Precipitation trends and ruptures effect on catchment hydrology and water resources availability for agricultural lands under climate change

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Introduction

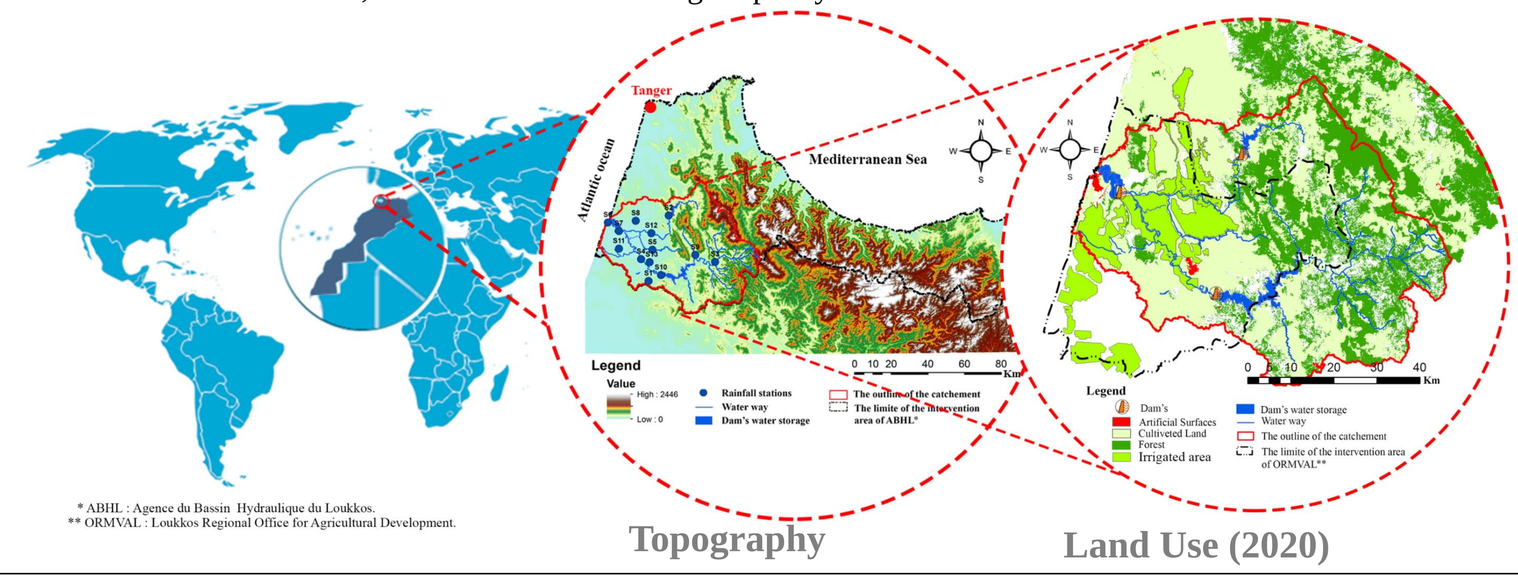
Morocco is located in the north of Africa in the Mediterranean region which is considered as a part of the 'HOST SPOT' of climate change (Giorgi, 2006; Huebener and Kerschgens, 2007). Several studies have been carried out in Africa to analyze and understand past and recent climatic trends and detect ruptures in stationarity in the time series of hydro-climatic parameters (Hallouz, et al, 2007 ; Meddi, 2007; Ouédraogo, 2001; Ardoin 2004). Previous research reveals a decrease in the annual precipitation since the early 1970s (VISSIN, 2003; Amraoui, 2011). Other studies show a rupture in the average of annual precipitation in the 1970s (SINGLA, 2010; Taibi ,2012). Also, a shift in the hydrological year was observed for the same period. Decrease of precipitation directly affects the hydrological cycle and the availability of water resources. It subsequently leads to a disruption of human activities. This variability in the water cycle causes a modification of the agricultural practices and an increase in the irrigated lands.

Questions

- In our study area, can we confirm the climate change observed during the 1970s in the northern region of Morocco?
- If a change in the precipitation regime has been identified, which effect will be expected on the watershed hydrology and on the availability of water resources?
- Did these changes contribute to the increase of irrigated lands area of the studied catchment study area? and what are the different actions to negative effects of climate change?
- How do national policies affects the irrigation lands extension? Are they enough to mitigate climate effect on water resources availability?

Study area

- The study area is the watershed called Bas-Loukkos located in north-west Morocco, with a total area of 3730 km².
- Agricultural area is about 2560 km², of which 508 km² is irrigated.
- Inside the studied catchment, 3 dams with a total storage capacity of more than 1190 Mm³.



Topography Land Use (2020)

Methods & Data

The data processing consists on:

- Selection of reliable data that best represents the spatial and temporal context of the study area (Clustering, correlation, etc.).
- Identification of significant ruptures in the selected time series using statistical tests (Pettitt, Buishand, Lee & Heghinian and the Hubert procedure).
- Summarizing the trends based on the Mann-Kendall test.
- Characterization of local drought (SPI).

Pettitt test (Pettitt 1979): is a Non-parametric test, allowing sudden change points detection and large variations characterisation in average in the time series.

Hubert's segmentation method (Hubert & al, 1987; Hubert, 1989; Hubert, 1997): Widely used to decompose an initial series into m under adjacent series according to the method of **small squares**. The **Scheffe** test (Dagnélie, 1975) is used to determine whether the means of two consecutive sub-series are significantly different.

Bayesian procedure of Lee and Heghinian (1977): Determines the posterior probability distribution of the mean and the variance. It assumes that: "there is a single rupture in the series". It uses the ***Bayes*** formula to establish the posterior distribution of these two parameters. It detects the most likely date for a change.

The Mann-kendall test (Mann 1945; Kendall 1975): is a non-parametric test based on ranks, it is generally used to find out whether a time series has a significant trend or not. The trend is said to be significant if the p-value is below the fixed threshold.

The Standardized Precipitation index (SPI) was designed by researchers at Colorado State University (McKee et al. 1993). It is widely used by researchers to analyze and characterize periods of drought in different spatial and temporal contexts. This index highlights if the year considered is in excess (SPI> 0) or in deficit (SPI <0) precipitation compared to a reference period.

Results

Precipitation

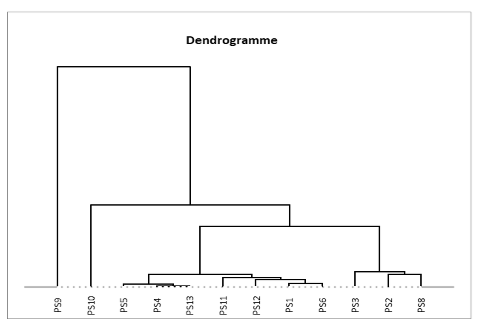


Figure 1: Clustering (Euclidean distance) obtained from annual precipitation over 17 years (1983-2001). The greater the length of the branches, the more heterogeneous the classes grouped together).

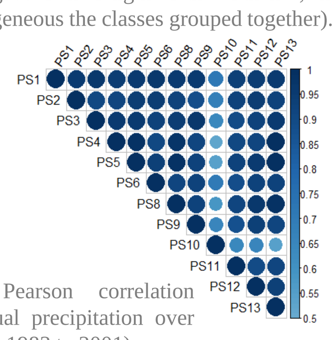


Figure 2: Pearson correlation matrix (Annual precipitation over 17 years from 1983 to 2001)

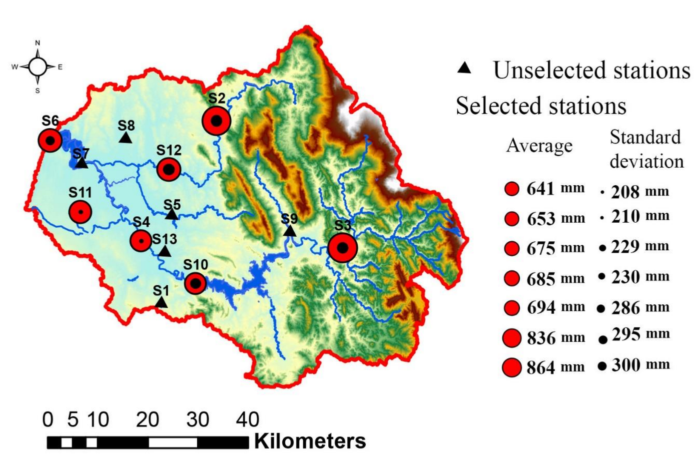


Figure 3: Locations of selected precipitation stations. The red circles indicate the average annual precipitation and the black circles indicate the standard deviation. The calculations have been made on periods of at least 40 years

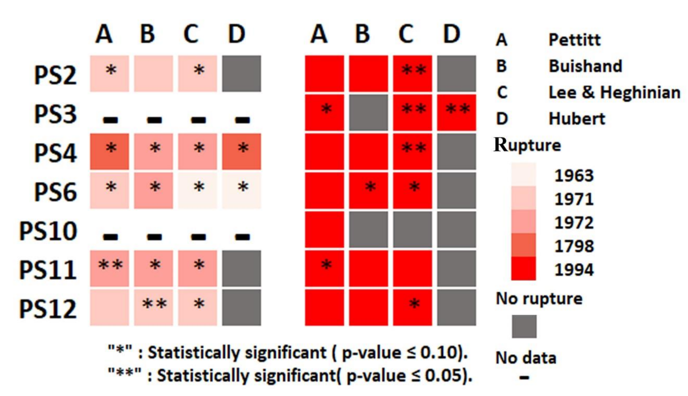


Figure 4: Rupture dates detected by statistical tests (probable ruptures) in the watershed (the first column presents the first probable rupture date (period tested 1962-2005); the second column presents the second probable rupture date (period tested 1975- 2005)).

Table 1: Results of statistical tests applied to annual precipitation in **Bas-LOUKKOS** watershed(in bold: the result is significant at a 5% threshold; " * ": the result is significant at 10%).

	Availbile data	Average (mm)	Standard deviation (mm)	Man-kendall P. de sen	1962 -2005 (first rupture)				1975 -2005 (Second rupture)			
					Pettitt	Buishand	Lee & he	Hubert	Pettitt	Buishand	Lee & he	Hubert
PS2	1962-2005	836.4	299.6	-3.72	1971* (-23%)	1971 (-23%)	1971 (-23%)	-	1994 (+26%)	1994 (+26%)	**1994 (+26%)**	-
PS3	1970-2005	864.5	295.0	4.81	-	-	-	-	1994* (+36%)	-	**1994 (+36%)**	**1994 (+36%)**
PS4	1962-2005	640.8	207.7	-4.26 *	1978* (-21%)	1972* (-25%)	1972* (-25%)	1978* (-21%)	1994 (+05%)	1994 (+05%)	**1994 (+05%)**	-
PS6	1962-2005	685.1	229.5	-4 *	1971* (-24%)	1972* (-21%)	1963* (-41%)	1963* (-41%)	1994 (+24%)	1994* (+24%)	1994* (+24%)	-
PS10	1975-2005	652.9	285.8	-0.67	-	-	-	-	1994 (+14%)	-	-	-
PS11	1962-2005	674.8	210.4	-3.31 *	**1972 (-22%)**	1972* (-22%)	1972* (-22%)	-	1994* (+19%)	1994 (+19%)	1994 (+19%)	-
PS12	1962-2005	693.6	229.9	-6.21 *	1971 (-23%)	**1971 (-23%)**	1971 (-23%)	-	1994 (+25%)	1994 (+25%)	1994* (+25%)	-

After an analysis of the collected data (correlation, classification, etc) , 7 precipitation stations over the period 1962-2005 (figure 1 et 2) were selected. The choice of these stations is based on two main criteria:

- the time series should cover the longest common period and with a good quality (no missing data)
- the selected stations must be spatially distributed over the studied area.

The application of rupture tests on annual precipitation records has led to the detection of several probable rupture dates.

- A decrease in precipitation varying between -21% and -26% was detected by these tests at thresholds which differ from one station to another and from one test to another.
- A decrease in average precipitation took place in the early 1970s.
- The Lee & Heghinian procedure and the segmentation of Hubert reported a probable rupture in 1963 at a threshold of 10% on station S6 with a reduction of -41%. This result may be due to the influence of the micro-climate (S6 is close to the ocean).
- The Mann-Kendal test indicates an overall downward trend with a variable slope from one station to another (between -0.67 mm/year and -6.21 mm/year) (figures 3;4 and table 1).

The analysis and presentation of SPI show the succession of periods of wet and dry years. According to the SPI values, the study period (1962-2005) can be divided into 3 periods:

a. before 1972: This period is characterized by less recurrent periods of drought (16.13%) of moderate intensity (maximum drought index of -1.4 (moderately dry)). This period can be considered as a very humid period with an average annual precipitation of 846.17 mm / year.
b. Between 1972 and 1994: the drought were more recurrent (percentage of dry years equal to 68.91%) and more intense (SPI index reaches a value of -2.26 (Extremely dry)). With durations exceeding 3 years on average.
c. After 1995: A succession of dry and wet years, the percentage of dry years is 51% with almost normal to moderate droughts. With an accentuation of extreme phenomena.

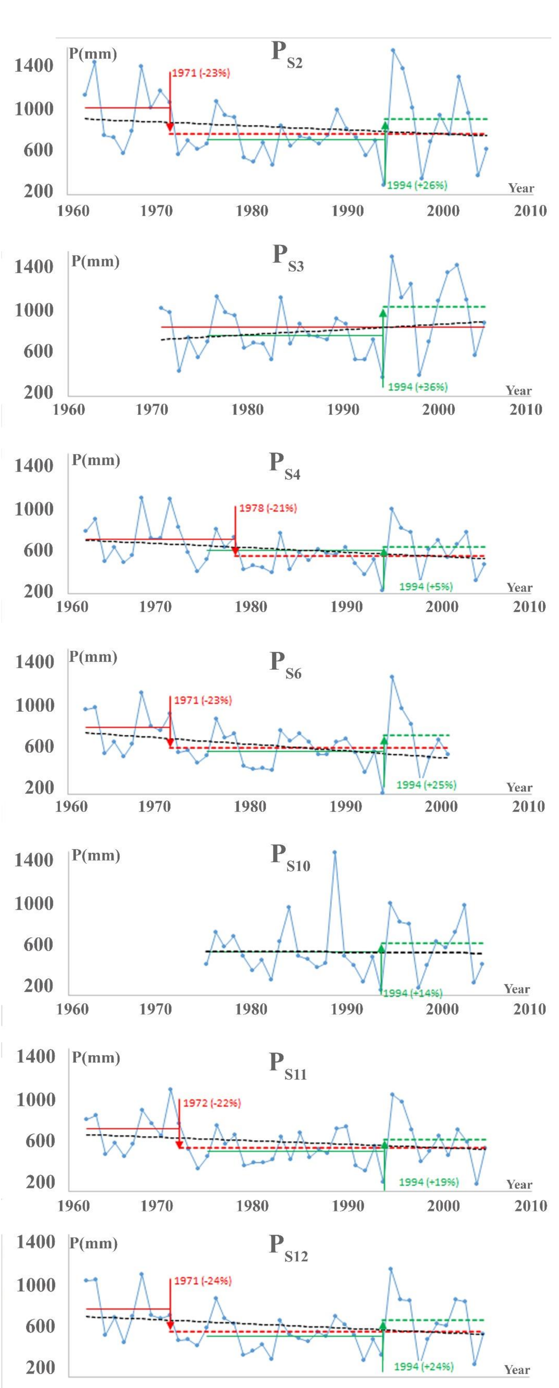


Figure 5: Series of annual average precipitation for the period 1962–2005 at the selected stations. [P (mm): annual average precipitation; M.1: the mean before the first rupture (1962-2005); M.2: the mean after the first rupture (1962-2005); M'.1: the mean before the second rupture (1975-2005); M.2: the mean after the second rupture (1975-2005); CT: trend line].

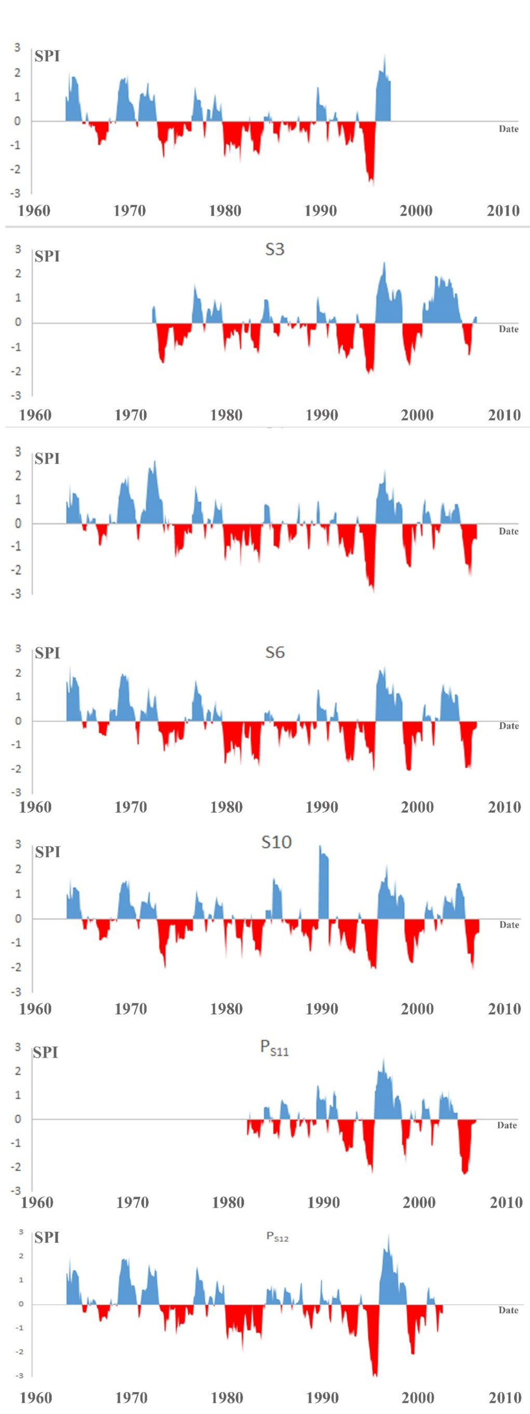


Figure 6: Evolution of the standardized precipitation index (SPI 12 months) for a fifty years period..

Discharge

Five discharge stations are available on the watershed. The time series have variable length, from 47 years (1960-2007) to 20 years (1975-1995). The times series were provided by Loukkos Hydraulic Basin Agency (ABHL).

The discharge rates have experienced an overall reduction since the 1970s. The Mann-Kendal test shows a significant reduction in multiple sub-basins (Table 2). Probable ruptures were generally observed at the end of the 1970s.

A comparison between the dates of ruptures in precipitation and discharge rates shows consistent results. The decrease of precipitation has led to a decrease in annual flows.

However, Station S2 is located downstream of a dam (date of impoundment 1978) which explains the reduction of discharge rates recorded at this station.

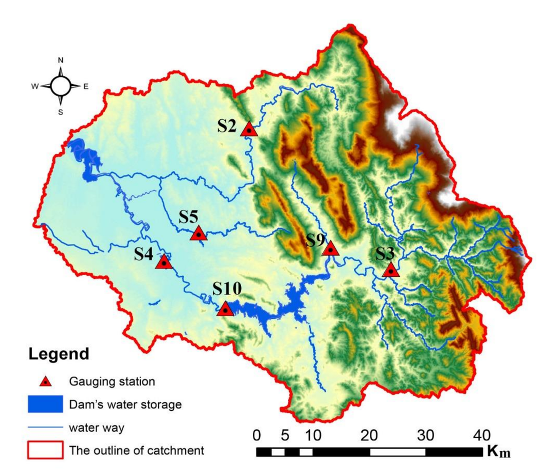


Figure 7: Locations of gauging stations

Table 2: Results of statistical tests applied to annual average flows in **Bas-LOUKKOS** watershed(in bold: the result is significant at a 5% threshold; " * ": the result is significant at 10%).

	Availbile data	Man-Kendall P. de Sen	Pettitt	Buishand	Lee & he	Hubert
Q_{S2}	1975-1995	**-0.249**	1978 (-61%)	**1978 (-61%)**	**1979 (-61%)**	**1978 (-61%)**
Q_{S3}	1969-2007	**-0.28**	1990 (-38%)	**1990 (-38%)**	**1997 (-55%)**	**1997 (-55%)**
Q_{S4}	1961-2007	**-0.47**	**1979 (-50%)**	**1979 (-50%)**	-	-
Q_{S5}	1970-2007	-0.001	1978* (-29%)	-	-	-
Q_{S9}	1975-2006	0.051	**1994 (+124%)**	1994* (+124%)	**1994 (+124%)**	**1995 (+124%)**
Q_{S10}	1961-2007	**-0.373**	**1978 (-44%)**	**1978 (-44%)**	**1970 (-49%)**	**1971 (-49%)**

Irrigated area extension

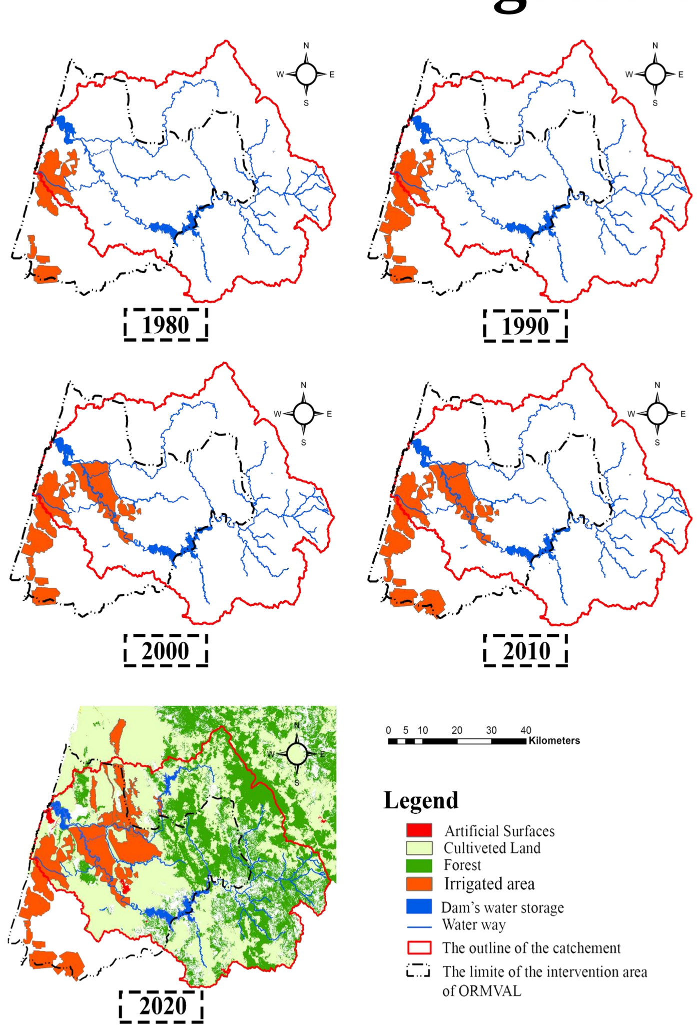
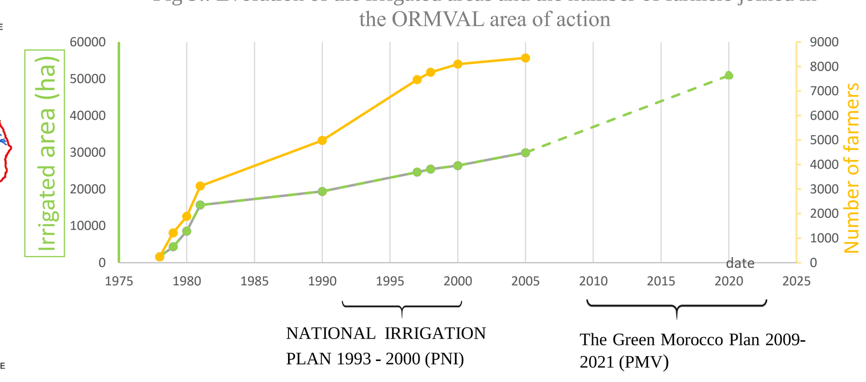


Figure 8:Evolution of irrigated area between 1980 and 2020

Fig 9.: Evolution of the irrigated areas and the number of farmers joined in the ORMVAL area of action



Since the end of the 1970s, the irrigated area has been continuously increasing, in the action zone of the ORMVAL (Loukkos Regional Office for Agricultural Development) more than 4 sectors have been equipped after the construction of the OUED l MAKHAZINE Dam. The total irrigated area reached 29888 ha in 2005 against only 1610 ha in 1978. A perimeter of 21000 ha is being completed and will be watered incessantly. As a result, the total area equipped for irrigation is 50888 ha. This extension of the irrigated areas has been solicited by the variability of the precipitation regime and the occurrence of dry years observed since the early 1970s, but it has also been encouraged by the different national strategies, either at the level of the Department of Agriculture (the PNI: the National Irrigation Plan, 1993) or at the level of the Department of Water (PNEE: the National Irrigation Water Saving Plan), or both (the Green Morocco Plan, 2009).These strategies have contributed in a very remarkable way to the increase in the surface areas of large, small and medium hydraulics. As well as the increase in individual equipment through subsidies granted to farmers for the hydro-agricultural development of their parcels.

Conclusion

- During the 1970s, the Bas-Loukkos basin experienced a change in its precipitation regime. This change results in a decrease in annual precipitation.
- Annual discharge rates are affected by declining trends. For all of the applied tests, more than half of the tests show a rupture, and indicate a drop in the average with a significant downward trend. This decrease may be due to the decrease in precipitation, or to the development of the basin and the construction of dams.
- Since the late 1970s, the Bas-Loukkos catchment has seen a remarkable expansion of irrigated areas. This increase in irrigated areas is encouraged by the different strategies of the State to adapt to climate change and improve agricultural productivity.

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