Larhyss Journal, ISSN 1112-3680, n°27, Sept 2016, pp. 277-297

FLOOD- DURATION-FREQUENCY MODELING APPLICATION TO WADI ABIODH, BISKRA (ALGERIA).

MODELISATION DEBIT-DUREE-FREQUENCE APPLICATION A OUED ABIODH, BISKRA (ALGERIE)

HACHEMI A[1,2], BENKHALED A.[3]

[1.] Department of Civil and Hydraulic Engineering , Faculty of Science and Technology, University of Biskra, Po Box No 145, BISKRA, 07000 RP Algeria.
[2.]Scientific and Technical Research Center on Arid Region, Omar El Bernaoui. BP 1682 RP Biskra 07000, Algeria.
[3.]Research Laboratory in Subterranean and Surface Hydraulics -LARHYSS, University of Biskra, PoBox No 145, BISKRA, 07000 RP Algeria.

alihachemi.hyd@gmail.com *benkhaleddz@yahoo.fr*

ABSTRACT

This paper presents a Flood Frequency Analysis (FFA), which takes into account the notion of characteristic duration. Instantaneous flood discharge data from Foum El Gherza station is used to develop flood-duration-frequency (QDF) curve, using the so-called converging model. Seven distributions widely used in FFA were considered in this study: The generalized extreme-value (GEV), Normal (NORM), Gumbel (Gumbel), two parameter log-normal (LN), Pearson type III (P3), Log Pearson type III (LP3) and Frechet (EV2). Different models selection criteria were applied, e.g. Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Anderson-Darling Criterion (ADC). The results showed that the Pearson type III (P3) distribution is the more appropriate to fit the considered data. QdF curves were fitted. Synthetic Mono-Frequency Hydrograph (SMFH) was then derived after the estimation of the characteristic duration of the watershed using the mean of non-dimensional hydrographs and the socose method. The main advantage of these hydrographs is that all the characteristics of the SMFH are related to the same return period. These design flood hydrographs can be used as input for hydraulic modelling and simulation in a region characterized by flash floods.

Key words: Flood Frequency analysis; Characteristic duration; Converging Flood-Duration-Frequency; Synthetic Mono-Frequency Hydrograph; Abiodh wadi; Biskra; Algeria.

RESUME

Cet article présente une analyse fréquentielle des crues (AF), qui prend en compte la notion de la durée caractéristique. Les débits instantanés des crues de la station de barrage de Foum El Gherza sur Oued Abiodh est utilisée pour la réalisation des courbes Débit-Durée-Fréquence, en utilisant le model convergeant. Sept distributions largement utilisés dans la FFA ont été considérés dans cette étude: La valeur extrême généralisée (GEV), Normal (NORM), Gumbel (EV1), deux paramètres log-normale (LN), Pearson type III (P3), Log Pearson type III (LP3) et Frechet (EV2). Différents critères de sélection des modèles ont été utilisés : le Critère d'Information d'Akaike (AIC), le Critère d'Information Bayésien (BIC) et le Critère d'Anderson-Darling (ADC). Les résultats obtenus montrent que la distribution de Pearson type III (P3) est la plus appropriée pour l'ajustement des données considérées. Les courbes QdF ont été ajustées et l'Hydrogramme Synthétique Monofréquence (HSMF) a été ensuite dérivé après l'estimation de la durée caractéristique du bassin versant en utilisant l'hydrogramme moyen des hydrogrammes adimensionnels et la méthode de SOCOSE. L'avantage principal de ces hydrogrammes est que toutes les caractéristiques de l'HSMF sont liées à la même période de retour. Ces hydrogrammes de crue de projet peuvent être utilisés comme entrée pour la modélisation et la simulation hydraulique dans une région où se manifestent les crues éclair.

Mots clés : Analyse fréquentielle des crues ; Durée caractéristique ; Débit-Durée-Fréquence convergeant ; Hydrogramme Synthétique Monofréquence ; Oued Abiodh ; Biskra ; Algérie.

INTRODUCTION

Water; source of life. It's also the worst weather-related hazard causing loss of life and excessive damage to property (Carpenter et al. 1999). Under climate change effect, it is expected that global warming will lead to an increase in intense rainfall events and therefore produce a more active hydrological cycle (Trenberth 1999; Trenberth et al. 2003; Bates et al., 2008). Africa risks being severely affected (Ipcc 2008). Algerian cities have experienced devastating floods caused by rainstorm of short duration and high intensity (Boukhelifa and Hubert 2011; Lahlah, 2004). In the Saharian areas, despite their penury in water, where the climate is generally very dry and hot, they are not safe against the phenomenon. The occurrence of floods can only be a paradox. Just over the last decade, this region has experienced several major flood events, some of them struck Adrar (January, 2009 and August, 2013), Ghardaïa (October, 2008 and January 2009), Biskra (September, 2009); Tamanrasset (March, 2015) and Tindouf (October, 2015) (Hafnaoui et al. 2009) (http://www.emdat.be/disaster_list/index.html) (http://floodlist.com/tag/algeria). Nevertheless, the phenomenon is less studied in this area.

The definition of the hydrological regime is an interesting and obligatory tool to design, assess infrastructures, management of water resources and reducing severe human and material losses (Javelle et al. 2002; Crochet 2012; Benameur et al. 2015). On this aspect, various methodological approaches can contribute, among which, one of the privileged tools used by hydrologists is the Flood Frequency Analysis (FFA). However, most often, FFA characterizes a flood event only by its instantaneous peak or its maximum daily flow. This information is essential but insufficient for many purposes. Flood severity is not only defined by its peak value, but also by its volume and duration (Javelle et al. 2003; Chen et al. 2013).

Several approaches have been proposed in the literature to deal with this problem, among them the peak-volume analysis approach developed by Ashkar (1980) and the volume over threshold analysis mentioned by Cunnane (1989). Theoretical derivations of the distribution of flood volumes have been discussed by Todorovic (1978), Ashkar and Rousselle (1982) and Correia (1987) (Javelle et al. 2003). In the 1990s, Sherwood (1994); Balocki and Burges (1994); Galea and Prudhomme (1997), among others, laid out the basis of the so-calledFlood-Duration-Frequency (QDF) model which takes into account the notion of duration (Chen et al. 2013; Cunderlik and Ouarda 2006; Javelle et al. 2003). Similarly to the intensity–duration–frequency (IdF) analysis commonly utilized for rainfall, QDF models are extensions of standard flood frequency models aimed at estimating design flood values as a function of both return period and flood duration (Galéa and Prudhomme 1997; Javelle et al. 1999; Javelle 2001; Meunier 2001; Javelle et al. 2003; Sauquet et al. 2004; Cunderlik and Ouarda 2006; Cunderlik et al. 2007).A developed converging approach to the QDF modelling based on the assumption of the convergence of different flood distributions for small return periods was carried out by Javelle et al (2002). This approach has been applied in many areas around the world such as Martinique (Meunier, 2001), France (Javelle et al., 2002b), Burkina Faso (Mar et al., 2003), China (Chen et al., 2013), Canada (Javelle et al., 2002a; Cunderlik and Ouarda, 2006), Romania (Mic, 2002) and Algeria (Bessenasse et al., 2003, 2006; Sauquet et al., 2004).

The Abiodh Wadi catchment in the area of Biskra is a very interesting example for studying floods in arid areas climate using converging QDF method. The Wadi has its source in the mountains of Aures and flows to Foum El Gherza dam. This last,built in the late1940s for the irrigation of palms. Currently the 2/3 of its capacity is silted and has serious water leakage problems (Toumi and Remini, 2004). Floods are really a major risk in this area. During the last decades, engraved extreme hydrological events occurred. The people keep telling recorded memories about how devastating were the floods of October 1966, September 1989, April 2004, May 2006 and the flood of October 2011. In this last flood, all the populations living downstream of the Foum El Gherza dam were evacuated (Benameur et al. 2015). Despite the catchment is well documented and information on floods is available, the papers are rare (Benkhaled et al. 2013).

The selection of the best fit distribution and associated parameter estimation is an important step in frequency analysis. In the literature, many statistical distributions have been investigated and tested all over the world for flood frequency analysis. The most commonly applied are : normal (NOR), log-normal (LN), exponential (EXP), Gamma (GAM), Pearson Type-3 (PR3), Log Pearson Type-3 (LP3), Extreme Value Type-1 (EV1), Generalized Pareto (GPA) and Frechet (EV2) (Laio et al. 2009; World Meteorological Organization 2009; Vivekanandan 2014; Vivekanandan and Shukla 2015). In the Algerian hydrological context, the study of Hebal and Remini performed a frequency analysis (FA) on 53 gauged stations in the northern of the country showed that 50% of the sample follow the Gamma distribution, 25% the weibull distribution and 22% follow the Halphen A distribution (Benameur et al. 2015). Bouanani (2004) performed a regional flood FA in the Tafna catchments and concluded that the annual maximum (AM) flows fit better to asymmetric distributions such as LP3, Pearson 3 and Gamma. The FA was also applied in the sediment context in Abiodh Wadi catchment by Benkhaled et al (2014) where the LN2 distribution was selected. In the same station the study of Benameur et al (2015) conclude that annual maximum (AM) approach is not relevant for the studied data and this suggests that the peak over threshold (POT) approach would be more appropriate and the generalized Pareto as an appropriate distribution. In fact, there is no theoretical basis for the use of a single distribution over others (Saf 2009). However, there appear to be a general world-wide agreement to use the L-moment based techniques to evaluate flood frequency procedures (Abida and Ellouze 2007). Laio et al, applied several criteria of goodness-of-fit (GOF) test to verify and identify the probability distribution of hydrological extremes in selected catchments around the United Kingdom (Laio et al. 2009). Therefore, one of the main objectives of this study is to identify the appropriate probability distribution to our samples using most recent techniques.

In the matter of hazard determination, the QdF models have to be completed by a project hydrograph representing the flood regimes. In order to estimate the impact of floods on human activities, hydrologists are asked to provide a hydrograph with a given return period. Consequently, the QdF approach is used here to compute a mono-frequency synthetic hydrograph (SMFH) (Renard and Lang 2007). Therefore, the findings from this research is to develop a statistical model describing the catchment flood regime that can be useful in the matter of water resource management and sustainable development in a region suffering from water penury and floods risk.

METHODOLOGY

Converging QDF modelling

The objective of the flood-duration–frequency analysis is to provide a continuous formulation of flood quantiles, $Q(d, F)$ as a function of probability, F, and duration, d (Cunderlik and Ouarda 2006; Chen et al., 2013). A series of mean streamflow values, $Q_d(t)$, averaged over a given duration d can be derived from an instantaneous streamflow time series, $Q(t)$, using a moving average technique. The approach is based on moving a window of fixed length d over the time series $Q(t)$. From the series, $Q_d(t)$, annual maximum values, $Q_d^{max}(t)$, can be extracted as:

$$Q_d^{max}(t) = \max_{t^- \le t \le t^+} \{Q_d(t)\} \tag{1}$$

Where t^- and t^+ are the first and last days of the t^{th} hydrologic or calendar year. A set of $Q_d^{max}(t)$ series, derived for different durations d is then used to relate flood quantiles to the return period and flood duration. The two underlying assumptions behind the converging QDF modelling approach (Javelle et al. 1999; Javelle et al. 2002; Sauquet et al. 2003) are that i) the distributions of annual maximum floods for the different durations, d, converge towards the same point P for small return periods and ii) for a given return period, T, the evolution of the quantile $Q(d,F)$ as a function of d can be described by a hyperbolic form. In these conditions the QDF model can be written as follows:

$$Q(d,F) = \frac{Q_0(d=0,F)-P}{1+{}^{d}/_{\Delta}} + P \tag{2}$$

where $Q_0(d=0,F)$ is the distribution of the annual instantaneous maximum flood quantile with a probability $F \in (0,1)$, d is the duration of flood, Δ is a parameter describing the shape of the hyperbolic form and related to the flood dynamics and P is the limit of the function when d tends to infinity. A large value of Δ often indicates a slow flood while a small value of Δ implies flash floods. Consequently parameter Δ can be considered as a characteristic flood duration for the studied basin (Javelle et al. 2002; Chen et al.,). This function can be simplified by taking P = 0 with a small loss of performance only (Javelle 2001):

$$Q(d,F) = \frac{Q_0(d=0,F)}{1+{}^{d}/_{\Delta}} \tag{3}$$

Equation (3) reveals that each distribution $Q(d,F)$ multiplied by 1+d/Δ is equal to the $Q_0(d=0,F)$ distribution. This property can be used to estimate parameter Δ. The annual maximum streamflow series $Q_d^{max}(t)$ is first scaled:

$$q_d^{max}(t) = Q_d^{max}(t)(1+\frac{d}{\delta}) \tag{4}$$

And Δ is estimated as the optimum value of δ that minimizes the dispersion of the scaled annual maximum stream flow values $q_d^{max}(t)$ around the mean scaled value:

$$\Delta = \delta^{opt} = min\left\{\frac{1}{N}\frac{1}{M}\sum_{i=1}^{N}\sum_{j=1}^{M}\left[\frac{q_{dj}^{max}(i)-\bar{q}_d(i)}{\bar{q}_d(i)}\right]^2\right\} \tag{5}$$

where $\overline{q}_d(t)$ is the mean scaled value calculated for M durations d_j, and N is the record length. Parameters of the distribution $Q_0(d=0,F)$ are estimated by fitting a distribution function to the series $\bar{q}_d(t)$(Javelle et al. 1999; Javelle et al. 2002; Cunderlik and Ouarda 2006; Chen et al., 2013).

The maximum value of flood durations d_{max} to be used in the QDF model calibration is basin-dependent. It should be of the same order of magnitude as the average duration of flood events (Javelle et al. 2003). Some studies have shown some flexibility on the choice of the duration d from $[D/2$, 5 to $6D]$ (Yahiaoui et al. 2011), where D is the characteristic flood duration.

On the basis of the QdF model, the mono-frequency synthetic hydrograph (MFSH) has been inferred. The advantage of SMFH is to ensure that all the characteristics of the hydrograph are attached to the same frequency of occurrence. The rising limb of the SMFH is assumed to be linear with time. The maximum is reached at time $t = D_{SOCOSE}$, defined as the value of the conditional median of ds for Qs equal to instantaneous maximal annual decade flow Q_{IXA10} , where Qs and ds are respectively the maximum flow rate and the duration for which $Qs/2$ is exceeded for each flood. The peak flood correspondent to the maximum instantaneous flood discharge of the selected return period T and the decrease is conditioned by the values of flood quantiles, $Q(d,F)$ of the QDF curves (Sauquet et al. 2003). The SMFH has been improved proposing nonlinear rising limb of flood respecting the mean shape of the flood hydrographs. It is based on the study of the hydrograph shapes. When the hypothesis of shape invariance can be accepted, a design hydrograph is computed using the mean of non-dimensional hydrographs, with the discharge divided by peak flow and a synchronization on peak flow (Sauquet et al. 2003; Garçon et al. 2002; Renard and Lang 2007). The characteristic flood duration corresponds to the needed time for exceeding the half peak-flow of the mean of non-dimensional hydrographs (Lang and Lavabre 2007).

Flood probability distribution function and parameter estimation

The frequency analysis of the flood data series for a given duration allows the estimation of the flood discharge of a given return period at a given site. The data used in the analysis must satisfy certain statistical criteria such as randomness, independence, homogeneity and stationarity (World Meteorological Organization 2009). Non-parametric statistical tests were then performed. Wald-Wolfowitz, Wilcoxon (Mann-Whitney) and Mann-Kendall tests were systematically used to test respectively data independency, homogeneity and stationarity.

Many probability distributions have been introduced in the hydrological literature to model extreme events but no particular model is considered superior for all practical applications (World Meteorological Organization 2009). Hence; seven distributions widely used in FFA were considered in this study: The generalized extreme-value (GEV), Normal (NORM), Gumbel (Gumbel), two parameter log-normal (LN2), Pearson type III (P3), Log Pearson type III (LP3) and Frechet (EV2). For the selection of the appropriate probability distribution, the following three goodness-of-fit (GOF) tests were adopted: (1)

Anderson–Darling criterion (ADC); (2) Akaike information criterion (AIC); and (3) Bayesian information criterion (BIC). The best model is the one which achieves the minimum tests value of the comparing models. Furthermore, plots of the observed floods and the fitted distributions are examined to make a visual assessment of the goodness-of-fit (Laio et al. 2009).

A number of statistical methods are available for evaluating distribution parameters by sample data but the commonly used ones are: method of moments (MOM), method of maximum likelihood (MLE) and the probability weighted moments (PWMs) and L-moments approach. Nowadays, the L-moments method is widely used for estimating various hydrometeorological variables (Peel et al. 2001; Zalina et al. 2002; Gubareva and Gartsman, 2010). The advantages of this method are that (i) they characterize a wider range of distributions than conventional moments, (ii) they are less sensitive to outliers in the data, (iii) they approximate their asymptotic normal distribution more closely, and (iv) they are nearly unbiased for all combinations of sample sizes and populations (Hosking, 1990). More information about the used probability distributions, parameter estimation methods and the GOF tests can be found in (World Meteorological Organization, 2009).

All the simulations in this study were carried out within the R environment, which is an open-source software for statistical computing and visualization (http:// www.r-project.org/), and using the freely library nsRFA (Viglione, 2014).

STUDY AREA AND DATA

Study Area

Originating in the Chelia (2326 m high) and Ichemoul (2100 m high) mountains in the Aures, the Abiodh Wadi has a length of 85 km and a drainage area of 1300 Km^2. It flows into the Saharian gorge Foum el Gherza, in the area of Biskra southern east of Algeria in North Africa (Figure 1). The valley of the wadi is mainly composed of sedimentary rocks, comprising alternating limestone, marl, soft sediments (sandstones, conglomerates) and some evaporites (gypsum) dated of Paleogene.

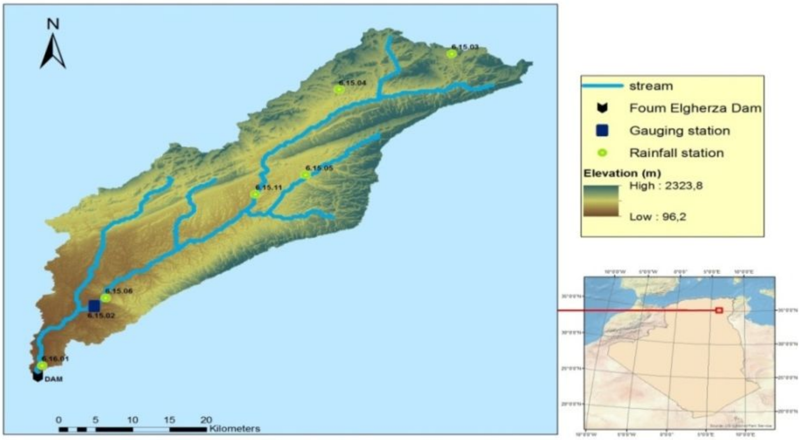

Figure 1: Location of the Abiodh Wadi basin

The watershed is characterized by its asymmetry, a mountainous area in the north to over 2000 m (Chelia) and another low in the south (El Habel 295 m). The relief is rugged, characterized by slopes ranging between 12.5% and 25% for half of the area, and from 3% to 12.5% for another 40% of the area. Land cover is a mix of rocky outcrops, highly eroded soil, sparse vegetation, a few forests, crops, gardens and pastures (Hamel, 2009). In the orographic and hydrographic point of view, Abiodh Wadi is characterized by two distinct climatic regions: the Aures, where rainfall averages are about 450 mm/year, and the Sahara plain with mean rainfall of 100-150 mm/year. The climate of Abiodh Wadi watershed is semi-arid to arid.

There are six rainfall stations (Medina, Arris, Tifelfel, Tkout, M’chounech and Foum El Gherza), and one hydrometric station (M'chounech), as shown in Figure 1. This station is located 18 km upstream of the Foum El Gherza Dam.

Data Description

The main gauging station used in this study is that managed by The A.N.B.T of Biskra (National Agency of Dams and Transfers) installed at the level of Foum El Gherza Dam spillway. Data extend over the period 1950-2012. It is the only station produce instantaneous flood discharge in the Abiodh Wadi catchment. The water level was recorded by limnimeter and transformed to flood discharge from the variation of the reservoir water level at scale time. The floods data are generally recorded at hourly scale time. This database reports sufficient information about the evolution of flood before and after discharge. The details relate to the mean flow, the maximum flow, the volume, the total duration, and the maximum water depth discharged by the spillway.

In the arid regions, a stream often experiences zero flows. The annual maximum instantaneous peak flow $Q_0^{max}(t)$ time serie is represented in figure 2. $Q_0^{max}(t)$ vary from a minimum value of 1.1 m^3/s corresponding to dry driest year, to a maximum value of 2152.00 m^3/s. However, since our objective is to study floods, only significant events of flood will be considered. All events where $\mathrm{Q_0^{max}(t)}$ lower than the “wet discharge”, denoted $\mathrm{Q_w}$, i.e. the yearly average wadi discharge of the days of running wadi (and not calculated over the full year) will beexcluded ($\mathrm{Q_w = 62\ m^3/s}$).

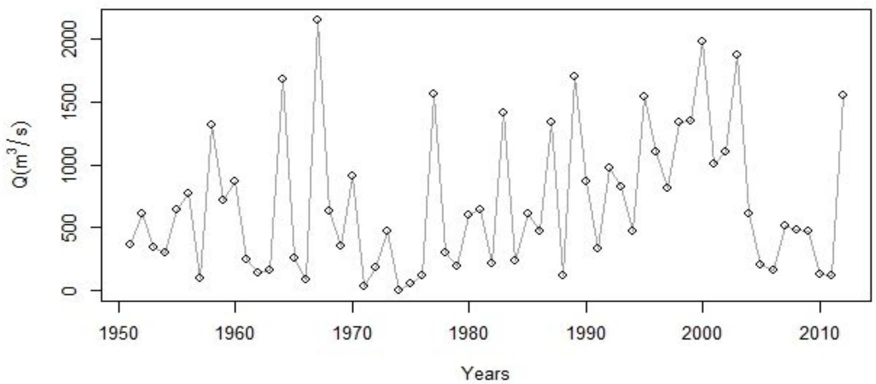

Figure 2: Time series of the *annual maximum instantaneous peak flow*

RESULTS AND DISCUSSION

The methodology described in section 2 was applied on the described data and lead to the following results:

Converging QDF modelling

Determination of the characteristic durations of the watershed.

The characteristic duration of the watershed was estimated using the mean of non-dimensional hydrographs and the socose method (figure 3).

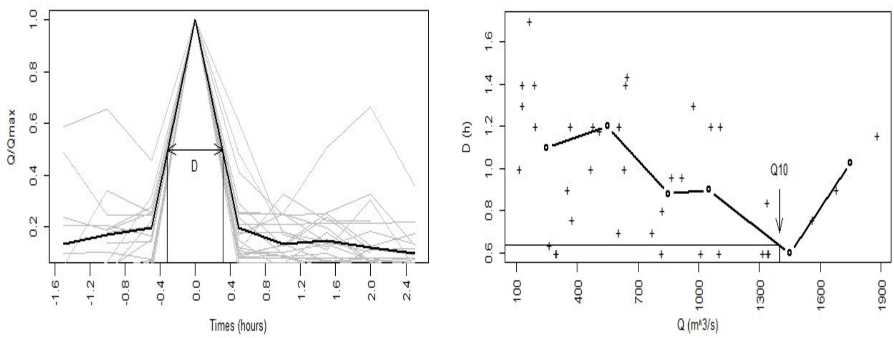

Figure 3: Characteristic duration of the watershed

The two methods gave similar results. The duration D of Wadi Abiodh floods is about $= 40\ min$. Basing on this duration five aggregation durations ($d_0 = 0$, $d_1 = 20min$, $d_2 = 40min$, $d_3 = 120min$, $d_4 = 240min$) were used for the extraction of annual maximum flow $Q_d^{max}(t)$ and the corresponding Δ parameter was calculated (Δ= 2.26). Many studies showed that there is a strong relationship between Δ and D, they conclude that the ratio $\Delta/_D$ is relatively constant and equal to 3.5 (Javelle et al. 2000; Javelle 2001; Sauquet et al. 2003). For the studied watershed of Wadi Abiodh the ratio $\Delta/_D = 3.39$ which confirm the estimated value of D. The small value of D and Δ reflect the flash floods tendency of the watershed.

Selection of Probability Distribution Function and QDF modelling.

Figure 4 shows the Box Plots of the annual maximum flow $Q_d^{max}(t)$ for different durations. For all durations the mean flow is greater than the median, which means that the distribution is right-skewed. The figure shows also the no existence of outliers for d_0, for the other durations the existence of outliers have no influence on the significance of the statistic tests.

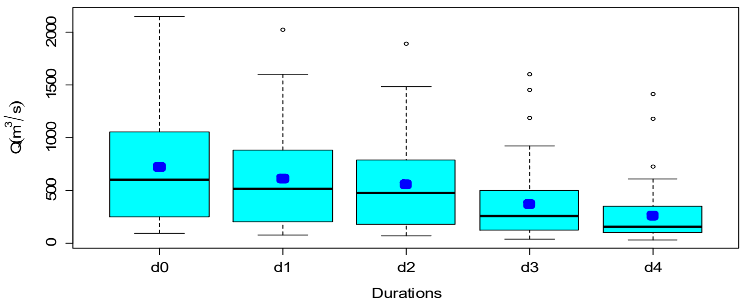

Figure 4: Box Plots of the annual maximum flow for different durations

The results of the required hypothesis testing on the considered data are given in Table 1. Applying Walf-Wolfowitz, Wilcoxon and Mann- Kendall tests respectively, we conclude that the independence, homogeneity and stationarity of the different durations are accepted at 5% significance level.

Table 1: Statistic tests results

Tests	Statitic	d_0	d_1	d_2	d_3	d_4	$\overline{q}_d(t)$
Wald–Wolfowitz	p-value	0.619	0.694	0.438	0.562	0.867	0.763
	a- value	-3.254	-4.759	-3.942	-6.907	-8.647	-6.242
Wilcoxon	p-value	0.106	0.091	0.654	0.795	0.144	0.094
	W- value	328	323	326	327	338	324
Mann-Kendal	p-value	0.116	0.170	0.174	0.136	0.166	0.154
	τ-value	0.198	0.123	0.122	0.134	0.124	0.128

The goodness-of-fit criteria tests (AIC, BIC and ADC) were taken as the discrimination criterions of the optimal statistical distribution for $\overline{q}_d(t)$. Empirical probability curves of all distributions are presented using Cunnane plotting position (Vogel and McMartin 1991; Shabri 2002).

$$F[x(k)] = \frac{k-0.4}{n+0.2} \quad (6)$$

As shown in Table 2 and figure 5, Pearson type III (P3) distribution is the best fitting model in Wadi Abiodh.

Table 2: Summary of goodness-of-fit tests

	AIC	BIC	ADC	Anderson– Darling GOF test	
				Statistic value	p-value
LN	888.5	892.6	0.142	0.375	0.416
GUMBEL	901.7	905.9	0.885	1.160	0.005
EV2	895.6	899.8	0.574	0.875	0.026
GEV	894.4	900.6	0.409	0.541	0.070
P3	885.3	891.6	0.048	0.488	0.215
LP3	890.1	896.4	0.162	0.329	0.357

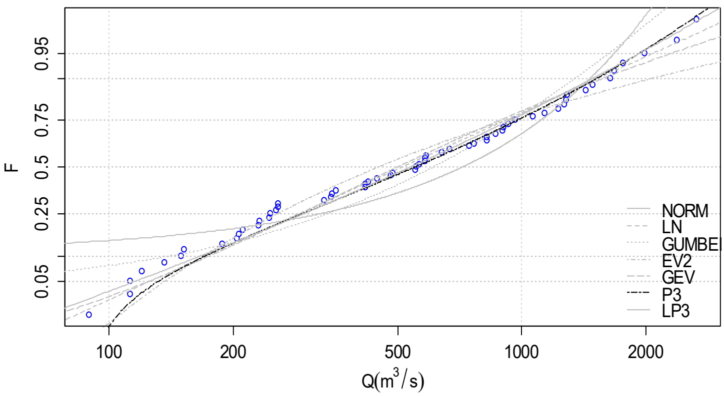

Figure 5: Probability plot of the studied distributions

The values of L-moment and the correspondent distribution parameter are estimated and shown in table 3. The distribution $Q_0(d = 0, F)$ is then fitted using the experimental series $\bar{q}_d(t)$ and the QDF curve are plotted (Figure 6). One of the objectives at-site FFA is to estimate a different return period associated with a given flood magnitude, which are useful for hydrologists in the planning and design of hydraulic structures. To gain this purpose, the values $Q(d, T)$ resulting from the fitted model are reported in Table 4.

Table 3: L-moment parameters estimation for $\overline{q}_d(t)$

Parameter	Value
L1 (Mean)	715.25
L2 (L-Scale)	312.40
L-CV	0.437
L-Skew (t3)	0.303
L-Kurt (t4)	0.125
Shape (α)	1.207
Location(ξ)	42.18
Scale(β)	557.48

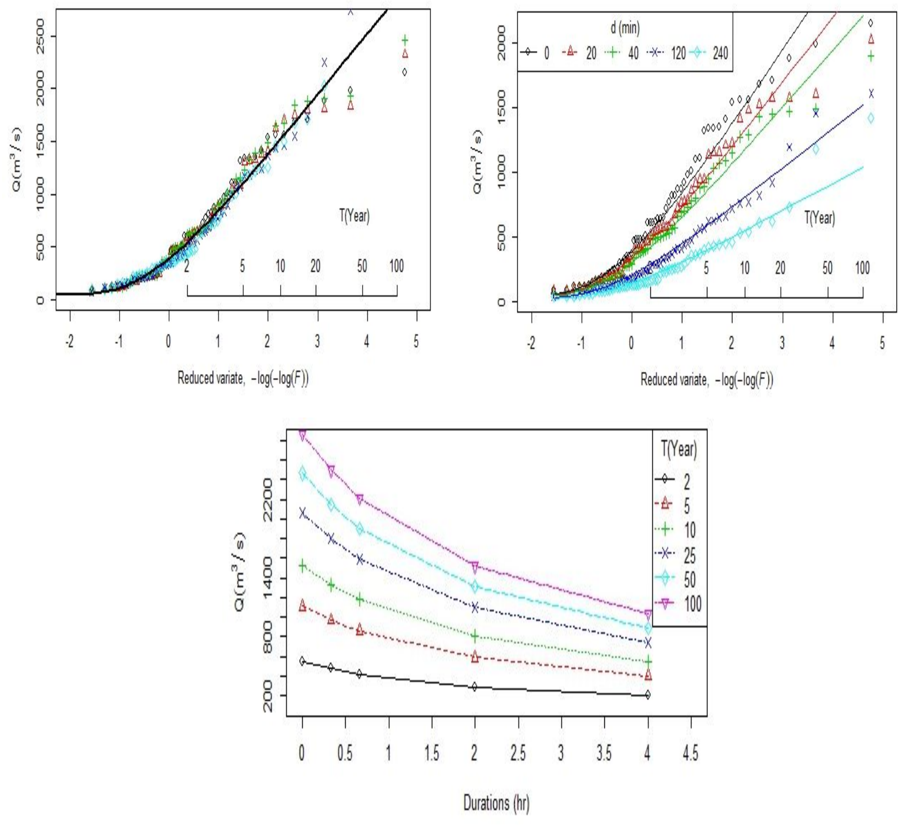

Figure 6: Converging QDF curves in Wadi Abiodh

Table 4: Quantiles Q (d,T)

d (min)	T (year)					
	2	5	10	25	50	100
$d_0 = 0$	541.20	1107.30	1521.53	2060.50	2464.18	2865.52
$d_1 = 20$	471.63	964.97	1325.96	1795.65	2147.45	2497.18
$d_2 = 40$	417.92	855.07	1174.94	1591.14	1902.87	2212.77
$d_3 = 120$	287.11	587.44	807.20	1093.13	1307.29	1520.20
$d_4 = 240$	195.38	399.76	549.31	743.89	889.62	1034.51

Construction of MFSH project hydrograph

Using the rising limb of the non-dimensional mean hydrograph (Figure 3), by the multiplication of this portion of the non-dimensional hydrograph by the quantiles of T return level, we will get the rising level of the project hydrograph corresponding to this return level. The falling limb correspond to the quantiles Q (d,T). In the figure 7, we present the resulting SMFH corresponding to 100 years return level.

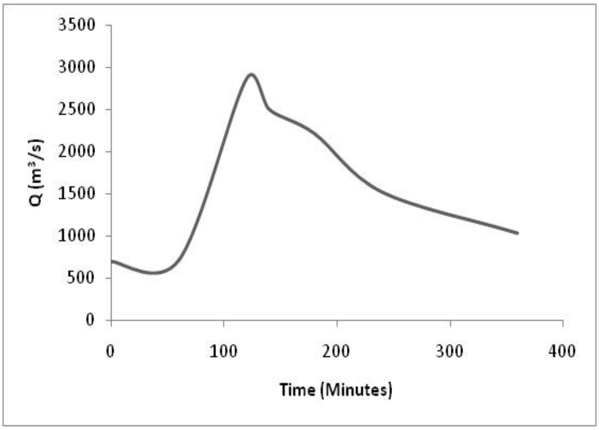

Figure 7: Synthetic Mono-Frequency Hydrograph (SMFH) corresponding to 100 years return level.

CONCLUSION

Based on the result of this study the main conclusion is even arid region can be subjected to major floods.Only events higher than the wet discharge have been considered, the motivation behind this choice is the big fluctuation of the *annual maximum* flow from year to other, and the scarcity of reference define flood in arid condition. As attempt for this study, we consider that the wadi is in flood only if the peak discharge of the event is higher than the “wet discharge”, i.e. the yearly average wadi discharge of the days of running wadi.

The observed floods hydrograph tend to be flashy with sharp peak hydrographs. The estimated characteristic duration of the watershed is about forty minutes ($D = 40min$). The time to peak from the beginning of the rising limb is about 20 minutes, with steep rising and falling limbs due to rainfall and geomorphologic condition of the catchment. This characteristic of floods was also observed in many other arid to semi-arid area (Pilgrim et al. 1988; Sharma 1997; Lin 1999; Osterkamp and Friedman 2000; Wheater 2008). The lack of vegetation cover removes protection of the soil from raindrop impact, and soil crusting has been shown to lead to a large reduction in infiltration capacity for bare soil conditions. Hence infiltration of catchment soils can be limited. In combination with the high intensity and short duration of rainfall characterising the arid area, extensive overland flow can be generated. This overland flow, concentrated by the topography, converges on the Wadi channel network, with the result that a flood flow is generated. (Wheater 2008).

Based on different selection criteria,it has been found that Pearson type III (P3) distribution is the right choice in the description of probability behaviours of extremes events in Foum el Gherza gauging station. Furthermore, flood-duration-frequency (QDF) curves were developed at this station.

The developed QDF plot can be used to estimate theavailability of water during specific time intervals (aggregation periods) and for different return periods within this catchment. The QDF plot had been completed by a synthetic mono-frequency hydrograph (SMFH) corresponding to 100 years return level. The knowledge of the probability distribution of the annual peak floods and the conceptualisation of QDF and SMFH in this station is very useful for the water resources management and other different water use applications.

Several application of this methodology needs to be carried out in the future. This study was performed for the maximum annual peak floods. It’s recommended to beextended to the peak over threshold time series. The estimation of flood quantiles in ungauged basins is one of the most challenging topics in hydrological applied research. Hence, other station in this region should be locally analysed and regional QDF model should be developed by merging the local QDF models.

REFERENCES

ABIDA, H., ELLOUZE, M., 2007. Probability distribution of flood flows in tunisia. hydrology and earth system sciences discussions, 4 (2), pp.957–981.

ASHKAR, F., 1980. Partial duration series models for flood analysis. Ecole Po PhD Thesis, Montréal, Canada.

ASKAR, F., ROUSSELLE, J., 1982. A multivariate statistical analysis of flood magnitude, duration and volume, in V.P. Si Singh (Ed.), Water Resource Publication, pp. 651-668.

BALOCKI, J. B., BURGES, S. J., 1994. Relationships between n-day flood volumes for infrequent large floods, Journal of Water Resource Planning and Management, 120(6) , pp. 794-818.

BATES, B.C., Z.W. KUNDZEWICZ, WU, S., PALUTIKOF, J.P., 2008. Climate change and water: ipcc technical paper VI, Geneva, 220 p

BENAMEUR, S., BENKHALED, A., MERAGHNI, D., CHEBANA, F., NECIR, A., 2015. Analyse fréquentielle complète des crues dans le bassin abiod biskra (Algérie). Rapport de recherche (r1607). INRS, Centre eau terre environnement, Quebec, Canada.

BENKHALED, A., HIGGINS, H., CHEBANA, F., NECIR, A, 2014. Frequency analysis of annual maximum suspended sediment concentrations in abiod wadi, Biskra (Algeria). Hydrological processes, 28 (12), PP.3841–3854.

BENKHALED, A., REZGUI, Z., SAKHRAOUI, F., 2013. Floods in abiod wadi : analysis of database. Journal, larhyss, 14, PP.179–191.

BESSENASSE, M., KETTAB, A., PAQUIER, A., GALEA, G., RAMEZ, R., 2003. Simulation numerique de la sedimentation dans les retenues de barrages : cas de la retenue de zardezas, Algerie. Revue des sciences de l'eau, 16(1), P.103.

BESSENASSE, M., GALEA, G., PAQUIER, A., 2006. Application du modele convergent de la methode hydrologique qdf au bassin versant du saf saf (algerie). Larhyss journal 05: 133–137

BOUANANI, A., 2004. Hydrologie, transport solide et modelisation etude de quelques sous bassins de la Tafna (NW – Algerie). These de doctorat. Universite de Tlemcen. 250 p

BOUKHELIFA, M. BENINA, B., HUBERT, P., 2011. Prévention du risque pluvial par l'élaboration des courbes intensité – durée – fréquence (IDF) : application à la ville de Tipasa dans le nord-ouest algérien. IAHS Publ. 347, pp. 36-42

CARPENTER, T.M., SPERSFLAGE, J.A., GEORGAKAKOS, K.P., SWEENEY, T.D., FREAD, L., 1999. National threshold runoff estimation utilizing GIS in support of operational flash flood warning systems. Journal of Hydrology, 224 (1-2), pp. 21–44.

CHEN, X., ZHANG, L., XU, C.-Y., ZHANG, J., YE, C., 2013. Hydrological Design of Nonstationary Flood Extremes and Durations in Wujiang River, South China: Changing Properties, Causes, and Impacts. Mathematical Problems in Engineering, pp.1–10.

CORREIA, F.N.,1987. Multivariate partial duration series in flood risk analysis, in V.P. Singh (Ed.) « Hydrologic frequency modelling » D. Reidel Publ. Co, pp.541-554,

CROCHET, P., 2012. Flood-Duration-Frequency modeling Application to ten catchments in Northern Iceland. Report N° VI 2012-006, Icelandic Met Office, 50p.

CUNDERLIK, J.M., JOURDAIN, V., OUARDA, T. B. M. J., BOBEE, B., 2007. Local Non-Stationary Flood-Duration-Frequency Modelling. Canadian Water Resources Journal, 32 (1), pp. 43–58.

CUNDERLIK, J.M. AND OUARDA, T.B.M.J., 2006. Regional flood-duration-frequency modeling in the changing environment. Journal of Hydrology, 318 (1-4), pp. 276–291.

CUNDERLIK, J.M. AND OUARDA, T.B.M.J., 2007. Regional flood-rainfall duration-frequency modeling at small ungaged sites. Journal of Hydrology, 345 (1-2), pp. 61–69.

CUNNANE, C., 1989. Statistical distributions for flood frequency analysis. Operational Hydrology Report No. 33, World Meteorological Organization. Genève. 61p.

GALEA, G., PRUDHOMME, C., 1997. Notions de base et concepts utiles pour la compréhension de la modélisation synthétique des régimes de crue des bassins versants au sens des modèles QdF. Revue des sciences de l'eau, 10(1), p. 83-89.

GARÇON, R., BOSSARD, E., LANG, M., LE CLERC, S., 2002. Revisiter la notion de scénario hydrologique de référence pour la caractérisation des inondations, Rapport commun EDF/DTG-Cemagref, Programme Risque Inondation RIO 1, 76p.

GUBAREVA, T.S., GARTSMAN, B.I., 2010. Estimating distribution parameters of extreme hydrometeorological characteristics by L-moments method. Water Resources, 37 (4), pp. 437–445.

HAFNAOUI, M. A., BEN SAID, M., FEKRAOUI, F., HACHEMI, A., NOUI, A., DJABRI, L., 2009. Impacts des facteurs climatiques et morphologiques sur les inondations de doucen. Journal algérien des régions arides, 08, pp. 81–95.

HAMEL, A., 2009. Hydrogéologie des systèmes aquifères en pays montagneux à climat semi aride. Cas de la vallée d'Oued El Abiod (Aures). Mémoire de Magister. Universite Mentouri: Constantine. 180 p

HEBAL A., REMINI, B., 2011. Choix du modèle fréquentiel le plus adéquat à l'estimation des valeurs extrêmes de crues (cas du nord de L'Algérie). Canadian Journal of Civil Engineering 38 (8): pp. 881–892

HOSKING, J.R.M., 1990. Of distributions using Linear Analysis and Estimation of Order Statistics Combinations by equating the Yet moment-based The alternative approach described here is based on quantities. Journal of the Royal Statistical Society, 52 (1), pp.105–124.

INTERGOVERNMENTAL PANEL OF CLIMATE CHANGE (Ipcc), 2008. Changements Climatiques 2007, Rapport de synthèse, publié par le Groupe d'experts intergouvernemental sur l'évolution du climat. OMM. Genève 2, Suisse, 114p

JAVELLE, P., GRESILLON, J.-M., GALEA, G., 1999. Modélisation des courbes débit-durée-fréquence en crues et invariance d'échelle. Comptes Rendus de l'Académie des Sciences - Series IIA - Earth and Planetary Science, 329 (1), pp. 39–44.

JAVELLE, P., GALEA, G., GRESILLON, J.M., 2000. L'approche débit-durée-fréquence : historique et avancées. Revue des sciences de l'eau, 13 (3), p.305.

JAVELLE P. 2001. Caractérisation du régime des crues : le modèle débit-durée-fréquence convergent Approche locale et régionale.institut national polytechnique de grenoble.

JAVELLE, P, OUARDA, T.B.M.J., LANG, M, BOBEE, B, GALEA, G, GRESILLON, J-M., 2002a. Development of regional flood-duration–frequency curves based on the index-flood method. Journal of Hydrology 258 (1-4): pp. 249–259.

JAVELLE, P, SAUQUET, E, GRESILLON, J. 2002b. Describing actual and future flood hydrological regimes. Celtic Hydrology Symposium (1): pp. 270–280

JAVELLE, P., OUARDA, T.B.M.J., BOBÉE, B., 2003. Spring flood analysis using the flood-duration–frequency approach: application to the provinces of Quebec and Ontario, Canada. Hydrological Processes, 17 (18), pp. 3717–3736.

LAHLAH, S., 2004. Les inondations en algerie. Actes des Journées Techniques/ Risques Naturels : Inondation, Prévision, Protection /Batna , 15-16 Décembre

LAIO, F., DI BALDASSARRE, G., MONTANARI, A., 2009. Model selection techniques for the frequency analysis of hydrological extremes. Water Resources Research, 45 (December 2008), pp. 1–11.

LANG, M., LAVABRE, J., 2007. Estimation de la crue centennale pour les plans de prévention des risques d'inondations, edition : Quae, 232 p.

LIN, X., 1999. Flash floods in arid and semi-arid zones. Technical Documents in Hydrology. No. 23 (23): 65 p

MAR, A.L., GINESTE, P., HAMATAN, M., MAHE, G., 2003. Modélisation Débit-durée- Fréquence appliquée à des bassins versants de grande taille du Burkina Faso. Sud Sciences & Technologies, 11, pp. 20–26.

MEUNIER, M., 2001. Regional flow-duration-frequency model for the tropical island of Martinique. Journal of Hydrology 247 (1-2): pp. 31–53

MIC, R.P., GALEA, G., JAVELLE, P., 2002. Floods regionalization of the Cris catchments : application of the converging QdF modeling concept to the Pearson III law. Conference paper : XXI th Conference of the Danube Countries - Bucharest, Romania, 2 - 6 sept, 8p.

OSTERKAMP, W.R., FRIEDMAN, J.M., 2000. The disparity between the extreme rainfall events and rare floods - With emphasis on the semi-arid american West. Hydrological Processes 14 (16-17): pp. 2817–2829

PEEL, M.C., WANG, Q.J., VOGEL, R.M., MCMAHON, T.A., 2001. The utility of L-moment ratio diagrams for selecting a regional probability distribution. Hydrological Sciences Journal, 46 (1), pp. 147–155.

PILGRIM, DH., CHAPMAN, T.G., DORAN, D.G., 1988. Problems of rainfall-runoff modelling in arid and semi arid regions. Hydrological Sciences Journal 33 (4): pp. 379–400

RENARD, B., LANG, M., 2007. Use of a Gaussian copula for multivariate extreme value analysis: Some case studies in hydrology. Advances in Water Resources, 30 (4), pp. 897–912.

SAF, B., 2009. Regional flood frequency analysis using L moments for the west Mediterranean region of Turkey. Water Resources Management, 23, pp. 531–551.

SAUQUET, E., GALEA, G., BESSENASSE, M., 2004. caractérisation du régime des hautes eaux en débit-durée-fréquence. Application au contexte algérien. La Houille Blanche, N°5, pp. 80-85

SAUQUET, É., JAVELLE, P., LE CLERC, S., 2003. Description des régimes hydrologiques des hautes-eaux: nouvelle formulation pour l'analyse en débit-durée-fréquence et applications en ingénierie. Revue Ingénieries-EAT, pp. 3–15.

SHABRI, A, 2002. A Comparison Of Plotting Formulas For The Pearson Type III Distribution. Jurnal Teknologi C, 36(C), pp. 61–73.

SHARMA, K., 1997. Flash floods and their control in the Indian arid zone. IAHS Publications-Series of Proceedings 239 (239): pp.305–313.

SHERWOOD, J. M., 1994. Estimation of volume-duration-frequency relations of ungauged small urban streams in Ohio, Water Resources Bulletin, 30 (2) : pp. 261-269.

TODOROVIC, P., 1978. Stochastic models of systems. Water Resource Research 142: pp. 345–356

TOUMI, A., REMINI, B., 2003. Barrage de Foum El Gherza face au problème de fuites d'eau. Larhyss Journal, n° 03, pp. 25-38

TRENBERTH, K.E., 1999. Conceptual framework for changes of extremes of the hydrological cycle with climate change. Climatic Change, 42 (1), pp. 327–339.

TRENBERTH, K.E., DAI, A., RASMUSSEN, R. M., PARSONS, D. B., 2003. The changing character of precipitation. Bulletin of the American Meteorological Society, 84 (9), pp. 1205–1217.

VIGLIONE, A., 2014. nsRFA: Non-supervised Regional Frequency Analysis. R package version 0.7-12.

VIVEKANANDAN, N., 2014. Comparison of Probability Distributions for Estimation of Peak Flood Discharge. OALib, 01 (04), pp. 1–7.

VIVEKANANDAN, N., SHUKLA, S., 2015. Flood frequency analysis using method of moments and L-moments of probability distributions. Cogent Engineering, 2 (1), 10 p.

VOGEL, R.W., MCMARTIN, D.E., 1991. Probability Plot Goodness-of-Fit and Skewness Estimation Procedures for the Pearson Type 3 Distribution. Water Resources Research, 27 (12), pp.3149–3158.

WHEATER, H.S., 2008. Modelling hydrological processes in arid and semi-arid areas: an introduction to the workshop "Hydrological modeling in arid and semi-arid areas" , Cambridge University Press, pp.1–39.

WORLD METEOROLOGICAL ORGANIZATION, 2009. Management of Water Resources and Application of Hydrological Practices, Publication of the WMO, Genève, N° 168, , 302 p

YAHIAOUI, A.,TOUAIBIA, B., BOUVIER, C., DECHEMI, N., 2011. Modélisation du régime de crue en débit - Durée - Fréquence du bassin de L'oued mekerra dans L'ouest algérien. Revue des Sciences de l'Eau, 24(2), pp.103–115.

ZALINA, M.D., DESA, M.N.M., NGUYEN, V.T. V., KASSIM, A.H.M., 2002. Selecting a probability distribution for extreme rainfall series in Malaysia. Water Science and Technology 45 (2): pp.63–68