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Characterization of dry spell events in a basin in the North of Tunisia

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SUMMARY – This contribution focuses on the analysis of dry spells for operation of dams based on an approach different from that of using observations carried out with regular time intervals. The case study is localized around the Ghézala dam in Northern Tunisia having a Mediterranean climate. Dry events are composed of series of dry days separated by rainfall events. Rainfall events are defined by uninterrupted series of rainfall days containing at least one day with a precipitation amount superior or equal to a threshold of 4 mm. The rainfall events are defined by depth and duration, which are found to be correlated. An analysis of the depth per event, given the event duration, has been undertaken. The negative binomial distribution appears to yield the best overall fit for the depth per event for one-day events. The duration of rainfall events follows a geometric distribution while that of dry events follows the negative binomial distribution. The chronological position of the first rainfall event in the rainy season seems to fit the "loi de Fuites". These event based results are applied to generate synthetic sequences of rainfall and dry events and can be used for reservoir simulation studies, estimation of irrigation water demand and the studies of the effects of climate change.

Key words: Dry events, dam operation, Mediterranean climate, rainfall event.

RESUME – *"Caractérisation des événements secs dans un bassin au Nord de la Tunisie". Cette contribution porte sur l'analyse des périodes sèches pour la gestion des barrages sur une base différente de celle des observations faites à intervalle de temps régulier. Le cas d'étude est le barrage Ghézala localisé au Nord de la Tunisie à climat méditerranéen. Les évènements secs sont constitués d'une série de jours secs encadrés par des évènements pluvieux. Un événement pluvieux est une série ininterrompue de jours pluvieux comprenant au moins un jour ayant reçu une précipitation supérieure ou égale à un seuil de 4 mm. Les événements pluvieux sont définis par leurs durées et hauteurs qui ont été trouvées corrélées. Une analyse de la hauteur de pluie par événement conditionnée par la durée de l'événement a été effectuée. La loi binomiale négative apparaît être la meilleure loi pour l'ajustement de la hauteur de pluie par événement de durée un jour. La durée de l'événement de pluie suit la loi géométrique alors que celle de l'événement sec suit la loi binomiale négative. La loi des Fuites s'ajuste à la position chronologique du premier événement pluvieux dans la saison pluvieuse. L'analyse par événements est appliquée pour générer des séquences synthétiques d'événements. Ces séquences permettent de définir et de calibrer des modèles de simulation pour la planification réaliste des réservoirs, l'estimation de la demande en eau d'irrigation et l'étude des effets d'un changement climatologique.*

Mots-clés : *Climat méditerranéen, événements pluvieux, gestion de barrages, événements secs.*

Introduction

Proper simulation of precipitation is important. Precipitation is a very important climatological element of climate that affects both the natural environment and human society. Events ranging from prolonged droughts to short-term, high intensity floods are often associated with devastating impacts both to society and the environment (Hui *et al.*, 2005). An alternative to the Markov chain process which is typically used to simulate the occurrence of precipitation, is to use a wet-dry spell or alternating renewal model based on the alternate extraction of wet and dry spell durations from their known probability distributions. Earlier studies using the wet-dry spell approach are, for example, Bogardi and Duckstein (1993), Semenov and Barrow (1997), Wilks (1999), Mathlouthi and Lebdi (2007). As said before this study focuses on the modelling of rainfall occurrences under a Mediterranean climate by a wet-dry spell approach. An event-based concept of analysis is favoured over continuous type data generations methods. Synthetically produced rainfall data can be used, for example, for reservoir simulation studies, estimation of irrigation water demand and the study of the effects of climate change. The paper concentrates solely on the characterization of the events of the dry spell in a basin in Northern Tunisia.

Data

The daily precipitation records have been collected by the Ghézala-dam rain gauge, located in the basin of Ichkeul in Northern Tunisia (lat. 37°02'75" N, long. 9°32'07" E). The rainy season starts in September and lasts until the beginning of May. The mean annual rainfall amounts 680 mm; the coefficient of variation is 0.25. The climate of the Ichkeul basin is classified as sub-humid; average annual rainfall is below 40 percent of the total annual potential evaporation. Except in wet years, most precipitation is restricted to the winter months in this basin. The dry season lasts from May to August. Daily values of precipitation are quite variable. There is also considerable variation from year to year. A complete time serie of daily precipitation exists for the period from 1968 to 2007. In this 40-year period the highest annual amount was recorded in 1982, with 1037.8 mm, and the lowest amount in 1977, with 394.8 mm. Of the 480 months that constitutes this sample, 13% of the months had less than 1.0 mm of rainfall. On average, the wettest month was December, with 105.5 mm of rainfall, and the driest months were July and August, with less than 3 mm of rainfall each.

Methodology

In a *wet-dry spell* approach, the time-axis is split up into intervals called *wet periods* and *dry periods* (Lima, 1998). A rainfall *event* is an uninterrupted sequence of wet days. The definition of an event is associated with a daily rainfall threshold value of 4 mm/d which defines a *wet day*. The choice of this threshold corresponds to the expected daily evapotranspiration rate, marking the lowest physical limit for considering rainfall that may produce utilizable surface water resources. In this approach, the process of rainfall occurrences is specified by the statistical distributions of the length of the wet periods (storm duration), and of the length of the dry periods (time between storms or inter-event time).

The rainfall event m in a given rainy season n will be characterized by its duration $D_{n,m}$, the temporal position within the rainy season, the dry event or inter-event time $S_{n,m}$ and by the cumulative rainfall amounts of $H_{n,m}$ of $D_{n,m}$ rainy days in mm:

$$H_{n,m} = \sum_{i=1}^{Dn,m} h_i \quad (1)$$

where h_i is positive and represent the daily precipitation totals in mm. Note that for at least one $h_i > 4\ mm$.

According to Lima (1998), the varying duration of events requires that the cumulative rainfall amounts of each event should be conditioned by the duration of the event. The identification and fitting of conditional probability distributions to rainfall amounts may be a problem especially in the case of short records and for events with extreme (long) durations (Foufoula-Georgiou and Georgakakos, 1991).

In this paper a rainy season, of random duration, starts and ends with a rainfall event. Its length L_n is defined as the time span between the start of the first and the end of the last rain event and is the sum of all durations of wet and dry events. Thus, if the number of wet events per rainy season is N_n, then the number of dry events is $N_n - 1$. The hydrological year A_n is determined by the time lapse between the onset of two subsequent rainy seasons.

Results

A regression analyses have been conducted in order to detect the interrelationship between the parameters extracted from the analysis by events. Table 1 summarizes, for some selected parameters, the maximum value of coefficients of determination. The relationship between event duration $D_{n,m}$ and the cumulative rainfall amounts $H_{n,m}$ is medium, while no significant pairwise correlation could be detected (Table 1) between $S_{n,m}$ and the duration $D_{n,m}$ and cumulative rainfall amounts $H_{n,m}$. Thus, the assumption that rainfall events in a rainy season are elements of an independent random process seems to be justified. Table 1 shows that the number of events per season, N_n, is roughly independent of the other parameters except, as might be expected, of the total event-based rainfall depth $H_{t,n}$ (sum of cumulative rainfall amounts $H_{n,m}$). The length of the hydrological year A_n is independent of the number of events per season N_n, however it shows a dependence of the length of the rainy season L_n.

Table 1. Coefficients of determination for the parameters of the analysis by events

Seasonal characteristics	N_n	$S_{n,m}$ max† (day)	A_n (day)
$H_{t,n}$ (mm)	0.49	0.50	0.02
L_n (day)	0.33	0.21	0.62
A_n (day)	0.22	0.23	1
Event-related characteristics	**$H_{n,m}$ (mm)**	**$D_{n,m}$ (day)**	
$D_{n,m}$ (day)	0.64	1	
$S_{n,m}$ (day)	0.02	0.02	

†$S_{n,m}$ max: Longest dry event of the rainy season (day)

Number of events per rainy season

By taking account of the assumption of the sequential independence of the rainfall events, as formulated above, the Poisson density function should adequately describe the distribution of the number of events per season:

$$f(N,\lambda)=\frac{e^{-\lambda}\lambda^N}{N!}\ ,\ N=0,1,2,\ldots \tag{2}$$

where N describes the number of events during a rainy season. The parameter λ is the average number of events per rainy season.

Figure 1 shows the fitted Poisson probability density function. The arithmetic mean is 22.54 and the standard deviation 4.67. The goodness-of-fit has been assessed by the Kolmogorov-Smirnov test at the 95% significance level using the SIMFIT software (Bardsley, 2004). The arithmetic mean appears to provide a stable estimate of the parameter λ of the Poisson probability distribution function (pdf), in preference to the sample variance, which shows more substantial fluctuations (Bogardi *et al.*, 1988).

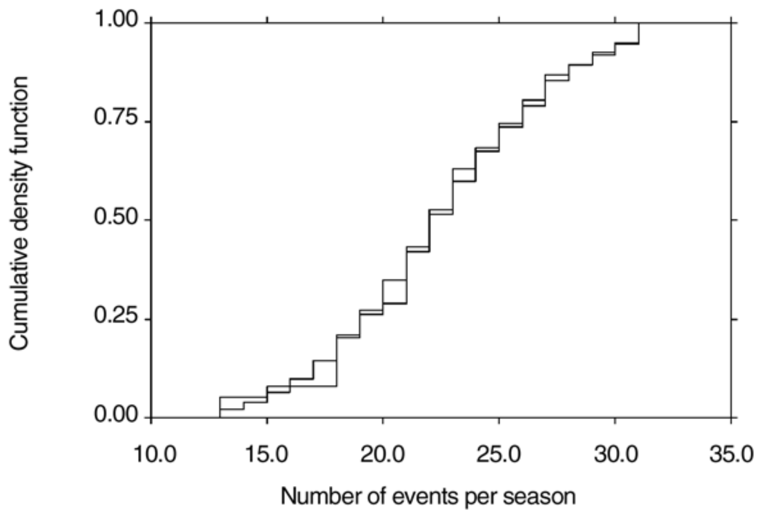

Fig. 1. Distribution of the number of wet events per season.

Duration of wet events

Approximately 33% of the events last one day (Fig. 2). The persistence of uninterrupted sequences of rainy days sometimes lasts more than a week (the maximum observed duration is 13 days). However, the frequency of long-duration events decreases rapidly with increasing duration. An arithmetic mean of 2.79 days and a standard deviation of 1.87 were obtained. The geometric pdf appears most adequate for fitting the observations:

$$f\,(m) = pq^{\,m-1} \tag{3}$$

where m is the duration of a wet event in days; $p = 1/\bar{m}$, being the reciprocal value of the mean event duration; and $q = 1 - p$.

The moment's method is used for the estimate of the parameters of the fitting.

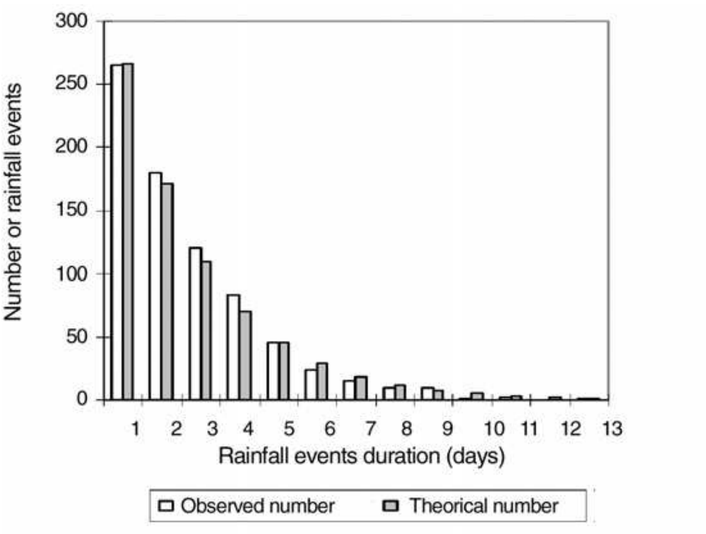

Fig. 2. Distribution of wet event duration.

Rainfall depth per event

Table 1 indicates the existence of a relationship between rainfall depth $H_{n,m}$ and duration. Therefore it is necessary to distinguish between pdf's of rainfall depth for different values of wet event duration. Here this is done by estimating six conditional pdf's for durations of 1 to 5 days and >5 days. The $H_{n,m}$-values are grouped into 4 mm wide classes, starting with the (4-8 mm) class. As an example, for the class of wet events lasting > 5 days the Gamma distribution provides the best fit (Fig. 3). Again, the goodness-of-fit has been assessed by the Kolmogorov-Smirnov test. For this class the arithmetic mean and the standard deviation are respectively 69.81 mm and 38.02 mm.

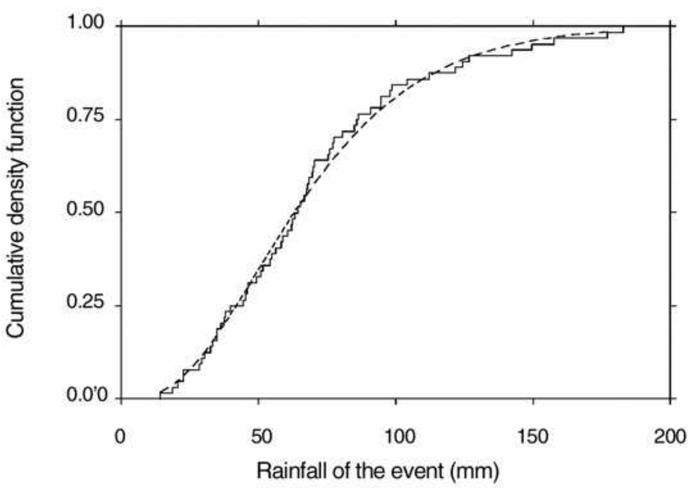

Fig. 3. Fitting Gamma distribution for the rainfall depth of the >5-day long wet events.

Duration of dry events

The regression analysis (Table 1) displays that the lengths of dry events can be assumed to be independent from the lengths of wet events and the rainfall depth per event. Thus the statistical distribution of dry events (inter-event time), which can only assume integer values, follows a single probability density function. The negative binomial pdf gives the best fit to describe the distribution of the dry events (Fig. 4). As Fig. 4 reveals, the shortest interruption (one day) is the most frequent one. Almost 20 percent of the observed dry events are only one day long. Dry periods up to 30 or even more days may be recorded (a 56 days maximum is recorded). The arithmetic mean and the standard deviation of dry events are respectively 7.3 and 7.9 days. For the sample of values of the longest dry event per rainy season, the arithmetic mean and the standard deviation are respectively 30.2 and 3.6 days.

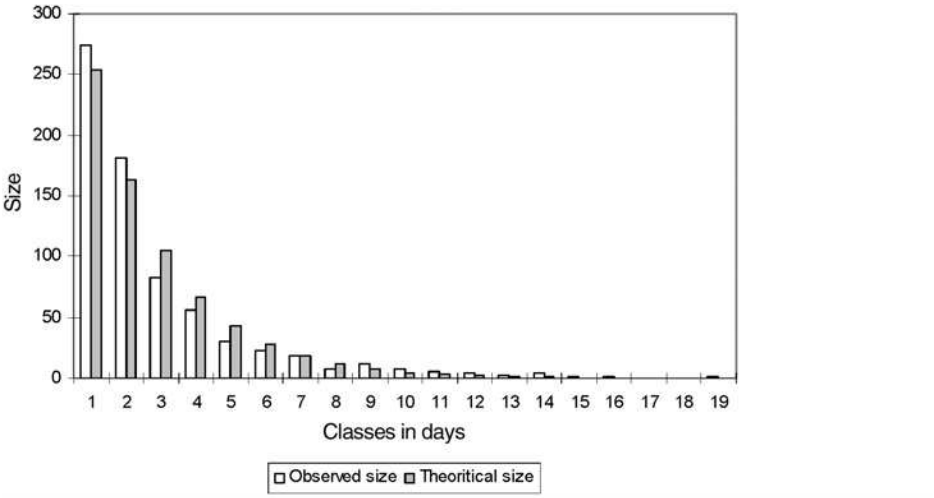

Fig. 4. Distribution of the time lapse between wet events or the distribution of dry event durations.

Advent of the rainy season

The 40 dates characterizing the beginning of the first wet event in the hydrological year were statistically analyzed. The best fit of this random variable is acquired by the so called "loi des Fuites" (Fig. 5), using HYFRAN software (INRS-Eau, 2002). It shows that on average the first rainfall event

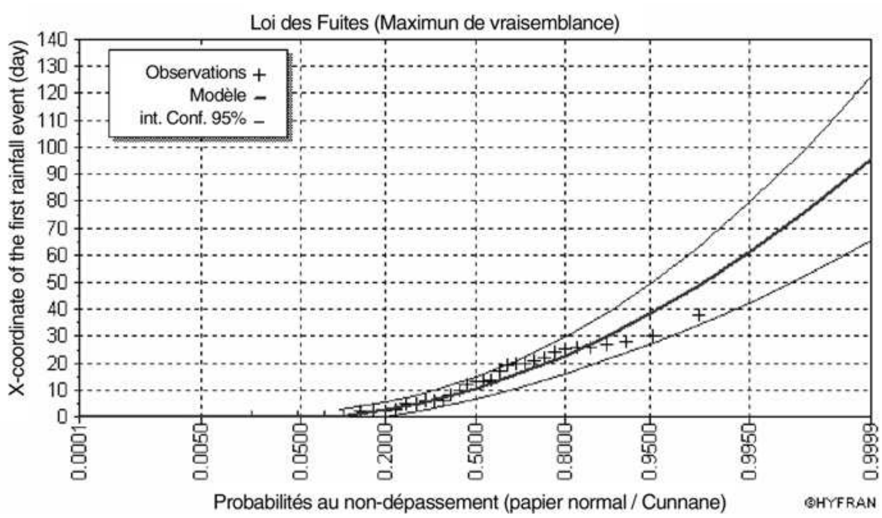

Fig. 5. Fit of the "loi des Fuites" for the chronological position of the first rainfall event in rainy season, starting from the first of September.

occurs in the mid-September whereas the probability of surpassing this value is 0.52 for a biennial return period. In the extreme case, the hydrological year starts in the first decade of October.

Conclusions

This case study, using rainfall records of the Ichkeul basin, illustrates the independency between the durations of wet and dry events. In this region dry spells can well be described by the negative binomial pdf.

The procedure defines the inter-event time as being the dry event period. For the wet event duration, the theoretical requirement of the fitted geometric pdf are satisfied (Fig. 2).

Event-based analysis can now be used to generate synthetic rainfall event time series (Bogardi *et al.*, 1988). By coupling this with a rainfall-runoff model, one can obtain synthetic streamflow series for reservoir simulation studies and for deriving design floods or for estimating water demand irrigation.

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