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Hydro-Pluviometric trend analysis at Abiod wadi basin, Biskra, Algeria

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Abstract: The Abiod wadi supplies Fom El Gherza dam and is susceptible to floods and drought. The trend analysis of hydro-pluviometric data is crucial for planning and managing various activities (agri-culture, design of hydraulic structures) in the basin. The objective of this study is to investigate the trends in the Abiod wadi basin's annual maximum, annual average, and instantaneous annual maximum discharge along with the annual maximum and yearly average rainfall. Four non-parametric tests for stationary tests and trend identification were used. The general pattern shows an increase over the years for the stations of Medina T'kout and Tiffelfel. However, the station of Fom El Gherza presents a decreasing trend. The hydrometric data shows a large interannual variability of flowrates with an increasing trend. However, stationarity tests show that at a significance level of 5% this trend is not significant.

Keywords: trend analysis; statistical test; Abiod wadi, hydro-pluviometric data, Biskra.

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1. Introduction

There is no denying that the global temperature is rising, and it is widely recognized that the effects of climate change will affect ecosystem services, water availability, and food security [1]. Global warming is anticipated to cause a rise in severe drought, heavy rainfall events, and consequently, a more vigorous hydrological cycle [2], [3]. For a series of hydrometeorological observations over time (temperature, rainfall, or stream flow), it is vital to know whether the values are going up or down or staying the same. For example, planning and managing water resources effectively requires a grasp of rainfall patterns and fluctuations [4]. The time series of stream flow consistently displays seasonality due to the seasonal patterns of rainfall and other weather factors [5]. It also reflects an integrated response of the entire catchment, while rainfall serves as a significant factor in the runoff processes.

An analysis of the hydrometeorological data reveals clear evidence of variability, trends, jumps, and seasonal patterns in hydroclimatic data. Therefore, it has been widely employed to evaluate the possible effects of climate change and variability on hydrological time series in different regions of the world during the previous several decades.

Numerous parametric and non-parametric tests were used to identify trends. Non-parametric trend tests are not as effective as those that are parametric. However, independent and regularly distributed data are needed for the parametric tests. Non-parametric trend tests, on the other hand, require that the data remain independent and tolerant of outliers.

The literature includes several trend identification techniques, such as Sen novel trend analysis, Sen slope estimator, Spearman rho, Mann-Kendall, and traditional linear

regression [6], [7]. One of the most popular non-parametric approaches to detecting trends within time series is the Mann-Kendall test [8], [9]. This last is employed to detect trends in hydro-meteorological data, including temperature, rainfall, evaporation, evapotranspiration, streamflow, and water quality [10].

Several studies have been given high attention in detecting the trend in climate variables (mainly rainfall and temperature) world-wide [11], [12], in the Mediterranean region [13], [14], In Africa [15], [16] and in Algeria [17–21]. However, to the best of our knowledge, this study has not been conducted in the region of Abiod wadi. Thus, the purpose of this paper is to examines and evaluates the trends of the hydrometeorological data (Streamflow and precipitation) in Abiod wadi catchment in Algeria to see whether the data are following some trend, whether the trend is increasing or decreasing with time, and whether or not they are significant.

2. Study area and data

2.1. Study area

The 1300 km² Abiod wadi basin rises from the Chelia (2326 m) and Ichemoul (2100 m) mountains in the Aures, flows through Tighanimine, and then gradually descends into Ghoufi and M'chouneche gorges. Finally, it flows into the Saharan gorge of Fom El Gherza (295 m) in the Biskra region southern east of Algeria, crossing a distance of 85 km from its origin (Figure 1). The climate varies from semi-arid to arid. Average annual precipitation is strongly modified by the relief and varies from 450 mm upstream to 100–150 mm in the Saharan plain.

The wadi valley consists primarily of sedimentary rocks, including alternating layers of limestone, marl, soft sediments such as sandstones and conglomerates, and some evaporites like gypsum. These rocks are dated to the Paleogene period [22]–[24].

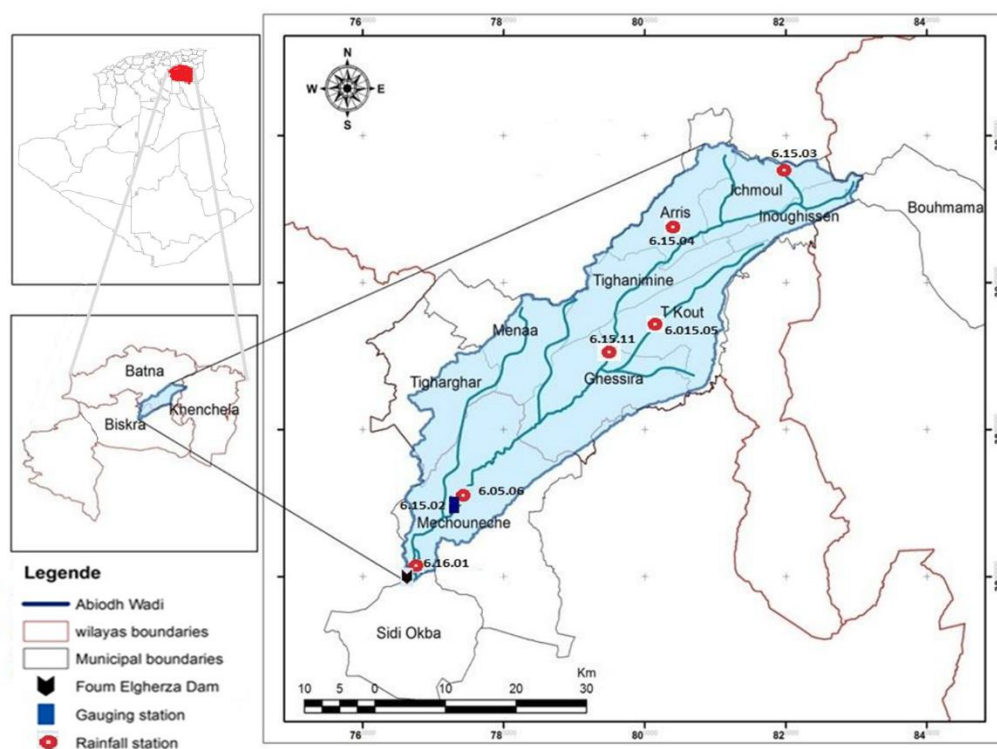


Figure 1. Location of the Abiod wadi watershed.

2.2. Data description

The National Agency of Hydraulic Resources of Biskra, oversees six rainfall stations; Medina, Arris, Tifelfel, Tkout, and Fom El Gherza, and one hydrometric station;

M'chounech, which is situated 18 kilometers upstream of the Foug El Gherza Dam and consists of the daily average discharges measured over the period 1971-1998. It was damaged during the strong floods of 1999/2000, since that the station is no more operational. Furthermore, it involves lacks in the records. the variability in the quality of the data and the length of the time series required a choice of stations based on two criteria. The length of observation and the importance gaps. Data with more than 20% of missing values can present significant biases [25]. Thus, only stations with less than 20% of lacks will be retained. Hence, M'chounech and Aris stations are excluded. The Foug El gherza station, located at the dam level, has no observation gap followed by the Medina station 1%, Tkout 10% and Tiffelfel 15%. Consequently, four rainfall station retained for rainfall analysis and only the flood discharge supplied by the A.N.B.T of Biskra (National Agency of Dams and Transfers) is considered (table 01). It is the only station produce instantaneous flood discharge in the Abiod wadi catchment. The water level was recorded by limnimeter and transformed to flood discharge from the variation of the reservoir water level at scale time. Indeed, the flood data are generally recorded at hourly scale time. However, some floods are recorded at a time step of 30 minutes and only the floods of August 25th, 1953 and September 5th, 1953 present readings in steps of 05 and 10 minutes. The data provided sufficient information about the evolution of flood before and after discharge. The total number of events is about 405 events recorded between 1950 and 2011, otherwise an average of 7 floods per hydrologic year is observed on Abiod wadi.

Table 1. Characteristics of the Wadi Abiod rainfall stations.

Rainfall Stations	Station code	Coordinates			Interannual average rainfall	Observation period
		Altitude (m)	Latitude	Longitude		
Foug El Gherza	06 16 01	100	34° 51' 12" N	5° 55' 33" E	116	1951-2011
Tiffelfel	06 15 11	740	35° 06' 53" N	6° 13' 57" E	140	1974-2011
Medina	06 15 03	1570	35° 19' 46" N	6° 31' 02" E	450	1969-2011
TKout	06 15 05	998	35° 08' 42" N	6° 18' 22" E	292	1970-2011

3. Methodology

Prior to any data analysis, the data was verified according to the existing literature or archives, where necessary. The daily rainfall series had been subject to basic quality-control procedures and gaps filling using double mass curve technic.

In this study, we have applied several non-parametric tests for stationary tests and trend detection of rainfall for four rainfall stations and the instantaneous annual maximum, annual maximum of the mean flowrate and the mean annual flowrate of one hydrometric station located at wadi Abiod watershed (Figure 1). The data do not need to be regularly distributed in order to use non-parametric tests, also referred to as distribution-free inferential statistical techniques. Given that the majority of hydro-meteorological time series data exhibit non-normal distribution. As a result, non-parametric techniques are frequently employed [26], [27]. Hence, four tests were used: the Mann-Kendall test, the Hubert test, the Buishand test, and the Pettitt's test. By analyzing the time series, these tests identify the break point, which is characterized as a shift in the variable's distribution within the time series (i.e., a change in the mean).

Pettitt test (1979) [28]

Consider a sequence of independent random variables $x_1, x_2, \dots, x_N$. It contains a break at time t if the series $x_1, x_2, \dots, x_t$ et $x_{t+1}, x_{t+2}, \dots, x_N$ have different distributions. The

null hypothesis (H_0 of no break) is tested using a non-parametric test. This test assumes that for any instant t varying from 1 to N , the two series defined above belong to the same population. We consider the variable $U_{t,N}$ such that:

$$U_{t,N} = \sum_{i=1}^t \sum_{j=t+1}^N D_{ij}$$

With $D_{ij} = \text{Sgn}(x_i - x_j)$ où $\text{Sgn}(x) = 1$ si $x > 0$, $\text{Sgn}(x) = 0$ si $x = 0$ et $\text{Sgn}(x) = -1$ si $x < 0$.

To test the null hypothesis H_0 , Pettitt proposed using the variable K_N , defined by the maximum absolute value of the variable for t varying from 1 to $N-1$. If k designates the value of K_N taken from the series studied, under H_0 , the approximate probability of exceeding the value of k : $\text{Prob}(K_N > k)$ is given by the equation:

$$\text{Prob}(K_N > k) \approx 2 \exp\left(\frac{-6k^2}{N^3 + N^2}\right)$$

For a risk α of the first kind, H_0 is rejected if this probability is less than α . In this case the series presents a break at time t defining K_N .

Hubert segmentation Test (1989)

The hydrometeorological series segmentation procedure was presented by Hubert and Carbonnel (1987) [29]. It was then completed by a test by Hubert et al (1989) [30]. The idea behind it is to split a series into m segments, making sure that the average of each segment is distinct from the average of the segment(s) next to it. This approach offers the benefit of allowing the search for multiple changes in mean in a hydrometeorological series.

Let $x_1, x_2, \dots, x_N$ be a time series of N values. Any series x_i , $i = i_1, i_2$ with $i_1 \geq 1$, $i_2 \leq N$ et $i_1 < i_2$, constitutes a segmentation of the initial series. A segmentation of order m of this series is any division of the original series into m segments.

Let a particular segmentation of order m be practiced on a proposed series and let i_k ($k = 1, 2, \dots, m$) be the rank in the initial series of the terminal end of the k^{th} segment. We have, by setting $i_0 = 0$, $i_0 < i_1 < \dots < i_k < \dots < i_{m-1} < i_m = N$. We note $n_k = i_k - i_{k-1}$ the length of the k^{th} segment and its average. The quadratic difference D_m between the series and the segmentation is defined as follows:

$$D_m = D(i_1, i_2, \dots, i_m) = \sum_{k=1}^{k=m} d_k = \sum_{k=1}^{k=m} \sum_{i=i_{k-1}+1}^{i_k} (x_i - \bar{x}_k)^2$$

To determine the best segmentation of a hydrometeorological series, it is a matter of minimizing the deviation criterion D_m . This condition is necessary but insufficient, the deviation criterion D_m decreases when the order of the segmentation increases and disappears for a segmentation of order n (the segmented series has as many segments as there are values in the initial series). To limit the order of the segmentation, the means of two contiguous segments must be significantly different such that $\bar{X}_k = \bar{X}_{k+1} \quad \forall k = 1, m-1$.

The Scheffé test is used to determine whether this restriction is satisfied which compares the difference between the averages at one or two critical values (one-sided or two-sided test) to declare whether the means are significantly different or not according to a risk of the first kind α (here α is taken equal to 1%). This test can be considered as a stationarity test where H_0 is the null hypothesis "the series is stationary".

Buishand Test (1982)

The Buishand test [31] makes it possible to determine if there is a break, a significant jump in the means. The test is constructed from the cumulative deviations from the mean up to a certain rank k by defining the following variable:

$$U(k) = \sum_{i=1}^k (x_i - \bar{X})$$

Under the hypothesis H_0 (no break) the cumulative difference should oscillate around 0, without reaching too large values. Conversely, a value that is too high at a point of rank k can be a sign of a break at that location.

The critical Z value of the statistical test is:

$$Z = \max \left(\frac{|U(k)|}{\sqrt{n}\sigma_x} \right)$$

The moment of rupture $\hat{k}$ can be estimated by the relation:

$$\hat{k} = \arg \max_{k=1, \dots, n} \left(\frac{|U(k)|}{\sqrt{n}\sigma_x} \right)$$

Mann-Kendall test

The non-parametric Mann-Kendall test [8], [9] makes it possible to study the presence or absence of a trend in a given time series. Given the series $X_t = (x_1, x_2, \dots, x_n)$, this method defines the multi-variable standard normal U_{MK} as:

$$U_{mk} = \frac{S}{\sqrt{Var(S)}}$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i)$$

$$\text{sgn}(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^n t_i i(i-1)(2i+5)}{18}$$

Where S denotes the relationship between the number of observation pairs, and n is the total number of samples. A time series has a clear trend, defined at the level

significance of 5%. In this test the null hypothesis H_0 "absence of trend" is accepted if the P -value is greater than 5%. In this case the chronological series studied does not present

trend. If the P -value is less than 5%, then the variable studied presents a trend. The direction of the trend is defined by the Mann-Kendall statistical coefficient. If U is positive, the trend is increasing, but if U is negative, then the trend is decreasing.

4. Results and Discussion

4.1 Preliminary Analysis

Figure 2 shows the variability of daily rainfall for the stations considered. The time series presents all data after the gaps are filled. It is very clear that the Foug El Gherza station has experienced very exceptional rainfall events which exceed 100 mm while its annual average is 116 mm. This record has never been exceeded since 1973.

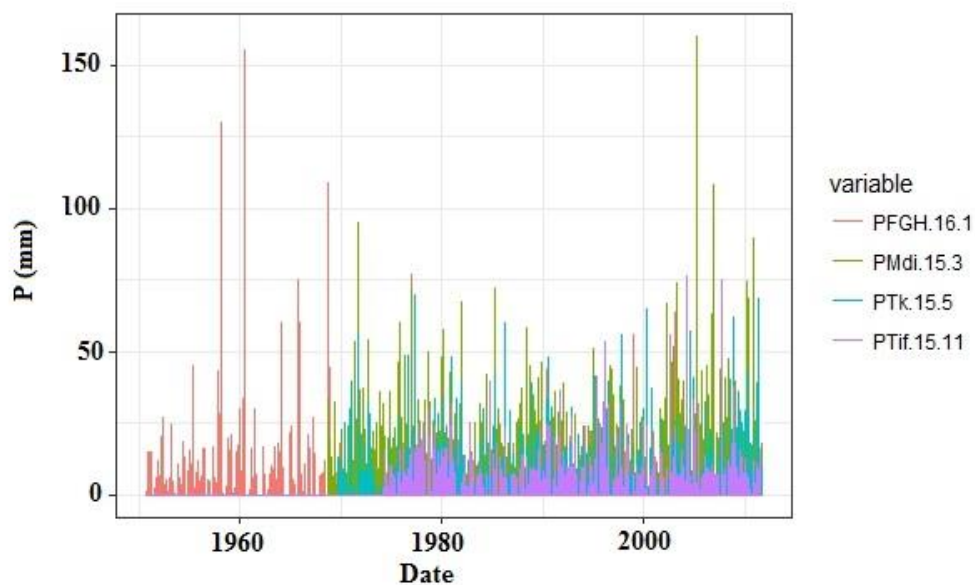


Figure 2. Daily rainfall time series.

For a clearer picture of the rainfall variability of the study region, the daily rainfall series was aggregated to monthly, seasonal and annual series.

Figure 3 highlights strong rainfall variability. Indeed, we can see that in general the months of September, October, November, March, April and May are the rainiest months for all the resorts. The maximum rainfall is recorded in the month of May followed by the month of December for the stations of Medina and T'kout. For the Tiffelfel station, the months of October and September are marked by the highest precipitation amounts.

These findings are clearly reflected in Figure 4, where we note that spring and autumn are the rainiest seasons.

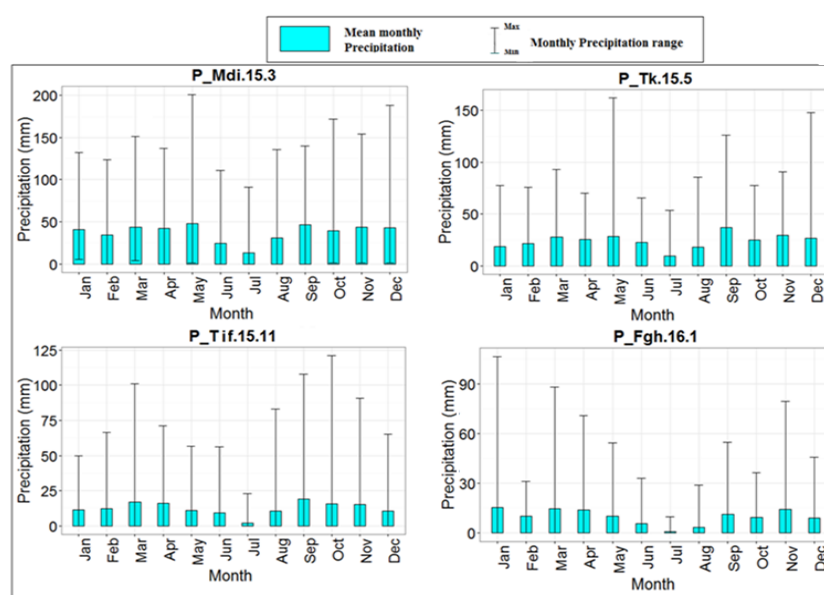


Figure 3. Monthly precipitation variability.

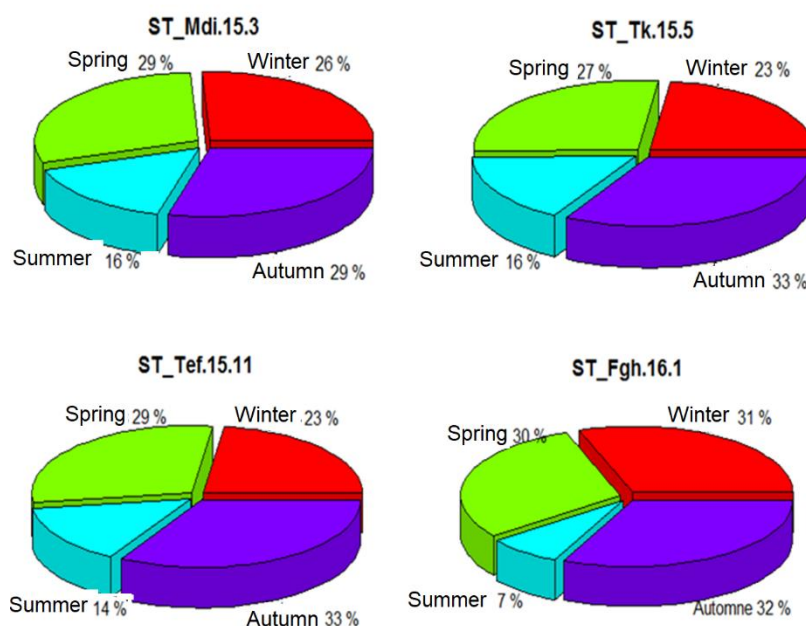


Figure 4. Seasonal variability of precipitation.

The analysis of flood data was the subject of work carried out by Benkhaled et al (2013) [23], where he observed that, at 20.30% of the annual total, September has the most events, followed by the summer (JJA) at 15.84% and the winter (DJF) at 16.83%. The study also shows that 28.46% of floods are observed in the spring months (MAM). From a magnitude point of view, 23.2% of floods greater than 10 m³/s appeared in September, of which 76% are greater than 100 m³/s and floods greater than 200 m³/s are double the class [100,200] floods. Followed by the month of October with a percentage of 13.6% of all events above 10 m³/s.

4.2 Trend of the hydro-pluviometric data

Annual precipitation experiences high variability. Precipitation fluctuations during the study period are very significant. Looking at the linear trend curve of this series, an increase in precipitation over the years was noted for the Medina, T'kout and Tiffelfel stations. On the other hand, the Foug El Gherza station experienced a decrease in precipitation over the same period (figure 5).

In order to see if this trend is significant or if a break is present, the Mann Kendall trend and Pettitt break detection, Buishand and Hubert segmentation tests are applied to the data series. The tests gave different results for the Medina and T'kout stations. The results show that at a significance level of 5%. The segmentation tests of Hubert, Pettitt, and Buischard show a significant break in 2001 for the Medina station, while stationarity is accepted by the Mann Kendall test. The latter rejects the hypothesis of stationarity for the T'kout station with the segmentation tests of Hubert and Buischard, the break was produced in 2002, only the Pettitt test accepted the hypothesis of stationarity. For the Tiffelfel and Foug El Gherza stations the annual trend is not significant. In fact, no break was detected.

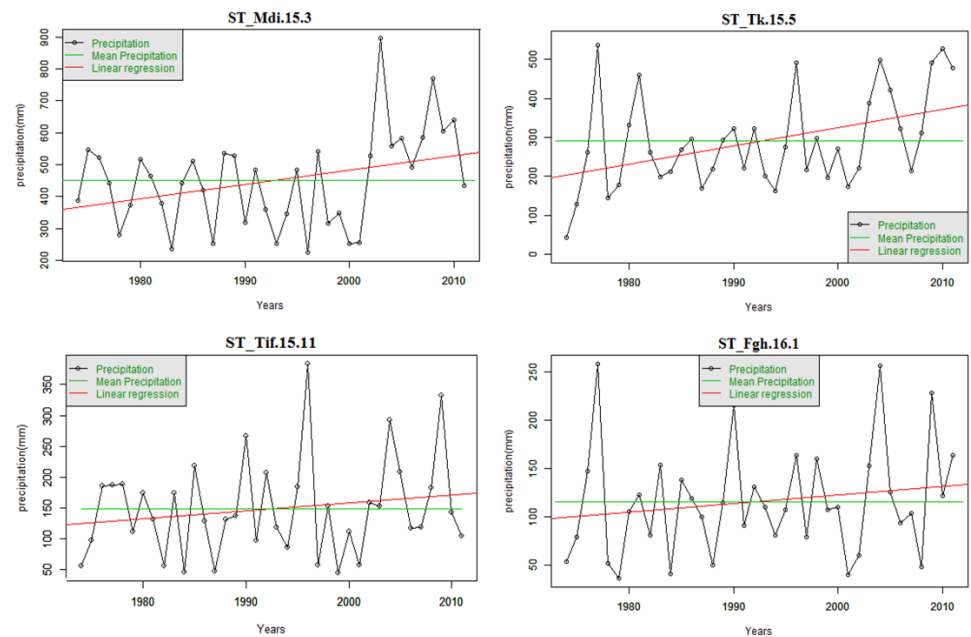


Figure 5. Interannual variability of precipitation.

Table 2. Break analysis results in annual rainfall series.

Test	Statistics	ST_06.15.03	ST_06.15.05	ST_06.15.11	ST_06.16.01
Hubert Segmentation	Break/ mean	1974-2001/393.8	1975-2002/261.6	No Break	No Break
		2002-2011/609.1	2003-2011/405.5		
Pettitt	p-value	0.005	0.06	0.78	0.86
	K	236	174	0.78	89
	T	2001	No Break	No Break	No Break
Mann-Kendal	p-value	0.063	0.016	0.466	0.303
	τ	0.212	0.279	0.084	0.118
Buischand	Q	10.77	8.54	4.21	4.49
	p-value	0.001	0.02	0.617	0.53
	T	2001	2002	No Break	No Break

Indeed; extreme floods are mainly linked to maximum daily rainfall. The interannual variability of the latter is presented in Figure 6. The trend line reflects an increase in maximum daily rainfall during the observation period. The results of the stationarity tests presented in Table 3 show that in general the trends are not significant for all stations. Only the Buischand and Hubert segmentation tests are significant for the Medina station under the effect of the extreme value recorded in 2005. A second verification, without this extreme value, gives non-significant trend results.

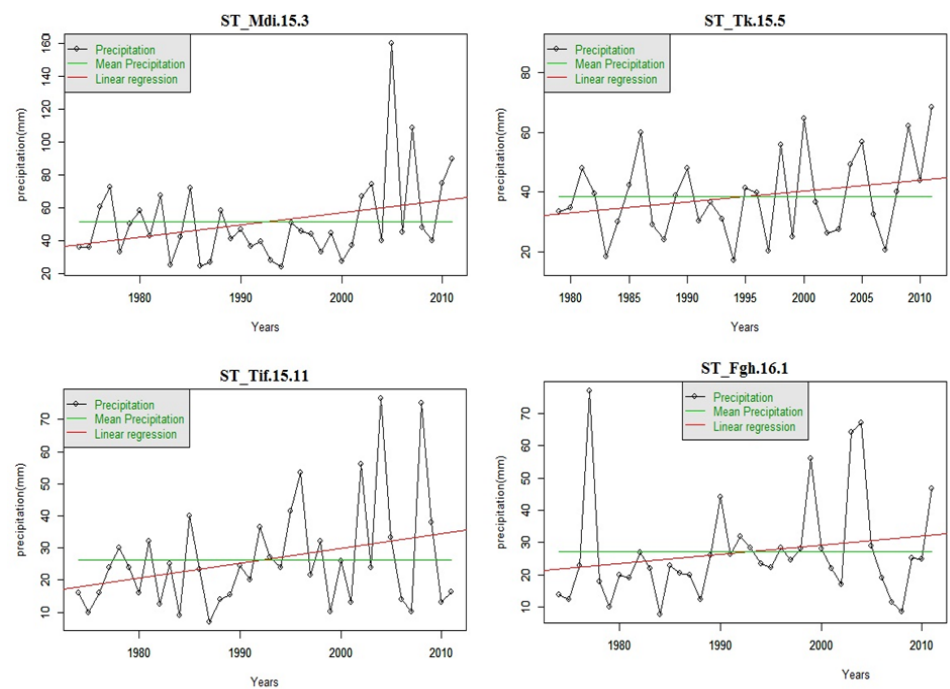


Figure 6. Interannual variability of maximum daily precipitation.

Table 3. Results of breaks analysis in the maximum daily rainfall series.

Test	Statistics	ST_06.15.03	ST_06.15.05	ST_06.15.11	ST_06.16.01
Hubert Segmentation		1974-2004/44.61			
	Break/ mean	2005-2005/160	No Break	No Break	No Break
		2006-2011/67.57			
Pettitt	p-value	0.068	0.574	0.263	0.061
	K	178	104	138	174
	T	2001	No Break	No Break	No Break
Mann-Kendal	p-value	0.155	0.089	0.137	0.077
	τ	0.162	0.197	0.169	0.204
Buischand	Q	9.03	5.26	6.99	4.65
	p-value	0.006	0.335	0.09	0.46
	T	2001	No Break	No Break	No Break

Figure 7 presents the interannual variability of annual average flows, annual maximum average flows (VMX) and annual maximum instantaneous flows (QIX). The figure shows a large interannual variability of flow rates with an increasing trend. However, stationarity tests show that at a significance level of 5% this trend is not significant (table 4).

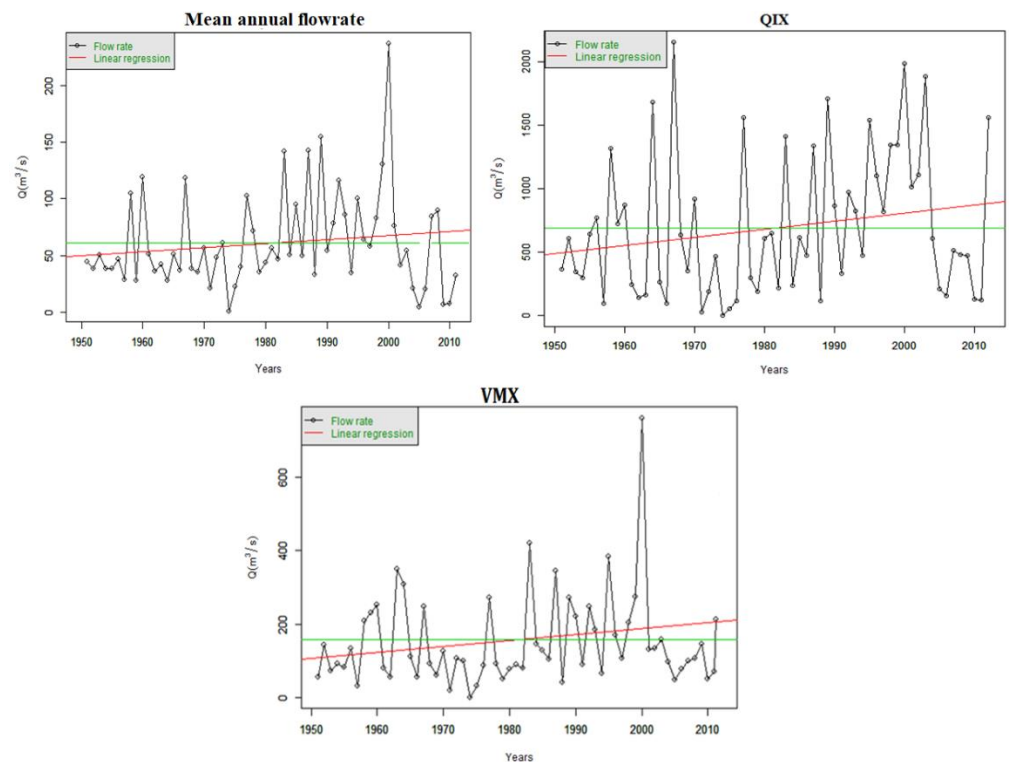


Figure 7. Interannual variability of flowrates.

Table Erreur ! Il n'y a pas de texte répondant à ce style dans ce document.. Break analysis results in the daily flowrate series.

Test	Statistics	Mean annual flowrate	Annual maximum of flowrates (VIX)	Annual maximum of instantaneous flowrates (QIX)
Hubert Segmentation	Break/ mean	No Break	No Break	No Break
	p-value	0.192	0.1261	0.100
Pettitt	K	300	334	348
	T	No Break	No Break	No Break
Mann-Kendal	p-value	0.347	0.253	0.130
	τ	0.083	0.100	0.132
	Q	8.875	8.152	9.102
Buischand	p-value	0.107	0.163	0.098
	T	No Break	No Break	No Break

5. Conclusion

The presented study is based on rainfall data collected from four station and one hydrometric station of Abiod wadi basin.

After the criticism and the filling of the gaps, the trend study showed that the average precipitation has experienced an increase over the years for the stations of Medina T'kout and Tiffelfel. The station of Foum El Gherza presents a decreasing trend. The rupture detection tests show that the rainfall regime experienced a change from the years 2001 and 2002 respectively for the Medina station and the T'kout station. The maximum daily rainfall tends to increase during the study period for the four stations. However, tests show that this trend is not statistically significant. The analysis of hydrometric data shows a large interannual variability of flowrates with an increasing trend. However, stationarity tests show that at a significance level of 5% this trend is not significant.

This study is useful for conceiving complementary studies required to determinate and understand the relationship between climate variability and availability of the water resources of the Biod wadi basin.

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