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Regional modelling with flood-duration-frequency approach in the middle Cheliff watershed

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Abstract

This study describes a statistical approach of watercourses hydrological regimes in flood, taking into account the latter duration *d* and return period *T*. The choice of Middle Cheliff watershed as study area is linked to disasters strong return period in the western region of Algeria. The Midlle Cheliff catchment basin, located in northwest Algeria, has particularly experienced severe floods over the last years. In view of the recurrence of these unusual events, the estimation and the predetermination of floods extreme quantiles are a strategic axis for prevention against floods in this region. The *a* curves are first of all locally determined, directly from a statistical analysis of flow continuously exceeded during a duration *d* (*QCXd*) on different durations from available data of the study region. Then, these curves are compared to those obtained by application of different regional models VFS (Vandenesse, Florac and Soyans) in which two indices of the watershed characteristic flood are taken into account, a descriptive duration of the flood dynamics (*D*) and the instantaneous maximal annual flow of 10 year return period (*QIXA*10). The final choice of the model is based on verification of certain criteria, such as: Nash and the root mean squared error (*RMSE*). The closest regional models to the local ones are Florac's for low duration and return periods, and Vandenesse's for large return periods, for different durations. These results could be used to build regional *Q-d-F* curves on ungauged or partially gauged Algerian basins.

Key words: *Algeria, characteristic duration, flood, flood-duration-frequency, Middle Cheliff, watershed*

INTRODUCTION

Algeria is among the Mediterranean countries the most vulnerable to floods caused by overflowin+g streams crossing towns and suburbs. These unexpected floods; are often difficult to predict, rapid rise time and relatively important specific flow, these floods are generally linked to intense rainy episodes and appear on middle size basins. Several catastrophes caused by those floods have been listed in Algeria (Algiers in November 2001, Sidi Bel Abbès in April 2007, Ghardaia and Bechar in October 2008, etc.).

Floods are often described by three main characteristics: the peak, the volume and the duration. In several works, this fact is linked to climate change [BOUCHEHED *et al*. 2017; GĄDEK *et al*. 2016; KRIŠČIUKAITIENĖ *et al*. 2015; LJUBENKOV 2015; NOOR *et al.* 2014; WAŁĘGA 2016; WOJAS, TYSZEWSKI 2013].

Although some studies had to be dedicated to *Q-d-F* models; an approach that is still not much used. The *Q-d-F* models have first been developed in 1990 in France GALÉA and PRUDHOMME [1994; 1997] The floods modelling by *Q-d-F* models among other has been applied to flood regionalisation of France watershed. Furthermore, a converging and continuous *Q-d-F* model has been proposed by JAVELLE *et al.* [1999]. It is based on properties of scale invariance of flood distribution applied by MEUNIER [2001] in Martinique, this model has also been combined to flood indices method [DALRYMPLE 1960] by JAVELLE *et al.* [2002; 2003] which brings some improvements to the estimation procedure and apply this corrected version of the model for spring floods to Quebec provinces and of Ontario (Canada) [CUNDERLIK, BURN 2003; CUNDERLIK *et al*. 2007].

Moreover, the *Q-d-F* modelling allowed studying of 1.200 ungauged sites in Himalaya [SINGH *et al.* 2001] and so on regions of Burkina Faso [MAR *et al.* 2002], of Romania [MIC *et al*. 2002]. In Algeria this method was successfully applied on some basins [BESSENESSE *et al*. 2003; 2004; 2006; 2014; KETROUCI *et al*. 2012; RENIMA *et al*. 2013; 2014; SADEUK BEN ABBES, MEDDI 2016; SAUQUET *et al*. 2004]. Application of *Q-d-F* modelling on three watersheds: VFS (Vandenesse, Soyans and Florac) by OBERLIN *et al.* [1989] allowed to define a regional typology of flow regimes which is wide spatial representation [GALÉA, PRUDHOMME 1997]. So, it has been shown that flood regimes could be adequately described with help of three regional models VFS, reprsentating the names of representative basins (in France) retained for each of the concerned regions. The goal of this article is to study the *Q-d-F* modeling application conditions and consequently, the determination of the corresponding curves on the Cheliff mean watershed in northwest Algeria. The *Q-d-F* curves are first determined locally, directly from a statistical analysis of the continuously exceeded during a duration *d* (*QCXd*) over different durations, based on the data available at the studied stations. These curves are then compared with those obtained by applying different regional models VFS, in which two of the catchment characteristic flood indices are taken into account, a descriptive duration of flood dynamics (*D*) and the instantaneous maximal annual flow of 10 year return period (*QIXA*10).

MATERIAL AND METHODS

STUDY AREA

The Cheliff basin is 44.630 km^2 in area, it is located between geographic coordinates 34° and 36°30' of latitude North, 0° and 3°30' of longitude East and takes the shape of an axe-blade North-South. Middle Cheliff watershed is located in North-West of the national territory. It is characterized by a Mediterranean arid to semi-arid climate with Sahara hot influences in the South and cool in both northern and eastern part of it. Rainfalls are very regular in time and space; we distinguish two extreme zones, the first one is rainy with annual average of 658 mm at the rain-control station 011806 (Elanab, Dahra) and 524 mm at the rain station 011605 (Theniet El Had, Ouarsenis), and another zone (the plain included in-between) less rainy with annual average, 355 mm at rain control station 012219 (Chlef National Agency of Hydraulic Resources – Fr. Agence Nationale des Ressources Hydrauliques – ANRH).

DATA

They are chronicles of river station flows, the flows' chronicles are at variable time step. These stations are located in Cheliff watershed code 01 recorded by ANRH (Tab. 1, Fig. 1).

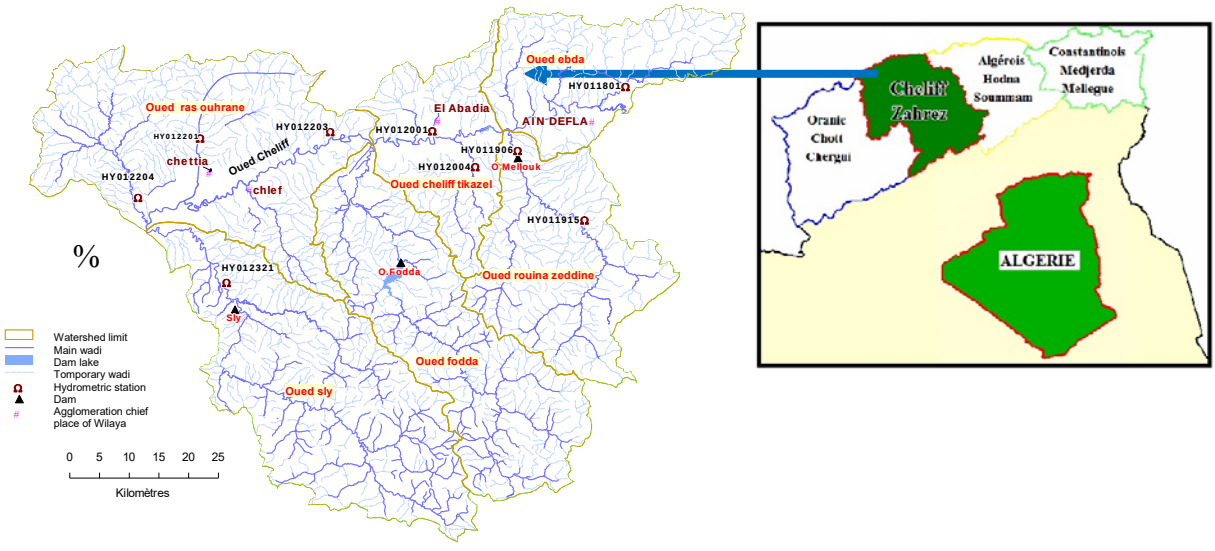

Fig. 1. Location of the study area; source: own elaboration

Table 1. Characteristics of hydrometric station

Station code	Wadi	Latitude N	Longitude E	*Z* m	Surface km^2	Available period
011905	Zeddine	36°6'	1°57'	376	872.57	1990–2013
012201	Ouahrane	36°13'	1°13'	181	262	1983–2012
012004	Tikazel	36°11'	1°44'	262	130	1990–2009
020207	Allala	36°28'	1°18'	120	295	1983–2009

Source: own elaboration.

SAMPLING METHODS

There are two commonly used methods [SAUQUET, RIBATET 2004].

1. Selecting the annual maximum is the simplest. It consists of selecting only one maximum over a hydrological year or a season-at-risk [ASSANI 1997]. The main disadvantage is that the formed sample may contain non-significant events (eg. no major events are recorded in a dry year) and lack of important ones happening during the same year.

2. Sampling by value greater than a threshold (sup-threshold). Consists in retaining the maximum value of a set of independent events having exceeded a given threshold [LANG *et al.* 1997]. 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.* [2014] in Serbia, FISHER and SCHUMANN [2014] in Germany and LANG [1999] in France showed this method is considered to be more reliable than the annual maxima method.

ESTIMATION OF *QIXA*10 AND DETERMINATION OF THE CHARACTERISTIC DURATION *D*

The concept of modelling in flood-duration-frequency has been established on an objective basis [GALÉA, PRUDHOMME 1993; 1997] and its extension towards ungauged watershed, supplies a theoretical frequency description of multi-duration of flood quantiles. It is essentially focused on hydrological variables representing 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 *QIXA*10 and flood characteristic duration of watershed *D*.

We retain as definition of the flood characteristic duration *D*, duration during which half of the peak flow *Qs* is continuously exceeded. For each observed and recorded flood, studied at the level of each sub-watershed, its characteristic duration *D* and its peak flow *Qs* have been determined. In a plan (*Qs*, *ds*), the characteristic duration of watershed flood *D* according to SOCOSE method of Technical Center for Rural Water and Forest Engineering (Fr. Centre technique du génie rural des eaux et des forêts) [CTGREF *et al.* 1980; 1982] is defined as being value of the *ds* conditional median for value of the corresponding instantaneous maximal annual decennial flow *QIXA*10. The pairs (*Qs*, *ds*) of the used flood periods in the Bir Ouled Tahar, refers the parameter *D* to the time when the mean peakflow is exceeded, when it shows the characteristic duration of Bir Ouled Tahar is 3 hours as it is shown in Figure 2 by using the same method the characteristic duration for Tikazel, Larabaa Ouled Fares and Sidi Akkacha are 3, 4 and 6 hours, respectively.

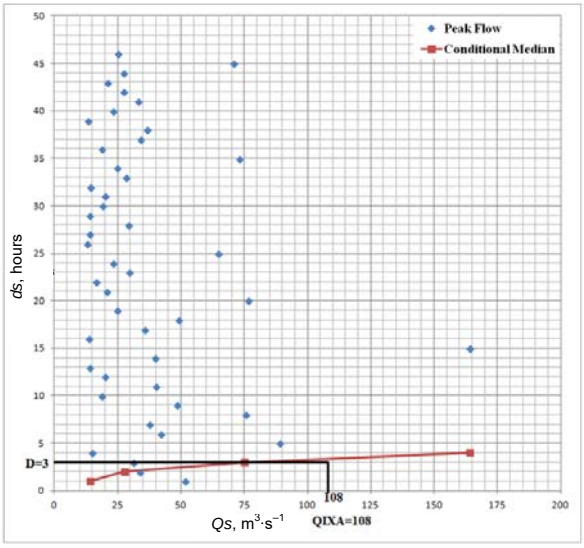

Fig. 2. Estimation of the characteristic flood duration; *D* = flood characteristic duration of watershed, *ds* = duration flow, *QIXA10* = instantaneous maximal annual flow 10 year return period; source: own elaboration

THE *Q-d-F* CONVERGING MODEL

The *Q-d-F* converging model is born from a property observed on a large number of treated hydrological chronicles: Adjustments $Qd(T)$ are the series of sup-threshold flows values, over a given duration *d* that can be derived from an instantaneous streamflow time series $Q(t)$ l likely to meet in the same point towards the weakest return periods.

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

Where: aq_d = flows Gradex or even scale parameter of adjustment law: $x_{0,d}$ = 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 volume on a continuous duration *d*, maximal during flood episode, *Qd* represents the threshold flow, continually exceeded on the duration *d* during the flood episode (Fig. 3).

The first manner to reach $V(d, T)$ and/or $Q(d, T)$ consists therefore in using mathematical expressions of a dimensionless bookshelf model named "Reference Model". It comes to choose the best model among the three VFS available according to meteorological criteria and to distort formulations with help of two characteristics: one in flow and another in duration, all of them obtained from study zone's interest-site. The second possibility is to apply the "converg-

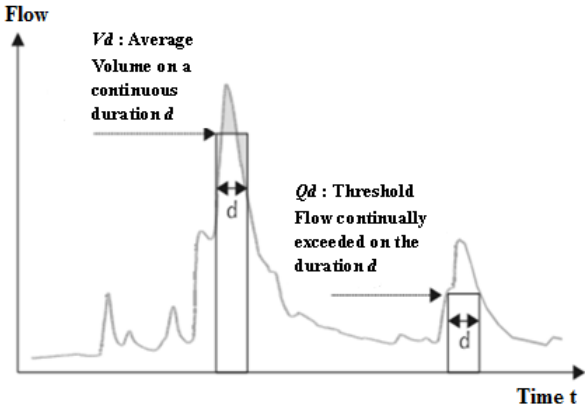

Fig. 3. The variables under consideration of flood episode; source: SAUQUET *et al*. [2003], modified

ing *Q-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 towards the weakest return periods and on orthogonal affinity property of theoretical laws of probability of relative quantiles of different durations [SAUQUET *et al*. 2004]. The converging *Q-d-F* model allows synthesizing in unique analytical formulation, quantiles of flood relating to different durations, independently of retained-probabilities laws.

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

Where: $V(0,T)$ = theoretical distribution of peak flows (*QIX*) consolidated by modelling: Δ = parameter to be set, homogeneous to a time and linked to flood dynamics.

One speaks of consolidated adjustment $V(0, T)$ because all durations participate in parameters estimation of the theoretical distribution. Distributions of duration d (2) are deducted from modelled distribution of the peak flows $V(0, T)$ knowing Δ. Several approaches may be considered to evaluate Δ and to simultaneously obtain a consolidated distribution $V(0, T)$ [JAVELLE *et al*. 2003; KOUTSOYIANNIS *et al*. 1998; MEUNIER 2001]. The preferred procedure introduces a Δ setting process by using successive iterations on the principle of the least squares. It presents an advantage of a simple and economical application in hypothesis.

From expression (2), and taking account of the following property:

$$V(d,T) = \frac{1}{d}\int_0^d Q(t,T)dt \tag{3}$$

We deduct an expression of quantiles estimations of threshold flows $Q(d, T)$:

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

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

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

and

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

Where parameters a_0, x_0 and Δ are to be determined.

MODEL TYPE OF "REFERENCE BASIN"

With help of *Q-d-F* model, supposed to represent the considered-watershed floods regime. The choice of this model among three other referenced in France is based on local rainfall and of instantaneous maximal annual flow of 10 year return period *QIXA*10 [GALÉA, PRUDHOMME 1997].

A *Q-d-F* model type of reference basin allows translating under an operational synthetic shape, the watershed large spatio-temporal variability of flows *QCXd*, observed or not [GALEA, PRUDHOMME 1994]. The formal representation of *Q-d-F* models in *QCX* is: for $0.5 \leq T(\text{yr}) \leq 20$: generalization of an exponential law with two parameters adapted to extreme values, according to *d/D* (continuous duration/characteristic duration) and *QIXA*10:

$$\frac{QCXdT}{QIXA10} = \frac{A_q\left(\frac{d}{D}\right)\ln T + B\left(\frac{d}{D}\right)}{QIXA10} \tag{7}$$

For $20 < T(\text{yr}) \leq 1\ 000$: generalization of extrapolation shape of esthetic Gradex by Gradex of maximal rains [MICHEL 1982] according to *d/D* and *QIXA*10:

$$\frac{QCXdT}{QIXA10} = \frac{QCX10d}{QIXA10} + \frac{A_p\left(\frac{d}{D}\right)}{QIXA10} \tag{8}$$

With *QCXdT* is the quantiles of maximum flow, for a duration *d* and of return period *T*, *QCX*10*d*, decennial quantile of volume flow is obtained from Equation 3. *Aq*, *B* and *Ap* are respectively: Gradex of the flows (is the Gradex of the maximum discharges provided by the convergent model for the duration *d*), position parameter of exponential law and rains Gradex; they are explained according to *d/D* by Equation (9, 10 and 11):

$$\frac{A_q\left(\frac{d}{D}\right)}{QIXA10} = \frac{1}{x_1\frac{d}{D} + x_2} + x_3 \tag{9}$$

$$\frac{B\left(\frac{d}{D}\right)}{QIXA10} = \frac{1}{x_4\frac{d}{D} + x_5} + x_6 \tag{10}$$

$$\frac{A_p\left(\frac{d}{D}\right)}{QIXA10} = \frac{1}{x_7\frac{d}{D} + x_8} + x_9 \tag{11}$$

To determine $x_1, x_2, \ldots, x_9$, three watersheds have been chosen including long series of quality data at variable time step and representing recognized regimes. These basins allow approaching a typology of flood regime:

– station of Dragne at Vandenesse, region of Bourgogne (Vandenesse),
– station of Roubion at Soyans, region of Rhône-Alpes (Soyans),
– station of Mimente at Florac, region of Languedoc-Roussillon (Florac).

These stations have been chosen by the Cemagref [GILARD 1998] for reliability and quality of their provided data, and due to hydro-meteorological context to which they belong. The Vandenesse model is represented by a station widely set under oceanic influence. The Soyans model based on a station located not far away from the Rhone valley and it takes into account more continental influences. As for Florac model, it is based on a station placed under Mediterranean influence. According to availability of rainfall data at level of the three watersheds *VFS*, parameters x_1, x_2, x_3, …, x_9 have been defined for each *Q-d-F* model in *QCX* (Tab. 2).

The Vandenesse model characterizes a sustained flood hydrologic regime on observable frequencies. The exceptional events are not very different from the rare ones, and the floods are rather voluminous than flash. The Florac model defines a fast-flow regime, with some rainfall storage. This leads to very common events, different from the average ones, which are themselves very different from the rare events. The floods are flash, not voluminous, but are part of the duration (storage restoration during floods). The Soyans model defines a fast flow regime, but with very low storage on the watershed. The exceptional events are very different from the average ones, the floods being very sharp and not that large. In general, the flood duration is relatively low.

Table 2. Parameter x_i for *Q-d-F* models in threshold flow *QCX*

Model's type	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
Florac	3.050	3.530	0.000	2.130	2.960	0.010	2.780	1.770	0.040
Soyans	2.570	4.860	0.000	2.100	2.100	0.050	1.490	0.660	0.017
Vandenesse	3.970	6.480	0.010	1.910	1.910	0.097	3.674	1.774	0.013

Source: own elaboration.

VALIDATION CRITERION

Having regard to the unavailability of rain-gradex for different durations, performances of one of the *Q-d-F* models of reference basin type are estimated in a framework using validation-setting. Two criteria have been used:

– criterion of Nash [NASH, SUTCLIFFE 1970]; the Nash's criterion can vary of ∞ to 1; optimal value is 1 (perfect setting); an upper value to 0.7 is usually considered as satisfactory; this criterion is expressed by equation:

$$Nash(T) = 1 - \frac{\sum_{i=D/2}^{5D} (QCXdT - QCXdt^{\text{model}})^2}{\sum_{i=D/2}^{5D} (QCXdT - \overline{QCXdt})^2} \quad (12)$$

Where:

$$QCXT_{moy} = \frac{\sum_{i=D/2}^{5D} QCXdT}{1 + 5D - D/2} \quad (13)$$

– the criterion of average root-mean squared error (*RMSE*), translates the average error between flows estimated or modelled, and flows calculated by one of the *Q-d-F* models (VFS), it is expressed by Equation (14):

$$RMSE(T) = \left(\frac{1}{d_2 - d_1 + 1} \sum_{i=d_1}^{d_2} (QCXdT - QCXdT^{\text{modele}})^2 \right)^{\frac{1}{2}} \quad (14)$$

RESULTS AND DISCUSSION

LOCAL DISTRIBUTIONS AND FLOOD QUANTILES

Figure 3 shows *Q-d-F* modelling obtained for floods of low or large return period, as well as samples observed or estimated by sampling of events above the threshold.

We recorded two or three exceptional events in peak of theoretical return period close to the centennial for all the studied stations and which flow on the large durations are rather scarce, or even very rare for one of them. As for time step, the relative extrapolation verifies the rare experimental quantiles estimated from sup-threshold samples adjustment by exponential law (Fig. 4). The calculations results are flows and flood hydrographs values. Each sampling duration has respective results: the average annual flow, maximum flows, threshold, adjustment parameters (scale parameter and position) and so number of flood corresponding events, at last, estimated theoretical quantiles. In effect, all values and flows diagrams are set in function of sampling duration or of the return period.

The sup-threshold events are well adjusted with the *QdF* curves for the Zeddine basins (Fig. 4a), Ouahrane (Fig. 4b) and Allala (Fig. 4d) except for the Tikezal basin events (Fig. 4c), the duration *Q* 1.5 hours to 15 hours (*T*).

CONVERGING DISTRIBUTIONS AND FLOOD QUANTILES

Six durations are considered, giving six series of threshold flows *Qd* with *d* included between 1.5 and 15 hours for Rouina basin, between 2 and 20 hours for Ouahrane basin, between 1.5 and 15 hours for Tikazel basin and between 3 and 30 hours for Allala basin. The converging model *Q*(*d*, *T*) is applied to series with sup-threshold values of flows *Qd* (Fig. 5). Chronicle examination of raw data of Rouina shows that water flows on durations less than 24 hours are substantially equivalent to peaks values. This is translated into distributions of quantiles *Q*(1.5 hours, *T*) and *Q*(15 hours, *T*) relatively close (Fig. 5a). However, adjustments obtained for basin of Ouahrane and

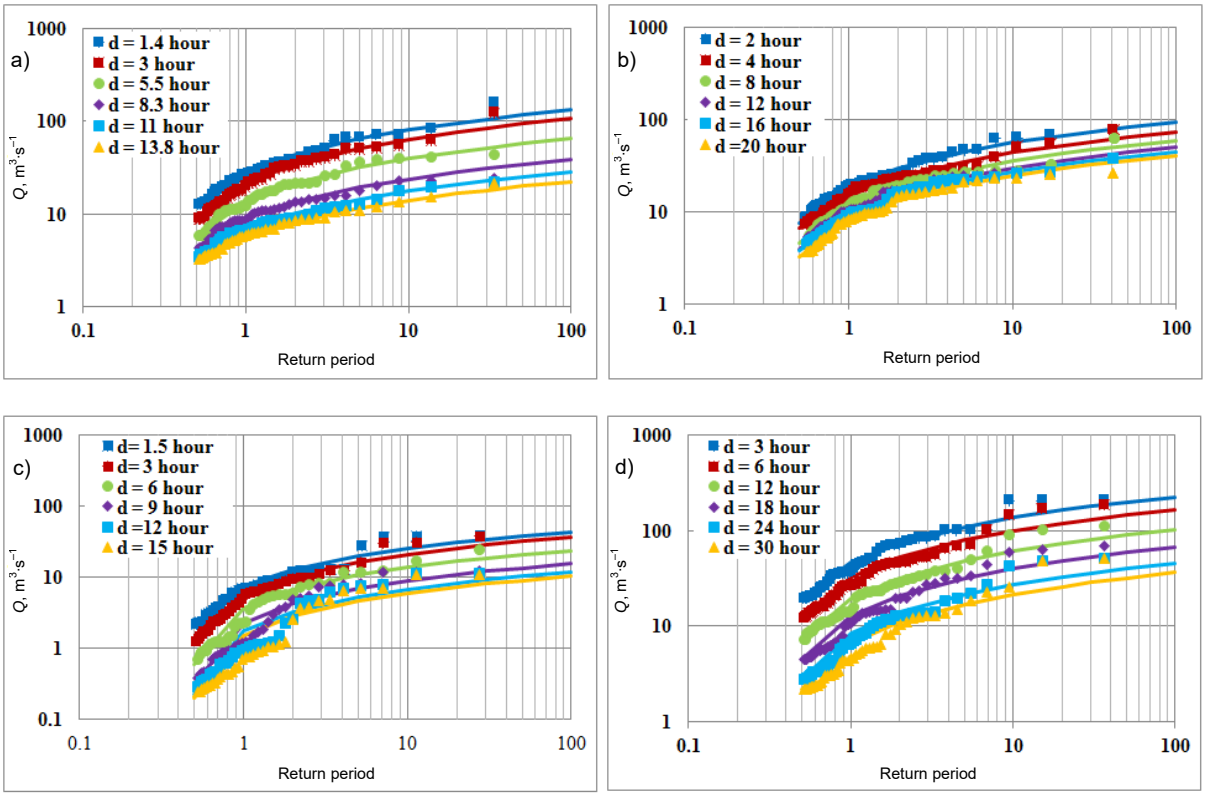

Fig. 4. Application of local model to threshold flows $Qd(T)$ of stations: a) Bir Ouled Tahar, b) Larabaa Ouled Fares, c) Tikazel, d) Sidi Akkacha; d = continuous duration; source: own study

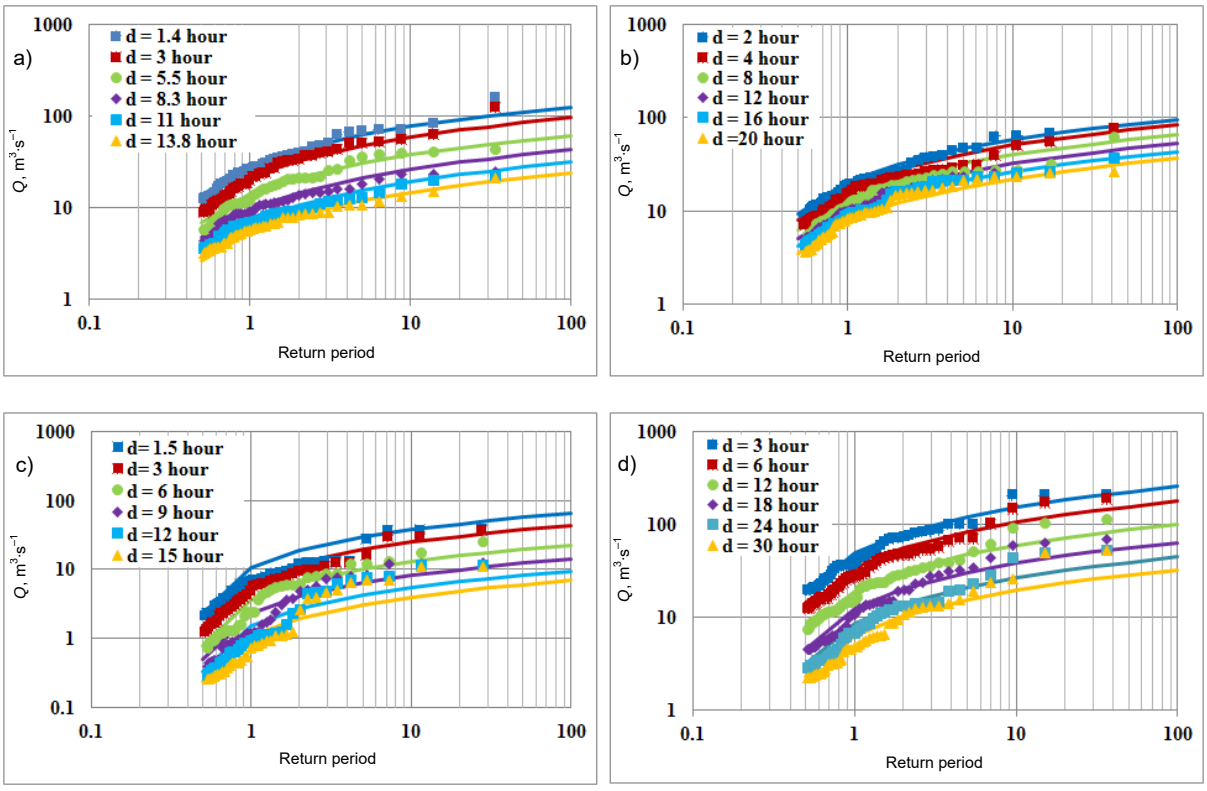

Fig. 5. Application of converging model to threshold flows $Qd(T)$ of stations: a) Bir Ouled Tahar, b) Larabaa Ouled Fares, c) Tikazel, d) Sidi Akkacha; d = continuous duration; source: own study

Tikazel for a range of lower durations less than 24 hours are very distinct and reveal a rapid collapse of water flows with duration (Fig. 5b, c). The quantile Q(1.5 hours, T) is the double of Q(24 hours, T) for this station. Parameter Δ gives shape of hyperboles defining quantiles $Q(d, T)$ for T fixed. If Δ is weak, hyperboles are much curved. Reversely, if Δ is strong, hyperboles are much flattened. Whereas is schematized by (Fig. 5), 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 average maximum flows on a duration d (for instance over one day, on figure 5d) is large. This difference between peaks flows and middle flows is translated for *Q-d-F* curves (in function of T, for d fixed) by more or less strong *Q-d-F* highly-arched curves (Fig. 5b, c). Reversely, if it is characterized by slow floods, its *Q-d-F* curves are more flattened (Fig. 5a). Parameter Δ is used to describe shape of hyperboles (Fig. 5), its value informs us thus, on the dynamics of studied floods. Δ, which has a time dimension, may therefore be considered as a characteristic duration of the studied basin's flood. On the other hand, duration Δ 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 convergence property of distributions. Duration Δ obtained for the four studied sub-basins, with rapid dynamics, is lower at 12 hours (Tab. 3). It is then necessary to calibrate the convergent model into a regional one according to the 3 basins of references (VFS).

Table 3. Estimation of characteristic duration of flood and *QIXA*10

Station code	*D* hour	*QIXA*10 $m^3 \cdot s^{-1}$	Δ hour	Q_{max} $m^3 \cdot s^{-1}$
011905	3	108	10.08	164
012004	3	33	6	40
012201	4	76	12	79
020207	6	220	12	214

Source: own study.

CHOICE OF REGIONAL MODEL "REFERENCE BASIN" TYPE

Results of the three regional models (Fig. 6, 7, 8) show that Florac's model is better adjusted to quantiles compared to that of Soyans and Vandenesse, quantiles obtained by Florac model are closest to those locally estimated by adjustment of exponential law, then sup-threshold events follow regional curves of Florac model for all return periods and for majority of considered durations. So, adjustments carried out present a hyperbolic shape and all converging towards low durations (Fig. 4, 5). By contrast, curves of Soyans and Vandenesse's models (Fig. 7, 8) are very flattened; experimental quantiles do not follow regional curves excepted for return periods upper to 10 years for majority of the stations. The regional *Q-d-F* models *VFS* represent correct distributions of flows characteristics, whatever variables and used procedures are.

Also, results of criteria (*Nash* and *RMSE*) Figures 9 and 10, and Table 4 show that the best values for the whole of the studied stations are obtained by *Q-d-F* Florac model and notably for observable frequencies field ($0.5 \leq T(\text{yr}) \leq 50$) while beyond frequencies ($T(yr) > 50$ years), Vandenesse and Florac *Q-d-F* models present similar values with light difference. Similar studies showed robustness of Florac model in Mediterranean contexts characterized by intense rainfall in Alcaucin du Vinuela basin (South Spain), *Q-d-F* of Vandenesse in basin of Tevere in Ponte Nuovo (Italia), and in France by GALÉA and PREDHOMME [1994], in Algeria, works conducted on Tafna basin show that Florac *Q-d-F* model is the most adapted for pre-determination of floods from watershed of Wad Isser. This result is similar to that one found by YAHIAOUI *et al*. [2011] during study of Mekerra flood regime, being a watershed neighbouring that of wadi Isser [KETROUCI 2014]. These results reinforce performance of the regional model of "Reference Basin" type in pre-determination of extreme flood flows.

Besides of these criteria, there is also the hydroclimatologic context where we found Middle Cheliff Watershed where region is influenced by local Mediterranean climate, and according to NOUACEUR *et al*. [2013], the response of pluviometry at The North Atlantic Oscilliation (*NAO)* shows that period of strong drought corresponds to positive indices *NAO* of strong intensity, which witnesses a reinforcement of anticyclone in the Azores and widening a depression in Iceland. In these conditions, depressions track moves towards Northern latitudes which favours implementation of dry and soft weather around the Mediterranean basin, notably in Maghreb.

Furthermore, several studies showed that variations of pluviometry regime in Mediterranean basin are linked to the general atmospheric circulation such as the North Atlantic Oscillation (*NOA*) [BRANDIMARTE *et al*. 2011] El Nino South Oscillation (*ENSO*) [MEDDI *et al*. 2010].

In Algeria, a study conducted by MEDDI *et al*. [2010] shows that temporal variability of annual rainfalls in West of Algeria is influenced by *ENSO*. TAIBI *et al*. [2015] have also found a significant relation between monthly rains of Algeria North-West including the Cheliff and indice *MO*. Which bring us to say, that the *Q-d-F* model is the most adapted for predetermination of floods of Algerian ungauged or partly gauged basins.

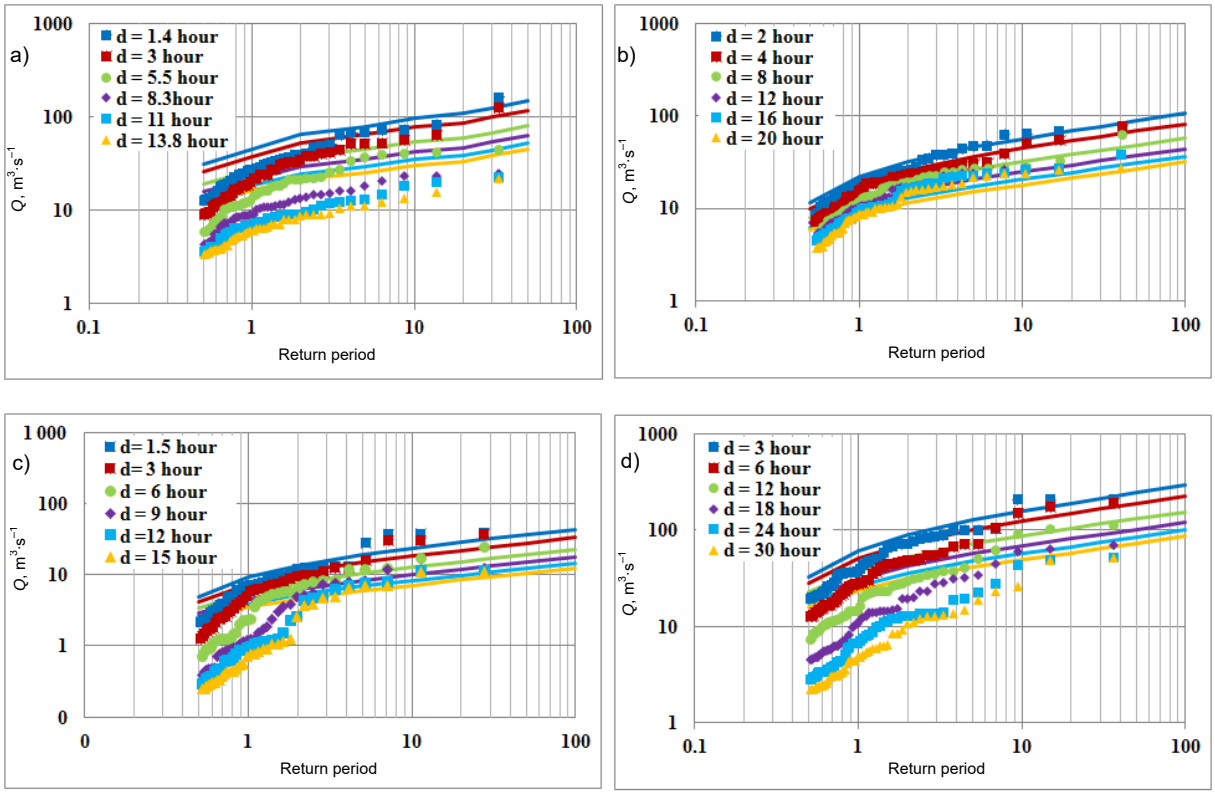

Fig. 6. The regional model of Florac for stations: a) Bir Ouled Tahar, b) Larabaa Ouled Fares, c) Tikazel, d) Sidi Akkacha; *d* = continuous duration; source: own study

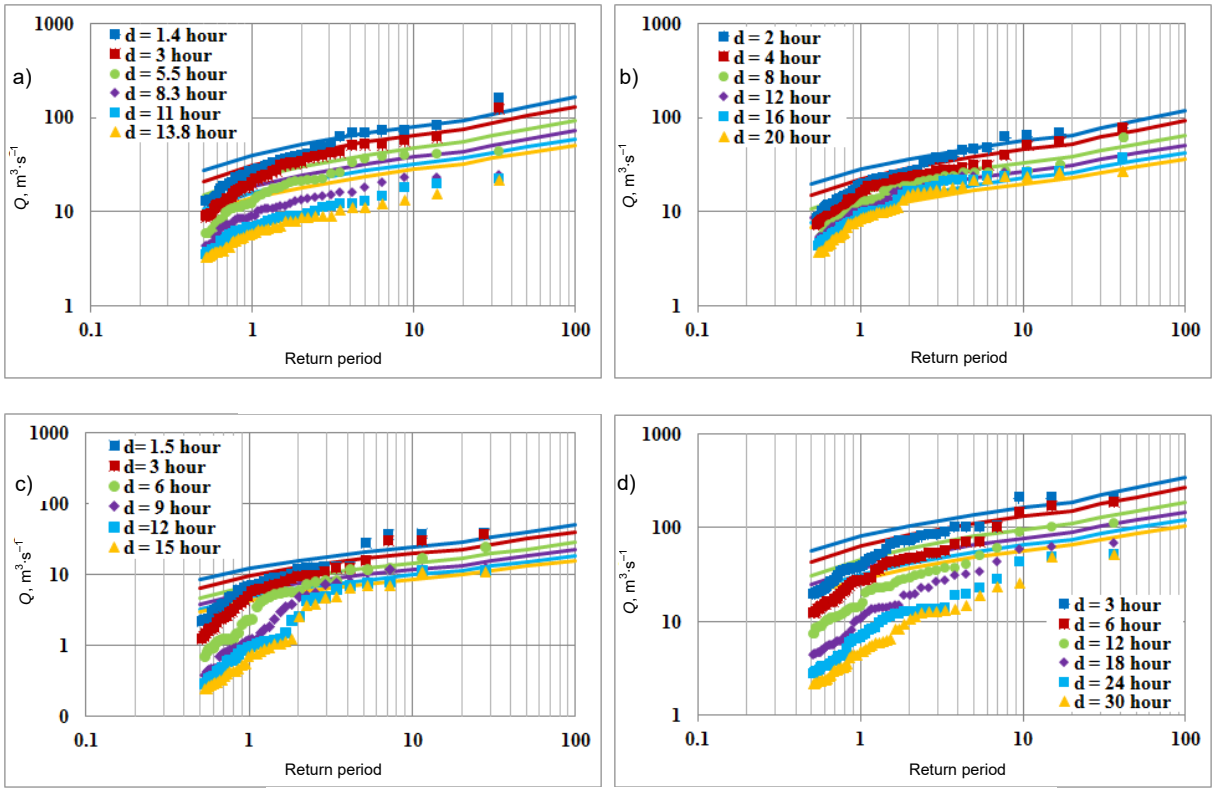

Fig. 7. The regional model of Soyans for stations: a) Bir Ouled Tahar, b) Larabaa Ouled Fares, c) Tikazel, d) Sidi Akkacha; *d* = continuous duration; source: own study

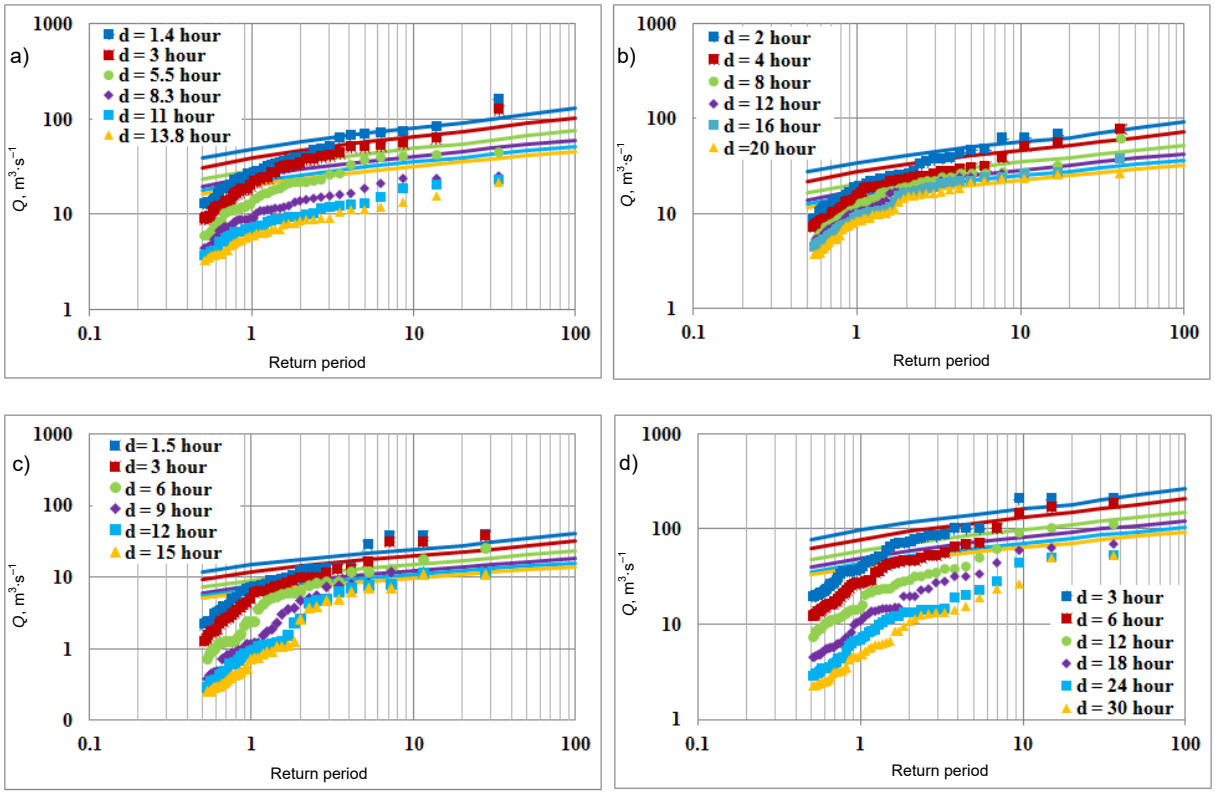

Fig. 8. The regional model of Vandenesse for stations: a) Bir Ouled Tahar, b) Larabaa Ouled Fares, c) Tikazel, d) Sidi Akkacha; *d* = continuous duration; source: own study

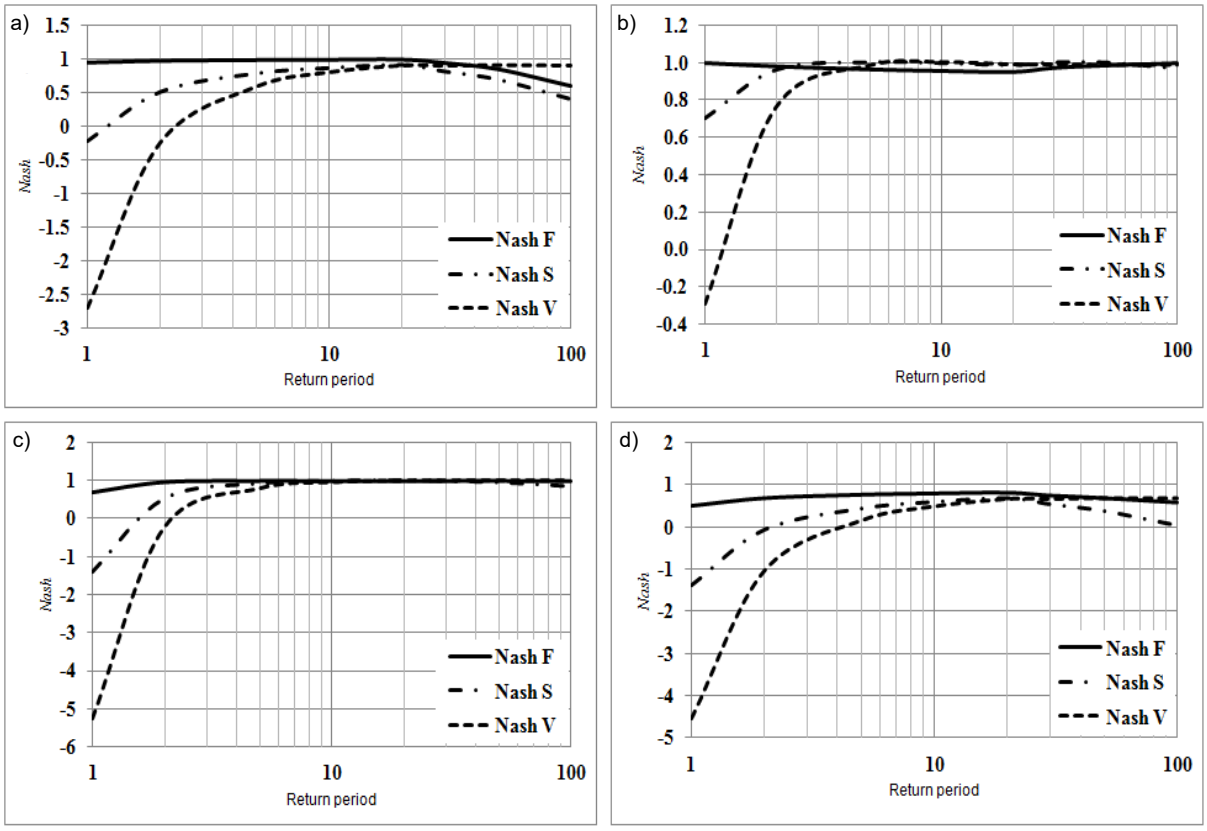

Fig. 9. Coefficient of *Nash* between local model and *Q-d-F* reference model for stations: a) Bir Ouled Tahar, b) Larabaa Ouled Fares, c) Tikazel, d) Sidi Akkacha; *d* = continuous duration, F = Florac watershed model, S = Soyans watershed model, V = Vandenesse watershed model; source: own study

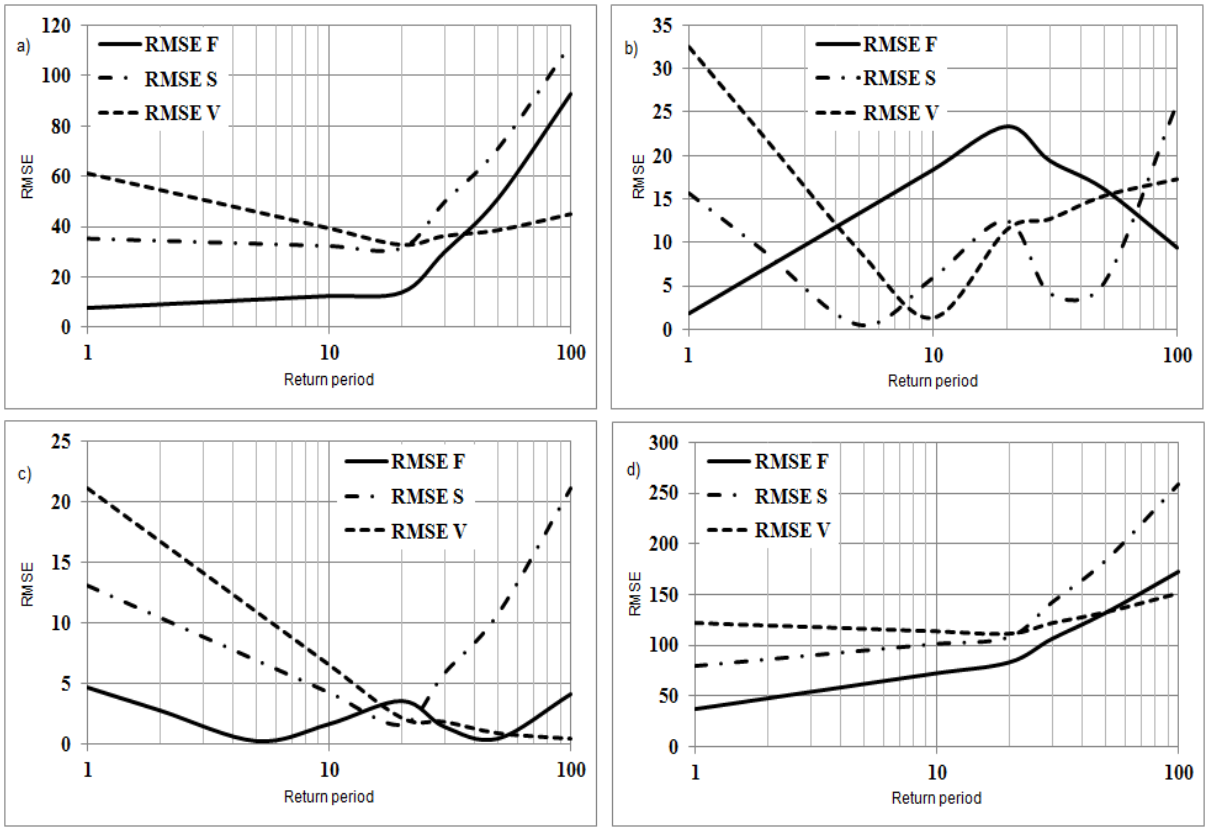

Fig. 10. Criterion of root mean squared error (*RMSE*) between local model and *Q-d-F* reference model for stations: a) Bir Ouled Tahar, b) Larabaa Ouled Fares, c) Tikazel, d) Sidi Akkacha; F, S, V as in Fig. 9; source: own study

Table 4. Coefficient of *Nash* and criterion of *RMSE* (root-mean squared error) between local model and *Q-d-F* reference model VFS (Vandenesse, Florac and Soyans watersheds) for all stations

T, year	*Nash* F	*RMSE* F	*Nash* S	*RMSE* S	*Nash* V	*RMSE* V
1	2	3	4	5	6	7
Zeddine basin (station of Bir Ouled Tahar)						
1	0.94	7.94	–0.22	35.18	–2.69	61.16
2	0.96	9.37	0.51	34.29	–0.24	54.60
5	0.98	11.27	0.79	33.11	0.59	45.91
10	0.98	12.70	0.87	32.22	0.80	39.34
20	0.98	14.14	0.91	31.33	0.90	32.77
30	0.93	30.15	0.82	49.75	0.90	36.31
50	0.84	51.39	0.70	71.06	0.91	38.61
100	0.59	92.93	0.40	112.70	0.91	44.99
Tikazel basin (Tikazel station)						
1	0.69	4.72	–1.39	13.05	–5.24	21.08
2	0.97	2.80	0.53	10.40	–0.22	16.69
5	1.00	0.25	0.92	6.90	0.79	10.90
10	1.00	1.67	0.98	4.25	0.95	6.51
20	0.99	3.60	1.00	1.59	1.00	2.13
30	1.00	1.45	0.98	5.83	1.00	1.81
50	1.00	0.45	0.95	10.71	1.00	0.87
100	0.99	4.17	0.84	21.06	1.00	0.41
Ouahrane basin (Larabaa Ouled Fares station)						
1	1.00	1.76	0.70	15.72	–0.29	32.54
2	0.98	6.77	0.96	9.18	0.76	22.37
5	0.96	13.39	1.00	0.54	0.98	8.93
10	0.95	18.40	1.00	5.99	1.00	1.24
20	0.95	23.41	0.98	12.52	0.99	11.41
30	0.97	19.47	1.00	4.20	0.99	12.65
50	0.98	16.20	1.00	5.32	0.98	15.33
100	1.00	9.37	0.97	26.05	0.99	17.26

cont. Tab. 4

1	2	3	4	5	6	7
Allala basin (Sidi Akkacha station)						
1	0.49	37.02	–1.39	79.93	–4.55	121.75
2	0.67	47.65	–0.07	86.51	–1.04	119.30
5	0.76	61.73	0.42	95.24	0.14	116.08
10	0.79	72.31	0.58	101.77	0.48	113.58
20	0.81	83.10	0.67	108.51	0.65	111.28
30	0.74	106.24	0.53	142.82	0.66	121.66
50	0.67	131.79	0.37	183.99	0.67	132.33
100	0.57	172.19	0.03	259.16	0.67	150.87

Source: own study.

CONCLUSIONS

Modelling of flood regime has been established according to quantiles of threshold flows coming from a statistic adjustment which are compared, taking into account characteristics of watershed flood regime (*QIXA*10 and *D*), to different counterparts quantiles from Flow-Duration-Frequency (*Q-d-F*) models of reference basin type of VFS.

The relative quantiles to low flows are better reconstituted than equivalent or superior quantiles to *QIXA*10. 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 *Q-d-F*, seems to be well adapted, 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 *Q-d-F*, whatever be the formulation, has several uses: estimation of floods quantiles in middle flows or threshold flows for estimate of hydraulic works, insertion in a typology of flood regime, definition of hydrologic scenarios of reference for flood risk estimation, validation of outputs of hydrologic models, characterization of regime evolution of high water level.

According to criteria of *Nash* and of *RMSE*, on the first hand, and the hydro-climatologic context of watershed, on the other hand, the Florac model is more adapted, which allows to have a general overview and deepen the obtained knowledge as well as hydrometric observations and simulations by conceptual models. We could use these results to determine flood regime on the middle Cheliff watershed and neighbouring sub-basins in the case where there is an inadequacy action or rating curves. However, it is necessary to spread this study to basins for which we dispose chronic flows of over 40 years, in order to build a regional model more forthright and adapted to Algerian context.

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Modelowanie regionalne z wykorzystaniem metody powódź–czas trwania–częstotliwość w zlewni środkowej rzeki Cheliff

STRESZCZENIE

W pracy opisano statystyczne podejście do reżimu hydrologicznego cieków w trakcie powodzi z uwzględnieniem czasu trwania *d* i okresu powtarzalności *T*. Wybór zlewni środkowej rzeki Cheliff wiąże się z krótkim okresem powtarzalności katastrof w zachodnich regionach Algierii. Zlewnia środkowej rzeki Cheliff usytuowana w północnozachodniej Algierii doświadczała w ciągu ostatnich lat silnych powodzi. Ze względu na powtarzalność tych ekstremalnych zjawisk ich ocena i przewidywanie mają znaczenie strategiczne dla zapobiegania powodziom w tym regionie. Krzywe *a* są najpierw oznaczane w skali lokalnej bezpośrednio w wyniku analizy statystycznej przepływu o czasie trwania *d*(*QCXd*) w warunkach różnego czasu trwania z wykorzystaniem dostępnych danych z regionu. Następnie krzywe te są porównywane z krzywymi uzyskanymi z zastosowania różnych modeli regionalnych VFS (Vandenesse, Florac i Soyans), w których bierze się pod uwagę dwa wskaźniki: opisowy przebieg dynamiki powodzi *(D)* i chwilowy maksymalny roczny przepływ o okresie powtarzalności 10 lat (*QIXA*10). Ostateczny wybór modelu opiera się na weryfikacji pewnych kryteriów, takich jak Nash i pierwiastek ze średniego błędu kwadratowego (*RMSE*). Modele regionalne najbliższe lokalnym to Florac dla krótkiego czasu trwania i okresu powtarzalności oraz Vandenesse dla długich okresów powtarzalności w warunkach różnego czasu trwania. Wyniki badań mogą być zastosowane do zbudowania regionalnych krzywych *Q-d-F* dla algierskich zlewni bez lub z częściową siecią punktów wodowskazowych.

Słowa kluczowe: *Algieria, charakterystyczny czas trwania, powódź, powódź–czas trwania–częstotliwość, zlewnia środkowa rzeki Chelif*