Analysis of Flood Characteristics in the Context of Climate Variability in Northern Algeria: Case of Cheliff Watershed

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Contents

Abstract Extreme hydrological events, such as floods and droughts, are some of the natural disasters that occur in several parts of the world. They are regarded as being the most costly natural risks in terms of the disastrous consequences in human lives and in property damages. The main objective of the present study is to estimate flood events in Cheliff watershed in giving return periods at the gauged stations, which is

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located in a semiarid region in the northwest of Algeria. The choice of this area is due to the significant floods observed in this watershed, which are occurring mainly from 1960 and 2006. A study is carried out to know the temporal variability and the place occupied by peak flows for both annual and monthly levels, which can finally determine the peak output of flood. We will try to understand the evolution of average and extreme flows according to rainfalls that are temporally associated with them. Frequency analysis is performed on different series of observed annual and monthly average discharges, including classical statistical tools as well as recent techniques. The obtained results show that the annual maximum approach is more appropriate in this case. This study also indicates the importance of continuous data monitoring in these stations.

Keywords Algeria, Annual maximum, Cheliff watershed, Floods, Peak flows

1 Introduction

During floods, the maximum levels of water, the maximum speed or the maximum flow, and the duration of the overflow can cause problems which are ever dangerous. For this reason, it is very important to do studies flow, not a single flow, but for many return periods and many durations, so many data flows.

Floods are one of the fundamental features of the regime of a watercourse. Unfortunately we do not have a long time series of flood data to draw global conclusions. Many studies on the genesis and the danger of the flood have been carried out for a few years in the world [1–7]. The prone Mediterranean countries which have been exposed to this type of phenomena that we can cite are France, Spain, and Italy [8], Morocco [9, 10], and Algeria [11].

Flooding is a common environmental hazard and a leading cause of natural disaster fatalities and economic damages worldwide [12–15].

It has been estimated that floods caused approximately 6.8 million deaths throughout the twentieth century and more than 500,000 fatalities between 1980 and 2009 [16]. In recent decades, we have also seen a steady increase in frequency and economic losses that come from flooding events [17, 18].

That raises the question of what factors contribute to the change of flood impacts, with a possible increase of exogenous flood hazard (e.g., extreme precipitation or high streamflow events) or increased vulnerability of populations and assets to flood hazards [17–19].

There are several definitions of the word flood. It refers to an event characterized by a rapid increase in flow [1, 20, 21]. Several parameters are used to describe a flood and peak flow. It is the maximum flow rate of the flood for a given period; it is defined as an instantaneous flow, which is difficult to estimate from one series of data flow records with long time steps (few hours a day).

The study of the Algerian watercourse floods remains a quasi-unknown field due to the very limited specific indications about data which are given in the Algerian hydrological directories [22–25].

In this work, we will study some characteristics of flows in some stations to characterize the phenomenon of floods. We are interested in the annual floods that marked the basin and observed at the different stations between 1960 and 2006, to know their temporal variability and the place occupied by peak flows for average flows at both annual and monthly levels. Finally, this study gives the methods to determine the peak of the flood and to understand the evolution of average and extreme flows according to the rains that are temporally associated with them.

2 Materials and Methods

2.1 Study Area

The Cheliff Basin numbered 01 according to the nomenclature adopted by NAHR (National Agency of Hydraulic Resources) corresponds to an intra-mountain basin. It is located in northern Algeria (see Fig. 1). It is situated between the two Tellian Atlas chains which are parallel to the Mediterranean coast. It lies between meridians 0° 12′ and 3° 87′ and latitudes between 33° 91′ and 36° 58′ North. This basin covers three sub-basins: the Cheliff upstream of Boughezoul, Upper and Middle Cheliff, and Lower Cheliff and Mina. They occupy an area of about 43,750 km^2, covering 77% of the total area of Cheliff-Zahrez watershed basin. Cheliff Basin is limited in the North by the Mediterranean Sea, in the South by the mountains of Ouarsenis, in the East by the Algiers basin, and in the West by the Oranian basin. This basin is crossed by the longest wadi in Algeria, which is Cheliff wadi, with a length of 750 km, in the end, the Mediterranean Sea, is near Mostaganem City.

The Cheliff wadi is a notable exception among the large North African wadis; it is the only one that drains a portion of the highlands and one of those with the longest watercourse and the significant flow. It is formed initially by Nahr Ouassel and Nahr Touil, which takes its initial source from the Atlas Sahara in Djebel Amour near to Aflou, and crosses a distance over 750 km, before joining the Mediterranean Sea, near Mostaganem City.

2.2 Data Collection and Analysis

The data set used in this study is provided by the National Agency for Hydraulics Resources (ANRH) of Blida. It consists of the daily average flows data collected at the gauge stations, based on daily hydrometric data for the available periods. We conducted an inventory of all annual flows (daily and instantaneous peak flow values for the year). The entire time series is represented in Fig. 2.

It was considered more methodologically sound to start this part by studying the flow to show the magnitude of the flood phenomenon in the basin and then to approach the rainfall analysis as an explanatory factor of the flow.

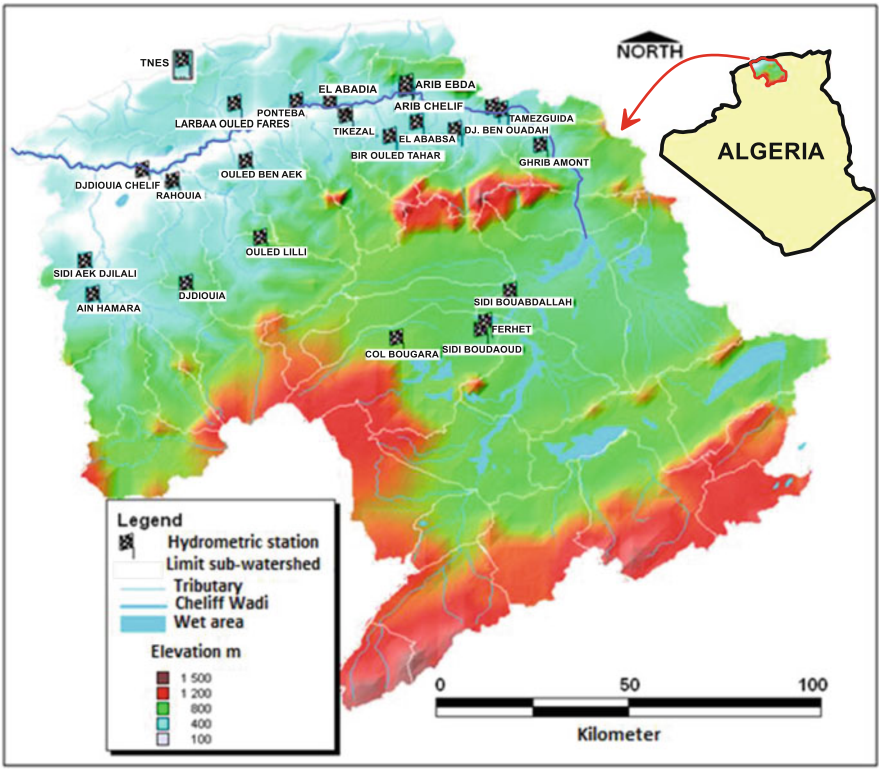

Fig. 1 Elevation map showing locations of hydrometric stations studied at the Cheliff watershed in Algeria

To detect exceptional floods and their ratio with average flows, we are based on the observed annual and monthly values of flow, and the recurrent values of the flows.

3 Results

3.1 Annual Maximum Flows (Variability and Duration of Recurrence)

3.1.1 Ababsa Station (011715)

Interannual Fluctuations

Figure 2 shows the interannual variations in mean annual, maximum daily, and maximum annual flows for Ababsa station. It shows a clear irregularity of the mean annual flow rates.

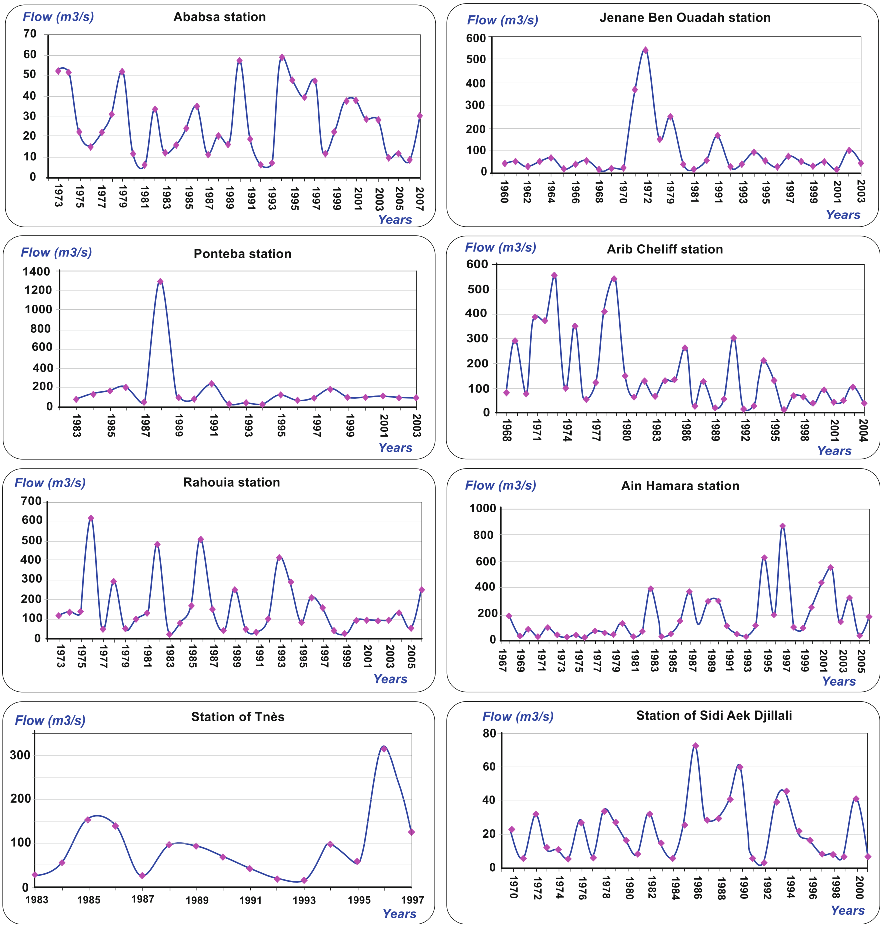

Fig. 2 Variations of annual flows in different stations in Cheliff watershed in Algeria

In the interannual flow of 35 values for the period 1973–2007, only 12 values exceed the average flow (27 m^3/s). The year 1994 recorded the highest value (59 m^3/s) of average flow, as well as the year 1990 also recorded an important value (58 m^3/s). Statistical characteristics of the observation series are given in Table 1.

Recurrence Times

The study of the interannual variability of the normal average flows is always supplemented by the frequential study. It has a goal to estimate the limit values reached or exceeded during a given period; this requires to seek the physical law, which is the most appropriate adjustment to the annual mean flow distribution, and then to estimate the parameters needed (mean and standard deviation), as well as the reduced variable used to calculate the quantiles.

Table 1 Statistical characteristics of different stations in the Cheliff watershed in Algeria (ANRH)

Stations	Code	N	Min	Max	Mean	SD	Median	CV	Skewness	Kurtosis
El Ababsa	011715	35	5	59	27	16	23	0.6	0.55	2
Djenane Ben Ouadah	011514	31	10	543	99.6	129	54	1.3	2.45	6.99
Ponteba	012203	21	18	1,300	160	267	96	1.67	4.26	15.8
Arib Cheliff	011702	37	10	562	154	149	99	0.966	1.37	3.52
Rahouia	012701	34	19	609	160	147	109	0.919	1.66	4.51
Ain Hamara	013302	35	8	878	177	198	109	1.12	2	6.15
Sidi A. Djilali	013401	32	3	73	22.1	17.4	18.5	0.788	1.13	3.6
Tenes	020207	15	18	313	89.3	75.8	70	0.849	1.94	5.27

N number of observations, *SD* standard deviation, *CV* coefficient of variation)

To do this, we proceed with the arrangement of flow rates in ascending order (or descending order) by assigning each variable its rank in the normal series, counted from 1, and then calculate the corresponding experimental frequencies according to the formula:

$$f = (i - 0.5)/n.$$

where (i: rank, n: number of years of observation).

By performing the rate-frequency correlation, it appears that the average annual flows of the Ababsa station (1973/2007) adjust to the log-normal distribution.

The theoretical values estimated by this appropriate adjustment of Ababsa flow rates are acceptable until a return period of 20 years (Fig. 3). Beyond this period, the estimated quantiles are very much exceeded.

3.1.2 Djenane Ben Ouadah Station (Code 011514)

Interannual Fluctuations

In Fig. 2, we note that before the 1970s, the flow rates are very low, but after 1970s we note that the power of the floods becomes very important until 1991 when we noticed the decrease of these flows. We observed an important flow in the years 1973 (543 m^3/s), 1979 (250 m^3/s), and 1991 (180 m^3/s) which took 20 years. After 1991, the floods became less important as it is illustrated in Fig. 2 and the flow rates are in general less than 100 m^3/s, and the very remarkable peaks are observed during the years 1992, 1994, and 2002. It is noted that the station is installed in a river regularized by certain hydraulic works; if not, the floods became three times more than that recorded at this station.

Recurrence Times

Recurrence times are obtained in the same way as the previous station. The results are shown in Table 1.

In Fig. 2, we can see that the extreme flows are greater than 500 m^3/s when the return period is 100 years, whereas the flows are above 300 m^3/s when the return period exceeds 20 years.

3.1.3 Ponteba Station Flows (Code 012203)

Interannual Fluctuations

The variation of the annual flows of the Ponteba station is represented in Fig. 2. According to Fig. 2, we note that the flows become more important from the year

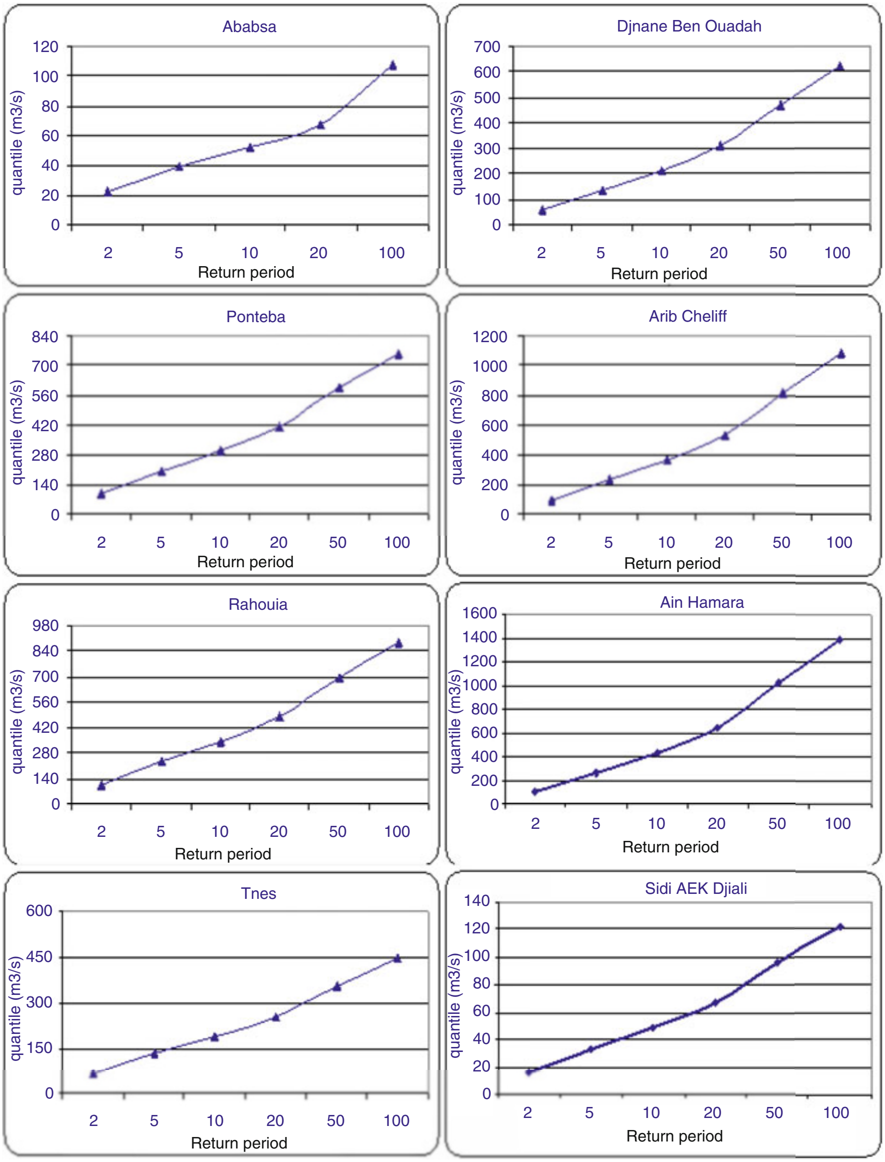

Fig. 3 Theoretical values of the quantiles according to their return period at different stations studied in the Cheliff Watershed

1988, where the maximum value is 1,300 m^3/s. After the year 1989, we recorded some remarkable peaks as these in years 1991 (230 m^3/s), 1995 (119 m^3/s), 1998 (186.75 m^3/s), and 2001 (111 m^3/s).

Recurrence Times

Figure 3 shows that the extreme values of max flow are greater than 500 m^3/s for return periods 50 and 100 years, while the average quantiles (200 m^3/s) will be recorded every 5 years.

3.1.4 Arib Cheliff Station

Interannual Fluctuations

Figure 2 represents the variation of the annual maximum flow rates of the Arib Cheliff station; the analysis of this figure shows three distinct periods: The first one extended from 1968 to 1980; it is characterized by important flow rates, with a maximum of 562.2 m^3/s which was recorded during the year 1973. The second period was in the period from 1980 to 1986 when the flows become important in months. Then we notice an increase in these flows from 1986 to 1994. The rest of the series is marked by a remarkable decrease of flows and became less than 100 m^3/s.

It is noted that this station provides a good representation of the Upper Cheliff's hydrological regime, as it is installed at the outlet of the basin and on the wadi Cheliff.

Recurrence Times

Frequency analysis of the observation series of Arib Cheliff station (Fig. 3) shows the return periods of extreme flows. It flows above 800 m^3/s in every 50 years, while the important flows more than 1,000 m^3/s have a chance every 100 years.

3.1.5 Rahouia Station (Code 012701)

Interannual Fluctuations

The flood hydrograph in Fig. 2 shows that the highest flow values are observed during the period 1976–1994 with maximum flows of 609 m^3/s, 478 m^3/s, 504 m^3/s, and 404 m^3/s recorded in 1976, 1982, 1986, and 1993, respectively (Table 1). After that 1994, the flows became less important (<250 m^3/s).

Recurrence Times

For the observation series of the Rahouia station (Fig. 3), the frequency analysis makes it possible to exit the return periods of the extreme flows, such as the flow rates higher than 400 m^3/s which they are every 20 years, whereas the flows above 800 m^3/s have a chance over 100 years.

3.1.6 Ain Hamara Station (013302)

Interannual Fluctuations

From the hydrograph of the floods observed in the Ain Hamara station (Fig. 2), it can be seen that these flows became more important from the year 1993 with a maximum of 878m^3/s which was recorded during the year 1998 (Table 1).

Recurrence Times

According to Fig. 3, the flows above 500 m^3/s are exceeded every 20 years, while flow rates of 1,000 m^3/s can return every 100 years.

3.1.7 Station of Ténès (020207)

Interannual Fluctuations

Flows at the Ténès station became powerful in the years 1995–1996, when the maximum was observed during 1996 with a value of 313 m^3/s (see Fig. 2).

Recurrence Times

From this graph (Fig. 3), we note that the quantiles higher than 400 m^3/s have the chance to reproduce once every 100 years, while the maximum average value which corresponds to a quantile of 313 m^3/s can have a chance on 50 years.

3.1.8 Station of Sidi Aek Djilali (013401)

Interannual Fluctuations

The Sidi Aek Djilali station was characterized by two distinct periods, the first from 1969 to 1984 when flows were very low, but the rest of the series was characterized by a power floods, where we observed flow rates exceeded 50 m^3/s, with a maximum of 73 m^3/s recorded during the year 1986 (Fig. 2).

Recurrence Times

In this station (Fig. 3), the maximum flow recorded is 30 m^3/s in the return period 5 years and 120 m^3/s for the return period of 100 years.

3.2 Monthly Variations of Maximum Flows

The analysis of the monthly flows makes it possible to highlight the regimes of the rivers and their interannual or interseasonal variations.

To achieve the objective, we will try to highlight the most abundant months in the surface flow by its maximum values (peak flows), in order to understand the maximum flow regime.

3.2.1 Ababsa Station (011715) (Harreza Watershed)

In fact, the wet period from February to May (spring) is the most abundant in maximum average flow, it is followed by another period from September to November (autumn), the average regime of Harreza basin is essentially rain-fed, with a maximum in October 58.82 m^3/s, followed by February (52.5 m^3/s).

3.2.2 Djenane Ben Ouadah Station (011514)

The area controlled by this station is characterized by a very wet period, compared to others, where the flow exceeds 300 m^3/s during January, February, and March. The maximum is recorded during March with a value of 543.24 m^3/s.

3.2.3 Arib Cheliff Station (011702)

According to the graph in Fig. 4, the wettest period is located between September and April, with a maximum of 562.2 m^3/s recorded in March.

3.2.4 Ponteba Station Flows (012203)

This station is characterized by two peaks; the first one characterizes the month of December, with a maximum flow of 1,300 m^3/s, and the second corresponds to March with a flow rate of 823.3 m^3/s.

3.2.5 Rahouia Station (012701)

At this station, the maximum flows are observed in the autumn period, of which the month of September presents the maximum value (609 m^3/s).

3.2.6 Ain Hamara Station (013302)

Figure 4 shows that the wettest month is in August, but this is still an exception, since the flow at this month is not much better than the average, except in the year of 1996 when the value recorded was 878 m^3/s.

3.2.7 Station of Tnès (020207)

In this graph (Fig. 4), it is noted that 5 out of 12 months have flow rates above average; the maximum recorded during April was 313.4 m^3/s.

3.2.8 Station of Sidi AEK Djilali (013401)

At Sidi Aek Djilali station, the maximum flows recorded during July was 35.78 m^3/s and in March was 35.41 m^3/s.

4 Discussions

Furthermore, several studies showed that the flows are low in the Upper plain of Cheliff, due to low rainfall, strong evapotranspiration, and high permeability of lithological formations [26–29]. On the other hand, the flows are relatively high in the Middle and Lower Cheliff, which combine the precipitation and low permeability of geological outcrops.

The flow trends of Cheliff Basin depended on decreases in precipitation and on the increase of temperatures. The current study highlights an irregularity of flow trends throughout the Cheliff Basin. The estimation of extreme quantiles for different return periods should take into consideration the recording period and the right tail of the distribution. The formally gauged record represents a relatively small sample of a much larger population of flood events. Thus, the extrapolation for long return periods is less accurate. In these stations, only the following return periods were considered for the estimation of quantiles: 2, 5, 10, 20, 50, and 100 years.

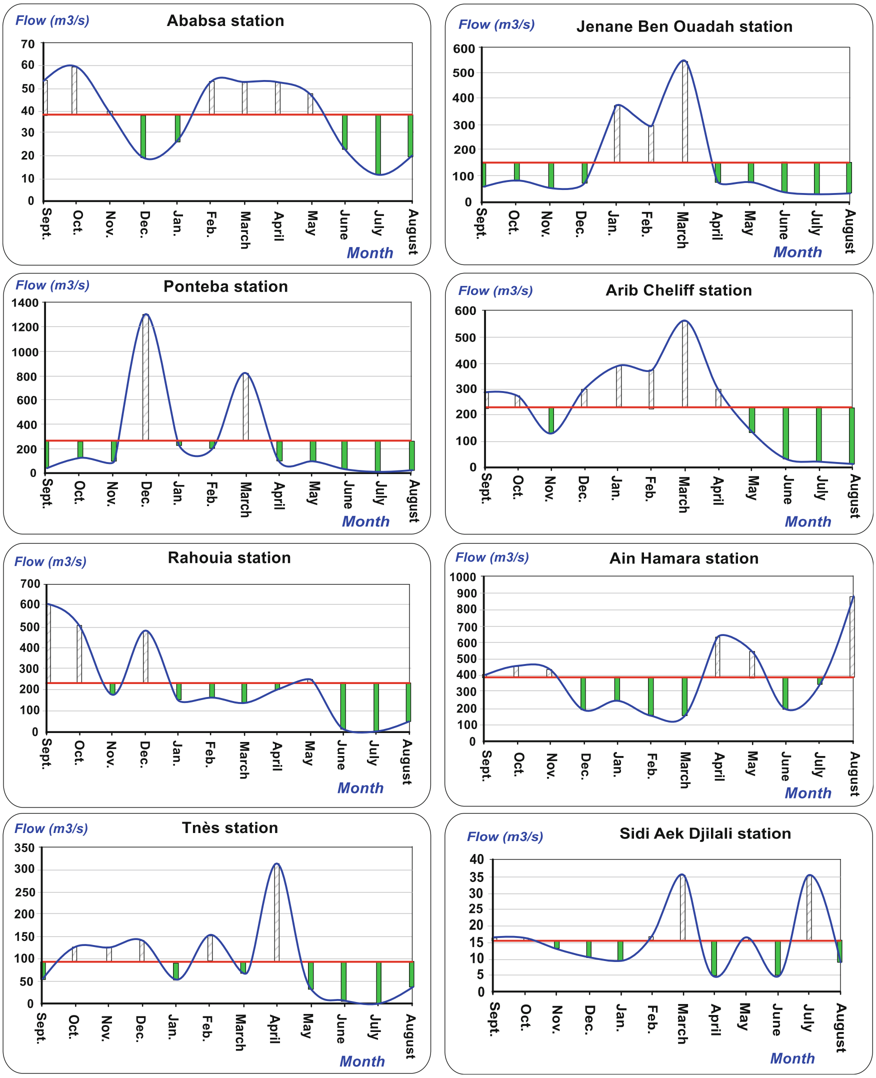

Fig. 4 Monthly fluctuations of maximum flows recorded at different stations across the Cheliff Watershed, Algeria

5 Conclusion

The study of the Algerian Wadis floods remains a quasi-unknown field as only some very specific indications are given in the Algerian hydrological directories. Floods are one of the basic features of a stream regime. The present study, which is the first one carried out in northern oust of Algeria, is based on the flow data recorded at the gauging stations of Cheliff watershed, which are available and considered in the present study.

The statistical study of the recorded flows of the different stations localized in the watershed of Cheliff shows the highest values of flows which were recorded in the station of Ponteba(1,300 m^3/s) and in the station of Ain Hamara (878 m^3/s).

Also, the most remarkable events were observed during the 1970s for the stations of Arib Cheliff, Rahouia, and Djenane Ben Ouadah, the 1980s for the station of Ponteba, and finally during the 1990s the stations of Ain Amara, Sidi Aek Djilali, and El Ababsa. We report here that the autumn floods characterize the 1990s and the winter floods for the 1980s.

In general, the different hydrometric stations show that there are two distinct periods in terms of duration and flood power. The first is the most important in terms of duration; it characterizes the spring season, with few floods sometimes. The other period is very short. It corresponds to the autumn season. It is characterized by flash floods. The flow is very abundant in March and October in second place. The analysis of rainfall and the monthly flows showed a relatively temporal concordance, where the rainiest months are usually the most abundant in flow.

In this region of Upper and Middle Cheliff, the average maximum flow reaches 400 m^3/s, if the rainfall is around 500 mm.

The fact of precipitation falls almost on the whole basin, so the flows are directly influenced by certain parameters like the state of the soil, the vegetation cover, and the air temperature.

6 Recommendations

Flood forecasting is defined as a process of predicting the magnitude and duration of flooding based on known characteristics of a watershed, to prevent damage to human life and to the environment. The use of flood forecasting models is of great importance to watercourse managers. The existence of foreseeable natural risk, over a region, must lead the decision-makers to prohibit or admit, under certain conditions, certain modes of occupation or land use. Also provide, if necessary, the implementation of collective safeguarding and protection measures. The preventive measures to be adopted aim to ensure, on the one hand, better control of the flood hazard, on the other hand, a limitation of the vulnerability of the people, the goods, and the exposed activities.

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