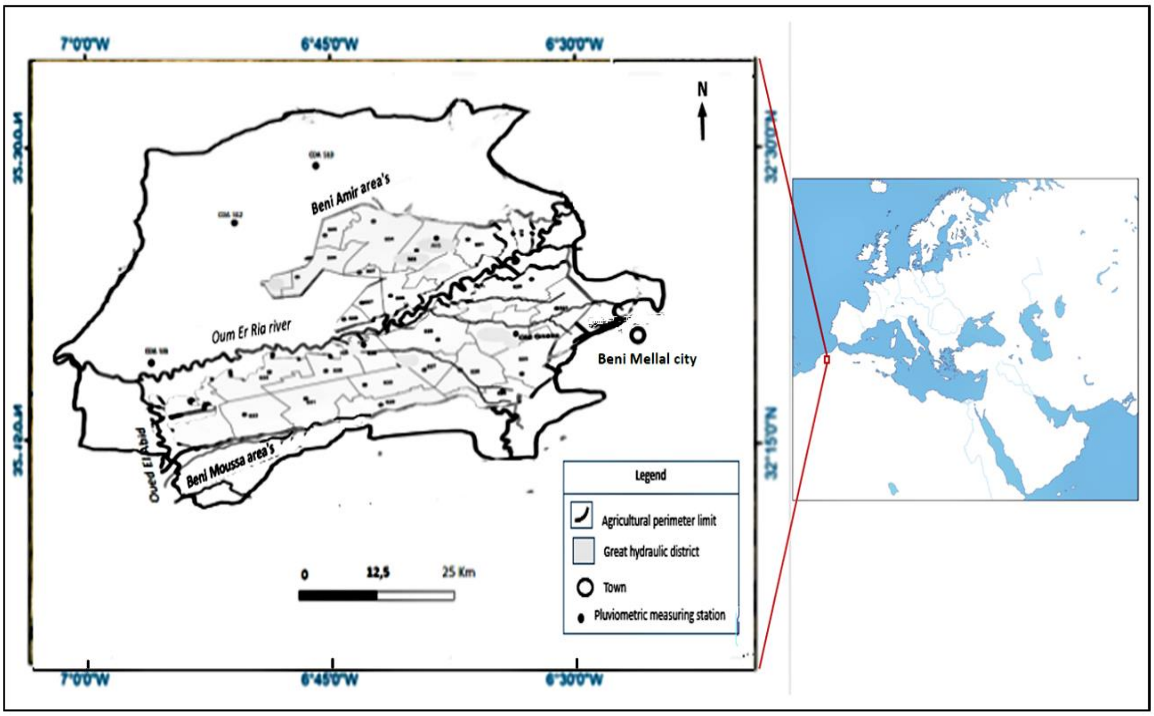

Fig. 1. Geographical location of the study area and location points of pluviometric studied stations.

Climate context

The climate is of a semi-arid zone, with dry period in April-October, while wet period in November-March. The air temperature is an average of 8°C, between extremes of 40 °C in August and 3.5 °C in January. The annual evaporation rate is 1800 mm and yearly average rainfall is 300 mm (ORMVA du Tadla 2019). The detailed characterization study of the rainfall regime in the area is the subject of this work.

Water-agricultural infrastructures

The study area is identified with the irrigated perimeter of the Tadla with a surface area of 120,000 ha and is equipped with large hydraulic infrastructures on 98,300 ha, divided between the Béni Moussa perimeter for 69,600 ha, served by the Bin El Ouidane water barrier with a capacity of 1.3 billion m^3 as well as the Béni Amir perimeter on 28,700 ha, by the EL Hansali water barrier with a capacity of 740 million m^3. The remaining 22,000 ha is irrigable by: pivot system, small and medium hydraulic of the Atlas piemond and groundwater pumping zone. The dominant irrigation method is gravity irrigation, which is planned to be replaced by another more rational method of water use, by integrating the area into the national irrigation water saving PNEEI program, with a view to convert 89,000 ha at localized irrigation, including 49,000 ha as a collective option and 40,000 ha as an individual option (Moroccan Ministry of Agriculture 2019).

Agricultural development

The agricultural economic development of the Tadla area is the result of favorable soil fertility conditions, the availability of water resources, the importance of hydro-agricultural equipment for irrigation and the supervision of farmers, hence allowing an annual crop rotation diversified into irrigated crops. In the 2016/2017, an area of

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148,700 ha was cultivated, of which 71 % is annual crops and 29 % fruit trees. In rainfed area at a useful agricultural area of 133,000 ha, a predominant winter cereal crop was caltivated on areas varied according to rainfall level of seasonal agriculture (ORMVA du Tadla 2019).

Pluviometric database

The rainfall data are from the network of 27 studied stations in the area of action of the regional office of agricultural enhancement of Tadla, a public establishment placed under tutelage of the Moroccan Ministry of Agriculture, including sites indicated on the map (Fig. 1), at a 60-year recorded period from agricultural seasons i.e., 1958/1959 to 2017/2018 (equals 1958-2018 period). A season begins from 1 September to 31 August. The characteristics of the studied stations are reported in Table 1 and gaps are filled by inverse distance weighting (referenced by I.D.W.) (Shepard 1968).

Table 1. Characterization of pluviometric studied stations, data sources for the study (Observation period: 1958-2019).

Perimeter	Hydro-agricultural district	Stations	N° station	Local Communities	Latitude (decimal degree)	Longitude (decimal degree)	Altitude (m)	Annual rainfall Mean (mm)	Standard deviation (mm)	Variation coefficient CV (%)
Béni Amir	AGR-Béni Amir	501	1	BRADIA	32,44904	-6,52868	439	311	112	36
		503	2	HEL MERBAA	32,49110	-6,61800	445	295	112	38
		AS	3	HEL MERBAA	32,46843	-6,59654	441	292	107	37
		504	4	KRIFAT	32,48430	-6,68850	436	292	110	38
		505	5	BENI OUKIL	32,50961	-6,75735	440	293	110	37
		507	6	OULED ZMAM	32,69192	-6,69192	415	283	113	40
		508	7	KRIFAT	32,44800	-6,77486	416	290	107	37
		510	8	BENI OUKIL	32,57349	-6,84426	465	293	114	39
		511	9	KHALFIA	32,51589	-6,53523	464	298	112	38
		512	10	BENI CHEGDAL	32,45697	-6,93983	409	277	112	40
Béni Moussa	AGR-Béni Moussa Est	520	11	BRADIA	32,41407	-6,49830	445	314	120	38
		521	12	SIDI JABEUR	32,36804	-6,45427	462	331	120	36
		OG	13	OULED GNAOU	32,30616	-6,50465	449	351	108	31
		523	14	OULED MBAREK	32,28061	-6,46358	476	336	112	33
		525	15	AFOURER	32,21005	-6,53183	474	334	108	32
		526	16	OULED	32,26538	-6,58727	438	305	114	38
		527	17	BOURAMOUNE	32,29153	-6,58631	430	307	119	39
		528	18	SIDI AISSA	32,34263	-6,65059	415	290	116	40
	AGR-Béni Moussa Ouest	529	19	BENI AYAT	32,24111	-6,65533	444	309	119	39
		530	20	SOUK SEBT	32,25353	-6,69301	434	297	114	38
		531	21	OULED NASSER	32,25321	-6,74462	417	292	122	42
		532	22	OULED AYAD	32,20524	-6,80568	439	285	122	43
		533	23	HAD BOUMOUSSA	32,23287	-6,94245	386	279	121	43
		534	24	DAR OULD	32,30551	-6,90118	376	280	123	44
		535	25	SOUK SEBT	32,28971	-6,69201	412	306	117	38
		536	26	OULED NASSER	32,30287	-6,76874	399	299	113	38
		538	27	HAD BOUMOUSSA	32.30088	-7.02236	353	274	121	44

The average annual precipitation volume per station varies from 274 to 336 mm/year. Coefficient of variation (CV %) in relatively high stations restricted between 31% and 44%, by tendency to increase as it moves from the East to the West, decreasing with more altitude. In terms of years, the average annual rainfall at all stations combined is generally 310 mm/year, evolving with strong oscillations and downward trend, as shown in Fig. 2.

Methods of analysis of rainfall aspects

The study of climate variability for the area rainfall regime in question uses appropriate methods (Sen 1968; Kendall & Stuart 1976; Lee & Heghinian 1977; Buishand 1984; Hubert *et al.* 1989; McKee *et al.* 1993; Nicholson & Palao 1993; Assani 1999; Sebbar *et al.* 2011; Abdou *et al.* 2008; Fossou *et al.* 2015; Krimissa *et al.* 2017; Traoré *et al.* 2017), relating to the following methods:

i) Methods for studying rainfall variability: confidence interval procedure, standardized precipitation index (SPI) (or Nicholson rainfall index) and weighting with a second order Hanning low-pass filter.

ii) Rainfall trend detection methods: by Mann-Kendall test, to identify whether or not there is a trend. If so, the direction and slope of the trend is by Sen's test.

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iii) Methods for detecting breakage in rainfall series: by Pettitt test, Lee and Heghinian bayesian method, Buishand U statistical method and Hubert segmentation; with computer data processing by KhronoStat 1.01 software, open access, related to the Research and Development Institute (RDI) and the University of Montpellier (Boyer 1998).

The necessary additional statistical processing is carried out by the software: R, SPSS and Excel.
The spatial and temporal distribution of precipitation is carried out by mapping the results of the above analyses using spatial and technical interpolation of the Geographic Information System (GIS).

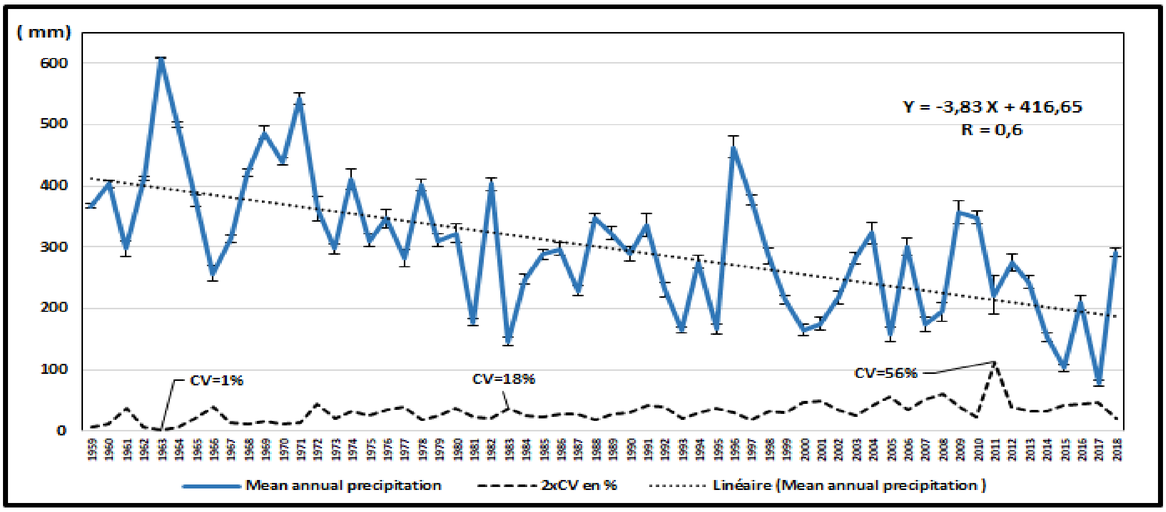

Fig. 2. Evolution of mean annual precipitation with margin of error, trend curve with linear regression line equation and evolution curve of the annual variation coefficient (CV %) at Tadla perimeter in 1958-2018 period.

Methods for studying rainfall variability

a-Confidence interval method

In this method, the normal year is the annual average rainfall in the time series and a limit is set for rainfall with or without a drought year or surplus. A confidence interval (I_c) is then defined by reference to the following statistical equation theory (McKee *et al.* 1995):

$$I_c = \left[\bar{x} - t_\alpha * \left(\frac{\sigma}{\sqrt{n}}\right) ; \bar{x} + t_\alpha * \left(\frac{\sigma}{\sqrt{n}}\right) \right]$$

Where $\bar{x}$: Estimated mean; t_α : Normal law value; $\frac{\sigma}{\sqrt{n}}$: Error- type ; σ: Standard deviation of the sample and n : Sample size.

An annual rainfall value below the lower bound of the confidence interval is climatically dry and conversely a wet year above the upper bound.

b-Pluviometric index of deviation from normal "En" (or Deficit Precipitation Index "DPI")

An observed rainfall is placed at the normal rainfall by the following formula (Jouilil *et al.* 2013):

$$\text{DPI (en \%)} = (P_i - P_m)/P_m \times 100$$

Where P_i: observed annual precipitation (in mm). P_m: annual average precipitation (in mm).
We note in a wet year if DPI is positive or dry if it is negative. A nil DPI in a year as normal.

c-Standardized precipitation index (or Nicholson rainfall index)

The rainfall trend is specified by the standardized rainfall index, referenced by SPI (McKee *et al.* 1995) or by Nicholson I_i's index (Nicholson & Palao 1993). Since 2009, SPI index has been recommended by the World Meteorological Organization (W.M.O.), anywhere as a reliable instrument for measuring the phenomenon of meteorological drought (W.M.O. 2012), which is calculated by the following equation:

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$$\textbf{IPS (ou } I_i) = (X_i - \overline{X}) / S$$

Where SPI: Rainfall index (or I_i); X_i: Rainfall for year i (in mm); $\overline{X}$: Average rainfall over the study period (in mm); S : Standard deviation of rainfall over the study period.

A dry year with an SPI index of less than (-0.5), in a normal year the SPI is between (-0.5) and (+0.5) and in a rainy year the SPI exceeds (+0.5) (McKee *et al.* 1995; Abdou *et al.* 2008).
If with reasoning over the entire specified area, dominated by a number of rainfall stations, SPI (or I_{Si}) is calculated by averaging the centred and reduced annual cumulative rainfall available at these stations for a given period, by formula below (Abdou *et al.* 2008):

$$I_{Si} = \frac{\sum_{j=1}^{N_j} \frac{(P_j^i - \overline{P_j})}{\sigma_j}}{N_j}$$

Where P_j^i : rain of year i at station j; $\overline{P_j}$: mean inter-annual rain of station j ; σ_j : standard deviation of the series of station j ; N_j : number of stations of year i.

d- Hanning low-pass filter of order 2 (weighted moving averages)
In order to eliminate seasonal variations in the time series of data, a second order Hanning low-pass filter is applied by weighted moving average and by the following equation (Assani 1999):

$$X'_{(t)} = 0{,}06X_{(t-2)} + 0{,}25X_{(t-1)} + 0{,}38X_{(t)} + 0{,}25X_{(t+1)} + 0{,}06X_{(t+2)}$$
$$[\text{In order to : } 3 \leq t \leq (n-2)]$$

$X'_{(t)}$: Total rainfall weighted to rank t of the series.
$X_{(t-2)}$; $X_{(t-1)}$; $X_{(t)}$; $X_{(t+1)}$; $X_{(t+2)}$ and $X_{(t+1)}$: Main rainfall totals at the rows of the series terms**.**

The weighted rainfall totals for the first two terms [$X_{(1)}$, $X_{(2)}$] and the last two terms of the series [$X_{(n-1)}$, $X_{(n)}$] are calculated by the following formulas (n being the size of the series):

$$X'_{(1)} = 0{,}54X_{(1)} + 0{,}46X_{(2)}$$
$$X'_{(2)} = 0{,}25X_{(1)} + 0{,}5X_{(2)} + 0{,}25X_{(3)}$$
$$X'_{(n-1)} = 0{,}25X_{(n-2)} + 0{,}5X_{(n-1)} + 0{,}25X_{(n)}$$
$$X'_{(n)} = 0{,}54X_{(n)} + 0{,}46X_{(n-1)}$$

In order to nuance periods of rainfall deficits from those in excess, transformation of the previous weights once they have been carried out into centred variables and reduced by the equation:

$$Y'_t = (X'_{(t)} - \overline{X'})) / \sigma$$

Where $\overline{X'}$, average of new series transformed to weighted values and σ its standard deviation.

This method is more effective in characterizing the variability of rainfall series (Assani 1999).

Statistical methods of rainfall trends
a-Test of Mann-Kendall
The Mann-Kendall non-parametric test, based on rank, determines whether the correlation between time and the variable studied is significant in the search for a trend in the time series. Sample stationarity of values independent of the random or time series variable is evaluated. This method then defines the multivariate standard normal U_{MK} and its sign defines the direction of the trend either upwards or downwards (Kendall & Stuart 1976).

b-Sen's method
Sen's method determines the slope of a time series of regularly spaced data, once detected using Kendall's test by calculating possible slopes of serial data and associating a confidence interval with it (Braumer 1997).

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Methods for statistical tests of homogeneity on annual rainfall series

a-Pettitt test

This test is a modified version of the Mann-Wihtney test, it allows to verify stationarity of rainfall series, which is subdivided into two groups of data with respective sizes m and n and whose values are grouped and classified in ascending order, followed by the calculation of the sum of the ranks of elements in each group. A statistical study allows to detect the existence or absence of a break (Pettitt 1979).

b-Lee and Heghinian bayesian method

It is a bayesian method that proposes a parametric approach, requiring a normal distribution of serial values. The absence of a break in the series is a null hypothesis (Lee & Heghinian 1977).

c-Buishand U-Statistics

The procedure has the same concepts and hypotheses considered in Lee and Heghinian's method, with the condition of normality of the series data studied, in particular the position of the possible break point to be identified by Buishand's U statistics (Buishand 1984).

d-Hubert segmentation

The segmentation in question consists in splitting the time series into segments. For two contiguous segments a significant difference is then identified as the break in the series (Hubert *et al.* 1989). This is by the Scheffé test of equality of distribution means (Dagnelie 1970).

Notably, the mathematical equations of these four statistical tests of homogeneity of rainfall series are reported in detail in the publications of de Traoré et *al.* (2017).

RESULTS AND DISCUSSIONS

RESULTS

Precipitation regime variability analyses

a- Confidence interval on rainfall (CI)

Drought thresholds in the study area fluctuate between 243 and 326 mm/year (Table 2).

b-Pluviometric index of deviation from normal (En) (or Deficit precipitation index (DPI))

The En index (or DPI) is at the drought threshold in proportions from (-11%) to (-8) %, for the limit above 243 mm/year (Table 3).

Table 2. Drought thresholds (determinated from confidence interval "CI" with deviation from normal) and frequencies for dry, normal and wet years at Tadla perimeter in 1958-2018.

Pluviometric stations	Drought threshold (Lower terminal to CI in mm)	Drought threshold deviation of normal (calculated by DPI %)	Frequencies of years			Pluviometric stations	Drought threshold (Lower terminal to CI in mm)	Drought threshold deviation of normal (calculated by DPI %)	Frequencies of years		
			Dry (D)	Normal (N)	Wet (W)				D	N	W
501	282.6	-9%	37%	20%	43%	523	307.6	-8%	35%	28%	37%
503	266.7	-10%	43%	15%	42%	525	307.3	-8%	38%	20%	42%
AS	323.6	-8%	42%	25%	33%	526	275.9	-9%	38%	23%	38%
504	264.8	-9%	42%	13%	45%	527	277.5	-10%	43%	18%	38%
505	265.6	-9%	43%	17%	40%	528	260.8	-10%	42%	22%	37%
507	254.8	-10%	40%	23%	37%	529	279.0	-10%	32%	35%	33%
508	263.5	-9%	42%	20%	38%	530	268.3	-10%	47%	13%	40%
510	264.1	-10%	40%	23%	37%	531	261.6	-11%	40%	18%	42%
511	270.0	-9%	35%	25%	40%	532	254.2	-11%	37%	22%	42%
512	249.1	-10%	35%	28%	37%	533	248.4	-11%	48%	15%	37%
520	283.3	-10%	40%	20%	40%	534	249.5	-11%	42%	23%	35%
521	301.1	-9%	37%	22%	42%	535	276.5	-10%	45%	15%	40%
OG	265.2	-9%	40%	20%	40%	536	270.5	-10%	38%	22%	40%
-	-	-	-	-	-	538	243.6	-11%	43%	20%	37%

Indeed, the frequencies by annual rainfall class were 32%-48%, 13%-32% and 33%-45% in dry, normal and wet years respectively. This makes it possible to identify effective drought periods in the study area from 1981 to 1995

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(14 years), after a delay of tree transitional years, resumption by new drought period 1998-2007 (9 years) (Figure 1).

c-Standardized Precipitation Index (SPI)

The global zone SPI index estimated frequencies in dry years (SPI<-0.5) at 33%, in normal years [SPI between (-0.5) and (+0.5)] at 35% and in wet years (SPI > 0.5) at 32% (Fig. 3).

The SPI trend analysis, supported by a 10-year moving average, identifies three rainfall phases, defined as follows (Fig. 2): Period 1 (1958-1971): Dominantly marked in heavy rainfall years; period 2 (1972-1979): Intermediate with annual rainfall close to normal and period 3 (1980-2018): Characterized by dry years, the situation still persists.

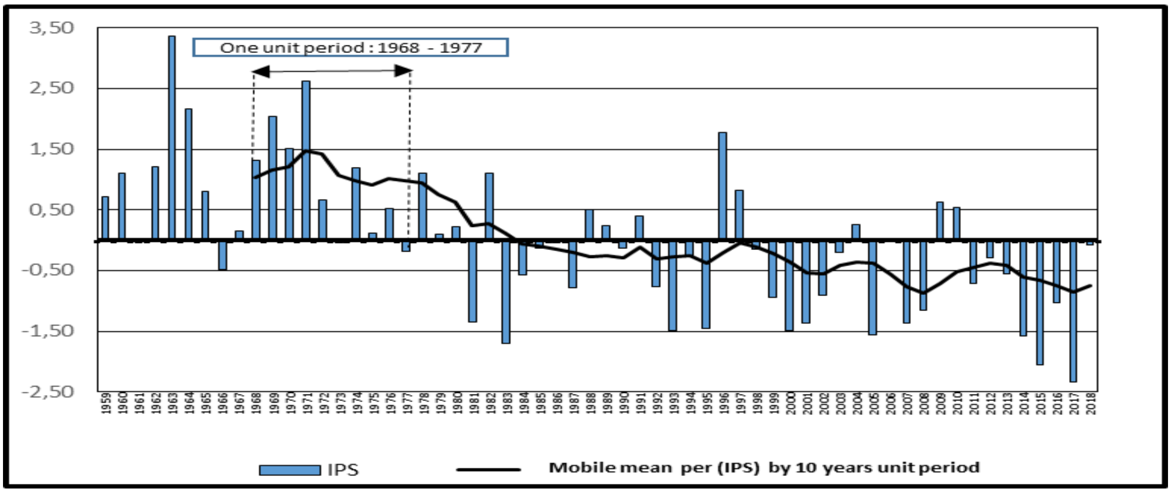

Fig. 3. SPI precipitation index at Tadla perimeter for 1958-2018.

d- Hanning low-pass filter of order 2 (weighted moving averages)

It is determined by this filter as three distinct phases including: Period A (1958-1979): Annual rainfall with a tendency to exceed normal; period B (1980-1987): Annual cumulative rainfall fluctuating over a decade in irregular alternation between wet, normal and dry years and period C (1988-2018): Dominance of deficit years prolonged until today (Figes. 4).

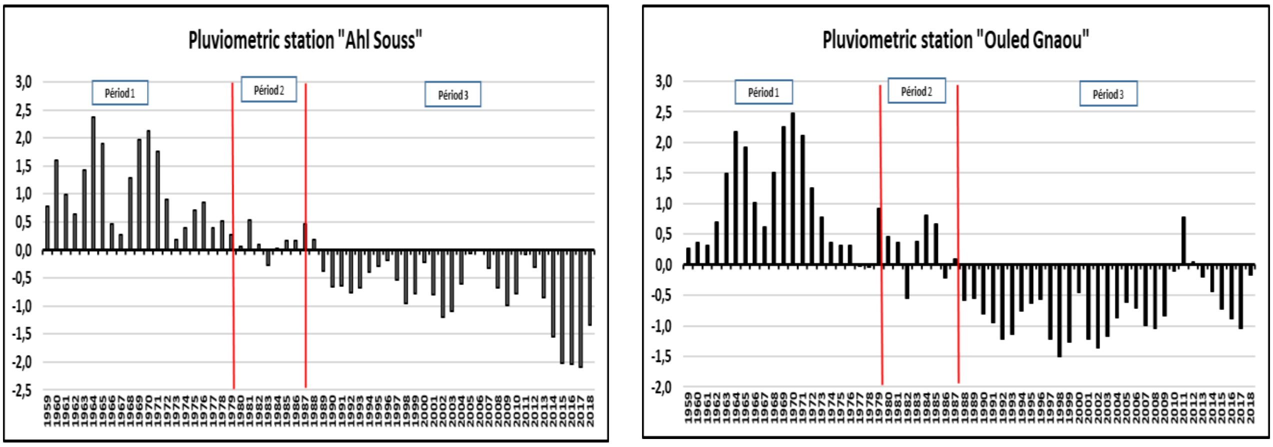

Fig. 4. Hanning low-pass filter indices of order 2 from 1958 to 2018 on annual rainfall at Ahl Souss (left graph) and Ouled Gnaou (right graph) stations.

Viewing similarity of trend between studied stations, evolution of weighted index is presented in Figure 5 for Ahl Souss model stations at Béni Amir perimeter and Ouled Gnaou at Béni Moussa perimeter.

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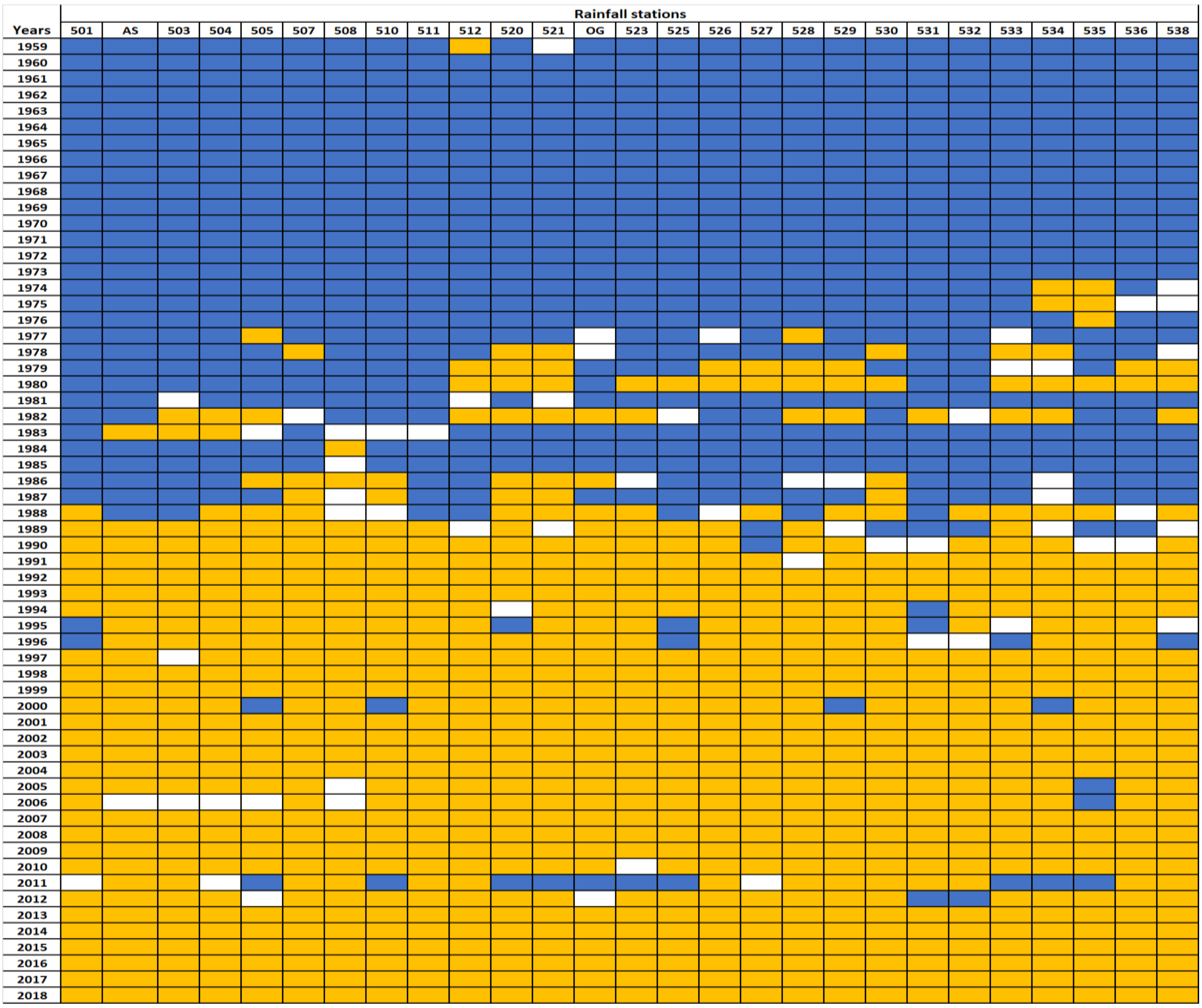

Fig. 4. Hanning low-pass filter rainfall indices of order 2 in 1958-2018

(Representations of positive, zero and negative indices in blue, white and orange boxes respectively).

Trend tests

a-Test Mann-Kendall

The results of trend test are reported in Table 3.

Table 3. Trend statistical tests by Mann-Kendall method on rainfall data-Tadla perimeter (1958-2018).

Pluviometric stations	Paramètres du test de Mann-Kendall					Pluviometric stations	Paramètres du test de Mann-Kendall				
	Kendall tau-B	U_{MK} Mann-Kendall	P-value of the test	Hypothesis Ho: No trend	Sense of trend		Kendall tau-B	U_{MK} Mann-Kendall	P-value of the test	Hypothesis Ho : No trend	Sense of trend
501	-0.39	-4.35	0.00001	No	Decrease	526	-0.47	-5.28	0.00001	No	Decrease
503	-0.35	-3.91	0.00005	No	Decrease	527	-0.44	-4.97	0.00001	No	Decrease
504	-0.31	-3.45	0.00029	No	Decrease	528	-0.41	-4.60	0.00001	No	Decrease
505	-0.35	-3.95	0.00004	No	Decrease	529	-0.43	-4.87	0.00001	No	Decrease
507	-0.44	-5.01	0.00001	No	Decrease	530	-0.41	-4.60	0.00001	No	Decrease
508	-0.35	-3.95	0.00004	No	Decrease	531	-0.49	-5.48	0.00001	No	Decrease
510	-0.33	-3.77	0.00008	No	Decrease	532	-0.49	-5.53	0.00001	No	Decrease
511	-0.37	-4.17	0.00001	No	Decrease	533	-0.44	-5.00	0.00001	No	Decrease
512	-0.43	-4.81	0.00001	No	Decrease	534	-0.44	-4.92	0.00001	No	Decrease
520	-0.41	-4.60	0.00001	No	Decrease	535	-0.36	-4.09	0.00001	No	Decrease
521	-0.42	-4.79	0.00001	No	Decrease	536	-0.43	-4.90	0.00001	No	Decrease
523	-0.39	-4.40	0.00029	No	Decrease	538	-0.50	-5.61	0.00001	No	Decrease
525	-0,33	-3.67	0.00013	No	Decrease	AS	-0.34	-3.79	0.00005	No	Decrease
-	-	-	-	-	-	OG	-0.28	-3.15	0.00118	No	Decrease

The very highly significant Mann-Kendall test implies a downward trend in annual rainfall chronologies and the predisposition to perform the next Sen's test.

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b-Sen's test

The results of this test are given in Table 4.

Table 4. Statistical trend tests using Sen's method on rainfall data of Tadla perimeter (1958-2018).

Pluviometric stations (Pl.. St.)	Sen's test				Pl. st.	Sen's test				Pl. st.	Sen's test			
	Confidence interval from trend slope to 95% significance			Ho:Non-significant trend (N.S.T)		Confidence interval from trend slope to 95% significance			Ho: N.S.T		Confidence interval from trend slope to 95% significance			Ho: N.S.T
	Lower terminal	Average value	Upper terminal			Lower term.	Average value	Upper term.			Lower term.	Average value	Upper term.	
501	-0.118	-0.081	-0.044	No	520	-0.129	-0.098	-0.066	No	531	-0.121	-0.093	-0.066	No
503	-0.112	-0.077	-0.042	No	521	-0.117	-0.087	-0.057	No	532	-0.122	-0.094	-0.066	No
504	-0.110	-0.074	-0.037	No	523	-0.116	-0.082	-0.048	No	533	-0.117	-0.087	-0.057	No
505	-0.114	-0,079	-0.043	No	525	-0.115	-0.078	-0.041	No	534	-0.115	-0.086	-0.057	No
507	-0.126	-0.094	-0.062	No	526	-0.128	-0.098	-0.067	No	535	-0.112	-0.079	-0.046	No
508	-0.120	-0.084	-0.048	No	527	-0.121	-0.091	-0.061	No	536	-0.126	-0.095	-0.063	No
510	-0.111	-0.077	-0.042	No	528	-0.120	-0.088	-0.056	No	538	-0.126	-0.095	-0.063	No
511	-0.118	-0.084	-0.050	No	529	-0.115	-0.084	-0.052	No	AS	-0.118	-0.081	-0.044	No
512	-0.112	-0.081	-0.050	No	530	-0.122	-0.089	-0.057	No	OG	-0.105	-0.067	-0.028	No

Sen's test gives the negative trend slope (median of the regressions) of an average of (-0.085), varying within the range of: (-0.098) at CDA 520 station to (-0.067) at Ouled Gnaou station.

Homogeneity tests for the detection of ruptures

A priori tests of homogeneity in the detection of ruptures in rainfall series, tests of required conditions are carried out on a random basis by correlation test on Mann-Kendall rank (Table 3) as well as independence by KhronStat software in auto-correlogram test (Traoré *et al*. 2017), the normal distribution per Chapiro-Wilk test and equal variance (homoscedasticity) per Ficher test along with Levene test after break-up of our rainfall series in rupture detection (Table 5).

Table 5. Tests on rainfall data distributions: Normality by Chapiro-Wilk test along with variance comparison by the Fisher and Levene tests.

Pluviometric stations (Pluv. St.)	p-value of normal test (Chapiro-Wilk test)		p-value of homogeneity test (before/after rupture)		Pluv. St.	p-value of normal test (Chapiro-Wilk test)		p-value of homogeneity test (before/after rupture)	
	Before rupture	After rupture	Levene test (alpha = 005)	Ficher test (alpha = 0.05)		Before rupture	After rupture	Levene test (alpha=0.05)	Ficher test (alpha=0.05)
501	0.936	0.177	0.203	0.53	523	0.114	0.853	0.743	0.71
503	0.999	0.170	0.966	0.83	525	0.569	0.455	0.393	0.65
AS	0,993	0.260	0.663	0.29	526	0.859	0.844	0.906	0.79
504	0.998	0.132	0.964	0.57	527	0.866	0.554	0.817	0.74
505	0.998	0.867	0.949	0.59	528	0.239	0.397	0.692	0.94
507	0.727	0.486	0.679	0.83	529	0.277	0.076	0.417	0.99
508	0.980	0.509	0.567	0.28	530	0.477	0.092	0.971	0.95
510	0.977	0.556	0.900	0.63	531	0.581	0.486	0.354	0.59
511	0.982	0.153	0.639	0.90	532	0.617	0.530	0.875	0.72
512	0.950	0.450	0.502	0.48	533	0.885	0.868	0.128	0.77
520	0.644	0.517	0.481	0.61	534	0.517	0.408	0.512	0.79
521	0.114	0.,853	0.544	0.71	535	0.803	0.358	0.731	0.65
OG	0.068	0.196	0.555	0.88	536	0.649	0.878	0.618	1.00
-	-	-	-	-	538	0.955	0.911	0,531	0.79

a-Pettitt rupture test

This test identifies major's ruptures of pluviometry during 1978-1989 (Table 6).

4- Synthetic analysis with spatio-temporal mapping of rainfall variability

The benchmark agricultural year used as a breakpoint is 1977/1978 (referenced by 1978) (Graph on the left of Fig. 6). In the period before break 1959-1978, average rainfall is 397 mm year^{-1} (confidence interval : 359 at 436 mm year^{-1}), followed by post-break to 1979 at 2018 with mean rainfall of 254 mm/year (confidence interval : 228 at 280 mm year^{-1}). So, mean rainfall reduction rate is to 36% (right-hand graph in Fig. 6).

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Table 6. Pettitt rupture detection test on rainfall chronologies at Tadla perimeter (1958-2018).

Stations (St.)	Pettitt test			St.	Pettitt test			St.	Pettitt test		
	Dates of rupture	Probability of exceeding	Level of significance (L.S.)		Dates of rupture	Probability of exceeding	L.S.		Dates of rupture	Probability of exceeding	L.S.
501	1978	3.16E-04	Very highly	512	1982	2.04E-04	VHS	529	1980	6.29E-05	VHS
503	1979	2.76E-03	Highly	520	1978	1.97E-04	VHS	530	1980	1.75E-05	VHS
AS	1979	4.91E-03	Highly	521	1980	4.83E-06	VHS	531	1982	2.76E-05	VHS
504	1979	4.43E-03	Highly	OG	1978	3.80E-04	VHS	532	1982	1.17E-05	VHS
505	1978	2.54E-03	Highly	523	1980	6.29E-05	VHS	533	1978	1.53E-04	VHS
507	1982	3.40E-05	Very highly	525	1992	7.53E-03	TS	534	1975	7.19E-05	VHS
508	1979	2.10E-03	Highly	526	1978	6.29E-05	TS	535	1980	7.80E-04	VHS
510	1982	4.66E-03	Highly	527	1980	1.46E-05	TS	536	1980	5.49E-05	VHS
511	1978	7.35E-04	Very highly	528	1978	2.62E-04	TS	538	1982	6.29E-05	VHS

b-Buishand rupture test

A test with a 99% significance, breaks in rainfall series over 1979-1982 in Table 7.

Table 7. Buishand rupture detection tests on rainfall chronologies at Tadla perimeter (1958-2018) .

Station	U max of Buishand		Station	U max of Buishand		Station	U max of Buishand	
	Dates of rupture	Level of Bois elliptical meaning (%)		Dates of rupture	Level of Bois elliptical meaning (%)		Dates of rupture	Level of Bois elliptical meaning (%)
501	1979	99	512	1982	99	529	1980	99
503	1979	99	520	1978	99	530	1980	99
AS	1979	99	521	1980	99	531	1980	99
504	1979	99	OG	1978	99	532	1982	99
505	1978	99	523	1980	99	533	1978	99
507	1982	99	525	1998	99	534	1980	99
508	1979	99	526	1978	99	535	1980	99
510	1978	99	527	1980	99	536	1980	99
511	1978	99	528	1978	99	538	1982	99

c-Lee and Heghinian rupture test

In this test, majority of rainfall breaks were grouped between 1978 and 1980 (Table 8).

Table 8. Lee and Heghinian rupture detection tests on rainfall series at Tadla perimeter (1958-2018).

Stations	Lee and Heghinian test		Stations	Lee and Heghinian test		Stations	Lee and Heghinian test	
	Dates of rupture	Associated probability		Dates of rupture	Associated probability		Dates of rupture	Associated probability
501	1979	0.35	512	1979	0.17	529	1980	0.18
503	1979	0.13	520	1978	0.,38	530	1980	0.28
AS	1979	0.17	521	1980	0.37	531	1980	0.15
504	1979	0.17	OG	1978	0.27	532	1980	0.14
505	1974	0.20	523	1978	0.25	533	1971	0.81
507	1978	0.22	525	1998	0.12	534	1975	0.46
508	1972	0.27	526	1976	0.27	535	1975	0.31
510	1972	0.15	527	1980	0.59	536	1980	0.18
511	1978	0.24	528	1978	0.18	538	1975	0.24

d-Hubert segmentation

Primary breaks in rainfall series in two periods of 1970-1975 and 1978-1980 at the respective rates per measured station concerned are 44% and 56% of cases (Table 9). Following the identified breaks and the comparison with the SPI index, the frequencies in dry, normal and wet years before break are 0%; 30% and 70% while after break reach to 50%; 35% and 15%. The spatial distribution of precipitation at Tadla perimeter during pre- and post-break periods was mapped. In the case of before break rainfall chronologies, we identified four homogeneous sub-areas of precipitations intervals, corresponding to the following classes of isohyets: [368; 383], [383; 396], [396; 409] and [409; 439 mm year^{-1}], revealing a gradient in the increased rainfall intensity from West to East (Fig. 7, left plate). After pluviometry rupture, also it was partitioned into four homogeneous subzones of precipitation intervals, corresponding to the following classes of isohyets : [220 ; 241], [241; 261], [261; 281] and [281; 302

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mm year[-1]], with the same West-East gradient. Consequently, following the chronological break in 1978, the reduction front of precipitation is to 120 at 150 mm year^{-1}, simultaneously affecting the four rainfall subzones with almost the same magnitude (Fig. 7, right plate).

Table 9. Hubert segmentation applied to rainfall temporary series at Tadla perimeter during 1958-2018.

	Hubert segmentation						Segmentation de Hubert				
Stations (St)	**Dates of rupture**	**Number of ruptures**	**Annual average before rupture (mm) (1)**	**Annual average after rupture (mm) ((2)**	**Reduction rate in %: [(1) - (2)] / (1)**	**St**	**Dates of rupture**	**Number of ruptures**	**Annual average before rupture (mm) (1)**	**Annual average after rupture (mm) ((2)**	**Reduction rate in %: [(1) - (2)] / (1)**
501	1978	1	402.8	264.9	34	523	1978	1	429.0	289.3	33
503	1979	1	364.5	255.2	30	525	1998	1	369.6	264.2	29
AS	1979	1	364.2	253.1	30	526	1974; 1998	2	421.9	300.4	29
504	1979	1	366.4	252.4	31	527	1980	1	406.7	249.9	39
505	1974	1	388.5	258.5	33	528	1978	1	384.3	242.6	37
507	1978	1	381.3	234.1	39	529	1978; 1995; 1996	3	403.9	274.5	32
508	1972	1	395.0	258.6	35	530	1980	1	392.5	241.4	39
510	1972	1	394.9	261.6	34	531	1974; 1999	2	413.2	295.5	28
511	1978	1	385.4	254.5	34	532	1974; 1999	2	410.7	281.3	32
512	1970 ; 1997	2	390.6	283.8	27	533	1971	1	429.0	237.3	45
520	1978	1	413.6	263.5	36	534	1975	1	409.3	229.5	44
521	1980	1	434.6	271.5	38	535	1975	1	408.5	265.2	35
OG	1978	1	437.3	307.2	30	536	1972; 1999	2	417.3	297.4	29
-	-	-	-	-	-	538	1971; 2010	2	422.0	255.8	39

All stations show rainfall deficits after the rupture and the rate of reduction in the annual volume of precipitation varies from 27% to 45% depending on the station.

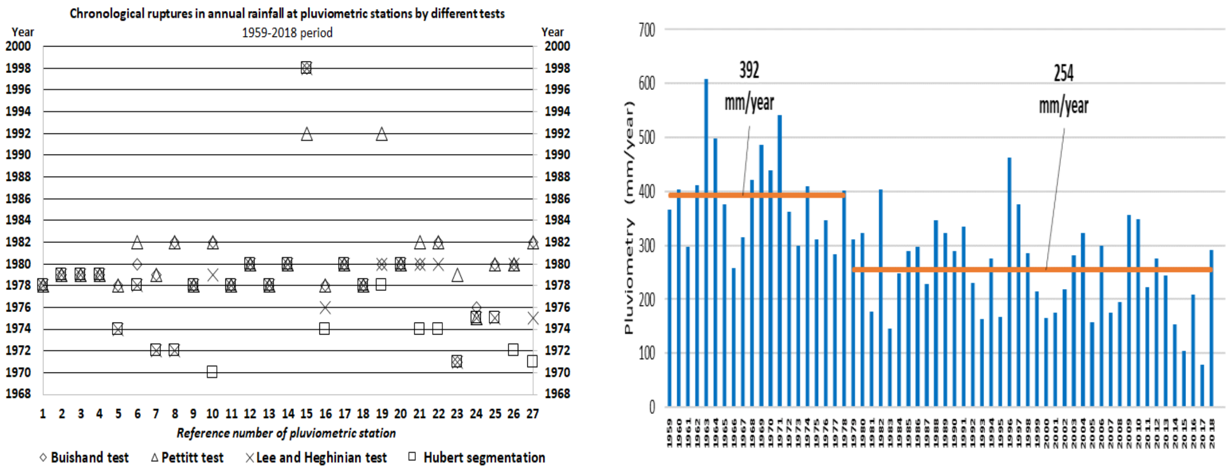

Fig. 6. Chronogram of pluviometric ruptures by homogeneity tests (left graph) and annual precipitation evolution before and after rainfall rupture (right graph) for Tadla perimeter during1958-2018.

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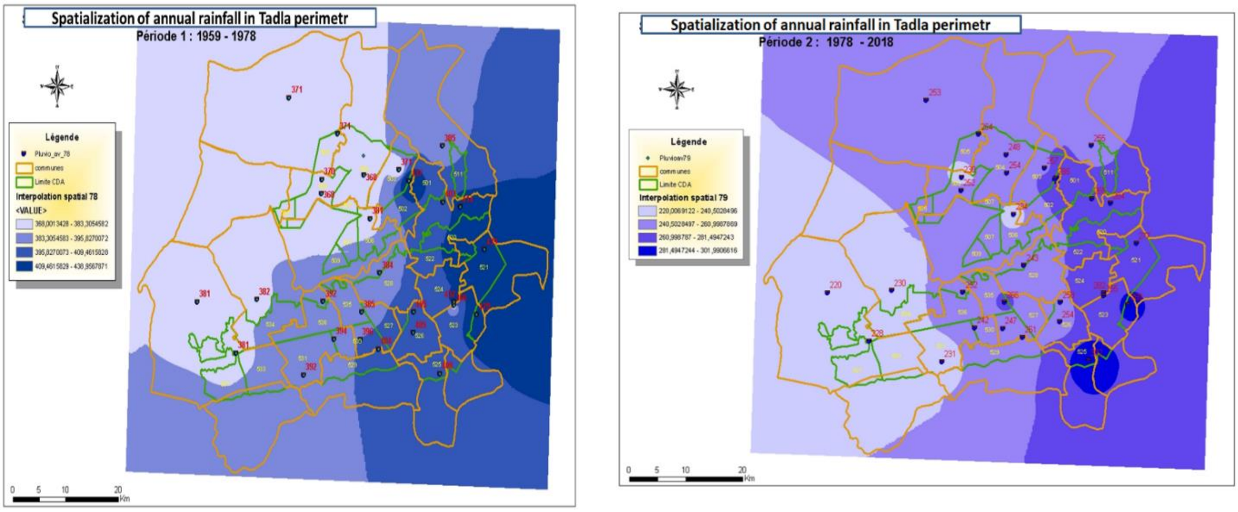

Fig. 7. Spatio-temporal maps of annual precipitation in Tadla perimeter during 1958-2018: *Before rupture (left plate) and after rupture (right plate) in rainfall chronologies.*

DISCUSSION

The confidence interval and precipitation index methods give frequencies almost similar to results for normal and wet years, while found to be higher in dry years (Jouilil *et al.* 2013; Krimissa *et al.* 2017). The downward trend in rainfall patterns confirms the situation in large areas of northern Morocco (Sebbar *et al.* 2011). The trend accuracy by weighting the Hanning low-pass filter of order 2, identified a restricted transitional rainfall during 1980-1987, compared to an interval of 1982-2006 in an adjacent area on the east side where the rainfall deficit was predominant (Krimissa *et al.* 2017).

The rate of reduction in rainfall in the study area after break of 36% is higher than that reported by Sebbar *et al.* (2011) who reported 8 to 15% over the period of 1935-2004, which may be due to a time lag with respect to our observation period, i.e., one and a half decades. The homogeneity tests (during 1958-2018) detect breaks in rainfall series in 1978, preceding breaks on most stations in neighboring areas by author Krimissa *et al.* (2017) during 1983-2015, however, in the only common studied station (Ouled Gnaou-station), no rainfall break was recorded. At two adjacent studied stations such as Beni Mellal’s town and Tadla’s town (during 1935-2004), rainfall rupture is comparable to that observed during 1972-1979 (Sebbar *et al*. 2011). Since the late 1960’s, ruptures have been observed in north-western Algeria (Taibi *et al.* 2013), in the upper Senegal catchment area (Faty *et al.* 2017) and in central-eastern Côte d'Ivoire (Fossou *et al.* 2015) for a decade earlier than our study. Our spatial distribution of rainfall released after chronological break is approximately similar to the annual rainfall map of moroccan territory over the period of 1960-2015 developed by El Ajhar *et al.* (2018) and Nahli *et al.* (2016), where their study area is globally integrated with a single wide rainfall range (200 to 300 mm year^{-1}), compared to four homogeneous subareas determined by our rainfall mapping.

CONCLUSION

The study of the rainfall regime in this potentially-irrigated agricultural perimeter, made it possible to demonstrate the relevance and inter-complementarity of methods for characterizing rainfall variability, methods for analyzing rainfall trends and statistical tests for detecting breaks over time series. In this case, rainfall in the study area is observed to be on a gradual downward trend, even subject to a break in time series at the end of the 1970’s, attesting to the cleavage in the rainfall pattern, initiated some 40 years ago. Moreover, the geographical configuration of the rainfall trend shows a gradient of increased precipitation from the West-East direction, but from the 1980’s onwards, a rainfall drying front uniformly affected the observed regional territory. It is approved that the regional area studied with a semi-arid climate has indeed undergone climate change for its rainfall aspect. So, the successful characterization of variability in spatio-temporal precipitations is proving to be useful in designing unavoidable programs of resiliency, mitigation or adaptation to the scarcity of rainwater resources, in order to judiciously exploit the diversity of crops grown on soils within the area studied or in such areas used for irrigated agriculture but vulnerable to the risk of water depletion.

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بررسی رژیم بارندگی متغیر در یک منطقه کشاورزی با آب و هوای نیمه خشک : مورد محیط آبیاری تادلا (قاره مراکش)

عبد الحق البوندی*، زهور آیت یاسین

مهندسی محیط زیست، دانشکده علوم و فناوری، دانشگاه سلطان مولای سلیمان، بنی ملال، مراکش

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چکیده

حاشیه تادلا ، یک منطقه کشاورزی آبیاری استراتژیک در مراکش است، اما منابع آب باران آن کمیاب‌تر می‌شوند. در واقع، این کار با هدف مطالعه روشهای مربوط به تغییرپذیری بارندگی در این محیط ، با آب و هوای نیمه خشک و با استفاده از ۶۰ سال (۱۹۵۸-۲۰۱۸) از داده های شبکه محلی ۲۷ ایستگاه هواشناسی انجام شده است. آستانه خشکسالی با ۲۴۳ میلی متر در سال تعیین شد و شاخص انحراف بارندگی (۱۱٪-) رسید. شاخص‌های کاهش یافته متمرکز، اطلاعاتی را در مورد همسانی مازاد بارندگی، سال‌های عادی و کسری بارندگی و سه دوره متوالی مربوط به شدت بارندگی به تعداد ارائه داد: ۱۳، ۸ و ۳۹ سال. وزن مرتبه دوم فیلتر هانینگ مرتبه دوم تناسبات را حفظ کرد، اما آنها ده سال آنها تداوم یافتند. آزمون من-کندال نیز کاهش بارندگی را تأیید کرد. تست سن شیب روند منفی را نشان داد. علاوه بر این، آزمون‌های آماری برای تشخیص گسستگی زمانی (Test پیتیت، لی و هژینین روش بیزی، روش آماری Buishand U، تقسیم هوبرت) گسستگی را در سال ۱۹۷۸ تشخیص داد و منجر به مشاهدات پس از گسستگی شد: کاهش ۳۶٪ بارندگی تداوم یافت. فراوانی سال‌های کم باران در جبران سال‌های مازاد روی داد و نقشه برداری از توزیع مکانی-زمانی بارش از سه منطقه همگن، از جمله ایزوایتی که بیشتر با توجه به خشک شدن از غرب به شرق جابه‌جا شداند. نتایج ما که تغییرات آب و هوایی عمیق منطقه ای را توصیف می‌کند، در مورد بارندگی، در ارتقای برنامه نویسی یا سازگاری با کمبود آب باران در چنین بیوتوپ‌های آسیب پذیر کشاورزی مفید است.

*مولف مسئول

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