Rainfall analyses and Hydrological modeling at monthly time step
Case Study
(Sub–basin of the large moulouya watershed – Eastern Morocco)

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Absract

The hydrological response of a watershed is the translation of the reaction of its components, following a rainfall event. The study of the latter according to appropriate methods, as well as according to the objective and the desired result, is essential to achieve a significant degree of precision with regard to the assessment of water potential, forecasting or prevention and the fight against the risks of overflow and flooding.

Through this article, we have tried to present the results of analyses and simulations focused on rainfall data (annual rainfall, maximum daily rainfall), and this, for a time series from 1990 to 2020, we have determined the probabilities of non-exceedance, the recurrence intervals and the return periods. And through modeling by the rural engineering model with monthly time steps (GR2M), we have determined the behavior of the basin in question, with regard to the fluctuations observed at the level of the production and routing reservoirs following the rainfall events recorded monthly.

Key words: Watershed, Rainfall, Modeling, Non-exceedance probabilities.

Introduction

The analysis of the rainfall event at several scales is the basis of the assessment study of such a watershed. The more the analysis targets specific criteria, the deeper the understanding of the hydrological response. The use of specialized software in the processing of the rainfall event is very useful to refine the analysis and obtain results based on a scientific foundation. Hydrological modeling is an essential tool for understanding the nature of the basin's reaction following the rainfall event, it allows to constitute a scientific basis leading to conscious decision-making when it comes to actions of evaluation, planning and forecasting of water resources.

Materials and methods.

We opted for the use of some hydrological software, such as: HEC-DSS, HEC-SSP, Hyfran-plus, GR2A, to perform frequency analyses on annual rainfall, maximum daily rainfall and instantaneous flow rates. The raw data used come from the Moulouya Hydraulic Basin Agency, as well as the supplement obtained from the site: https://power.larc.nasa.gov/data-access-viewer/, which provides meteorological data sets from NASA research. We tried to determine the probabilities of not exceeding the annual, monthly and daily rainfall thresholds according to several recurrence intervals. Modeling with the rural engineering model (GR2M) was applied at the monthly time step to assess the behavior and hydrological response of the basin in question.

Localisation du site étudié

Tamaloute is a sub-basin located at the extreme upstream of the Moulouya watershed (figure 1), it occupies an area of 622 km2. The average rainfall observed during the time series (1990-2020) is 368mm.

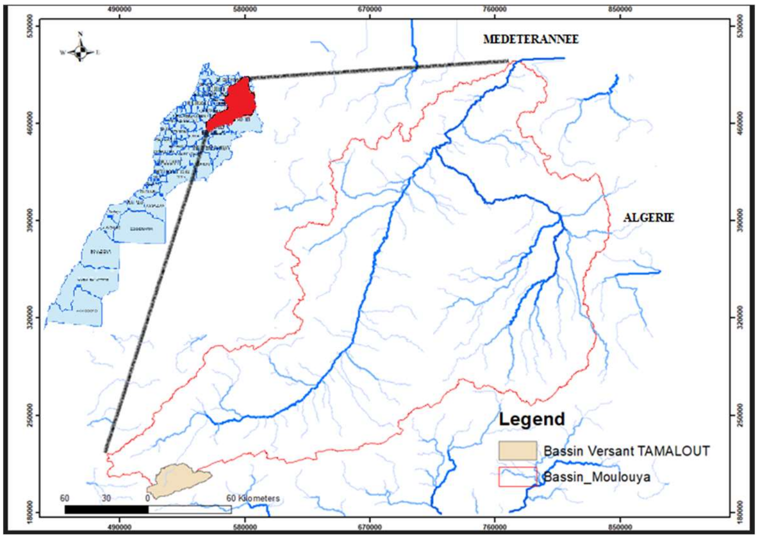


Figure 1: location of the Tamaloute watershed

The rainfall recorded in this basin is random (figure 2). A maximum was observed in 1996 with 699mm, the fall continued until 2002. The context pluviométrique tend vers a slight increase until 2005, then another fall in 2006 followed by an almost continuous increase around 2010. After this date, falls and increases alternate below the threshold of 500 mm which has proven to be the maximum for the last decade.

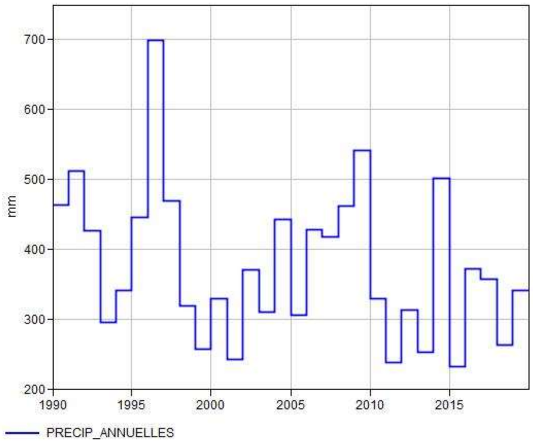


Figure 2: Temporal distribution of annual rainfall from upstream to downstream of the Tamaloute watershed (1990-2020).

Results and discussions

Frequency analysis of annual rainfall in the Tamaloute watershed.

The statistical distribution with the best fit for our sample is the generalized Pareto distribution (Figure 5). The majority of observations fall within the limited confidence interval between 5% and 95%.

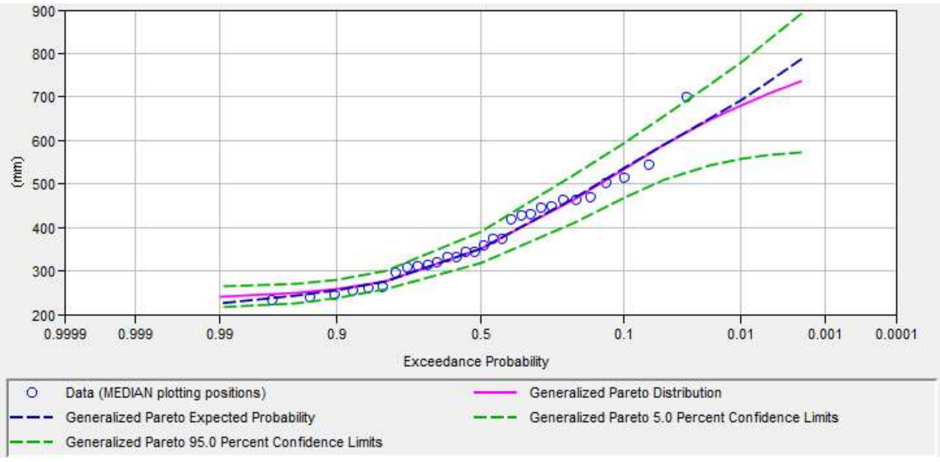


Figure 5: Probability of exceedance for annual rainfall recorded in the Tamaloute basin (Adjustment by the general Pareto distribution law).

The simulation carried out to know the values of the average rainfall, as well as those probable according to the confidence limit of 5% and 95%, and which correspond to the fixed return periods, shows that the arithmetic mean of the recorded rainfall and which is 368mm, belongs to the return period of 2 years. While the maximum recorded in 1996 (699mm) approaches the average value which corresponds to a return period of 200 years.

The majority of observations belong to the 2-year and 5-year return periods (Table 1).

Table 1: Results obtained by the Pareto general distribution law

Return period	Average (mm)	Probable values (mm)	Confidence limits	
			5%	95%
2	350,59	350,93	389,75	319,14
5	466,09	469,17	521,35	412
10	534,27	535,63	594,42	467,18
20	589,4	590,27	656,12	508,38
50	646,43	650,72	727,91	541,73
100	680,1	691,34	779,83	556,53

Frequency analysis of maximum daily rainfall

The statistical processing carried out on the series of rainfall relating to the Tamaloute basin shows that the maximum recorded daily rainfall was 72.5 mm, while the minimum was 14.3 mm. The average of these maximum daily rainfalls is 32.1 mm (Table 2).

Table 2: Pjmanx statistics (Tamaloute basin, 1990-2020)

Number of individuals: 34	Characteristic of the sample
Minimum	14.3
Maximum	72.5
average	32.1
Standard deviation	14
Median	27.7
Coefficient of variation (Cv)	0.437
Skewness coefficient (Cs)	0.999

Kurtosis coefficient (Ck)	3.19

Maximum daily rainfall exceeding the 40 mm threshold has a probability of not being exceeded of more than 80% (Figure 6).

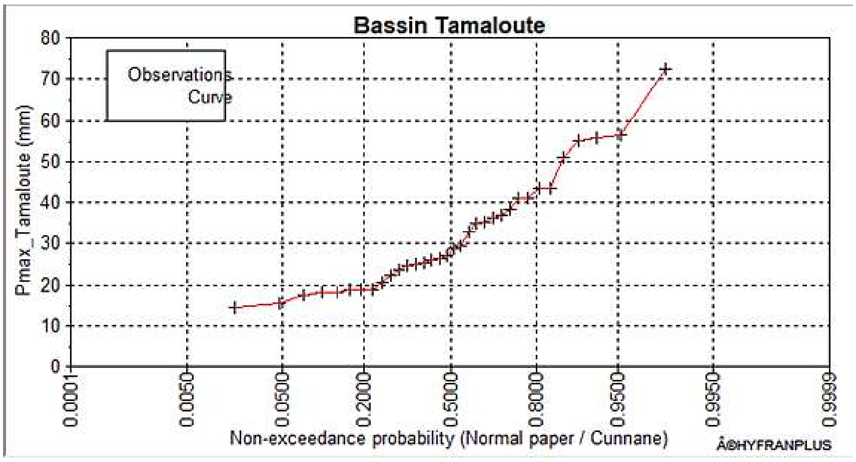


Figure 6 : Probabilités au non dépassement des Pjmax du bassin versant de Tamaloute.

The treatment of the duration studied shows that the intervals of Pjmax (10-20mm), (20-30mm), (30-40mm), (40-50mm), (50-60mm) and (70-80mm) represent respectively the following ratios: (23.52%), (35.35%), (17.67%), (11.67%), (11.67%) and (2.94%). It appears that the maximum daily rainfall that characterizes this basin is between 20 and

30mm (figure 7).

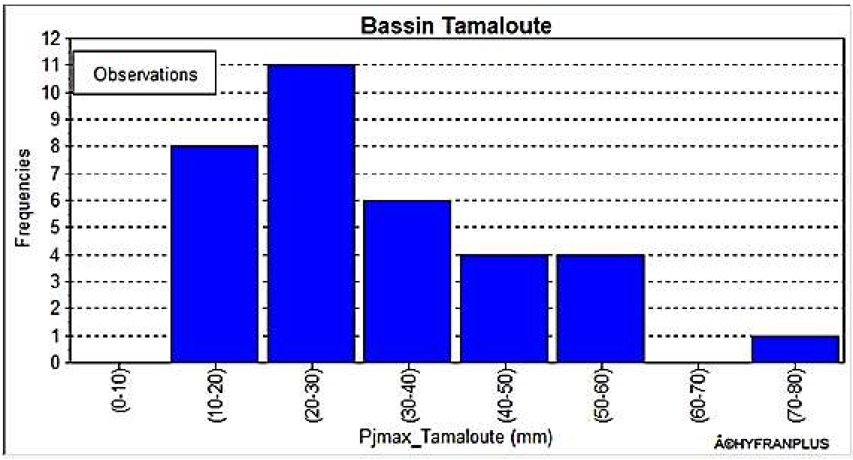


Figure 7: Frequencies of Pjmax in the Tamaloute watershed.

Through the extension of the rainfall time series up to 2023, it can be seen that maximum daily rainfall exceeding 45mm is rare. This exception was recorded only five times during: 2000, 2015, 2020, 2021 and 2022 (Figure 8).

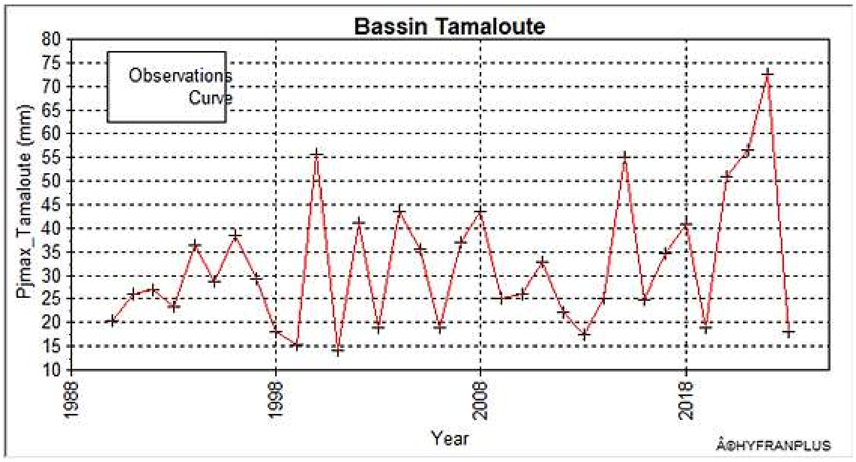


Figure 8 : les Pjmax enregistrées dans le bassin versant de Tamaloute.

Determination of maximum daily rainfall according to the recurrence intervals of 10, 20, 50 and 100 years.

To determine the values of the maximum daily rainfall corresponding to the ten-year, twenty-year, fifty-year and centennial return periods, we used the choice of the independence test (Wald-Wolfowitz), allowed by the Hyfran-Plus software. The null hypothesis corresponds to the independence of the observations. After confirming the acceptance of this hypothesis at a confidence level of 5%, we looked for the law that offers the best result. This approach led us to the choice of the Gamma adjustment law (Maximum Likelihood).

The statistical adjustment by the Gamma law (figure 9), shows that the ten-year frequency is known by a Pjmax which is 49.7mm. The centennial frequency is 70.4 mm (Table 3).

Table 3: Return periods of each Pjmax (Tamaloute basin).

Return period	Pjmax	Probability of not exceeding	Confidence Interval
10	49.7	0.9	41.7 – 57.7
20	56.4	0.95	46.5 – 66.3
50	64.6	0.98	52.2 - 77
100	70.4	0.99	56.1 – 84.7

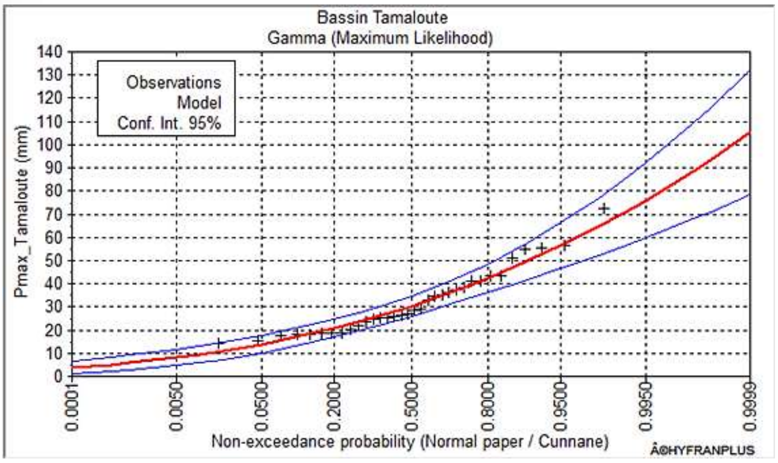


Figure 9: Adjustment of the Pjmax recorded in the Tamaloute watershed by the Gamma law.

Modeling the rainfall-runoff relationship at monthly time steps.

In order to monitor the behavior of the Tamaloute watershed in terms of its hydrological response to the effect of monthly rainfall, the rural engineering model was used for calibration (figures 11 and 12) and validation (figures 13 and 14) over the sub-periods (90-2002) and (2003-2020).

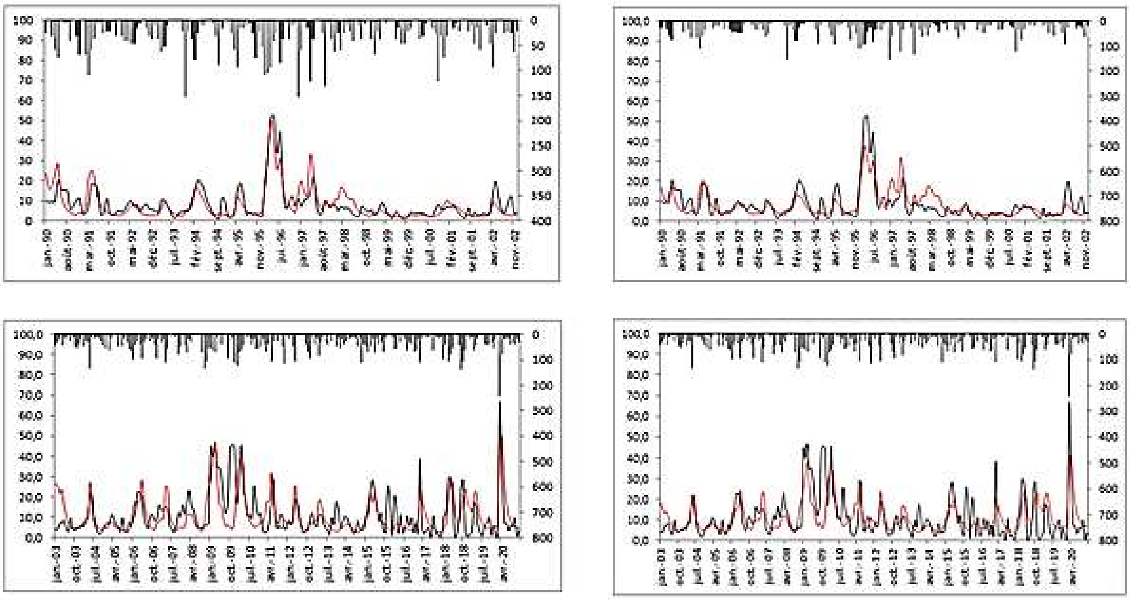
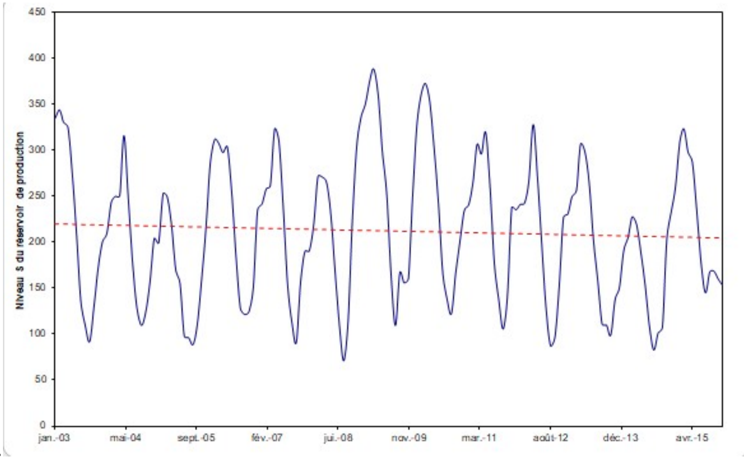


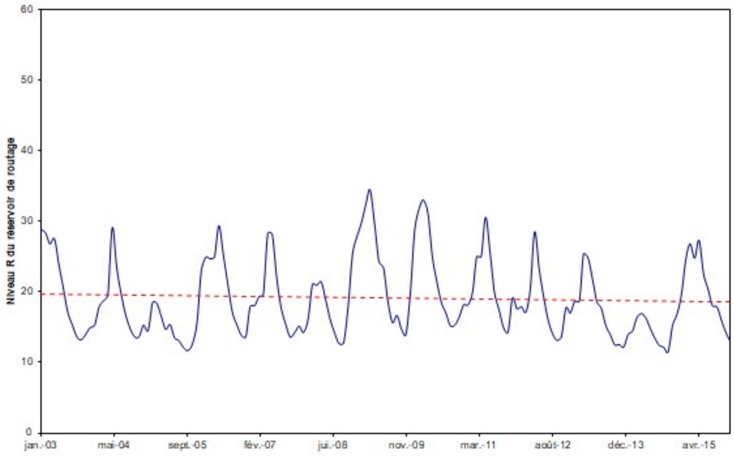
Figure 11 and 12: 90 setting; 2002 and 2003; 2020 Figure 13 and 14: validation 90; 2002 and 2003; 2020

In short, it was found that the efficiency criteria (Nash criterion which represents the degree of approximation between observed and simulated flows by the model) are satisfactory and significant, which confirms the robustness of the model in the simulation at the monthly time step. Several observations can be drawn from the hydrographs obtained by this modeling regarding the behavior of the basin with respect to the hydrological response. In order not to exceed the limit of the recommended pages, we are content to present only the result showing the evolution of the capacity of the ground reservoir (Figure 15) and the routing reservoir (Figure 16) during the sub-period 2003-2015



Evolution of the capacity of the production reservoir of the Tamaloute basin

Monthly fluctuations in the infiltration capacity of the soil reservoir are sensitive to rainfall pulsations. Particularly since 2008, the production capacity has increased. But the year 2013 mentions a very remarkable decrease due to the combined effect of high evapotranspiration and low rainfall, adding to this the unavoidable effect of the state of the vegetation cover and its impact on the infiltration rate. The general trend in the capacity of the production reservoir is a slight decrease from 2003 to 2015.



Evolution of the capacity of the Tamaloute basin routing reservoir

The routing reservoir (gravity water) has marked a rise since 2008, and given the values of the parameter X2 (Groundwater exchange parameter), the system is still gaining, under the effect of the underground contribution of the hydrogeological basin. In general, the trend is also towards a slight decrease during the period studied.

Conclusion

The processing and analysis carried out on the rainfall and hydrometric records using several software programs shows that on an annual scale, the majority of observations belong to the 2-year and 5-year return periods. Maximum daily rainfall between 20 and 30 mm represents the highest frequency (35.35%) of all observations during the last three decades, and that this frequency ratio hardly exceeds the maximum daily rainfall of the 10-year return period which is 49.7 mm. The hydrological response of the Tamaloute basin depends on the intensity of the downpours and the soil moisture status. The late response observed according to the hydrographs obtained by the monthly time step modeling shows the contribution of the aquifer system (underground exchange) in feeding the routing reservoir. The general trend has been a slight decline since 2003, whether for the production or routing reservoir.

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