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Characterization of climatic and hydrological droughts in the central Middle Atlas, case of the Srou wadi watershed, Upstream Oum Er Rbia, Morocco (1976-2016)

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Summary: The characterization of climate change and variability is of great importance in the management and planning of water resources. The present study concerns the analysis of rainfall variability of the Srou wadi, the first tributary of the Oum Er Rbia wadi in the Middle Atlas, and the characterization of their impact on the flows. To show this variability, we applied the reduced centered NICHOLSON index and to eliminate the seasonal variations of the rainfall and hydrometric series we applied the HANNING low-pass filter of order 2. The data used come from the hydrological services of the Oum Er Rbia hydrological basin agency. The results obtained show significant rainfall variability. Long periods of droughts are installed on the whole basin broken by short wet periods. These periods of drought have caused a reduction in surface and groundwater resources in the area. This work constitutes an important basis for the characterization of the impact of climate change on water resources in North African basins.

Keywords: Climate change, Oued Srou, Oued Oum Er Rbia, hydro climatic variability, NICHOLSON index, HANNING low-pass filter of order 2.

1. Introduction

Climate change and its influence on the environment and society are major issues in the modern world. The consequences of these phenomena on water resources are particularly strong and affect many sectors of activity. Studies of climate variability and change have interested the world community following several large-scale climate events (Dezetter et al, 2008). Climate change resulted in the succession of periods of drought in North Africa, West and Central Africa and in the Mediterranean rim from the end of the 1960s and the beginning of the 1970s (Nicholson et al, 1994; Aka et al 1996; Servat et al, 1998)

Morocco, whose economic development was based on agriculture, is very sensitive to the climate context. Precipitation represents the major component of the climate and is the most affected by the variability of its regimes on seasonal, annual and interannual scales (Martin, 1981). Climate variability, for its part, has resulted in an irregularity in the precipitation regime both in time and in space. This influenced the water potential of the Middle Atlas, considered for a long time, the reservoir of water resources on the scale of the country (El Fellah Idrissi, 2017). These surface and deep-water resources are today subject to major upheavals and are becoming insufficient to meet the agricultural, domestic, and industrial needs of the region (Meko, 1985).

Previous work in Morocco shows a longer persistence of drought in the interior of the country than in the coastal areas (Yacoubi, 2001). A study of a pluviometric series relating to 13 synoptic stations distributed over all climatic regions of Morocco, was carried out by the Ministry of Public Works in 1997, shows 11 periods of climatic drought, the extension of which has been generalized to most of from the country: 1904-1905, 1917-1920, 1930-1935, 1944-1945, 1948-1950, 1960-1961, 1974-1975, 1981-1984, 1986-1987, 1991-1993 and 1994-1995 (Yoli Baudet, 2017). Another study on the Sebou watershed shows that the dry sequences are more extensive in space and more persistent over time than the wet sequences (El Bouqdaoui, 2005).

The basin of the wadi of Srou, a tributary of the wadi Oum Er Rbia, in the high basin is part of the Middle Atlas, by their geographical location, their lithological constitutions and their structures, experiences strong annual and inter-annual hydro-climatic variability. Over the past twenty years, climate variability has resulted in an increased frequency of extreme events such as floods and droughts (Kouassi, 2007;Norrant, 2007). These events are cautiously attributed to climate change and are currently considered to be natural interannual climate variability (Paturel et al, 1997). These climatic variabilities, tackled on a global scale, have been the subject of more targeted studies in West and Central Africa by (Kouassi, 2010; Maloba Makanga, 2000), Congo by (Jouilil, 2013) and in Morocco (Serbout, 2001). Even if climate variability has already been demonstrated by several authors, it remains useful to practice these studies and these methods on other watersheds. The main objective of this study is to characterize the distribution and the spatio-temporal evolution of the interannual dry and wet periods and to trace the climatic variability as well as their impact on the flows of the Srou watershed (Middle Atlas, Morocco). The approach adopted to achieve this goal consists in analyzing the impacts of the interannual variability of rainfall and flow by calculating the reduced Nicholson centered indices and the second-order Hanning low-pass filter. The main objective of this study is to characterize the distribution and the spatio-temporal evolution of the interannual dry and wet periods and to trace the climatic variability as well as their impact on the flows of the Srou watershed (Middle Atlas, Morocco). The approach adopted to achieve this goal consists in analyzing the impacts of the interannual variability of rainfall and flow by calculating the reduced Nicholson centered indices and the second order Hanning low-pass filter. The main objective of this study is to characterize the distribution and the spatio-temporal evolution of the interannual dry and wet periods and to trace the climatic variability as well as their impact on the flows of the Srou watershed (Middle Atlas, Morocco). The approach adopted to achieve this goal consists in analyzing the impacts of the interannual variability of rainfall and flow by calculating the reduced Nicholson centered indices and the second order Hanning low-pass filter.

2. Methodology

2.1. Presentation of the study area

The watershed of the Srou wadi is located southwest of the central Middle Atlas, in the province of Khenifra (Figure 1), between 32 ° 35 'and 33 ° north latitude and 5 ° 05' and 5 ° 50 ' west longitude. It is limited to the west by the Hercynian Massif Central, to the north by the Causse d'Ajdir and to the south-east by the plain of the upper Moulouya. The wadi Srou is one of the tributaries of the wadi Oum Er Rbia, with which the confluence at the Ahmed Elhansali dam. It originates at an altitude of around 2300 m and flows from the northeast to the southwest. Its main tributary, Wadi Chbouka, is on its right bank. The watershed covers an area of 1307 km².

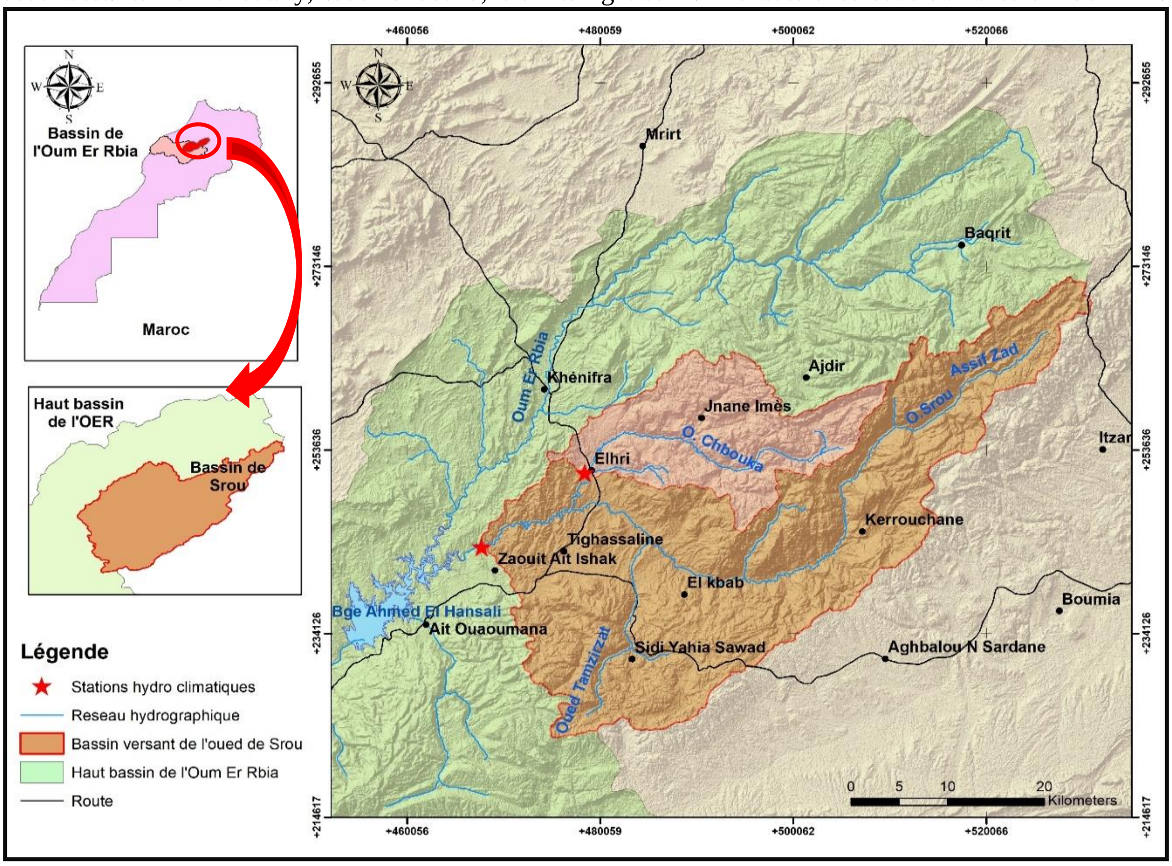

Figure1: Presentation of the study area

The basin of the wadi of Srou offers a mountainous character and the altitudes there are between 700 and 2350 m. The geological formations of the watershed of the wadi of Srou, range from the Paleozoic to the Quaternary, are composed of subtabular limestone rocks and liasic dolomitic limestones. The pelvis is permeable (52.75%) (Table 1) (Kouassi, 2007,Nguimalet, 2015).

The average rainfall in the stations of the Srou watershed (Tamchachat, Aval Elhri and Chacha N'mallah) is around 548.5 mm for the monitoring period from 1976 to 2016. Rainfall characterizes the months between November and April, the wet period.

	Station	S in (Km²)	Permeability	Modules in (m3 / s)	Specific Q in (l / s / Km2)
Srou	Chacha N'mallah	1377	52.75%	7.7	5.5
Chbouka	Aval Elhri	276	68.8%	2.4	8.6

Table 1: Hydrological characteristics of the Srou wadi watershed

The flows experience significant annual and spatial variability. At the ChachaN'mallah station, the flow is 7.7 m3 / s, at the Elhri downstream station it is 2.4 m3 / s. Contrasts appear during periods of high water and floods; the flows of the wadi of Srou can reach 111.2 m3 / s at the outlet of the basin (average for the month of February in 2010). During the low water period, the flow of the Srou wadi at the outlet can drop to 0.3 m3 / s (a flow observed during the month of August 2008). This situation can modify the balance of the Srou regime and leads to extreme situations (severe floods and low water levels) (Table 1).

The average population density of the study region is 42.32 inhabitants / km2 according to the 2014 census. In Ait Ishaq and Tighassaline the population density is higher, it is 70 inhabitants / km2, in the areas where arable land is abundant, areas generally of low slope (<5%) slope (Kouassi, 2007).

2.2. Data

The data used for this study are precipitation and hydrometric data collected at the service of the Oum Er Rbia Hydraulic Basin Agency (ABHOER), all of which are at monthly time intervals. In order to make a good hydroclimatic study, these data (rainfall and flow) were organized according to the calendar year starting in January. The annual rainfall was used to calculate the interannual average, the annual rainfall index. As for the hydrological modules, they were used to calculate the interannual average, the annual runoff index. This data set was used over the period 1976 - 2016 (41 years) according to WMO standards (Table 2).

Table 2: Characteristics of the data used

Type of stations	Station names	Geographical coordinates		Data used	Chronicles
		X	Y		
Rainfall	Chacha N'mallah	467800	243300	Monthly and yearly	1976-2016
	Aval Elhri	478500	251200	Monthly and yearly	1976-2016
Hydrometry	ChachaN'mallah	467800	243300	Monthly and yearly	1976-2016
	Aval Elhri	478500	251200	Monthly and yearly	1976-2016

2.3. Methods

The methodology used for this study is that already used by several authors in the different in different watersheds such as that of Ouémé in Béterou in Benin; (Yao, 2012) on the Oubangui in the CAR; (Paka, 2018) in west-central Côte d'Ivoire in the Lobo watershed; in Morocco on Oum Er Rbia by (Serbout, 2001) and on SEBOU (Elbouqdaoui, 2005); (Soro et al, 2011) on the Alima watershed in Congo. This method consists in highlighting the variability and the climatic trends and then seeing the impacts on the hydrological regimes of the rivers of the watershed of the Wadi of Srou.

The Nicholson index and the HANNING Low Pass Filter of order 2 make it possible to highlight climatic and hydrological variability, as well as the characterization of hydroclimatic trends and to differentiate between dry periods and wet periods (Nicholson et al, 1988). These indices are calculated from data from the two rainfall and hydrometric stations in the study area for a period of 41 years of observation.

2.3.1. Nicholson Rainfall Index

This index measures the deviation from an average established over a long period by referring to station data. The annual index is the reduced centered variable of the annual rainfall averages (or annual modules). The Nicholson index calculated for each year is expressed by Equation (1) (Assani, 1999).

$$I = \frac{\mathbf{Xi - Xm}}{\boldsymbol{\sigma}} \quad (1)$$

With, Xi: Annual rainfall in mm (or annual modules in m3 / s); Xm: Interannual average rainfall in mm (or interannual moduli in m3 / s) over the reference period; σ: Standard deviation of interannual rainfall over the reference period.

2.3.2. 2nd order Hanning low-pass filter ("weighted moving averages")

The second orderHanning low-pass filter, also known as the weighted moving average, eliminates seasonal variations in a time series. To do this, the rainfall totals and the discharges are weighted according to Equation (2) (Nejjari et al, 2001):

$$X(t) = 0.06\ x\ (t-2) + 0.25\ (t-1) + 0.38\ (t) + 0.25\ (t+1) + 0.06\ (t+2) \qquad \text{for } 3 \leq t \leq (nt) \qquad (2)$$

The weighted rainfall totals of the first two terms [x (1), x (2)] and of the last two terms [x (n-1), x (n)] are obtained respectively with the following Equations:

$$X(1) = 0.54\ X(1) + 0.46\ X(2) \qquad (3)$$

$$X(2) = 0.25\ X(1) + 0.50\ X(2) + 0.25\ X(3) (4)$$

$$X(n-1) = 0.25\ X(n-2) + 0.50\ X(n-1) + 0.25\ X(n) \qquad (5)$$

$$X(n) = 0.54\ X(n) + 0.46 X(n-1) \quad (6)$$

The centered and reduced indices of the weighted annual rainfall heights obtained are calculated to better distinguish the periods of rainfall deficit and excess. The flow series are subject to the same calculation procedures as the rainfall series.

The hydraulic coefficient (CH) is used to check the results obtained by the method of NICHOLSON.

3. Results

3.1. Interannual variability of precipitation

The interannual variations in rainfall at the Chacha N'mallah stations on the Srou and Aval Elhri on the Chbouka are highlighted by the NICHOLSON index and the HANNING low pass filter of order 2 (Figure 2). The year-to-year variability decreases but is still significant after using the low-pass filter. The average annual precipitation observed in the stations of Chacha N'mallah and Aval Elhri respectively 490.8 mm and 606.4 mm as well as the monthly averages observed are respectively 40.7 mm and 50.5 mm.

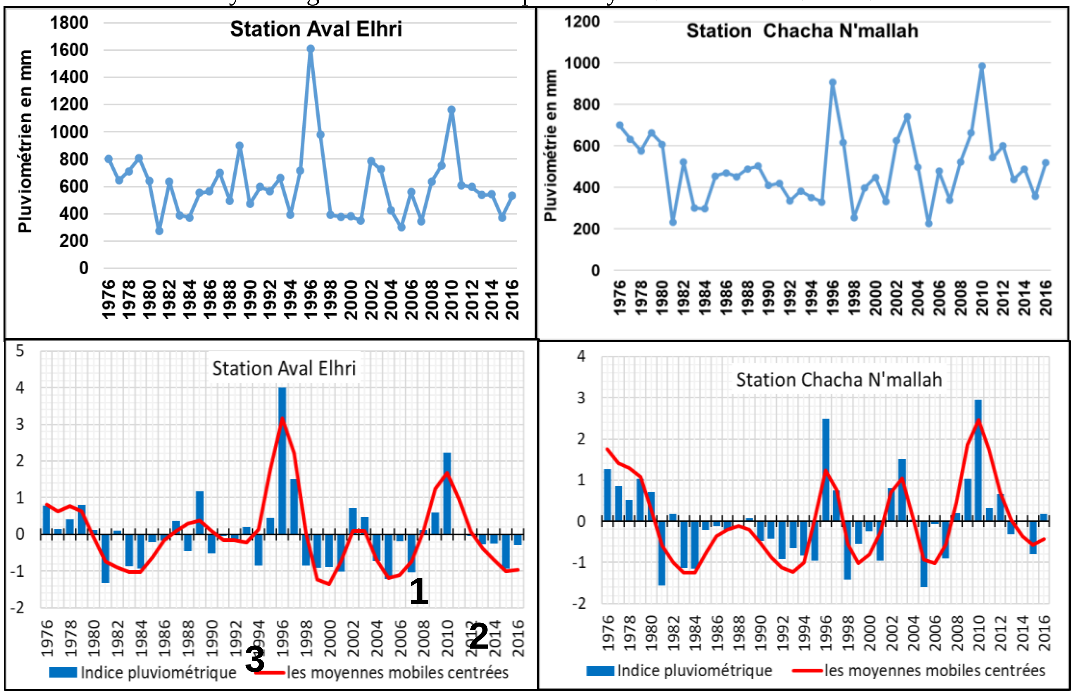

Figure 2: Interannual evolution of rainfall at Aval Elhri and Chacha N'mallah stations with reduced centered indices of rainfall amounts and weighted annual rainfall totals.
1 - Wet period; 2 - Normal period; 3 - Loss period

The inter-annual fluctuation in rainfall observed at the Aval Elhri and Chacha N'mallah stations is characterized by wet, normal, and dry periods. A normal period is defined as a period in which the indices are distributed in a balanced way on either side of the zero of the x-axes. The rainfall at the two stations shows substantially an identical development with the same wet and dry periods. However, the intensity and duration of these rains show a considerable difference between Srou and Chbouka. Slight differences also appear in the distribution of dry and wet periods. The characteristics of these periods are shown in Table 3.

Table 3: Breakdown of the rainfall chronicle of the stations of the Srou basin in wet, normal, and dry periods

Station	Average rain (mm)	Period	Duration	Average period (mm)	Type
Aval Elhri	606	1976-1980	5	720.6	Wet
		1981-1986	7	464.1	Dried
		1987-1993	7	627.1	Normal
		1995-1997	3	1103.7	Wet
		1998-2001	4	375.8	Dried
		2002-2003	2	756.4	Normal
		2004-2007	4	406.5	Dried
		2008-2012	5	751.4	Wet
		2013-2016	4	515.5	Dried
Chacha N'mallah	490.8	1976-1980	5	636.9	Wet
		1981-1994	14	401.7	Dried
		1995-1997	3	617.9	Wet
		1998-2001	4	358.6	Dried
		2002-2004	3	621.9	Wet
		2005-2007	3	347.7	Dried
		2008-2012	5	625.5	Wet
		2013-2016	4	455.6	Dried

These results show that in the two stations studied, that of Aval Elhri is marked by an alternation of wet, normal, and dry period, and that of Chacha N'mallah is characterized by a large dry period which is established between 1981 and 1994. Indeed, the region has a period of rainfall decrease which is felt on the two stations in the last decades of our study. In both stations, the great surplus period (1976-1980) was followed by a long period of deficit which began in 1981. It was felt throughout the region. The wettest period of the chronicle is observed in Downstream Elhri between 1995 and 1997 with a historical average of 1103.7 mm (Table 3).

3-2. Interannual variability of flows

The annual flows of Wadi Srou and its tributary Wadi Chbouka vary greatly from one year to another (Figure 3). This variability is well illustrated by the average annual flows in extreme years. For the two stations, the year 2010 is the most abundant, the driest year is variable; it was in 1995 in Chacha N'mallah and in 2007 in Downstream of Elhri. These two years correspond to periods of exceptional droughts observed throughout the country (Table 4).

Tale 4: Flow rates in extreme years at the Aval Elhri and Chacha N'mallah stations

Stations	**Modulus (m3 / s)**	**The driest**		**The wettest**	
		Year	**Q (m3 / s)**	**Year**	**Q (m3 / s)**
Aval Elhri	2.4	2007	0.7	2010	7.7
ChachaN'mallah	7.5	1995	1.6	2010	29.7

The HANNING order 2 low-pass filter applied to the hydrological series (Figure 3) shows an interannual regularity of the flows in the Srou basin at Chacha N'mallah and on the Chbouka in Downstream Elhri during the study period of 41 years.

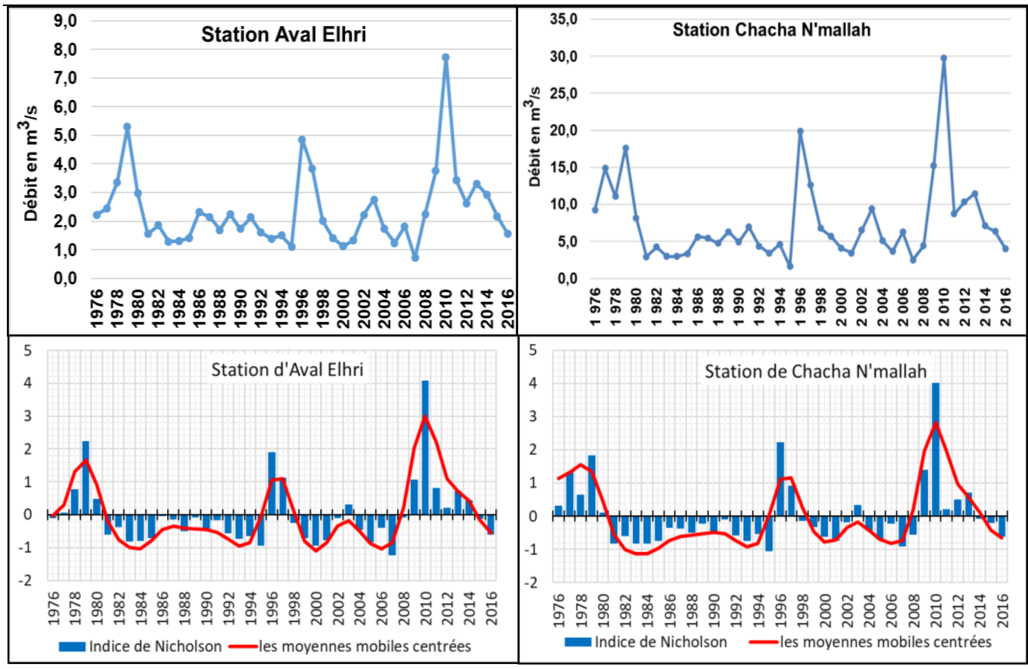

Figure 3: Interannual evolution of the flows of the Chbouka wadi at the Aval Elhri station and of the Srou wadi at the Chacha N'mallah station with the reduced centered indices and the weighted annual flow totals from 1976 to 2016.

These results show that the irregularity is less important than that already observed in the rainfall. An alternation of five major phases was distinguished in the two stations of the basin, long periods of deficit divided by short periods of surplus (Table 5). A long deficit period is observed in the two stations, between 1981 and 2007 cut by a short surplus period of two years. This situation is felt throughout the region.

Table 5: Breakdown of the hydrometric chronicle of the stations of the Srou basin in deficit and surplus periods

Station	M3 / s module	Period	Duration	Q avg m3 / s	Type
Aval Elhri	2.35	1976-1980	5	3.3	Surplus
		1981-1995	15	1.7	Deficit
		1996-1997	2	4.3	Surplus
		1998-2007	10	1.6	Deficit
		2008-2014	7	3.7	Surplus
		2015-2016	2	1.9	Deficit
Chacha N'mallah	7.53	1976-1980	5	12.2	Surplus
		1981-1995	15	4.3	Deficit
		1996-1997	2	16.2	Surplus
		1998-2007	10	5.4	Deficit
		2008-2014	7	12.4	Surplus
		2015-2016	2	5.2	Deficit

4. Discussion

The interannual fluctuation in rainfall is quite significant at the basin stations. Dry and wet periods therefore appear more clearly after filtering out seasonal variations as in the study (Qadem, 2015). There is a strong tendency towards drought, 60% of the years in the chronicle are in deficit. The longest period of drought affecting most of the basin, spread from 1981 to 1994, with some intercalations of wet episodes lasting between 1 and 4 years depending on the station. This same period was observed in several regions of Morocco and

Africa. This is the work of (Bahin et al, 2017,Kingumbi et al,2000) in northern Morocco where they find a drop in rainfall from 1970. These results are of the same order as those observed in central Tunisia between 1976 and 1989, or (Sebbar et al, 2011) show a significant decrease in annual precipitation. (Brou, 2005,Mahe et al, 1995) mentioned the start of a long deficit phase in Côte d'Ivoire from 1975.

The analysis made up of the interannual evolution of the flows on the two watersheds, using the NICHOLSON index and the HANNING Low Pass Filter of order 2, makes it possible to break down the series of flows from the two stations of the basin in five similar surplus and deficit phases.

The Chbouka and Chacha N'mallah watersheds show a long period of deficit between 1981 and 2007, cut by a short-wet phase. The latter lasted only two years, between 1996 and 1995. The greatest increases in flows were recorded during 2010. The greater decrease in flows compared to that in precipitation may be linked to the long duration of the deficit. rainfall. The succession of years with insufficient rainfall also negatively marks the flow. For some authors (Bricquetet al, 1997; Mahe et al, 2000; Gille et al, 2000), the explanation for this difference between rainfall and hydrological deficit comes from a reduced contribution of contributions from underground sources to surface flow since the 1970s.

The wet periods favored the rapid reconstitution of water reserves and the recharge of the aquifer. While the dry period or the recent drought was persistent and very severe especially for the years 1981, 1995 and 2007. This hot and dry trend resumed in 2015, marking the continuity of the major phase of drought that began more than age 36 (1981). This causes the reduction of groundwater and surface water resources in the area. Several authors (Obda, 2004; Sary et al, 2000; Nezzal etIftini-Belaid, 2013) insisted on the unprecedented extent of the drought in the Middle Atlas through its cumulative aspect of deficits over nearly 15 years.

These results are also compared with those of other North African watersheds, West Africa and Central Africa and they show almost total agreement (Sebbar et al, 2011; Paturel et al, 1997; Soro et al, 2011).

5. Conclusion

The objective of this article is to examine the existence of climatic variability in the upper basin of the Oum Er Rbi in the Middle Atlas, particularly in the basin of the Wadi of Srou and to show its impact on the flow of this tributary. The methods for determining the NICHOLSON index and the second order HANNING Low Pass filter were applied to the rainfall and flow data from the rainfall and hydrometric stations in the study area. These applications have identified wet, normal and wet dry periods. These have considerable repercussions on the surface flows of the Srou wadi and its tributary of the Chbouka wadi.

The results of this study constitute an important database for the assessment of the vulnerability of climate variability and its impacts on the hydrological regimes of the rivers in the area. In this context, the improvement and strengthening of rainfall and flow observation systems at the level of the various stations are necessary in order to better characterize the evolution of the climate and contribute to a better adaptation to the probable harmful effects of the changes. climatic on the surface flows of the wadi of Srou, a tributary of the Oum Er Rbia. Indeed, the succession of dry years in Morocco could therefore create an unfavorable gap between the growing demand for water and the available water resources. Thus the situation of water reserves becomes worrying,

6. References

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