

# Hydrograph Flood Forecasting in the Catchment of the Middle Cheliff



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**Abstract** The impact of climate changes on flood peaks was the subject of several studies. However, a flood is not characterized only by its peak but also by the time, duration of the tip, as well as the rise time and shape of the flood hydrograph according to geographical distribution, leading to an understanding of these extreme hydrological hydrographs and to detect areas vulnerable to flood hazards. The flood-duration-frequency observed rate of chronic  $Q(t)$  provides a theoretical multi-term flood quantiles description, directly meeting the needs of an integrated hydrological hydraulic modeling of the catchment. This article describes a statistical approach that aims to characterize the river in flood hydrology taking into account the notion of duration “ $d$ ” and the return period “ $T$ .” We realize that samplings were carried out for flood flows of 04 gauging stations in the watershed of the middle Cheliff, which reveal a higher value than the threshold. For this analysis, F-d-F was requested to define synthetic mono-frequency hydrographs (SMFH).

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## 1 Introduction

Among the Mediterranean countries, Algeria is the most vulnerable to floods caused by streams overflowing crossing towns and suburban. The sudden onset floods are often difficult to predict, rapid rise time and specific flow relatively important, these floods are generally linked to intense rainy episodes and are manifesting on middle size basins. Several catastrophes caused by those floods have been inventoried in Algeria (Algiers in November 2001, Sidi Bel Abbès in April 2007, Ghardaia and Bechar in October 2008, etc.)

Although some studies had to be devoted to F-d-F models, this approach remains not much used. The F-d-F models began to be developed in the year 1990 in France [1, 2]; the floods modeling by F-d-F models among other have been applied in France to a watershed regionalization flood. Furthermore, a converging and continuous F-d-F model has been proposed by Javelle et al. [3]. It is based on properties of flood distribution scale invariance. Applied in Martinique, by Meunier [4], this model has also been combined to flood index method [5] by [6, 7] bringing some improvements to the estimation procedure and applying this corrected model version for spring floods to Quebec provinces and in Ontario (Canada) [8, 9].

Moreover, the F-d-F modeling allowed to study 1,200 sites engaged in the Himalaya [10] and so on regions of Burkina Faso [11] and of Romania [12]. In Algeria this method was successfully applied in some basins [13–22]. Application of QdF modeling on three watersheds, Vandenesse, Soyans, and Florac, by Oberlin et al. [23] allowed defining a regional typology of flow regimes which makes it as a wide spatial representation [2]. In this work, one was thus interested in the study of the hydrographs of the extreme flood in the middle Cheliff watershed. In order to know the various types of hydrographs in the semiarid environment, by the analysis of the peak output, the form of the hydrographs, the fall and boarding times, to lead to a comprehension of these hydrographs hydrological extremes and to detect the zones vulnerable to the risks of the flood. There are many studies about the genesis and the danger of foods have been carried out for last years in the world Requina et al. [24], Zischg et al. [25], Mediero et al. [26], Hirpa et al. [27, 28], in the prone Mediterranean countries have this type of phenomena like France, Spain and Italy [29] in Saidi et al. [30], Boumenni et al. [31], and in Algeria [32–36]. Finally, this study also went on the determination of the peak output of flood. For that, the F-d-F analysis was requested to define hydrograph synthetic mono-frequency (HSMF) which ables to characterize the behavior of a flood for a given period of return.

## 2 Material and Methodology

The basin of Cheliff occupies area of 44,630 km<sup>2</sup>; it is located between geographic coordinates 34° and 36°30' of latitude North and 0° and 3°30' of longitude East. It affects the shape of an axe-blade north-south (Fig. 1). The middle Cheliff watershed is located in the north-west of Algeria. It is characterized by a Mediterranean arid to semiarid climate. Rainfall in this watershed is very regular in time and in space, and we can distinguish two extreme zones: the first one is rainy with an annual average of 658 mm (Elanab in Dahra station) and 524 mm (Theniet El Had station in O), and the other zone has an annual average of 355 mm (Chlef NAHR station).

These stations are located in the watershed of Cheliff code 01 recorded by NAHR (National Agency of Hydraulic Resources). The flow chronicles show irregularities in the time (Table 1 and Fig. 2).

For the interpretation of graphics, two commonly used methods were used [37]:

*Selecting the annual maximum values.* It consists to select only one maximum value over a hydrological year or a season-at-risk [38]. The main disadvantage is that

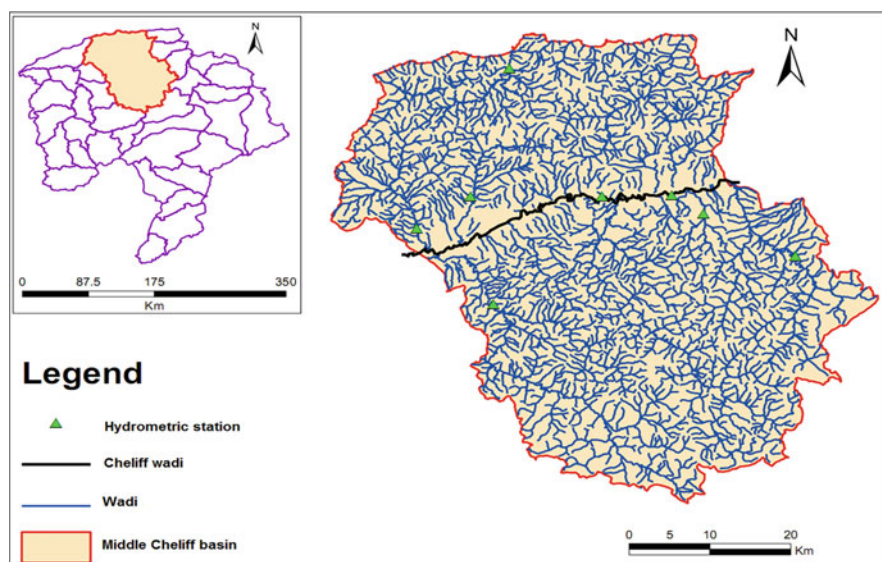


Fig. 1 Location of the study area

Table 1 Characteristics of hydrometric posts

Station code	Wadi	Latitude	Longitude	Z (m)	Surface (km <sup>2</sup> )	Available period
11905	Zeddine	36.°6'	1.°57'	376	872.57	1990–2013
12201	Ouahrane	36°13'	1°13'	181	262	1983–2012
12004	Tikazel	36°11'	1°44'	262	130	1990–2009
20207	Allala	36°28'	1°18'	120	295	1983–2009

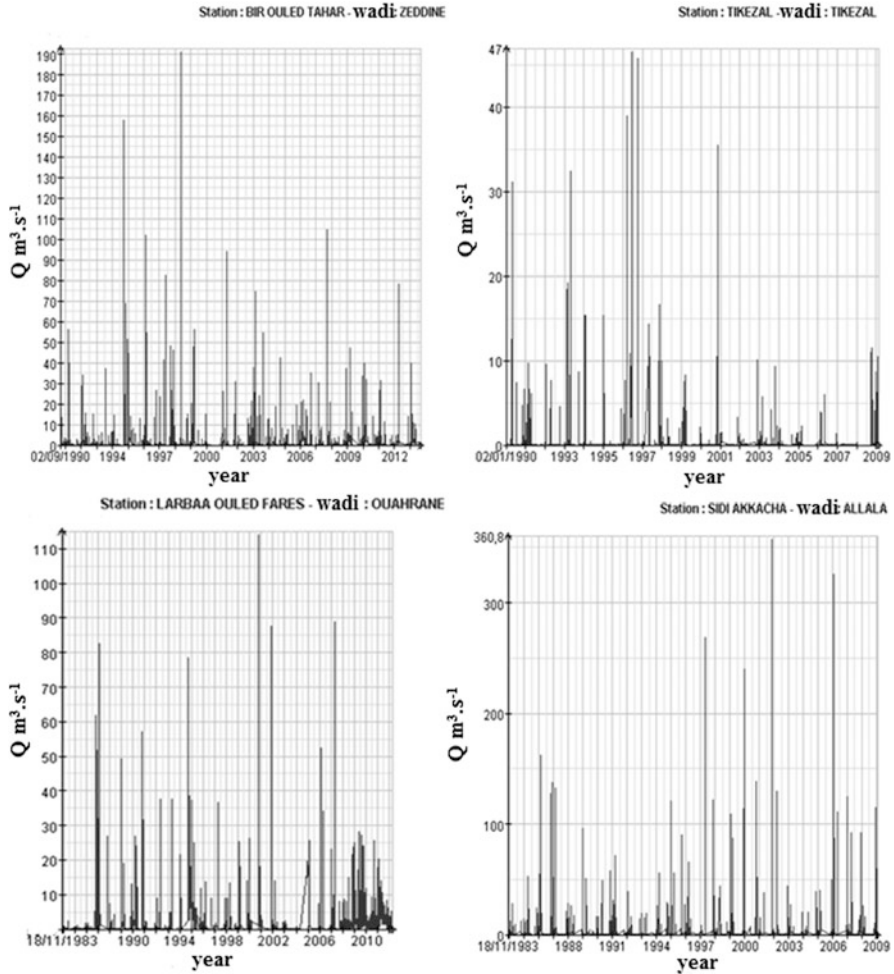


Fig. 2 Chronic of discharge of the middle Cheliff

the formed sample may contain non-significant events (e.g., no major events are recorded in a dry year) and lack of important ones happening during the same year.

*Sampling the greater value than a threshold (sup-threshold).* It consists in retaining the maximum value of a set of independent events having exceeded a given threshold [39]. It offers greater flexibility and robustness since it allows a greater number of selected events to be gathered, if the threshold is high enough; only the major events will be retained. Bezak et al. [40] in Serbia, Fischer and Schumann [41] in Germany, and Lang et al. [42] in France considered this method more reliable than the annual maxima method.

The concept of modeling the flood-duration-frequency has been established on an objective basis (Galéa and Prudhomme [2, 43]) and its extension toward ungauged

watershed; it supplies a theoretical frequency description of multi-duration of flood quantiles. It is essentially focused on hydrological variables representing by basin flood regime, extracted from annual flows chronicle  $Q(t)$ . In addition to hydrological variables, two indices of watershed flood regime are essential to be determined, which are the maximum instantaneous flow of 10-year return period  $Q_{IXA10}$  and flood characteristic duration of watershed  $D$ .

We can retain as a definition of flood characteristic duration  $ds$ , the duration during which half of the peak flow  $Q_s$  is continuously exceeded. For each observed and recorded flood, it studied the level of each subwatershed, and its characteristic duration  $ds$  and its peak flow  $Q_s$  have been determined. In a plan  $(Q_s, ds)$ , the characteristic duration of watershed flood  $D$  according to SOCOSE method [44] is defined as being the value of the  $ds$  conditional median for the value of the corresponding instantaneous maximal annual decennial flow  $Q_{IXA10}$ . The pairs  $(Q_s, ds)$  of the used flood periods in the Bir Ouled Tahar refers the parameter  $D$  to the time when the mean peak flow is exceeded when it shows the characteristic duration of Bir Ouled Tahar is 3 h as shown in Fig. 2. By using the same method, the characteristic duration for Tikazel, Larabaa Ouled Fares, and Sidi Akkacha are 3, 4, and 6 h, respectively (Fig. 3).

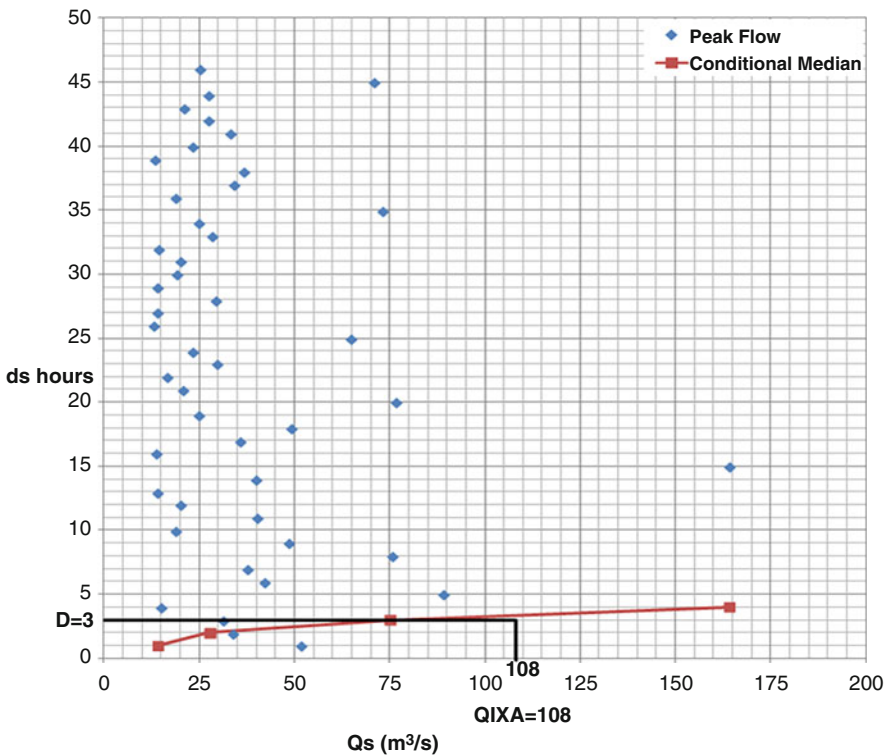


Fig. 3 Estimation of the characteristic flood duration

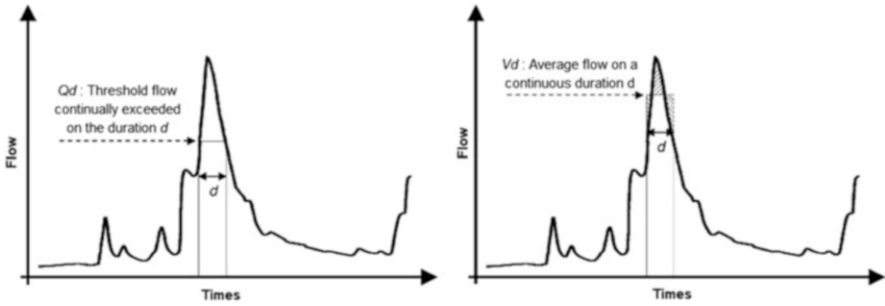


Fig. 4 The variables under consideration of flood episode [45]

The converging F-d-F model is born from a property observed on a large number of hydrological chronicles treated: adjustments  $Qd(T)$  have tendency to meet at the same point toward the weakest return periods

$$Vd(T) = aq_d \ln(T) + x_{0,d} \tag{1}$$

where  $aq_d$  is the grades of flows or even scale parameter of adjustment law;  $X_{od}$  is the position parameter of adjustment law or simultaneously on the whole durations by adjustment of a mathematical function  $V(d, T)$  and/or  $Q(d, T)$  on samples,  $Vd$  and  $Qd$  knowing that  $Vd$  is the average flow on a continuous duration  $d$ , maximal during the flood episode;  $Qd$  represents the threshold flow, continually exceeded on the duration during the flood episode (Fig. 4).

The first manner to reach  $V(d,T)$  and/or  $Q(d,T)$  consists therefore to use mathematical expressions of a dimensionless bookshelf model named “by reference.” It comes to choose the best model among the Vandenesse, Soyans, and Florac according to meteorological criteria and to distort formulations with the help of two characteristics: one inflow and other in duration, all of them obtained from interest site of the study zone.

The second possibility is to apply the “converging F-d-F”; this formulation is based on a property observed on a great number of treated hydrological chronicles: adjustments  $Vd(T)$  have tendency to meet in the same point toward the weakest return periods and on orthogonal affinity property of theoretical laws of probability of relative quantiles of different durations [16]. The converging F-d-F model allows synthesizing in the unique analytical formulation, flood quantiles relating to different durations, independently of laws of probabilities retained.

$$V(d, T) = \frac{V(0, T)}{1 + d/\Delta} \tag{2}$$

With:

- V(0,T): theoretical distribution of peak flows (QIX) consolidated by modeling
- $\Delta$ : parameter to be set, homogeneous to time, and linked to the flood dynamics

One speaks of consolidated adjustment  $V(0,T)$  because all durations participate in parameter estimation of the theoretical distribution. Duration distributions of  $d(2)$  are deducted from modeled distribution of the peak flows  $V(0,T)$  knowing  $\Delta$ . Several approaches may be considered to evaluate  $\Delta$  and to obtain simultaneously a consolidated distribution  $V(0,T)$  [7, 43, 46]. The preferred procedure lets intervene a setting process of  $\Delta$  by using successive iterations on the principle of the least squares. It presents advantages to be a simple application and economical in the hypothesis.

From the expression Eq. (2), and taking into account the following property:

$$V(d, T) = \frac{V(0, T)}{1 + d/\Delta} V(d, T) = \frac{1}{d} \int_0^d Q(t, T) dt \quad (3)$$

We deduct a formulation for quantiles estimations of threshold flows  $Q(d,T)$ :

$$Q(d, T) = \frac{V(d, T)}{(1 + d/\Delta)^2} \quad (4)$$

In case of adjustment  $V(O,T)$  for the exponential law, it comes:

$$V(d, T) = \frac{x_0 + a_0 \ln(T)}{(1 + d/\Delta)^2} \quad (5)$$

$$Q(d, T) = \frac{x_0 + a_0 \ln(T)}{(1 + d/\Delta)^2} \quad (6)$$

where parameters  $a_0$ ,  $x_0$ , and  $\Delta$  are to be determined.

The statistical analysis shows that it is possible, starting from a sampling multi-durations of hydrometric chronicles presumed stationary, to describe the characteristics of the raw catchment area studied in flow-duration-frequency [47]. Work of synthesis is completed on the description of the hydrograph synthetic mono-frequency (HSMF) of a hydrometric station starting from three parameters characteristic of the area catchment, namely, the flow ( $Q$ ) instantaneous annual maximum decennial  $QIXA10$ , duration characteristic of believed of area catchment  $D$ , and boarding time characteristic of believed of the area catchment. Synthetic mono-frequency hydrographs are built by making the first assumption over the time boarding of believed and an assumption. It consists in a linear rise of the hydrographs, between an initial basic flow. It can be the quantile of flow continuously exceeded for the fifth length of time sampled ( $D$  in days) for one period of 1-year return and points of raw or the maximum instantaneous flow of the period of return considered  $QIXT$  (Fig. 5).

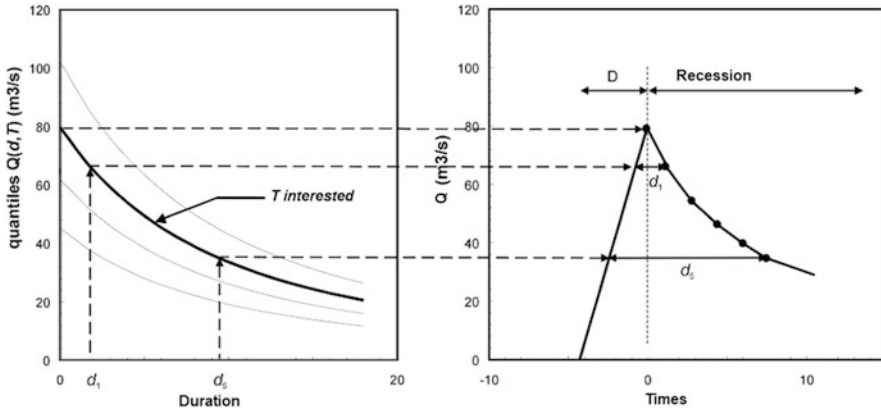


Fig. 5 The procedure of construction of SHMF synthetic hydrographs mono-frequency

### 3 Results

Figure 6 represents the hydrographs in basin of middle Cheliff with the time of appearance of each rising and the averages of these risings in black thick. These hydrographs show that the extreme risings are mainly concentrated in autumn and winter seasons, with a very marked occurrence of the extraordinary events practically for the whole of the stations with 37.5% of total reserves for the season of autumn, 32.5% for the season of winter, and for the season of spring represented by 27.5% of these risings.

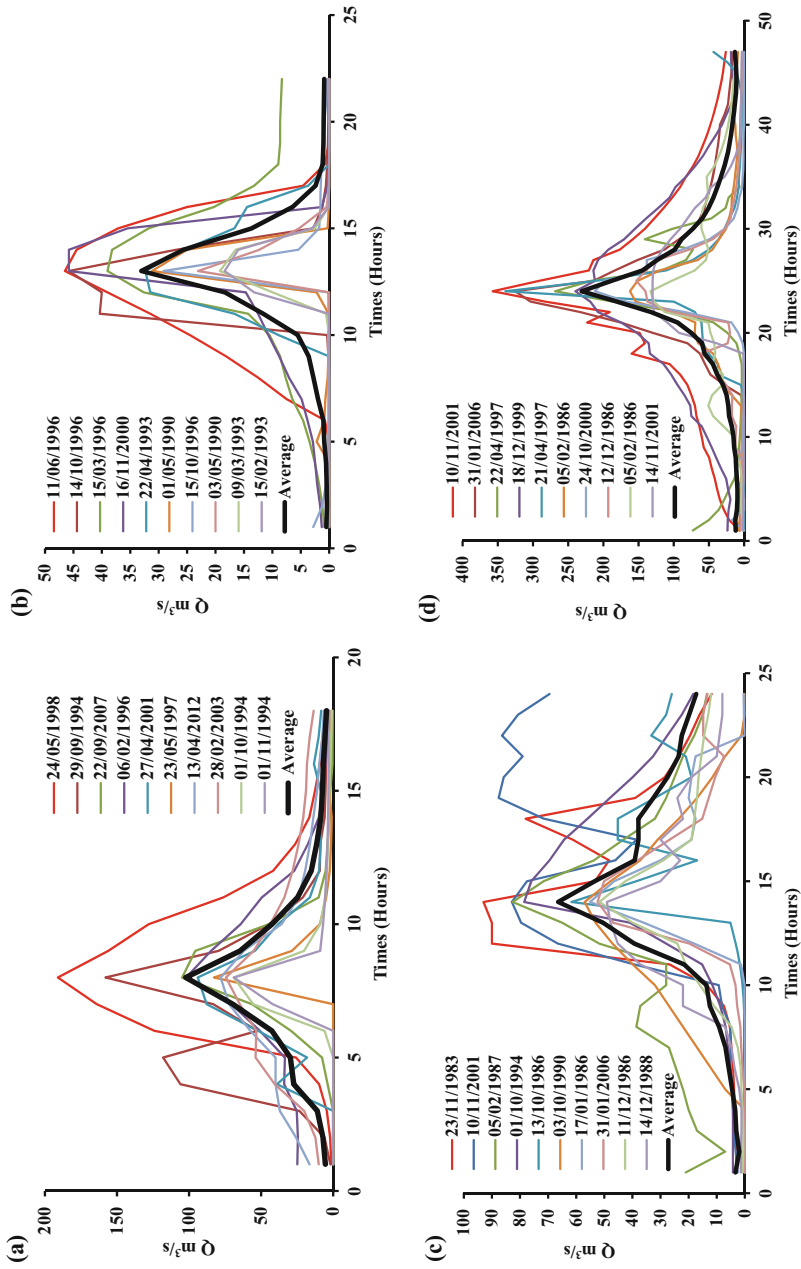
Figure 7 visualizes the F-d-F modeling obtained for floods of the low or large return period and so samples observed or estimated by events sampling exceeding a threshold.

### 4 Discussions

We recorded two or three exceptional peak events of theoretical return period close of the centennial for all stations studied. It flows on the large durations, with a little scarcer, even very rare for one of them. As for time step, the relative extrapolation checks the rare experimental quantiles estimated from sup-threshold samples adjustment by an exponential equation (Fig. 7). Each sampling duration has respective results: the average annual flow, maximum flows, threshold, adjustment parameters (scale parameter and position) and many flood events corresponding, and at last a theoretical quantiles estimated. In effect, all values and flow diagrams are set in the function of sampling duration or in the return period.

The sup-threshold events observed in the hydrographs are adjusted very well with the QdF curves mainly for the hydrometric stations of Zeddine (Fig. 7a), Ouahrane





**Fig. 6** Hydrograph of observed floods of the basin of the middle Chelif: (a) Bir Ouled Tahar, (b) Tikazel, (c) Larabaa Ouled Fares, and (d) Sidi Akkacha

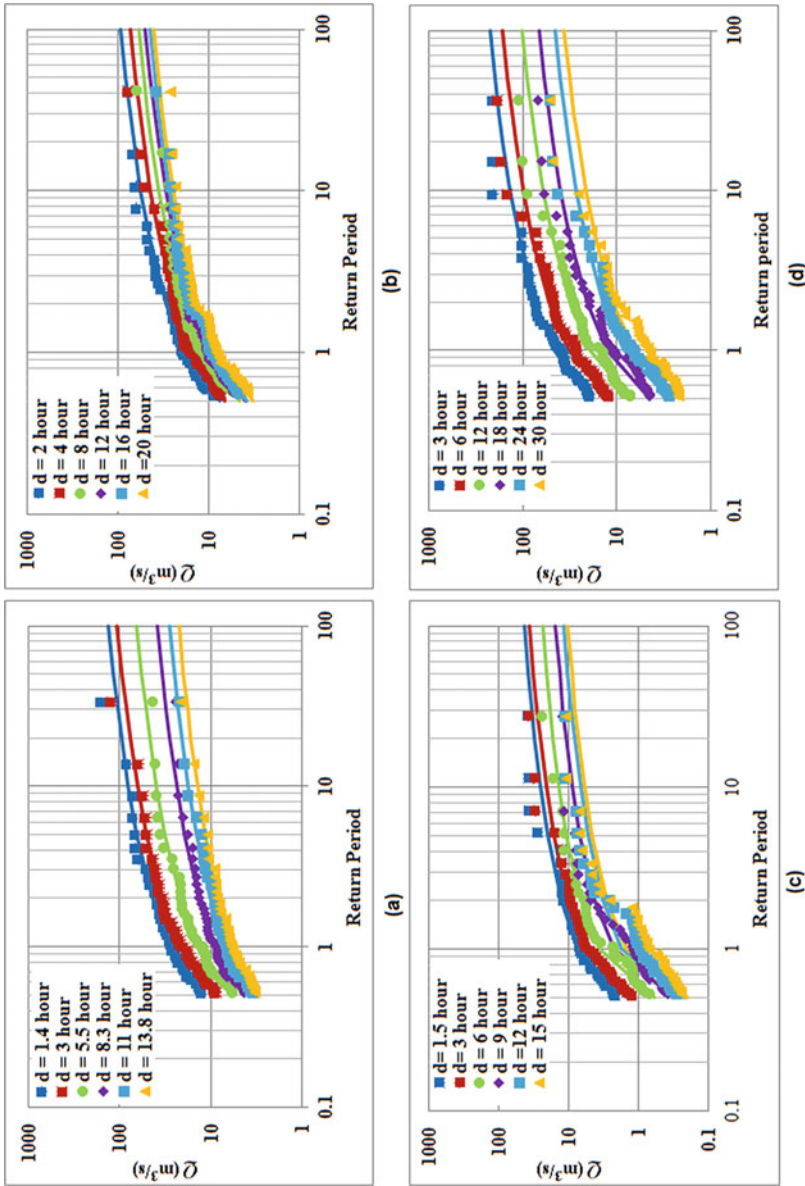


Fig. 7 Application of a local model for threshold flows  $Q_d(T)$  of stations: (a) Bir Ouled Tahar, (b) Larabaa Ouled Fares, (c) Tikazel, and (d) Sidi Akkacha

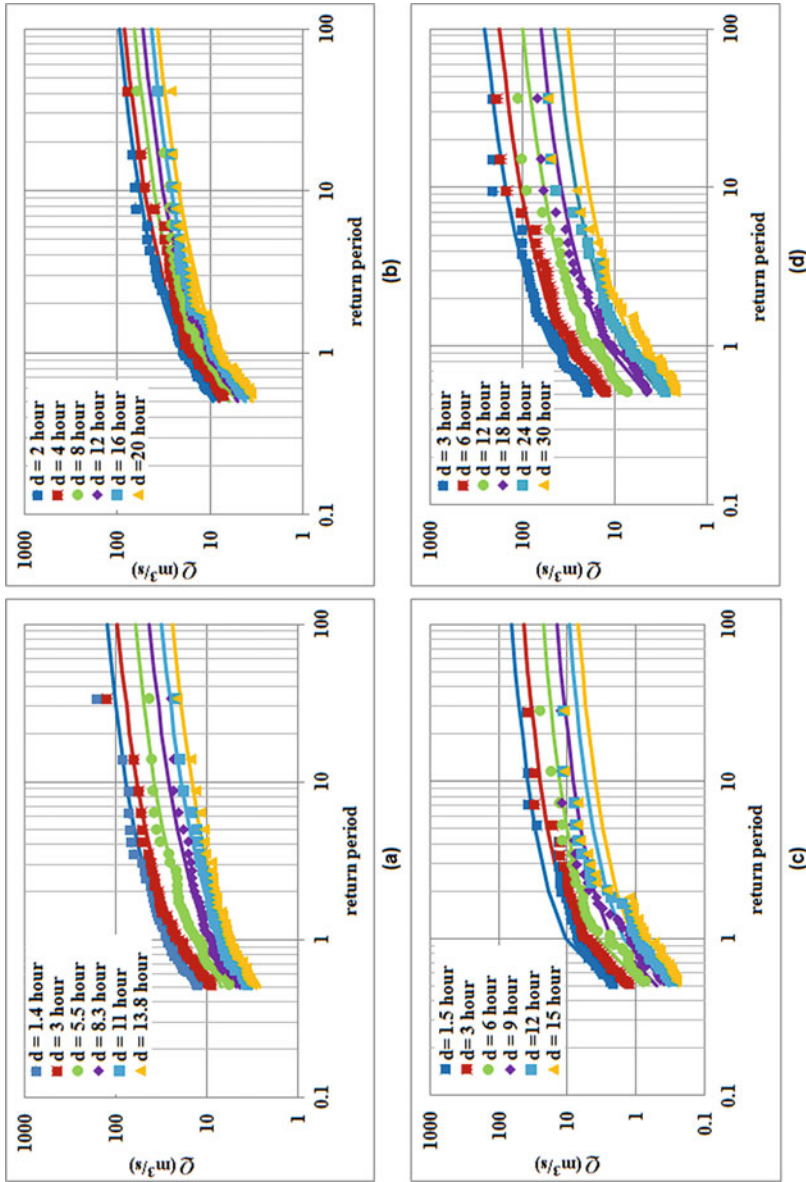
(Fig. 7b), and Allala (Fig. 7d), except the Tikazel station (Fig. 7c) which has duration  $Q$  from (9 h,  $T$ ) to  $Q(15$  h,  $T$ ).

Six durations are considered, giving six series of threshold flows  $Qd$  with  $d$  included between 1.5 and 15 h for Rouina basin, between 2 and 20 h for Ouahrane basin, between 1.5 and 15 h for Tikazel basin, and between 3 and 30 h for Allala basin. The converging model  $Q(d, T)$  applied to a series with sup-threshold values of flows  $Qd$  (Fig. 8). Chronicle examination of the raw data of Rouina shows that water flows on durations less than 24 h are substantially equivalent to peak values. This is translated into distributions of quantiles  $Q(1.5$  h,  $T$ ) and  $Q(15$  h,  $T$ ) relatively close (Fig. 8a). However, adjustments obtained for basin of Ouahrane and Tikazel for a range of lower durations less than 24 h are very distinct and reveal a rapid collapse of water flows with duration (Fig. 8b, c). The quantile  $Q(1.5$  h,  $T$ ) is the double of  $Q(24$  h,  $T$ ) for this station. Parameter  $\Delta$  gives the shape of hyperboles defining quantiles  $Q(d, T)$  for  $T$  fixed. If  $\Delta$  is weak, hyperboles are much curved. Reversely, if  $\Delta$  is strong, hyperboles are much flattened. Whereas is schematized by (Fig. 8), the shape of hyperboles is linked to those of the floods observed.

In effect, the whole studied flood is rapid, more is the difference between peak flows, and the average maximum flows on a duration  $d$  (for instance over one day, on Fig. 8d) is large. This difference between peak flows and middle flows is translated for  $F$ - $d$ - $F$  curves (in function of  $T$ , for  $d$  fixed) by more or less strong  $F$ - $d$ - $F$  highly arched curves (Fig. 8b, c). Reversely, if it is characterized by slow floods, its  $F$ - $d$ - $F$  curves are more flattened (Fig. 8a). Parameter  $\Delta$  is used to describe the shape of hyperboles (Fig. 8); its value informs us, thus, on the dynamics of studied floods.  $\Delta$ , which has a time dimension, may, therefore, be considered as a characteristic duration of the studied basin flood. On the other hand, duration  $\Delta$  may also be translated by the following way. Distribution of threshold flows relative to this duration is at half-distance between instantaneous flows, distribution  $Q(0, T)$ , and the right being ordinate of convergence point. This relation is checked whatever be  $T$  due to the convergence property of distributions. Duration  $\Delta$  obtained for the four studied subbasins, with rapid dynamics, is lower at 12 h (Table 2).

The procedure of construction (Fig. 5) makes it possible to have different hydrographs synthetic mono-frequency from the basin of the middle Cheliff (Fig. 9). The events of rising really observed in the rivers cannot be qualified in terms of frequency or period of return for the good reason that this one varies according to the duration over which one analyzes the phenomenon observed.

The knowledge of the flow threshold made it possible to trace the synthetic mono-frequency hydrographs, which are essential components of hydrodynamic model entry in order to determine the risk of a flood characterized by a return period. The station of Sidi Akkacha (Allala) and the station of Bir Ouled Tahar (Rouina-Zeddine) are characterized by very important quantiles for long return periods.



**Fig. 8** Application of converging model to threshold flows  $Q_d(T)$  of stations: (a) Bir Ouled Tahar, (b) Larabaa Ouled Fares, (c) Tikazel, and (d) Sidi Akkacha

**Table 2** Estimation of the characteristic duration of flood  $D$  and  $QIXA10$ 

Station	$D$ (h)	$QIXA10$ (m <sup>3</sup> /s)	$\Delta$ (h)	$Q_{max}$ (m <sup>3</sup> /s)
ST011905	3	108	10.08	164
ST012004	3	33	6	40
ST012201	4	76	12	79
ST020702	6	220	12	214

## 5 Conclusions

The flood regime modeling has been established according to quantiles of threshold flows coming from the statistic adjustment, which is compared with taking into account flood regime characteristics of the watershed ( $QIXA10$  and  $D$ ), to different counterparts quantiles from F-d-F models.

The relative quantiles with low flows are better reconstituted than equivalent or superior quantiles to  $QIXA10$ . The converging model applied to tested basins constitutes equivalent values to those which could be obtained by adjustment on each duration taken separately. In general terms, using approach of F-d-F seems to be well adapted, and it is able to take into account duration, which is the essential notion when we are speaking about flood; it therefore considers “variable time step.” So the description in flow-duration-frequency, whatever be the formulation, has several uses: estimation of flood quantiles in middle flows or threshold flows to estimate of hydraulic works, insertion in a flood regime typology, definition of hydrologic reference scenarios for flood risk estimation, validation of hydrologic models outputs, and characterization of the regime evolution of high water level.

The knowledge of the flow threshold made it possible to trace the hydrograph synthetic mono-frequency, which are essential components of hydrodynamic model entry in order to determine the risk of a flood characterized by a return period. The station of Sidi Akkacha (Allala) and the station of Bir Ouled Tahar (Rouina-Zeddine) are characterized by very important quantiles for long return periods.

## 6 Recommendations

The synthetic hydrographs are potentially useful and easy to use for the determination of project floods, but they have several limitations because they are based on the return period and describe the specific behavior of a watershed by ignoring the variability of the processes represented by different types of floods. This property ensures consistency between hydrograph and the average flow rate corresponding quantile as we highlighted theoretical studies on these hydrological operators. As a result, their use in studies of floodability [47] ensures coherence between the rolling effects or volume management study and quantification of synthetic variables for defining risk.

The flood events actually observed the river could not be described in terms of frequency or return period for the reason that it varies according to the period over

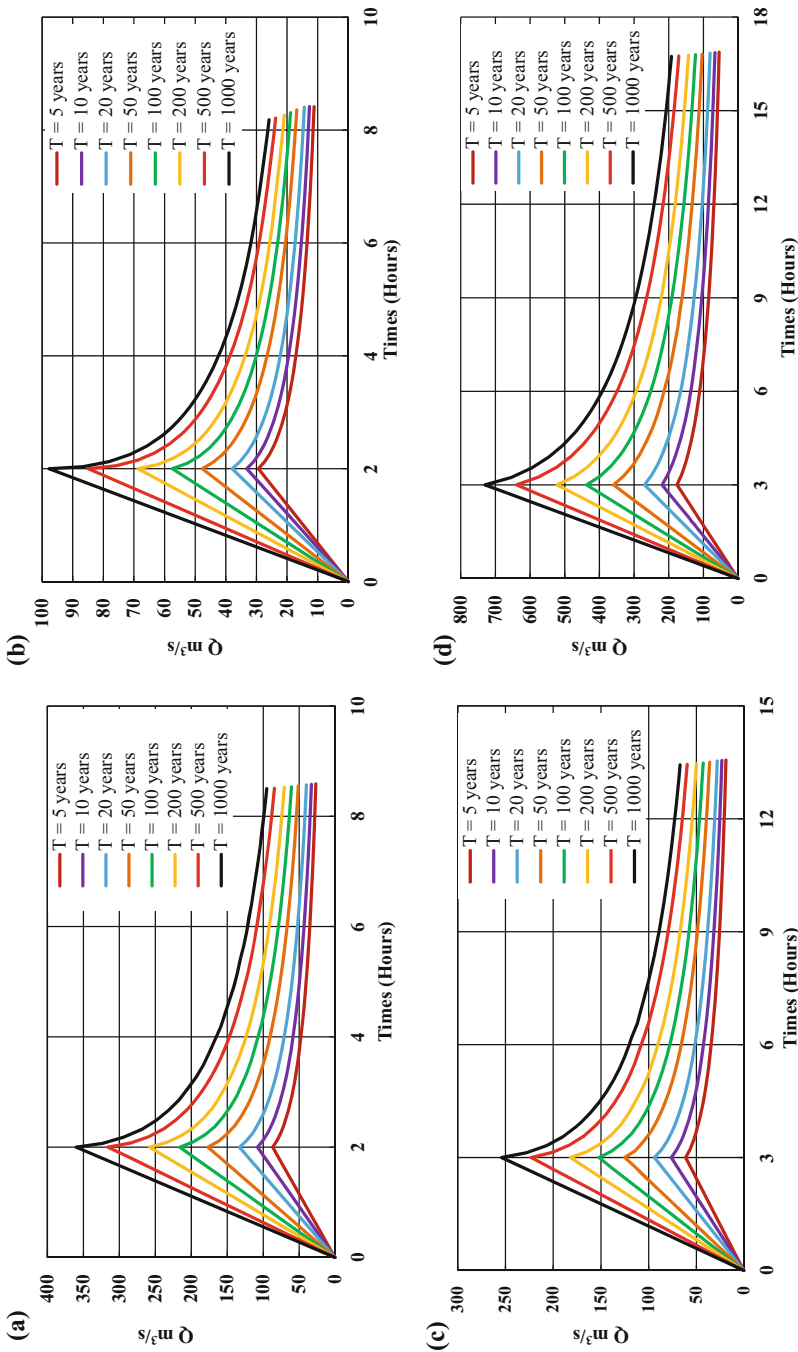


Fig. 9 Hydrograph synthetic mono-frequency of the basin of the middle Chelif: (a) Bir Ouled Tahar, (b) Tikazel, (c) Larabaa Ouled Fares, and (d) Sidi Akkacha

which we analyze the phenomenon observed. For this reason, it seems irrelevant to us to analyze the flood risk on the basis of an actual flood that can be pessimistic and optimistic peak volume or vice versa.

The contributions to the hydraulic model will be calculated simply from QdF models. If working steady, reading the maximum instantaneous flow rates obtained for different return periods gives the rates corresponding to the inputs of hydrodynamic models (such as Saint-Venant). If working in a transient state, it is first necessary to build single-frequency synthetic hydrograph.

Another common use of single-frequency synthetic hydrograph is used in flood routing in order to determine the height poured through a spillway of a dam because these hydrographs are also a hydrometric characteristic of the watershed.

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