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Determination of Design Floods by Aspects of Peak Flow and Flood Hydrograph in Watershed of Larbaâ River, Taza (Morocco)

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Abstract

The major task of a hydrology study is to compute the design flow. There are conceptual and empirical methods for computation of design flow. The following paper shows the Gradex method estimating the design flood and the volumes corresponding of flows. This approach allowed us to know the design floods by aspects of peak flow and flood hydrograph. The study is based on long series of observations (49 years) of the annual maximum daily rainfall, and the Intensity-Duration-Frequency curves of the raingauge station of Taza located in the Larbaâ catchment. The Gradex method aims to find the maximum flow of floods for the rare frequency of occurrence (return time over 100 years). Hence, we attempted to explains why and how the combined use of rainfall and floods of different sub-catchments of Larbaâ River.

Keywords

Taza city; Larbaâ catchment; Gradex method; Design flow

Introduction

The predetermination of the flood is to combine the certain flows exceeding the probability of the occurrence. For many years, hydrologists have been working with the idea; in a watershed, of a maximum flow rate possible. This notion of maximum possible flood is generally refuted today. We consider that if the probability of exceeding flows x tends to 0; this flow itself tends to infinity [1].

Morocco, is like the rest of the world, suffers from the problems of management of water resources. These problems necessitate a good knowledge of the spatiotemporal variability of the hydrological regime of rivers (floods and low flows) in order to achieve a flood management in watershed and in floodplains [2].

This study looks at the phenomenon of extreme floods of the Larbaâ River in the city of Taza (Taza region, Morocco). These floods are a risk that threatens all spatial components: houses and infrastructures. These overflows, having occurred in recent years, especially during the years 2000, 2002 and 2010, caused casualties and material damage [2].

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The major task of a hydrology study is to compute design flow. There are conceptual methods and empirical methods for computation of design flow. Data and information required for hydrologic analysis varies from method to method. To determine what data are needed, the designer must determine which hydrologic analysis method(s) will be used. And the design flows estimated with any method used should be confirmed and validated by comparing the predicted design flow for the selected frequency with observed flows and with the design flows obtained by other method especially to assess reasonableness [3].

The watershed of Larbaâ river is located in the Eastern Prerif between latitudes (34° 00 385, 30 and 34° N) and longitudes (3° 30 '622 and 4° 00' E 645). The catchment area is estimated as 780 Km². The watershed covers mainly an area of hilly prerifan. In the north it is bounded by the watershed of Lamsoun River, in the South and the East by the tributaries of Moulouya River and west by the watershed of Lahdar River (Figure 1).

The study area belongs to the administrative division of the province of Taza. Topographic maps of 1/50 000 covering the watershed of the Larbaâ River are Taza, Bab Mrouj, Al Ain Bou Kellal and Ain Bahera.

Materials and Methods

We have used the hydrological study because of the lack of the daily stream flow data that can facilitate the statistical analysis of ancient floods. This approach allows us to know the design floods by aspects of peak flow and flood hydrograph.

The flood study was performed by using Gradex method. This method is used to extend the volume frequency curves. The methodology was first introduced by [4] and recently refined by [5]. This method enables to achieve two main objectives. This method has been shown to be a valuable tool in the estimation of design floods. Its application is strongly suitable where no streamflow data are available [6].

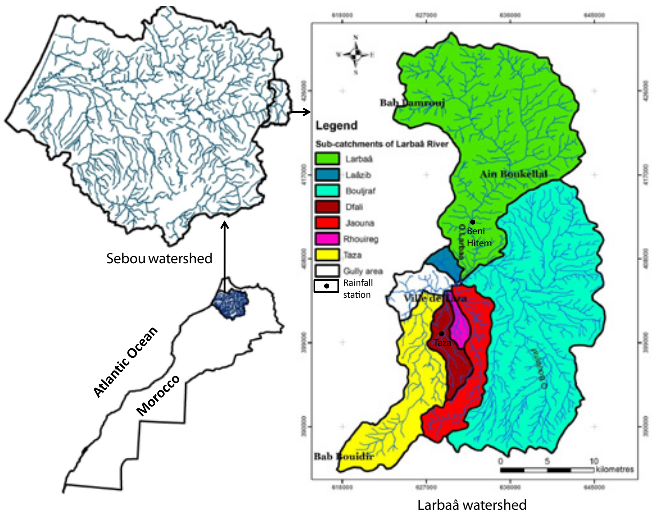

Figure 1: Situation of study area.

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- Estimation of peak flows (Qf) at the outlet of the watershed studied, for return periods ranging from 10 to 100 years.
- Determination of the flood hydrograph shape and the estimation of the floods volumes.

The method is considered applicable [7] for return periods Tr between 2 and 100.000 years for non-Karst basins whose area ranges from 10 to 10.000 Km². In other ways, this method has been verified by many authors in different areas of the world (the French metropolitan area, the United States, Australia, South Africa and Israel [8,9].

The Gradex method aims to find the maximum flow of floods for the rare frequency of occurrence (return time over 100 years). It applies in particular when it has a long series of rainfall on the study basin. This method is based on the following hypothesis [1]:

-The desired maximum flow is provoked only by maximum rainfall, uniformly distributed on the catchment. Therefore, the creation of flood doesn't have multiple origins.

- The Maximum rainfall and the corresponding flow, so-called the extreme because of the nature phenomenon researched (rare flood), follow the same statistical distribution. This expresses the fact that the above asymptotic law of rainfall distribution and flow are identical. The Gumbel law [10,11] is often used for this purpose and in this case only. The exponential character of this distribution is described by the slope of the adjustment of observed and measured rainfall on an appropriate diagram of probability. The slope of this line is the gradient of the exponential distribution.

Gradex method is applied following the next steps:

- Adjusting of maximum daily rainfall (MDR) by Gumbel distribution and determination of (MDR) for time (T) ranging from 2 to 1000 years.
- Determination of daily gradex (Gp (24)).
- Choosing a unit hydrograph.
- Calculation of Gradex by time of concentration Gp (Tc) from gradex.
- Calculation of the reference flow Qp (T 10 years) using the empirical formula of Caquot.
- Calculation of peak flow volume of water and runoff of the different return periods by the classical method of Gradex.

Available data

The study is based on the annual maximum daily rainfall of two rainfall stations (Taza and Beni Hitem), and on the Intensity-Duration-Frequency (IDF) curves of the raingauge station of Taza located on the Larbaâ river catchment. The coefficients of Montana are necessary for the application of some formulas related to the Gradex method [12]. The parameters “a” and “b” for the Gradex method application are deduced from (IDF) curves of Taza (Figure 2).

The catchment area covered by this study was delineated on a topographic map of 1/50000. The geometrics characteristics of different sub-catchments of Larbaâ river (area, thalweg length, maximum altitude difference, Gravelius index Kg ...) are shown in the Table 1.

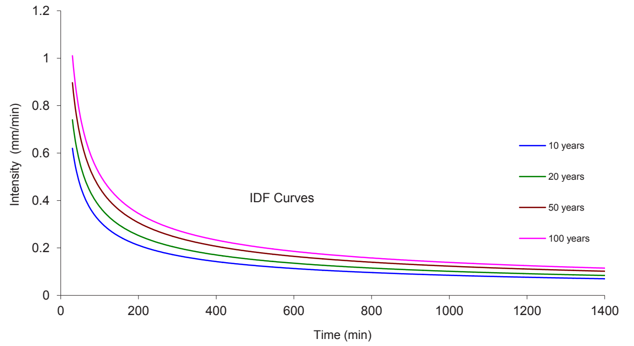

Figure 2: IDF Curves of Taza meteorological station.

Theoretically the Concentration time Ct is estimated that is the duration between the end of the net rainfall and the end of runoff. Practically the time of concentration can be derived by measurements from field or estimated by using empirical formulas. In this study we calculated the time of concentration by three empirical formulas. The adopted values are averages of results of the three formulas (Table 2).

Giondotti expression:

$$T_C = \frac{4\sqrt{S} + 1.5L}{0.8\sqrt{\Delta H}} \qquad (1)$$

Tc: the time of concentration in hours.

S: the surface of the catchments area in km².

L: the length of the trough in Km

ΔH : the maximum altitude difference of the watershed.

The Kirplich expression:

$$T_C = 0.01947 \times L^{0.77} \times I^{-0.385} \qquad (2)$$

Tc: the time of concentration in min.

L: the Thalweg length of in m.

I : the average slope of the stream in m / m.

Turrazza expression:

$$T_C = 1.662 \times S^{½} \qquad (3)$$

Tc: time of concentration in min.

S: the catchment area in Ha.

Results and Discussions

The gradex estimation

To estimate Gradex, different approaches are possible. In this case, the number of observation is long (49 years), the simple and the most effective is to directly adjust the annual maximum rainfall in Gumbel distribution [13].

It is generally agreed that fifteen years of observations gives a fairly reliable estimate of gradex. This approach to estimate the Gradex allows extrapolating the return periods of rainfall up to several thousands of years [14].

Among the laws of distribution that can account for the statistics of extreme phenomenon, is the Gumbel distribution that the best suitable for the rainfall variables. The Gumbel distribution is expressed as:

Table 1: Geometric characteristics of the sub-catchments of Larbaâ River.

Sub-catchments	C.A In Km²	Thalweg L Km	Max H m	Min H m	ΔH	catchment Perimeter Km	Gravelius index Kg	Slope by %
Larbaâ	284	43	1361	439.5	921.5	90	1.51	2.14
Bouljraf	302	37	1182	439.5	742.5	96.5	1.57	2.01
Jaouna	48	22	1525	437	1088	47	1.91	4.95
Rhouireg	8	7.5	817	434.5	382.5	15	1.50	5.10
Dfali	22.5	13.5	1520	434	1086	28.5	1.69	8.04
Taza	43	15	1770	421	1349	33	1.42	8.99
Laâzib	7.5	5	642	437.5	204.5	13	1.34	4.09

$$F(x) = \exp\left[-\exp\left(-\frac{x - x_0}{g}\right)\right] \quad (4)$$

With $u = \frac{x - x_0}{g}$ (5)

In a Gumbel graph the distribution is written as follows:

$$u = -\ln[-\ln(f(x))] \quad (6)$$

U is the variable of Gumbel. The term g represents the slope of the adjustment line. Often, and especially for the rains, we call g "the Gradex" (contraction of the exponential gradient) [1].

In hydrology, the values probability of an observed sample is given by several formulas. But the most used in hydrology is that defined by Hasen.

$$F_i = \frac{i - 0.5}{n} \quad (7)$$

i is the rang and n is observed sample.

In this study, we adjusted by the Gumbel distribution the maximum daily rainfall (MDR) of the meteorologicals stations of Taza and Beni Hitem for a fairly long series of observations (49 years). This adjustment allowed us to estimate the values of rainfall for different return frequencies (Figure 3).

From the graphical representation we could determine the Gradex and maximum daily rainfall for different return periods. The values of maximum rainfall represent daily values (Table 3). The passage to rainfall in 24 hours will be realized by multiplying the daily values by a factor equal to 1.15.

Estimation of reference flow QF (T=10 years)

The transformation of rain into flow discharge is one of the main problems facing the hydrologists and technicians charge of the improvement of the sanitation of urban centers. For this reason the hydrologists have been looking to find the relation (rainfall-flow) by developing multiples empirical models to simulate this physical phenomenon [15]. The Caquot model is the most used in morocco [16]; it allows knowing the peak flow Q (Tr) of return period (Tr). The determination of the design flood of reference is necessary of Gradex method. This is why we will use the Caquot model with which we can calculate the flow with the exceeding frequency *f*.

Table 2: Concentration time adopted in Gradex method.

Rivers	Kirplich	Turazza	Giondotti	adopted values
larbaâ	5.27	4.67	5.43	**5.12**
Bouljraf	4.81	4.81	5.73	**5.12**
Jaouna	2.28	1.92	2.30	**2.17**
Rhouireg	0.98	0.78	1.44	**1.07**
Dfali	1.30	1.31	1.49	**1.37**
Taza	1.35	1.82	1.66	**1.61**
Laâzib	0.78	0.76	1.61	**1.05**

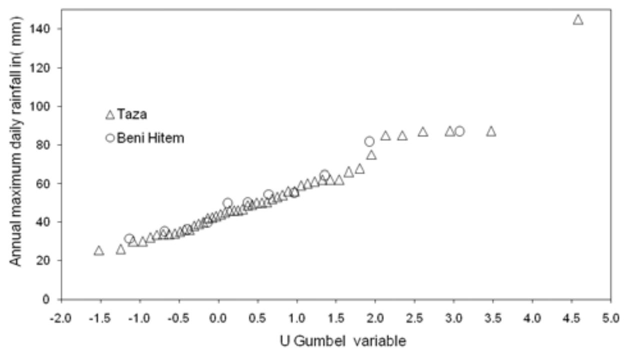

Figure 3: Graphical adjustment for annual maximum daily rainfall.

Table 3: Maximum daily Rainfall and rainfall in 24H for different return period.

		Gradex	P2	P5	P10	P20	P50	P100	P1000
Taza	MDR	16.45	50	69	86	92	108	120	146
	Rainfall in 24 h	18.9	57.5	79.35	98.9	105.8	124.2	138	167.9
Beni Hitem	MDR	14.65	50	67	82	88	102	110	131
	Rainfall in 24 h	16.8475	57.5	77.05	94.3	101.2	117.3	126.5	150.65

In this study, the Gradex method is based on a certain frequency called the reference T, generally included between 10 years and 20 years frequency [16], depending of the soil permeability. In the case of the catchment covered by this study, we will consider as reference frequency the decennial frequency (T = 10 years).

The empirical formula of Caquot takes the following form:

$$Qf(T = 10years) = K^{\frac{1}{U}} I^{\frac{V}{U}} C^{\frac{1}{U}} A^{\frac{W}{U}} \quad (8)$$

$Qf(T = 10years)$: is the reference flow of the 10 years frequency.

I: is the average slope of the Thalweg.

C: is the runoff coefficient taken equal to 20%.

A: is the drainage area in hectares.

The expressions coefficients for K, U, V and W are calculated by

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Table 4: Corrected flow.

Rivers	L in Hm	ΔH in Ha	M	m	$Qf(T=10years)$ m³/s	Corrected $Qf(T=10years)$ m³/s
larbaâ	430	168.522	2.55	0.9076975	173	157
Bouljraf	370	173.781	2.13	0.975433	167	163
Jaouna	220	69.282	3.18	0.8320951	52	43
Rhouireg	75	28.284	2.65	0.8939182	13	12
Dfali	135	47.434	2.85	0.8691247	33	29
Taza	150	65.574	2.29	0.9479996	57	54
Laâzib	50	27.386	1.83	1.0369085	11	12

following formulas.

$$K = 0.5^{b(T)} \frac{a(T)}{6.6} \quad (9)$$

$$U = 1 + 0.287b(T) \quad (10)$$

$$V = -0.41b(T) \quad (11)$$

$$W = 0.95 + 0.507b(T) \quad (12)$$

The parameters values of a(T) and b(T) are deduced from (IDF) curves by using the Montana formula:

$$i(t,T) = a(T)t^{b(T)} \quad (13)$$

The Caquot formula becomes by return period (10 years) as follows:

$$Qf(T=10years) = 0.9987\ I^{0.2783}\ C^{1.195}\ A^{0.791} \quad (14)$$

After this step we calculated the coefficients of influence (m) for different watersheds, these allowed us to correct the flows calculated by the Caquot empirical formula.

$$m = \left(\frac{M}{2}\right)^{0.7b(T)} \quad (15)$$

With $M = \frac{L}{\sqrt{A}}$ 16)

L is the thalweg length in hm, and A *is* the drainage area in ha.

The reference flows by the Caquot empirical formula, and the corrected flows for different Rivers are represented in the Table 4.

The determination of influence coefficient is based on rainfall parameter deduced from IDF curves and catchment geometric characteristics (A and L). These factors influence the shape of the catchment and of the time of concentration. When the catchment shows an elongated shape with long stream length (Jaouna, Rhouireg, Dfali, Taza larbaâ and Bouljraf River) the correction factors takes part to decrease the values of reference peak flow and vice-versa.

Regarding the comparison between the reference (calculated by Caquot formula) and the corrected flow, we have recorded that the correction goes to decline the flow for all Rivers, except Laâzib River. This decrease is variable between the Rivers, it running from 1 m³/s for Rhouireg River to 16 m³/s for Larbaâ River. The flow decrease variation of different Rivers is explained by the variation of catchment parameters (A and L). Contrary to these Rivers, the flow for Laâzib River presenting the shorter length of Thalweg grow up relatively by 1 m³/s.

Estimation of runoff and volume of water for the reference frequency

The Determination of the flood hydrograph is necessary for the estimation of runoff and the water volume for the reference frequency. This determination can be made directly if we know the couples rain-flood, or otherwise by empirical methods or by comparison with analogous catchments. In this study we adopted empirical methods that allowed us to determine a unit hydrograph (triangular simplified) (Figure 4) with a time base equal to twice the peak time which is taken equal to the concentration time of the watershed.

The volume of water of reference V (T = 10years chosen unit) corresponding to the reference flow (T = 10 years) is deduced from the hydrograph for this study by multiplying concentration time of the catchment by the corresponding flow of reference.

$$V(T=10) = \frac{Q \times 2Tc}{2} \quad (17)$$

The runoff of reference frequency Rf (T = 10years) is deducted from the reference volume V (T10 years) divided by the area of the cachment. The results are grouped in the Table 5.

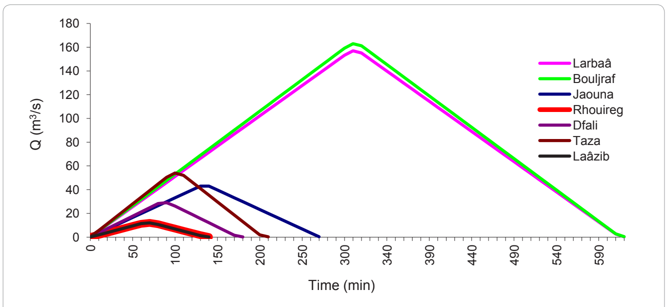

Figure 4: Typical unit hydrograph for different Rivers of Larbaâ catchment.

Table 5: Flow, runoff and volume of water of reference frequency.

Rivers	Qp (T=10) en m³/s	V (T = 10years) Mm³	Rf (T = 10years) mm
Larbaâ	157	2.90	10.19
Bouljraf	163	3.00	9.94
Jaouna	43	0.34	7.02
Rhouireg	12	0.05	5.69
Dfali	29	0.14	6.27
Taza	54	0.32	7.33
Laâzib	12	0.04	5.88

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Table 6: Runoff, volume of water and flow for different frequencies.

Watershed	Runoff in mm				Volumes of water in Mm³				Q in m³/s			
	10 yrs	20 yrs	50 yrs	100 yrs	10 yrs	20 yrs	50 yrs	100 yrs	10 yrs	20 yrs	50 yrs	100 yrs
Larbaâ	10.19	13.56	31.12	44.28	2.9	3.85	8.84	12.57	157	209	480	682
Bouljraf	9.94	14.13	32.43	46.14	3	4.27	9.79	13.93	163	232	531	756
Jaouna	7.02	9.87	22.64	32.21	0.34	0.47	1.09	1.55	43	61	139	198
Rhouireg	5.69	7.65	17.55	24.97	0.05	0.06	0.14	0.2	12	16	36	52
Dfali	6.27	8.46	19.41	27.62	0.14	0.19	0.44	0.62	29	39	89	126
Taza	7.33	9.51	21.81	31.04	0.32	0.41	0.94	1.33	54	71	162	231
Laâzib	5.88	7.75	17.79	25.31	0.04	0.06	0.13	0.19	12	15	35	50

$$\mathrm{Rf}\,(\mathrm{T}=10) = \frac{V}{Sbv} \quad (18)$$

Calculation of the runoff and the peak flows for different frequencies

The principle basic on which we relied in the Gradex method is that the flood is even more important in terms of peak flow, if the watershed considered liable to a rainfall in the duration coincides with the concentration time of the catchment. Besides, it is considered that a rain of a return period T leads to a flood for the same return period.

- The passage from the rainfall of 24 hours Rl (24) to the rainfall over the time of concentration Rl(Tc) for different frequencies is recovered by using the following formula:

$$Rl(Tc) = Rl(24)\times\left(\frac{Tc}{24}\right)^{(1-b)} \quad (19)$$

Therefore, the runoff Rf (T/ Tc) over the time of concentration and for different return periods is obtained using the equation below:

$$Rf(T/Tc) = Rf(T_r/Tc) + G_p(Tc)\times[U(T)-U(T_r)] \quad (20)$$

with $U(T) = -\ln(-\ln(1-\frac{1}{T}))$ is the Gumbel variable; $Rf(T_r/Tc)$ is the runoff of reference.

Gp (Tc) is the gradex over the concentration time; it is deduced from the gradex in 24 hours by the following formula:

$$G_p(Tc) = G_p(24h)\times\left(\frac{Tc}{24}\right)^{(1-b)} \quad (21)$$

From the runoff of different frequencies we can deduce the volume of flood for different return period by multiplying the runoff with the drainage area of the catchment. In other ways the peak flow is extracted by injecting the flood volume of different frequency in the unit hydrograph.

Finally, results are shown in the Table 6.

Conclusion

In the context of hydraulic design, hydrologic analysis provides estimates of flood magnitudes as a result of precipitation. These estimates consider processes in a watershed that transform precipitation to runoff and that transport water through the system to a project's location.

Gradex method is considered as the reference method of Morocco of design flood. Today, this approach is the most used for hydraulic design. The Gradex method allowed us to know the peak flows for different return periods ranging from 10 to 100 years. These results constitute a helpful document for hydraulic modeling that allows the calculation of flow profiles and flood propagation in the floodplain.

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