Frequency Analysis of Hydrological Events using Statistical Methods: Case of the Kert Watershed, Morocco

Imane Boutahri[1], Taieb Boumeaza[2], Rachida Elmorabet[3]

[1, 2, 3]Faculty of Art and humanities of Mohammedia, University of Hassan II, Casablanca Morocco

[1]Email correspondance: *Imane.boutahri[at]gmail.com*

Abstract: ***Floods are the most common natural disasters in the world, putting people and infrastructure at risk. Morocco, having an arid to semi-arid climate, is often faced with heavy rainfall events that can generate fatal floods. Projected variations in rainfall and estimated temperatures lead to an intensification of extreme events, requiring improved flood planning and water resource management. This research aims to provide a means for the prediction and forecasting of floods from the statistical data of flows collected and analyzed by the agencies of the hydraulic basin in Morocco. The objective of this study is to analyze the frequencies of floods in the Kert basin and to estimate the most appropriate frequency distribution of floods at the local scale for all the data relating to annual flood peaks. Four statistical distributions often considered in such cases, namely: the generalized logistical distribution, the generalized distribution of extreme values and the Pearson type 3 distributions, with and without logarithmic transformation, are evaluated by means of two robust goodness-of-fit tests for a large sampling of annual flood peaks. Adjustment assessments are analyzed from a variety of flood sampling characteristics, including annual maximum flows and instantaneous flood peaks. The flood quantiles obtained are compared with the real hypothetical quantiles to evaluate the quality of the prediction of the distribution considered. The results show that the generalized distribution of the extreme values is better than the other distributions considered because of its acceptance, for the two stations tested, and of its closest value to the estimated real hypothetical quantiles. This study provides the basis for recommending distribution for the local frequency analysis of floods in the Kert basin.***

Keywords: Flood frequency analysis, statistical distribution, annual peak flow, Kert basin

1. Introduction

Climate change is one of the greatest challenges facing humanity in the 21st century. They now constitute a potentially major threat to the environment and sustainable development. Climate change leads to an increase in the frequency of hydro-climatic events. The IPCC considers it very likely (90 to 95% probability) that extreme heat and heavy precipitation events will continue to become more frequent, more intense, and above all increasingly variable from one year to the next[1]. Several authors had mentioned the increase in the frequency of extreme events such as droughts, floods, and very intense rains[2]–[4]. These extreme meteorological and climatic phenomena will condition vulnerability to future extreme phenomena by modifying already fragile ecosystems. The number of hydro-meteorological disasters (droughts, floods, etc.) has increased considerably over the past decades.

In addition According to the IPCC report published in February 2012, global warming will increase the frequency and intensity of extreme events with, in particular, an increase in periods of heat waves and an extension of flood and drought zones[5]. Poor communities will be the most vulnerable due to their limited adaptive capacities and their high dependence on climate-sensitive resources such as water resources and agricultural production systems. West Africa, the poorest region of the continent will suffer the most from extreme events[6]. The Kert basin, like the other basins in north-eastern Morocco, has experienced several extreme events linked to current climatic variations. These disturbances are becoming more and more real, and intense and produce significant impacts on the modes and means of existence of the populations[7]. These impacts place populations and their development activities in a situation of repetitive and increasing vulnerability. The objective of this research is to make a frequency analysis of extreme hydro-climatic events in the Kert basin.

Past floods can be used to predict future floods so that prevention and mitigation practices can be developed or improved. Flood frequency analysis (FFA) is an important technique for estimating the magnitude of floods, and their associated frequencies, based on the use of historical flood data. This technique often serves as the foundation for proactive flood management projects such as the design of infrastructure for flood control and floodplain mapping for the identification of regions at risk [8][9]The main problem of FFA in Morocco is the lack of statistical distributions, probably due to the large expanse of the country where water resources are traditionally managed.[10] Several distributions are examined by studies launched by the water basin agencies in Morocco; however, no analytical study has been conducted in terms of identifying a preferred distribution for Morocco. All of the research carried out was often presented as case studies applied to selected regions. Choosing a statistical distribution and parameter estimation method has been a major research topic in FFA, where investigators have focused on finding the optimal combination for the region of interest. Several distributions are frequently selected for modeling the annual peak flow. The generalized extreme value (GEV) distribution [11], which summarizes the 2-parameter shapes Gumbel (EV1), Frechet (EV2), and Weibull (EV3) distributions. The use of the GEV distribution is supported by sound theoretical reasoning, in particular, the density function is explicitly derived by the probability of occurrence of independent extreme events. The Log Pearson Type III (LP3) distribution, Pearson Type III (PE3) distribution with logarithmic transformation of flood values, is mandatory for all US federal agencies [12]. Approval by the United States Water Resources Council[13] elevated the use of LP3 worldwide in major countries such as China[14] and parts of Canada. The LP3 distribution is also one of the recommended distributions in Australia along with the GEV distribution [15]. Generalized Logistic Distribution (GLO) is more realistic for modeling floods so that flood potential will not be limited by a maximum flow value [16]. Fit and discrimination tests are standard techniques for assessing the adequate fit of the distribution within a certain degree of confidence [17]. Several tests are applied and the preferred distribution is the one accepted by the majority of proofs [18]

Predicting extreme hydrological events are all exercises that require knowledge of the maximum flows of a watercourse and their variability. This point discharge can be obtained from the statistical analysis of the series of discharges recorded from the statistical analysis of the precipitation data accompanied by the study of the characteristics of the watershed. Therefore, this work aims to explore empirical formulas for determining maximum flow which are Mallet-Gauthier, Transposition of Francou- Rodierand Rational method in accordance with the nature of the data available; rainfall and the characteristics of the basin, as well as the static adjustment with the following laws: The exponential law, the generalized Pareto law, Gumbel's law, Weibell 's law, Normal law, Galton's law (or called Log normal), the Gamma law and the Pearson III law.

In this study, a statistical method based on rainfall was also used. Generally, flow samples are much less dense than rain samples. This means that if we rely solely on the flow sample, it will be difficult to extrapolate beyond return times of the order of 10 or 20 years, on the contrary, rain echoes are generally longer. It will be possible to determine the centennial, millennial value with sufficient accuracy. This study uses the gradex function in order to be able to take into account the rain information and estimate the probabilities of extreme floods as well as to rationally support the design of spillways[3]. This method, developed by MM Guilo and Duband of EDF Grenoble in 1970, makes it possible to remedy the weakness of the flow sample by using the rain sample.

This study has two main objectives: first, to determine the estimate of peak flows, for return periods ranging from 10 to 10,000 years, from the average daily or even instantaneous flows and the average daily rainfall. Secondly, determine the shape of the flood hydrograph and at the same time estimate the flood volumes, in order to be able to protect the city of Driouch.

2. Presentation of Study Area

2.1 Location of Kert Basin

Kert basin is located in the province of Driouch in the northeast of Morocco, it is surrounded by mountainous areas: the jebel Driouch in the south, the Temsamane massif in the west, and the jebel Tistoutine and its gap towards the plain Gareb in the East. Administratively, the basin overlaps with three Provinces: the Province of Driouch, The western zone of the governorate of Nador, and the northern part of the governorate of Taza. Hydraulically, it is delimited to the north by the Mediterranean Sea, to the south, and to the east by the Moulouya basin. It is located between -3°37′ and -3°85 ′ longitudes and 34°60′ and 35°00′ altitudes with an area of about 3014.85 km^2.

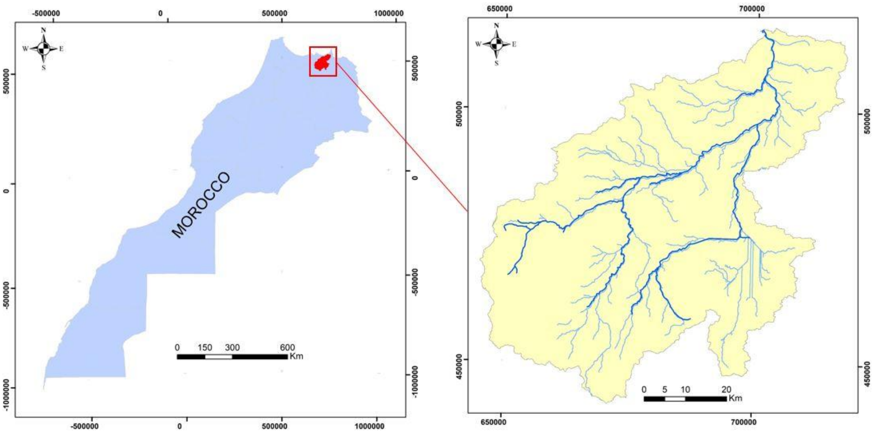

Figure 1: Location of Kert Basin

2.2 Hydrology of Kert basin

It essentially consists of three sub-basins: Chemmar sub-basin, Irane sub-basin and El Maleh sub-basin. Wadi Kert is the main collector of the network.

In order to study the hydrographic functioning of the hydrographic network of the various sub-watersheds, we tried to classify their hydrographic networks in order to obtain their hierarchy and consequently their degree." The classification of a hydrographic network (or topology) is a way of ranking all the branches of a hydrographic network by attributing to each one an integer value which characterizes its importance" [14] . The Strahler order calculated for the Kert watershed is order 7. This calculation was made using ArcGIS software, giving the following data as input: The digital model of the terrain, flows direction and flows accumulation.

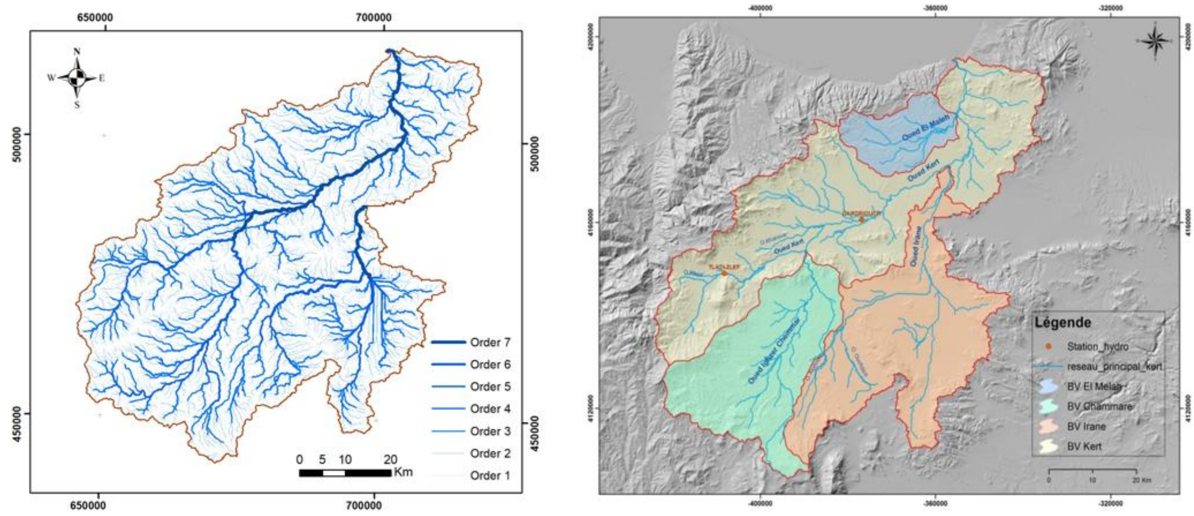

Figure 2: Hydrography of Kert Basin

2.3 Catchment characteristics

The catchment area covered by this study is the catchment area of the town of Driouch. It was delimited on a topographic map at 1/ 50,000th . The geometric characteristics of this basin are recorded in the table below:

Table 1: Characteristics of Driouch Basin

B.V.	Surface (Km^2)	Length (Km)	Hmax (m)	H min (m)	DH (m)	Perimeter (Km)	Form Index	Trough slope %
City Driouch	1133.65	57.12	1658	273	1385	211.55	1.76	2.43%

The geometric characteristics of the basins of the hydrological stations used in this study, taken from topographic maps at 1/50,000th scale , are recorded in the following table:

Table 2: Characteristics of stations Basins

B.V.	Surface (Km^2)	Length (Km)	Hmax (m)	H min (m)	DH (m)	Perimeter (Km)	Form Index	Trough slope
Dar Driouch Station	1124.29	47.64	1384.71	292.40	838.56	226.18	1.89	2.3
TletAzlef Station	197.66	19.11	1384.71	579.58	805.13	81.87	1.63	4.2

3. Materials and Methods

3.1 Data used

For the purposes of the study, the data used are:

1) Annual maximum daily rainfall and total annual rainfall at Dar Driouch and TlatAzlef posts. The characteristics of these rainfall stations are presented in the table below:

Table 3: Location of stations

Post	N	X	Y	Z	Period available
Dar Driouch	2761	684000	487500	270	1968/69 – 2017/18
TletAzlef	8592	658400	477600	610	1966/67 – 2017/18

2) The Montana coefficients of the Nador substation presented in the following table:

Table 4: Montana coefficients

	10 years	20 years	50 years	100 years
a	6.072	7.643	8.811	9.97
b	0.575	0.571	0.570	0.568

3) The annual maximum instantaneous flows at the following hydrological stations:

Table 5: Annual maximum instantaneous flows

Station	X	Y	Period available
Dar Driouch	684000	487500	1969/70 – 2011/12
TletAzlef	658400	477600	1969/70 – 2015/16

The most representative hydrometric station of the flow regime of the Oudoudou dam watershed is the Dar Driouch station located on the same watercourse as Driouch townhas a similar watershed area. However, we will also use the TletAzlef station for comparison.

3.2 Data processing technology

To carry out the flood study, the following steps were followed:

1) Delimitation of the watershed on a topographic map at 1/50,000th scale and determination of the its geometric characteristics (area, length of the talweg, maximum drop, etc.).
2) Calculation of the concentration time Tc (or peak time) using the most used empirical formulas in Morocco, and adoption of the results of the formulas which give values

close to the rise times of the floods recorded at the reference station.

3) Peak flows were calculated for rare frequencies (1/10, 1/20, 1/50, 1/100, 1/1000 and 1/10000) using the Gradex method.
4) The gradex pivot (Q(t=10years)) was calculated by the following methods:
   - Statistical adjustment of the peak flows recorded at Dar Driouch station then transposition by the Francou-Rodier formula to the Driouch basin object of the study.
   - Mallet-Gautier's empirical formula.
   - Fuller's Empirical Formula II.
5) Use of the Gradex method at the watershed of the reference station (Dar Driouch) and transposition of the results obtained to the Driouch basin by the Francou-Rodier formula.
6) Use of the rational method as an example and comparison despite the fact that this method is not suitable for large watersheds like that of the city of Driouch studied. To do this, this method will be applied first to the basin of the Dar Driouch reference station in order to calibrate the runoff coefficients. Then, it will be applied to the watershed studied using the same coefficients set previously.

3.2.1 Statistical fit method

This method consists in submitting the Qp(Qimax) samples to the "HyfranPlus" computer tool which makes it possible to determine the law that best fits the sample and the Qp values for different return periods[4], [16]. The main probability distributions tested by the statistical fit tool are as follows:

- The exponential distribution,
- Generalized Pareto distribution,
- Gumbel's distribution,
- Weibell,
- normal distribution,
- Galton's distribution (or so-called Log Normal distribution),
- Gamma distribution,
- Pearson type III distribution.

These laws are well adapted to extreme phenomena, indeed, the peaks correspond to rare events. Fit tests were used to judge the validity of the adjusted law.

The method of statistical adjustment does not make it possible to estimate the flood flows of a frequency beyond the fiftieth year, and this because of the size of the samples of the peak flows which is limited.

3.2.2 Mallet Gauthier formula:

This formula is written in the following form:

$$Q(T) = 2k\log\,(1+aH(T))\;A\sqrt{(1+4\log T - \log A)}\;/\;\sqrt{L}$$

With: Q(T) = peak flow for the return period T (m3/s).
L = length of the main drain in km.
T = return period.
A = area of the BV in km².
H(T) = annual return period rainfall T in m.
a = coefficient equal to 20 for Morocco.
k = coefficient equal to 2 for Morocco.
For watersheds with an area greater than 20 km²:

3.3.3 Fuller's Formula II

The expression of this equation takes the following form:

$$Q_T = (1 + a.\log T)\left(A^{0.8} + \frac{8}{3}A^{0.5}\right)\frac{4}{3}\frac{N}{100}$$

QT: peak flow of return period T in m3/s.
T: is the return period (in years).
A: area of the catchment area (in km²).
a: variable coefficient depending on the region:
$0.7 < a < 0.8$: large watersheds and well-watered regions
$0.8 < a < 2$: arid regions
$3 < a < 3.5$: Saharan wadis
N: regional coefficient which varies between 60 and 100:
N = 60-70 for plain
N = 70-80 for hilly regions
N = 80-100 in the mountains

3.3.4 Transposition of Francou-Rodier

The principle of this method consists in transposing the peak flows for different return periods known at the level of a gauged watershed to an ungauged watershed provided that the latter is adjacent and has geomorphological characteristics similar to the first.

The FrancouRodier coefficient Kp is given by the following formula:
$Kp = 10\,(1 - Ln(Q_1/10^6) / Ln(Sbv_1 / 10^8))$
Where Q_1 and Sbv_1 are respectively the peak flow and the area of the gauged area.
The peak throughput for each frequency at each site is calculated using the following formula:
$Qp(T) = (Sbv_2 / 10^8)^{(1-0.1\,Kp)} * 10^6$
Where Sbv_2 is the area of the catchment area of the considered site.

3.3.5 Rational method

According to this method, the peak flow for a given return period T is written:
Q= C(T)* I(tc,T)* S
With:
C(T): runoff coefficient which depends on the return period T and the nature of the watershed considered.
S: area of the watershed in km².
I(tc,T): maximum average intensity corresponding to the return period concentration time T, i.e.: I(tc,T) = a tc-b

This formula is generally applied especially for small watersheds where area does not exceed 50km², and in areas where IDF (intensity duration frequency) curves or Montana coefficients are available.

3.3.6 Gradex method

For the application of the gradex method, the following steps are followed:

- Adjustment by Gumbel's law of maximum daily rainfall and determination of Pjmax(T) for T ranging from 2 to 10,000 years.
- Determination of daily gradex (Gp(24)). The transition from daily values to 24-hour is obtained by increasing

the daily values by 15% to take into account the sliding of the rain.

- Choice of a unit hydrograph from the analysis of major flood hydrographs recorded at the reference hydrological station.
- Calculation of the rain gradex on the Gp(Tc) concentration time from the rain gradex in 24 hours.
- Calculation of the reference peak flow Qp(T*) (pivot of the gradex) using the statistical adjustment method then the transposition by Francou-Rodier and the Mallet Gautier and Fuller II formulas.
- Calculation of peak flows and runoff layers of water for each return period using the classic gradex method at the Driouch basin.
- Calculation of peak flows at the reference station using the Gradex method, then transposition of the results obtained to the Driouch basin using the Francou-Rodier method. The Gradex pivot is deduced from the statistical adjustment of the Qimax recorded at the reference station.

4. Results and discussion

4.1 Calculation of concentration time

The calculation of the concentration time at the catchment level of the Oudoudou dam sites at the hydrological stations using the different empirical formulas gave the following results:

Table 6: Concentration time (in hours)

Formula	Driouch	Station Dar Driouch
Giandotti	**7.40**	**7.78**
Ventura	27.46	28.12
Kirplich	6.25	5.55
TurazzaPassini	27.85	26.89
USCS	3.56	3.66
Of the garden	6.19	6.35
Sogreah	8.55	8.72
Desbordes	3.26	3.32
Van Te Chow	5.38	4.88
Spanish	13.16	11.59
Us Corps	12.82	11.27
Californian	7.66	6.95
Adopted value	***7.40***	***7.78***

Below is an analysis of the major floods recorded at the Dar Driouch station:

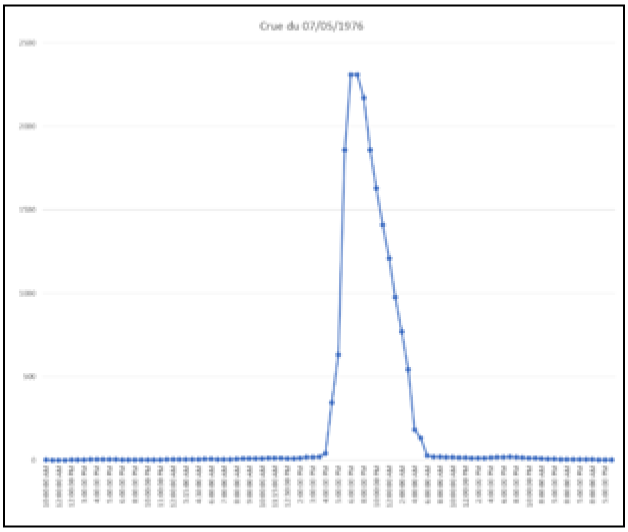

Figure 3: The rise time = 2 hours and the base time = 12 hours

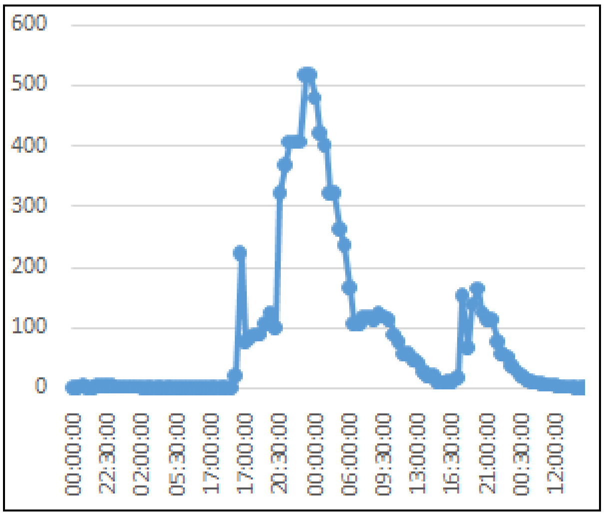

Figure 6: The rise time = 8.5 hours and the base time = 25.5 hours

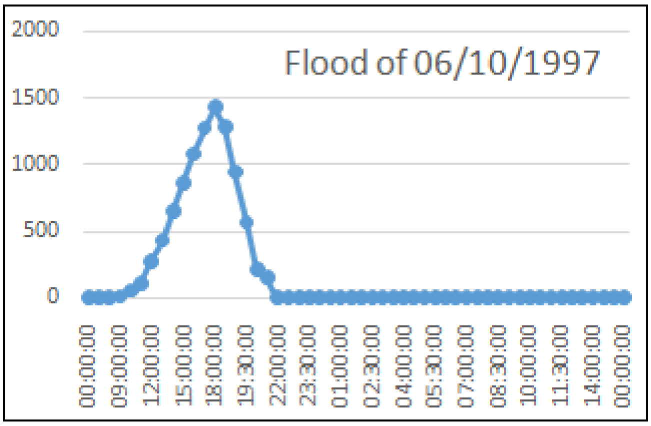

Figure 7: The rise time = 8 hours and the base time = 13 hours

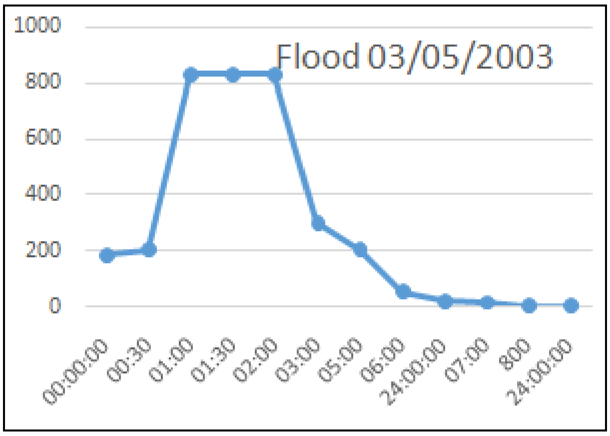

Figure 8: The rise time = 1 hour and the base time = 16 hours

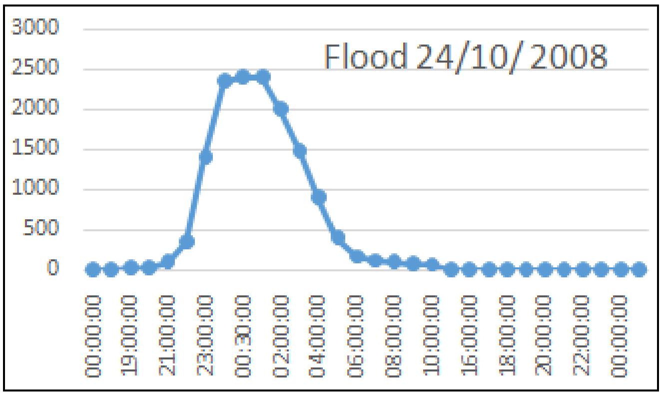

Figure 9: The rise time = 4.5 hours and the base time = 9 hours

The rise time of the floods analyzed at the Dar Driouch station varies from 1 to 8 hours. Peak times of less than 8 hours correspond to a partial contribution of the watershed in the genesis of the flood. The rise time to be considered for the Dar Driouch watershed is 8 hours, which corresponds to the value derived from Giondotti's formula.

4.2 Statistical adjustment method and transposition by Francou-Rodier

These Qimax samples were subjected to frequency analysis. The results of this analysis are presented in the table below:

Dar Driouch Station:

Law of adjustment	Suitability Test C²	Q2	Q5	Q10	Q20	Q50	Q100
Exponential	7.95	286	676	972	1270	1660	1950
Pareto	10.41	244	628	974	1380	2010	2580
gumbel	40.27	325	816	1140	1450	1860	2160
Normal	71.36	417	884	1130	1330	1560	1710
Lognormal	17.77	142	921	2450	5490	13600	24900
Pearson 3	16.95	227	724	1120	1530	2080	2500
Weibell	**5.09**	**218**	**661**	**1060**	**1500**	**2130**	**2640**
Gamma	7.14	209	686	1100	1530	2130	2590

The law that best fits the Qimax sample at the Dar Driouch station, according to the adequacy tests, is the Weibull law. The adjustment charts are shown below:

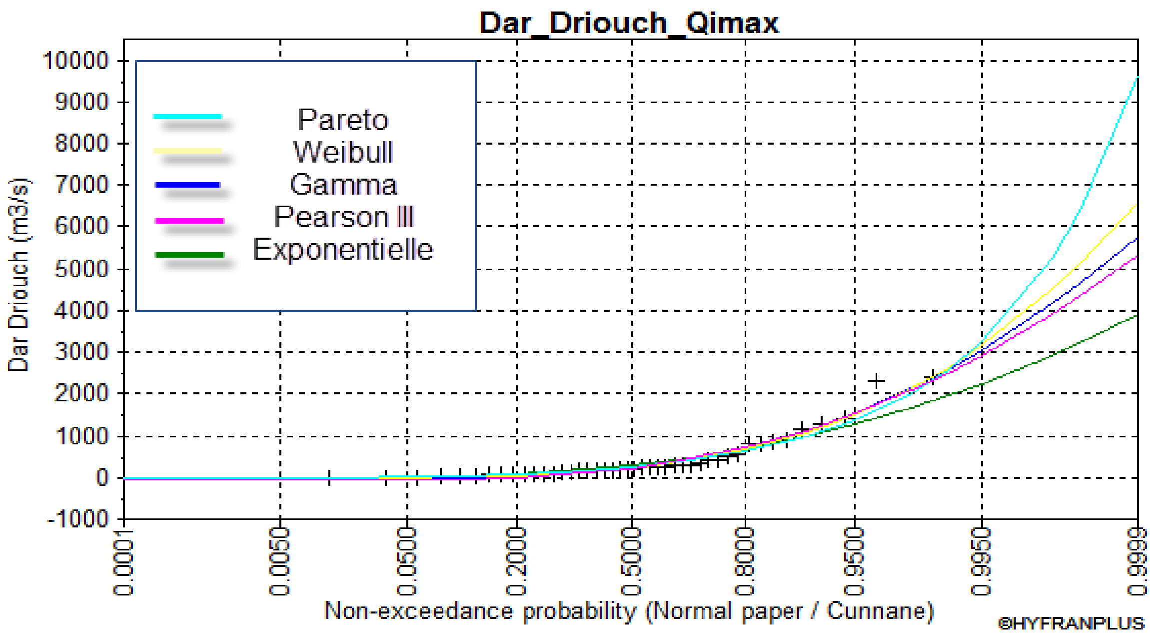

Figure 10: The law that best fits the Qimax sample at the Dar Driouch station

The transposition of the results of the statistical adjustment of the peak flows recorded at the Dar Driouch hydrological station to the Driouch watershed gives the following results:

Law of adjustment	Sbv in km²	Q5	Q10	Q20	Q50	Q100
Dar Driouch station (m^3/s)	1124	661.00	1060.00	1500.00	2130.00	2640.00
kp	-	3.58	3.99	4.29	4.60	4.79
Peak flows downstream of Driouch town (m^3/s)	1133	**664.64**	**1065.46**	**1507.33**	**2139.85**	**2651.78**

4.3 Rational method

Before applying the rational method to the catchment area of the city of Driouch, it was applied, initially, to the right of the catchment area of the hydrological station dar Driouch to proceed with the calibration of the runoff coefficients. The results obtained are as follows:

T	10 years	20 years	50 years	100 years
%VS	31.60%	35.00%	42.85%	46.36%
I mm/h	10.639	13.724	15.919	18.236
Q m^3/s	**1060**	**1500**	**2130**	**2640**

The IDF curves used are those of the Nador substation. Thus, each watershed will be assumed to be subject to a rainfall intensity equal to the value recorded at this station.

The rainfall duration considered for each watershed will be equal to its adopted concentration time.

The application of the rational method by adopting the runoff coefficients resulting from the calibration gives the following results for the site of the town of Driouch:

T	10 years	20 years	50 years	100 years
%VS	47.8%	62.9%	81.8%	95.3%
I mm/h	10.944	14.116	16.373	18.754
Q m 3 /s	**1089**	**1555.26**	**2209.29**	**2737.85**

4.4 Mallet Gautier method

The application of the Mallet Gautier method to the watershed studied gives the following results:

Area (Km²)	BV name	Return Period			
		10	20	50	100
1133.65	City of Driouch	647.58	823.96	1010.95	1132.07

By choosing the following parameters:

a	K
20	2

4.5 Fuller II method

The application of the method of Mallet Gautier on the watershed studied gives the following results

Area (Km²)	BV name	Return Period T			
		10	20	50	100
1133.65	City of Driouch	881.98	999.98	1155.97	1273.97

By choosing the following parameters:

has	NOT
0.88	100

4.6 Gradex method

4.6.1 Maximum daily rainfall

The statistical adjustment of these samples of annual maximum daily rainfall to Gumbel's law leads to the following results shown in the table below, in which are the maximum daily rainfall for different return periods.

Table 1: Maximum daily rainfall by return period

STATION	P2	P5	P10	P20	P50	P100	P1000	P10000
Dar Driouch	34.4	51.3	62.4	73.1	87.0	97.4	132	166
TletAzlef	36.4	55.4	68.1	80.2	95.8	108	146	185

These values correspond to daily values. The transition to rain in 24 hours is done by multiplying the daily values by a coefficient equal to **1.15** that takes into account the sliding of the rain.

The precipitation values for different return periods adopted correspond to the values of the Dar Driouch station because it is the closest station to the outlet and more representative of the watershed, unlike the TletAzlef station which only represents the upstream part of this basin (mountainous part).

The graphs of the statistical adjustments of the Pjmax samples to Gumbel's law are presented below:

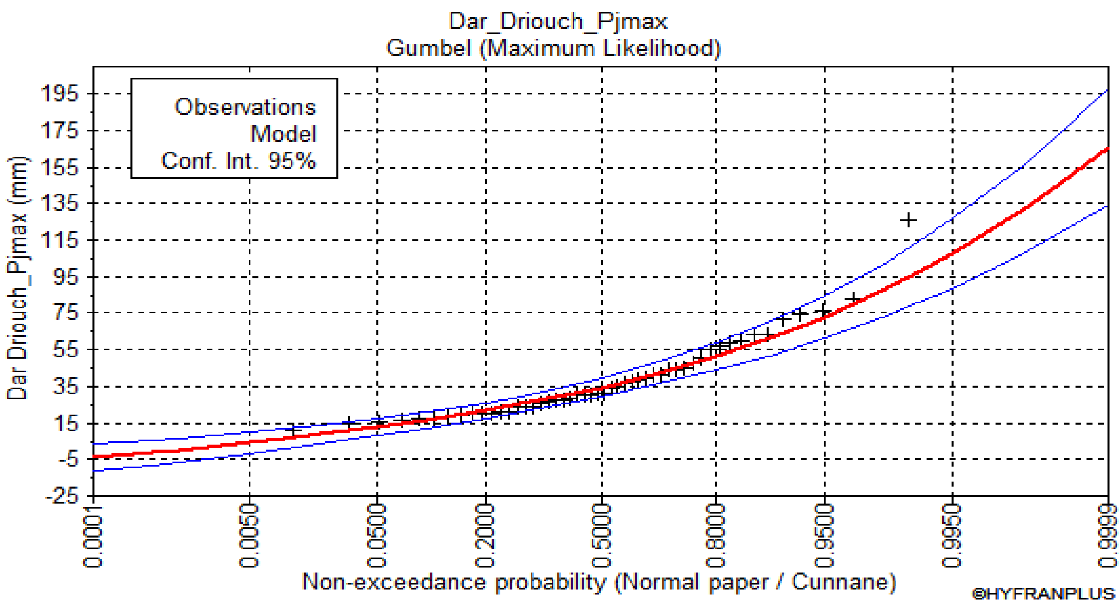

Figure 11: The law that best fits the Pjmax sample at the Dar Driouch station

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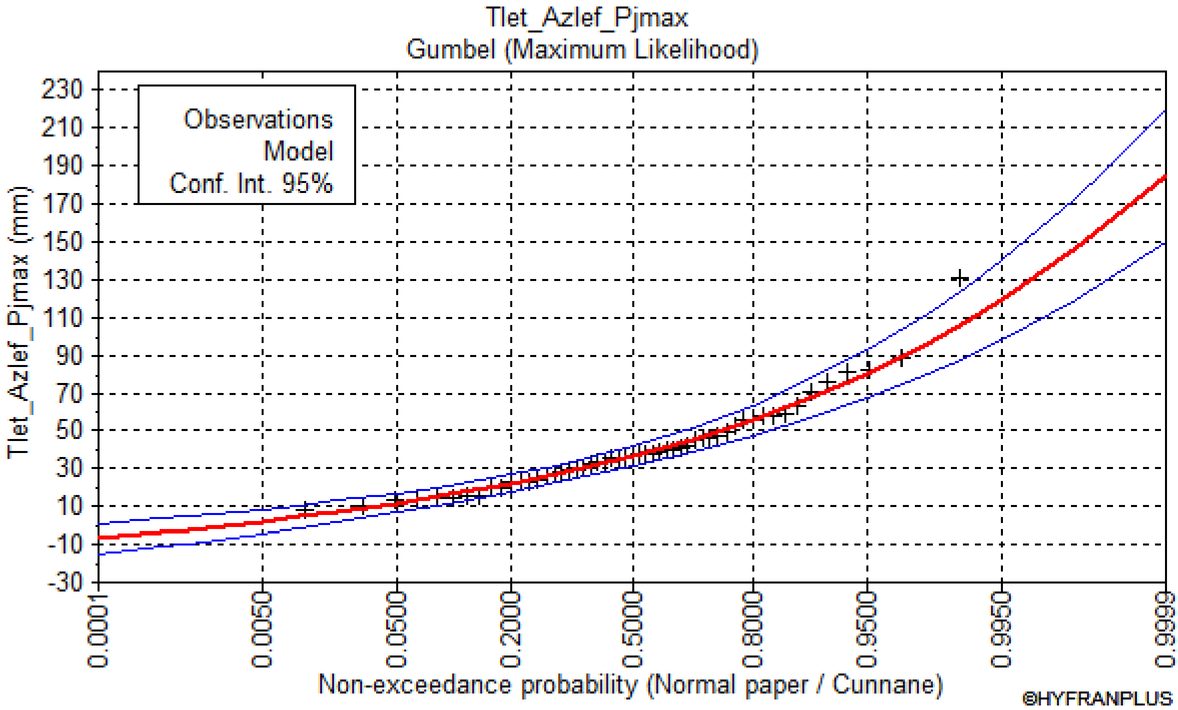


Figure 12: The law that best fits the Pjmax sample at the TelatAzelafstation

4.7 Shape of the Flood Hydrograph

The floods recorded in the Dar Driouch station above have a triangular hydrograph. For the remainder of the study, this form will be adopted with a base time equal to twice the rise time.

4.8 Reference Flow Estimation

The gradex method is based on the fact that beyond a certain so-called reference frequency T* (generally between the ten-year and twenty-year frequency, depending on the permeability of the soil), most of the rain that falls runs off, otherwise, any additional rain generates additional runoff equal in volume. For the case of the catchment area covered by this study, the ten-year frequency (T* = 10 years) will be considered as the reference frequency. The following table summarizes the peak flow values for the ten-year frequency at the outlet of the studied watershed calculated by different methods:

Method	Q10 – BV of the city of Driouch
Statistical adjustment + Transposition from Dar Driouch	1065.30
Gautier Mallet	647.58
Fuller II	881.98
Adopted value	1065.30

The value adopted corresponds to the value resulting from the method of transposition from the catchment area of the Dar Driouch station (reference station).

The runoff layer and the volume corresponding to the reference flow (T*=10 years) were deduced from the chosen standard hydrograph. The results are grouped in the table below:

Watershed	Qp (T*=10years) m^3/s	V (T*=10years) mm^3	R (T*=10years) (mm)
City of Driouch	26.4	29.661	1060.0
Dar Driouch Station	25.0	28.379	1065.5

Table 2: Layer of runoff water for T* = 20 years

R(T*=10 years) is the reference runoff layer, it is deduced from the reference volume V(T*=10 years) by dividing the latter by the area of the catchment area.

4.9 Calculation of runoff water layers and peak flows for different frequencies

The basic principle the gradex method uses to calculate floods, is that floods are greater in terms of peak flow if the considered catchment area is subject to a rainfall event whose duration coincides with the concentration time of the basin. On the other hand, it is considered that a rainfall with a return period T generates a flood with the same return period.

Consequently, the duration of the rain to which the watershed is subjected will be considered equivalent to the time of concentration. The volume of the flood will be deduced by multiplying the sheet of runoff water by the total area of the catchment area. The peak flow is deduced by injecting this volume into the chosen typical hydrograph. The following table presents the results obtained for the Dar Driouch site:

T	U(T)	P(Tc) mm	R(Tc) mm	V Mm3	Qp m3/s
10	2.3	30.6	25.0	28.379	1065.5
20	3.0	35.6	30.1	34.132	1281.4
50	3.9	42.4	36.8	41,760	1567.8
1 00	4.6	47.3	41.8	47.377	1778.7
1000	6.9	64.1	58.6	66.439	2494.4
10000	9.2	80.7	75.1	85.170	3197.6

A peak safety coefficient of 1.5 at the level of Morocco is applied. The results are shown tn the table below:

Q10	Q20	Q50	Q100	Q1000	Q10000
1598.19	1922.17	2351.77	2668.07	3741.55	4796.42

In addition, the gradex method is applied to the right of the Dar Driouch station. The results obtained are recorded in the following table:

T	U(T)	P(Tc) mm	R(Tc) mm	V Mm3	Qp m3/s
10	2.3	30.1	26.4	29.661	1060.0
20	3.0	35.7	32.1	36.046	1288.2
50	3.9	43.3	39.6	44.521	1591.1
1 00	4.6	48.8	45.1	50.689	1811.5
1000	6.9	67.4	63.7	71.665	2561.1
10000	9.2	86.2	82.5	92,800	3316.4

A peak coefficient of 1.5 at the level of is applied. The result becomes as follows:

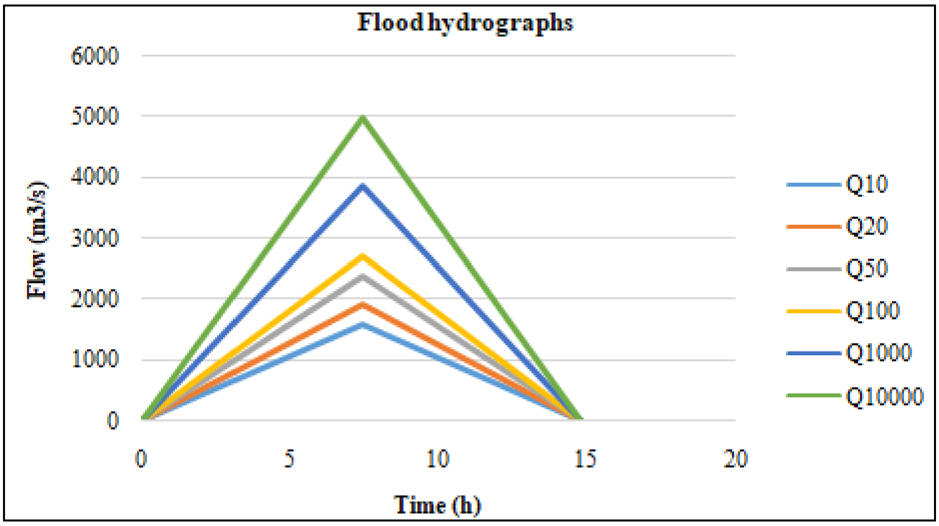
Q10	Q20	Q50	Q100	Q1000	Q10000
1590	1932.29	2386.63	2717.24	3841.68	4974.64

The flows obtained by the gradex method at the Dar Driouch station were transposed to the watershed of the town of Driouch by the Francou-Rodier formula. The results obtained are as follows:

Station	**Sbv**	**T=10**	**T=20**	**T=50**	**T=100**	**T=1000**	**T=10000**
Dar Driouch	**1124**	1590.00	1932.29	2386.63	2717.24	3841.68	4974.64
kp		4.35	4.52	4.70	4.82	5.12	5.35
BV Driouch	**1133**	**1597.70**	**1941.37**	**2397.47**	**2729.31**	**3857.74**	**4994.47**

The following table shows the peak flows at the Oudoudou dam site for different return periods, resulting from the different methods used:

Method	2 years	5 years	10 years	20 years	50 years	100 years	1000 years	10,000 years
Frequency analysis + Transposition from Dar Driouch	219.38	664.64	1065.46	1507.33	2139.85	2651.78	-	-
Gradex	-	-	1598.19	1922.17	2351.77	2668.07	3741.55	4796.42
Rational	-	-	1089	1555.26	2209.29	2737.85	-	-
Gradex in Dar Driouch + Transposition			1597.70	1941.37	2397.47	2729.31	3857.74	4994.47
Value adopted (m^3/s)	**219.38**	**664.64**	**1597.70**	**1941.37**	**2397.47**	**2729.31**	**3857.74**	**4994.47**
Flood volume (Mm^3)	**5.8**	**17.7**	**42.6**	**51.7**	**63.9**	**72.71**	**102.77**	**133.05**



The values adopted correspond to the results of the Gradex method applied to the catchment area controlled by the hydrological station of Dar Driouch then transposed to the basin studied.

5. Conclusion

In this work, the behavior of the maximum flows of Oued Kert basin, compared to the chosen statistical laws is studied. The approximate statistical models derive from the Theory of Extreme Values. We first applied the method of annual maxima to the maximum flows selected. The maximum floods analysis show that floods more frequent in September with twelve floods, against sixty-two floods.

The non-stationarity of the data could be observed visually during the graphic representation of the annual maximum flows as a function of time, a clear positive trend was observed. Thus, the method of annual maxima does not apply to the flows of Oued Kert. To support this conclusion, different tests to the maximum instantaneous flow rates as well as to the average daily flow rates are applied. The statistical tests approved the assumptions of independence and rejected the homogeneity assumptions at the levels of significance of 5%.

The frequency analysis of the maximum precipitation and peak flow data from the Driouch and TelatAzlaf stations was carried out using daily data covering the period 1968-2018. Maximum daily precipitation amounts and peak flows for each year were extracted from each station. The tests of stationarity and independence hypotheses were conclusive on all the series of maximum precipitation and peak flows. From the estimated quantiles, it can be seen that the return period of maximum daily precipitation and peak flows varies from 10, 20, 50, 100, 1000 and 10000 years. Recurrent floods T=10 vary between 1060 m^3/s and 1590 m^3/s in the Driouch sub-basin. Floods with a flow rate varying between 3316 m3/s and 4974 m3/s at Driouch is exceptional, this is the case for T= 10000. Similarly, the most recurrent flood volumes have a value of 42.6 Mm^3 according to the Driouch station. The exceptional flood volumes reach the value of 133.05 Mm3 in the same station. These estimated variables constitute an important decision-making tool in the search process for strategies to combat hydro-climatic risks in general and floods in particular.

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