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Estimation of the peak flows in the catchment area of Batna (Algeria)

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Abstract: The limited knowledge of the variations, both spatial and temporal, of the flow patterns at the watershed level invariably leads to poor space management, generating great and often irreversible damage. Therefore, measuring peak flows appears to be not only important but even essential. Due to the absence of hydrometric stations at the outlet of the sub-basins that are part of comprehensive prevention strategy, and were established because of the high vulnerability of the city of Batna, this study provides a transformation model of rainfall into flows in the Batna watershed. This work aims to model the transformation of rainfall into flows. To estimate the Q max, two formulas were used, and Turazza's seems to be the most adequate, because it demonstrates a cumulative sub-basins flow close to the result recorded by the only hydrometric station at the outlet of Batna Watershed. From this modeling, it is possible to estimate the extreme quantiles with the return periods of 10, 20, 50 and 100 years for each sub-basin. Its purpose is to help design of hydraulic works and increase the resilience of development projects that might be exposed to floods.

Keywords: Flows; Floods; Empirical methods; Rainfall; Turazza

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Introduction

The floods in Algeria are among the ten major hazards plaguing the country. Batna is not exempted either, the flooding has caused great damage and traumatized the people. To cope with the floods in this city, a methodical hydrological study based on reliable statistical models is essential. The purpose of this initiative is to design the hydraulic structures used to prevent flooding and to draw up a map identifying areas exposed to this hazard.

The modelling of an object or a situation in most scientific fields is a technical process aimed at getting knowledge and taking action (Garambois P A, 2012). Hydrological modeling facilitates the understanding of natural phenomena such as flash floods, and attempts to simulate the complex hydrological processes that lead to the transformation of rain into flow (Khaddor I *et al*. 2016).

Hydrologists consider hydrological modelling fundamental in terms of flood forecasting. It has also become a major tool for supporting decision-making in the management of water resources, particularly with regard to the assessment of flows for hydraulic installations and other projects (Aurore D *et al*. 2008). Hydrological modeling aims to replicate the hydrological behavior of a watershed (Beckers E *et al*. 2011).

The elementary space unit in surface hydrology is the watershed (catchment area) (Fouchier C, 2010). Hydrological risk studies mainly make use of statistical analysis of past events and aim to estimate the probability of a given hydrological event (Arnaud P and Lavabre J, 2000). The measurement of stream peak flows, which includes their probability of occurrence, is essential and

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plays a major role in the design of hydraulic works and the resilience of development projects that might be exposed to floods. Waterways not equipped with hydrometric stations could pose difficulty for forecasting, which requires statistical methods dealing with the transformation of rains into flows. Empirical formulas should only be used exceptionally, for instance when sufficient hydrometric data are not available.

The choice of calculation methods depends on the availability of the data. We used two empirical methods the Turazza formula, on the one hand which uses rainfall intensity, runoff coefficient, time of concentration and the watershed's surface to estimate peak flows in ungauged watersheds; and the Burkli-Ziegler's formula, on the other hand, which involves the aforementioned parameters, but also factors in the catchment area's slope.

After comparing the cumulative flows calculated using both methods with those estimated by the frequency analysis, the Turazza formula appeared to be more adequate than the Burkli-Ziegler formula because its results are the closest to the local reality.

1 Study area

Located in eastern Algeria, the Batna catchment area (Fig. 1) covers an area of 284.6 km^2, between latitudes 35° 25' and 35° 42' North and between longitudes 6° 5' and 6° 24' East.

The region has a semi-arid climate, characterized by irregular rainfall. However, in the absence of hydrometric stations in the various sub-basins, the rainfall data allowed the empirical estimation of the peak flows. The table below shows the PJ max values for each Batna sub-basin and for the different return periods in mm. The only hydrometric station is that of Fesdis (Fig. 1), located at the outlet of the Batna catchment area. The series of flows recorded at this station (obtained from Agence Nationale des Ressources Hydriques-ANRH, 2012) covers a period of 18 years, from 1969 to 1986.

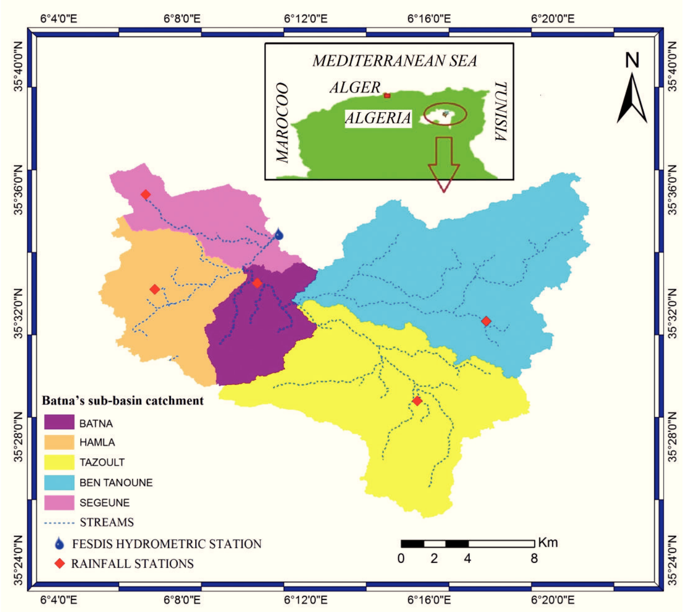

Fig. 1 Batna catchment area

Table 1 PJ max values for each sub-basin and for different return periods in mm (Guellouh S *et al*. 2016)

Return period sub-basins	10 years	20 years	50 years	100 years
Batna City	56.9	65.5	76.6	84.9
Hamla	57.1	68.6	84.9	98.1
Tazoult	70.8	81.5	95.3	106
Ben Tanoune	58.7	67.9	79.8	88.7
Seguene	79.6	94.3	114	129

Table 2 Physical characteristics of the sub-basins

Sub-basins	Min altitude (m)	Max altitude (m)	Mean altitude (m)	Surface area (km^2)	Main Talweg's length (km)	Mean slope (%)
Batna City	1 015	1 768	1 389	26.6	4.94	9.16
Hamla	1 021	1 751	1 385	43.56	6.82	8.12
Tazoult	1 055	1 859	1 456	90.12	12.96	9.21
Ben Tanoune	1 053	1 657	1 345	96.20	17.37	7.30
Seguene	1 009	1 773	1 383	28.14	3.28	12.14

Table 3 Statistical parameters of the series of recorded flows

Parameters	Number of values	Min value m^3/s	Max value m^3/s	Mean value m^3/s	Median	Standard deviation	Skewness Coefficient (CS)	Coefficient of variation (CV)	Coefficient of flattening (CK)
Fesdis Station	37	5	350	88.4	60	69.3	1.48	0.784	6

2 Materials and methods

2.1 Frequency analysis of the maximum flow rates of the Fesdis hydrometric station

We used the peaks-over-threshold (POT) methodology for the sample. The frequency analysis performed on the time series of recorded flows allowed the estimation of extreme quantiles with the return periods of 10, 20, 50 and 100 years using the HYFRAN (Hydrological Frequency Analysis) software developed by the INRS-EAU of Canada.

The peak flow series is constructed using data above a threshold of 5 m^3/s of recorded flows each year. The statistical parameters are calculated and summarized in Table 3.

In accordance with the frequency analysis methodology, it is necessary to ensure the independence, homogeneity and stationarity of the series (Wilcoxon F, 1945).

The independence hypothesis was validated using the Wald-Wolfowitz test. The homogeneity and stationarity tests used were respectively those of Wilcoxon and Kendal. The results of the three tests indicated that the observations are valid at a threshold of 5%, as shown in Table 4.

Fig. 2 shows that the data fit well according to Gumbel's law. In Algeria, this law is the most used by the official meteorological services (Benkhaled A, 2007).

Table 4 Results of statistical tests applied to peak flows (Fesdis station)

Stationarity test	Independence test	Homogeneity test
(K)=1.07	(U)=0.641	(w)=1.23
(P)=0.286	(P)=0.522	(P)=0.218

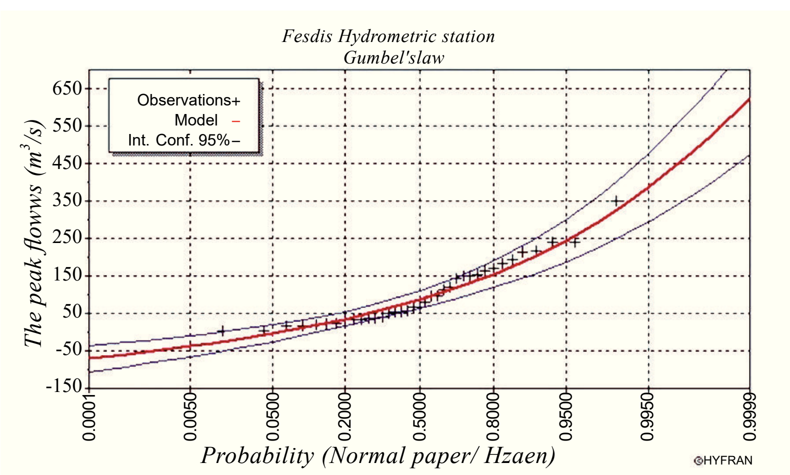

Fig. 2 Adjustment of peak flows through Gumbel's law

2.2 Calculation of flows for each sub-basin

2.2.1 Turazza formula (1867)

The formula states that peak flows to be concerned about at the outlet of a watershed are reached when the duration of the rain is equal to at least the time of concentration

The expression is formulated as:

$$Q\ Max= C*I(T_c)*A/3.6*T_c \quad (1)$$

Where:

Q is maximum flood flow in m^3/s;

C is the runoff coefficient of the flood considered;

$I(T_c)$ is peak precipitation intensity for a duration equal to the time of concentration in mm/h;

A is surface area of the watershed in km^2;

T_c is time of concentration.

The results are summarized in the table below.

2.2.2 Burkli-Ziegler formula (1880)

The Burkli-Ziegler equation is a modification of the rational formula that explicitly introduces the shape of the basin in the calculation procedure. This formula places more emphasis on the influence of the basin's slope in estimating peak flows (Beloulou L, 2008). Expressed in Anglo-Saxon units, according to Watt (Watts S B and Tolland L, 2005), it takes the following form:

$$Q\ Max = C_r * I(T_c) *A * (IBV/A)^{0.25} \quad (2)$$

Where:

Q is Peak flow in Cubic feet/ second (1 m^3/s = 35.3 Cfs);

$I(T_c)$ is intensity of rain for a duration equal to the concentration time in inch/h;

T_c is basin time of concentration in hours;

A is area of catchment area in acre;

C_r is runoff coefficient;

IBV is the slope of the basin (‰).

2.3 Calculation of parameters

2.3.1 The runoff coefficient for each sub-basin

The runoff coefficient (Cr) is the ratio of the height of runoff to the precipitation of water during a downpour. The runoff coefficient depends mainly on the intensity of the rains, the nature of the soil, the slope and the vegetation cover.

Nevertheless, the notion of runoff coefficient remains rather tricky because it is far from being constant. At the same site, it could vary according to the nature, volume and intensity of the rain, as well as the types of surfaces (Pratt C J *et al*. 1984).

We calculated the Cr values using the following formulas:

$$C_r = 0.8\ [1-(P_0/ P_{J\ max})] \quad (3)$$

Where:

$P_{J\ max}$ is maximum daily precipitation for a return period T.

$$P_0= \Sigma P0I * AI \quad (4)$$

Where:

P0I is initial retention of vegetation cover i;

Ai is percentage of ve getation cover area i.

Table 5 Estimated initial retention P_0 (Sogreah P, 1996)

Vegetation cover	Morphology	Slope (%)	Coarse sand soil	Loamy soil	Clay soil or compact and rocky
Woods Garrigue	Almost flat	0-5	90	65	50
	Rolling	5-10	75	55	35
	Hilly	10-30	60	45	25
Pastureland	Almost flat	0-5	85	60	50
	Rolling	5-10	80	50	30
	Hilly	10-30	70	40	25
Crops	Almost flat	0-5	65	35	25
	Rolling	5-10	50	25	10
	Hilly	10-30	35	10	0

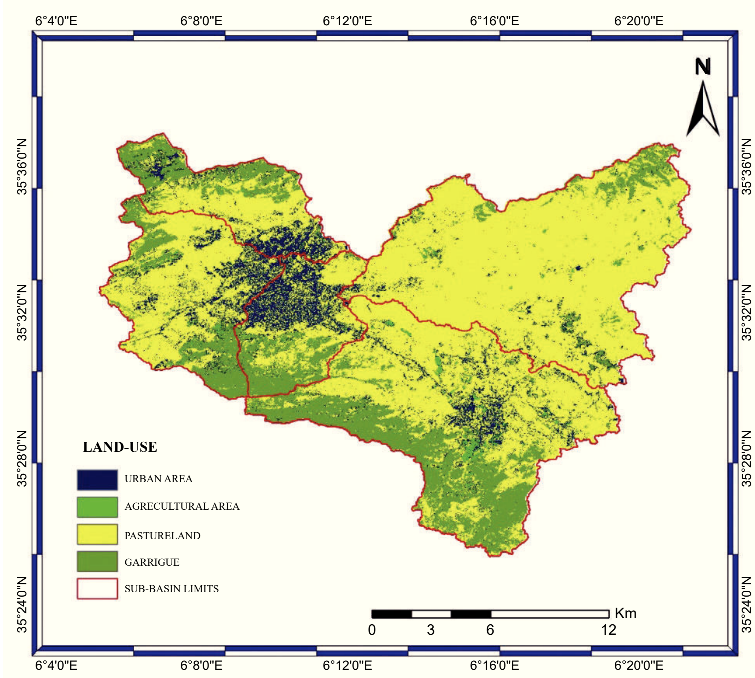

Fig. 3 Land-use map

To estimate the surface spatial distribution of each type of vegetation, we performed a supervised classification on a Land SAT 8 satellite image with a 30-meter resolution covering all the sub-basins.

We chose the coloured composition of channels 4, 3, and 2, which maked it possible to identify the various land-use units objectively.

Classification in remote sensing involves clustering the pixels of an image to a (relatively small) set of classes, so the pixels in the same class have similar properties. Supervised classification, however, does require prior knowledge of the ground cover in the study site (Ismail M Hasmadi *et al*. 2009). The purpose of this analysis is to classify the characteristics of a satellite image, using the visual interpretation elements to identify homogeneous groups of pixels (each pixel contains spectral information depending on the type and nature of land use); this method represents surface classes using a test data based on the previous knowledge of the study area.

On the basis of this classification we have been able to extract information on the nature of land-use for each sub-basin:

Sub-basin of Batna: 30.43% urban area (impermeable), 27.63% garrigue (scrubland), 0.49% crops (agricultural) and 41.42% pastureland.

P_0 Batna city = 0.4142*30 + 0.0049*10 + 0.2763*35 = 22.09 mm

Sub-basin of Hamla: 16% urban area, 44.16% garrigue, 0.55% crops and 63.58% pastureland.

P_0 Hamla = 0.6358*30+0.0055*10+0.4416*35 = 35.08 mm

Sub-basin of Tazoult: 9.49% urban area (impermeable), 31% garrigue, 1.05% crops and 58.52% pastureland.

P_0 Tazoult = 0.5852*30+0.0105*10+0.31*35 = 28.51 mm

Sub-basin of Ben Tanoune: 3.17% urban area, 6.35% garrigue, 0.16% crops and 90.31% pastureland.

P_0 Ben Tanoune = 0.9031*30 + 0.0016*10 + 0.0635*35 = 31.94 mm

The Seguene sub-basin: 19.75% urban area (impermeable), 27.72% garrigue, 0.53% crops and 52% pastureland.

P_0 Seguene = 0.2772*25+0.0053*10+0.52*25 = 20 mm

2.3.2 The time of concentration for each sub-basin

The time of concentration of the catchment area T_c, defined as the time spent by a single drop of rain falling at the basin's furthest point in order to reach the outlet, is one of the most important parameters in the study of floods. Given that the most devastating rainfalls are those that last longer

Table 6 Cr values for each sub-basin and for various return periods

Return period sub-basins	10 years	20 years	50 years	100 years
Batna City	0.49	0.53	0.57	0.59
Hamla	0.30	0.39	0.47	0.51
Tazoult	0.47	0.52	0.56	0.58
Ben Tanoune	0.36	0.42	0.47	0.51
Seguene	0.59	0.63	0.66	0.67

than the basin response time, uncertainties over the time of concentration will cause an error in peak flood flow (Beloulou L, 2008). In practice, the time of concentration can be either derived from field measurements or mostly evaluated through empirical formulas (Layan B, 2012).

We used three formulas (expressions) for calculating T_c.

(a) The Giondotti expression:

$$T_c = \frac{4\sqrt{S} + 1.5L}{0.8\sqrt{H_{moy} - H_{min}}} \quad (5)$$

Where:

T_c is the time of concentration in hour;

S is the area of the watershed in km^2;

L is the length of the main road in km;

H_{moy} is the average height of the catchment area in meter (m);

H_{min} is the minimum height of the watershed in m.

(b) The Turazza expression

Formulas used for calculating the time of concentration are the most used in the Mediterranean region according to several authors (Layan B *et al*. 2012; Tahiri M *et al*. 2017; Lahsaini M *et al*. 2018).

$$T_c = 0.108\frac{6\sqrt[3]{LS}}{\sqrt{I}} \quad (6)$$

Where:

T_c is the time of concentration in hour;

L is the length of the main road in km;

S is the area of the watershed in km^2;

I is the average slope of the watershed in %.

(c) The Ventura expression

$$T_c=76.3* A\ 0, 5/I\ 0, 5 \quad (7)$$

Where:

T_c is the time of concentration in minutes;

A is the watershed area in km²;

I is the average slope of the basin in %.

We have retained the average time obtained from the three above formulas:

(d) Peak intensity of precipitation for a period equal to the time of concentration

The intensity of the rains fallen during a time equal to the time of concentration can be calculated by the following formula:

$$I_{Tc} = P_{J\,max} * (T_c /24)^{1-b} \quad (8)$$

Where:

$P_{J\,max}$ is the daily peak precipitation for a return period T;

T_c is the time of concentration of the catchment;

b is the Montana's regional coefficient equal to 0.284.

Table 7 Time of concentration for each sub-basin

Sub-basins	T_c in hrs (Giondotti)	T_c in hrs (Turazza)	T_c in hrs (Ventura)	Retained T_c in hrs
Batna City	1.81	1.10	2.16	1.69
Hamla	2.4	1.52	2.94	2.28
Tazoult	3.58	2.25	3.90	3.24
Ben Tanoune	4.77	2.84	4.61	4.07
Seguene	1.68	0.84	1.9	1.47

Table 8 I_{Tc} values for each sub-basin

Return period sub-basins	10 years	20 years	50 years	100 years
Batna city	8.51	9.8	11.45	12.7
Hamla	10.58	12.71	15.73	18.18
Tazoult	16.87	19.43	22.72	25.27
Ben Tanoune	16.74	19.05	22.39	24.9
Seguene	10.77	12.76	15.43	17.46

Table 9 The peak flows and 95% confidence intervals of the Fesdis hydrometric station using the Gumbel distribution

Return periods	10 years	20 years	50 years	100 years
Peak flows	168	207	254	289
95% confidence intervals	[133-209]	[161-254]	[196-312]	[223-356]

3 Results and discussion

The results of the flow series frequency analysis of the Fesdis station and their 95% confidence intervals are summarized in the table.

According to the frequency analysis, there is a one-in-ten chance of flood occurring with a flow between 133 m^3/s and 209 m^3/s, and one in a hundred probability of occurrence of a flow within a 223 m^3/s to 356 m^3/s range, taking place downstream of the Batna catchment area.

The results show that the Burkli-Ziegler formula gives lower values than those calculated with the Turazza formula. The introduction of the sub-basin slope in the Burkli-Ziegler formula has led to a significant drop in the peak flows calculated, in particular in the Seguene sub-basin, by up to 47%.

The results are summarized in the Table 10-Table 12.

Table 10 Peak flow rates according to the Turazza formula in m^3/s

Return period sub-basins	10 years	20 years	50 years	100 years
Batna City	18.23	22.7	28.53	32.76
Hamla	61.26	78.06	98.3	113.24
Tazoult	16.84	26.3	39.23	49.20
Ben Tanoune	39.56	52.53	69.09	83.37
Seguene	33.78	41.07	54.15	62.20

Table 11 Peak flow rates according to the Burkli-Ziegler formula in m^3/s

Return period sub-basins	10 years	20 years	50 years	100 years
Batna City	10.5	13.08	16.44	18.87
Hamla	49.68	63.3	79.72	91.83
Tazoult	11.23	17.53	26.15	32.80
Ben Tanoune	37.61	50	65.67	79.25
Seguene	17.91	22.57	28.70	32.97

Table 12 Comparison of results

Return periods/ Calculation methods	10 years	20 years	50 years	100 years
Fesdis station	168	207	254	289
Turazza's formula	169.67	220.66	289.3	340.77
Burkli-Ziegler's formula	126.93	167.22	216.78	288.69

4 Comparison of results and validation

The peak cumulative flows reached by the Turazza and the Burkli-Ziegler methods are relatively close to those measured by the Fesdis hydrometric station.

The cumulative maximum flow rate determined by the Turazza method is higher than that measured by the hydrometric station of Fesdis in contrast to the Burkli-Ziegler method. In this case, we have adopted the results of the Turazza method, which maximizes the results to enable an efficient prediction level and to increase the level of safety and protection against the risk of flooding.

5 Conclusions

The absence of surface flow measuring equipment at the sub-basins of the Batna catchment area led us to determine peak flows through empirical methods. According to the frequency analysis of the flow series recorded by the only hydrometric station at the outlet, there is:

A one in ten probability of flood occurring downstream of the sub-basins draining the town of Batna with an estimated flow ranging between 133 m^3/s and 209 m^3/s;

A one in a hundred chance of occurrence of a flood with a flow ranging between 223 m^3/s and 356 m^3/s;

A one in a thousand chance of an occurrence of a flood between 310 m^3/s and 501 m^3/s.

To estimate the Q max, two formulas were used and Turazza's has been adopted because it shows a cumulative sub-basins flow close to that estimated by the frequency analysis; it also maximizes the calculation results which can provide more effective forecast.

These empirical formulas should be used exceptionally only when hydrometric data are insufficient.

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