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The December 1984 exceptional storm: A reference event for watercourses management and flood control plans in the Saf-Saf wadi watershed, NE of Algeria

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Abstract

Flood hazard prevention plans and watercourse management require a lot of data; the most important is the flood event that will serve as a reference. In practice, this reference flood is often assumed to be the greatest ever known historical flood or the 100-year flood if the latter would be greater than the recorded historical one. The purpose of this paper is to provide some data that help in the elaboration of such plans. Indeed, analysis of severe storms and extreme discharge records in the Saf Saf wadi watershed and statistical data processing (frequency analysis) revealed that the December 28th, 1984 to January 1st, 1985 heavy storm is an exceptional event with respect to the intensity (324mm in 5 days), the magnitude of the generated flood (peak discharge: 754m^3/s, flood volume: 75hm^3 at the Zardézas dam) and the extent of property damages and human losses (11 dead). Historical data and frequency analysis results show that this deadly well documented event could be a good reference to elaborate flood control and watercourse management plans to reduce vulnerability to flooding in the Saf-Saf wadi basin.

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Introduction

Sustainable flood risk management is a matter of reducing the vulnerability of people and property to floods by adopting rational policy measures. It is a much more efficient and a preventive way than controlling water flow by hydraulic structures that rapidly lose their performance during high floods. Reducing vulnerability is not to increase the number of people and activities subjected to flood hazard and to take actions to limit damages for those already located in flooding areas.

In Algeria, this new flood prevention strategy has been introduced by the 24 and 25 clauses of Law No 04-20 of December 25, 2004 on major hazards and disasters management prevention within the context of sustainable development (RADP, 2004). This law is issued following several deadly floods; the most important is the 2001 Algiers Bab el Oued flood (more than 700 deaths). To elaborate flood hazard prevention and watercourse management plans requires efficient data on historical river discharges and heavy rain events in order to define the reference flood. Somme foreword steps should therefore be followed: maximum discharge and severe storms frequency analysis, rainfall-runoff modeling and flood hazard mapping.

At the outlet, to the East of Skikda City, this 55 km long river and its tributaries drain an 1158 km² area (Fig. 1). The Saf-Saf hydrographic system originates at the confluence of the Bouhadjeb and the Khemakhem wadis in the Constantine Mountains and flows North to the Mediterranean Sea. Along its course, the river traverses the upstream Zardezas rolling hills and the Salah Bouchaour-Ramdane Djamel-Hamrouche Hamoudi flood plains. Its tributary, the Zeramna wadi drains the southwestern part of the basin and flows into the large plain of El Hadaiek-Merdj Eddib to join the Saf-Saf in the vicinity of the petrochemical industrial zone. These flatlands are urbanized and, therefore, highly vulnerable to flooding.

In this study, we attempt to extract some useful information from the December 1984 extreme rainfall event and the generated deadly flood in order to present some guide values that help in elaborating such a plan in the Saf-Saf wadi basin.

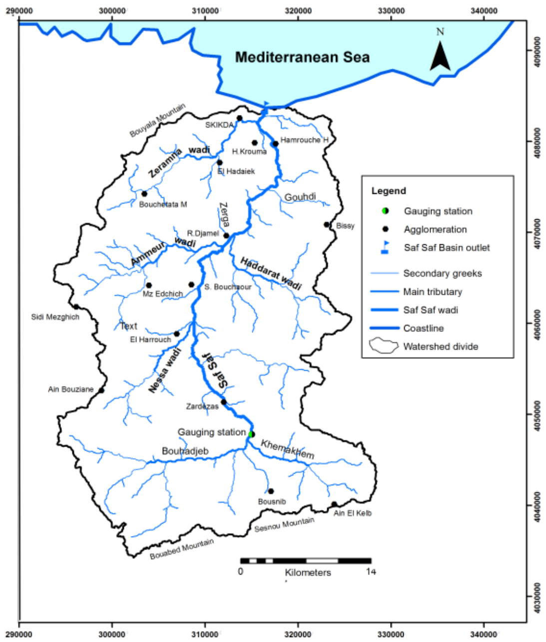

Fig. 1. Saf Saf wadi basin-Situation and hydrographic network map.

Material and methods

The December 1984 exceptional rainfall event characteristics

The December 1984 flood is the result of a series of severe and exceptionally intense storms that struck the entire Saf-Saf wadi basin (452.5mm in 16 rainy days, 137mm recorded rain on December 29th, 1984 at the Zardezas Dam rain gauge). Similar daily intense rainfall events were also observed on the same day at other stations in the watershed (75.6mm in Bousnib, 111.2mm in Ramdane Djamel and 73.5mm inSkikda). Table 1 gives some rainfall indices recorded in the watershed between the 28 and 30th of December, 1984.

For more details on this exceptional event, rainfall recording charts at the Zardezas Dam are analyzed. The rain started falling on the December 28th, 1984 at 2:45 and ended on the January 1st, 1985 at 12:11. Automatic data processing allowed obtaining hyetographs and maximum intensities observed for different reference durations. In Table 2 rainfall depths recorded during a 6 hour duration interval are presented in the following diagram (Fig. 2).

Table 1. Rainfall indices related to the December 1984 flood (mm).

Rain gauge name	Code	12/28	12/29	30/12	Cumulative : December, 1984	Year : 1984/85
					Upstream part of the watershed	
Bousnib	030905	-	75.6	-	269.8	783.6
Ain El Kelb	030904	-	103,2	-	212,0	650,3
Zardezas	030903	-	137	-	452.5	1039.4
					Middle stream part of the watershed	
El Harrouch	030906	41.8	93.8	97.6	379.6	932.2
Ramdane Djamel	030909	73.6	111.2	84.3	427.8	1028
					Downstream part of the watershed	
Skikda	030801	50.9	73.5	72.3	347.5	1148.9

Table 2. Hyetograph outputs for a 6-hour duration at the Zardezas Dam (Rainy periods: 12/28/1984 - 01/01/1985).

Reference duration (h)	Rainfall depth (mm)			Composite hyetograph (Dec 28th, 1984-Jan 1st, 1985)
	Dec 28th 1984	Dec 29th -30th 1984	Dec 31th, 1984- Jan 1st, 1985	
0-6	11,5	27,2	37,4	11,5
6-12	19,5	49,7	9,5	20,0
12-18	8,9	33,5	3,7	8,5
18-24	19,0	35,1	11,6	19,0
24-30	4.0	11,6	3,9	4,0
30-36		17,7	18,9	9,1
36-42		1,3	0,1	41,9
42-48				39,5
48-54				50,0
54-60				8,8
60-66				20,9
66-72				21,6
72-78				30,2
78-84				3,7
84-90				4,8
90-96				9,6
96-102				12,6
102-108				8,4
Total (mm)	63,0	176,0	85,0	324,0

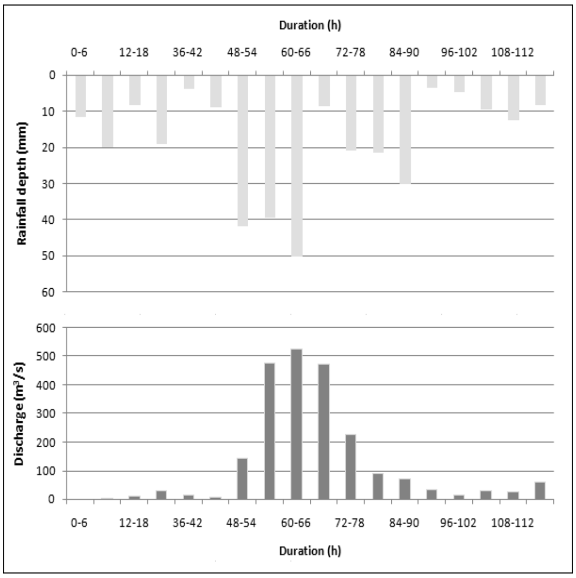

Fig. 2. Hyetograph and hydrograph of the 28/12/1984 to 01/01/1985 flood.

A close look at the analysis results of this extremely severe storm event shows that the rainfall recorded on 29 and 30 December at the Zardezas Dam is marked by very high intensities (50.0, 89.5 and 131mm in 6, 12 and 18 hours, respectively, and 324mm in 4 days). These nonstop torrential rainfall events and saturated soil by antecedent rainfalls conditions (63mm recorded on December 28) are the main factors that affected the rapid rise of water levels in the stream. Maximum peak discharges and volumes are 559 and 754m^3/s at the Khemakhem discharge gauging station and the Zardezas Dam spillway, respectively, on December 30 at 4:00 am. Respective flood volumes are estimated to be 50 and 75h m^3 corresponding to 157.0 and 218.0mm of runoff in 4 days.

The volume that entered the dam is equivalent to 2.4 times the initial dam capacity of 31hm³.The December 1984 Rainfall-Runoff event main characteristics are summarized in Table 3.

Table 3. Characteristics of the 28/12/1984 to 01/01/1985 *Rainfall-Runoff* event.

Charactéristics	Khemakhem gauging station	Zardezas Dam gauging station
Rainfall depth (mm)	324.0	345.0
Runoff (mm)	157.0	218.0
Runoff coefficient (%)	48.5	67.3
Begining of flood	12/28 at 00:00	12/28 à 00 :00
End of flood	01/01 at 13:00	01/01 at 13 :00
Peak discharge	559	754
Peak discharge date and hour	30/12 at 04:00	30/12 at 04 :00
Flood volume (Hm³)	50.5	75.2

Flood frequency analysis

Relevant estimate of extreme hydrological events is critical because of the significant risks associated with poor knowledge of these variables. Frequency analysis of hydrological data is a preferred approach to obtaining good estimates of extreme events if sufficient information is available at the site of interest. However, due to the large extent of the watershed and the hydrographic network, the question of estimating extreme events in sites where little or no information is available often arises.

The objective of this section is to predict the absolute maximum flows (Q_p or peak flows) for given return periods (T) or probabilities of occurrence (P) of the Saf-Saf wadi at the Khemakhem gauging station. The outcomes are then transposed to different temporal and spatial scales defined by the main sub-basins, assuming that the latter belong to the same hydrological unit. Furthermore, the validity of the results of the frequency analysis is strongly dependant of the length of the time series and the method used to evaluate the intensities of rare events (Comby, 2001). In this purely probabilistic approach, the evaluation of rare events is usually summarized by the fitting of a probability distribution model to the empirical frequency distribution of maximum observed flows.

Low frequency flow rates are deduced from the extrapolation of the adjusted statistical law and the T-year flows are used to define reference floods to develop flood hazard prevention and watercourse management plans in the Saf-Saf basin. In hydrology, several frequency models are often used to describe the statistical behavior of extreme values. The validity of the results of the frequency analysis depends on the choice of the frequency model (and more particularly on its type). Indeed, this analysis, which makes use of various statistical techniques and powerful automatic calculation programs, constitutes a complex process which must be dealt very rigorously.

Data processing and reliability analysis of peak flow time series

In frequency analysis, where the observed information over a relatively short series is to be transferred to longer series, the question of the quality and reliability of the data often arises. Should all available data be used? Or, on the contrary, should some values be considered as outliers for one reason? In this work, this question is approached using various techniques to detect potentially undesirable values because the presence of exceptionally low or high values in a data sample may lead to an overestimation of the standard deviation, an important parameter that describes the adjusted probability law.

From a mathematical point of view, the frequency distribution study of a random variable requires, in addition to the relevance of data, the verification of some basic hypotheses, in particular the random and homogeneous nature of the values taken by the variable in question. Peak discharge records (absolute maximum flow or peak flow: Q_p) were subjected to an exploratory data analysis (Tukey, 1977) and to a series of hypothesis tests in order to check the suitability of the peak discharge time series to frequency analysis. In addition to graphical tests (histogram, box plot, stem and leaf diagrams), the non-parametric tests of Wald-Wolfowitz for randomness (in Kanji, 2006) and Mann-Whitney for homogeneity (in Dodge, 2006) as well as the Grubbs and Beck test for outliers (Grubbs and

Beck, 1972, Carletti, 1976; Planchon, 2005; Verma and Q-Ruiz, 2006 and Kaya, 2010) integrated into the Hydrological Frequency Analysis and Statgraphics Centurion XV softwares have been applied.

Exploratory analysis of a 34 year observation period (1968/69-2000/01) and statistical tests results show that the peak flow time series is suitable for frequency analysis. They also point out the presence of three extremely large events in the series (Fig. 3). These events are retained because they are not considered as outliers; they correspond to the highest floods generated by the heavy rains during the observation period.

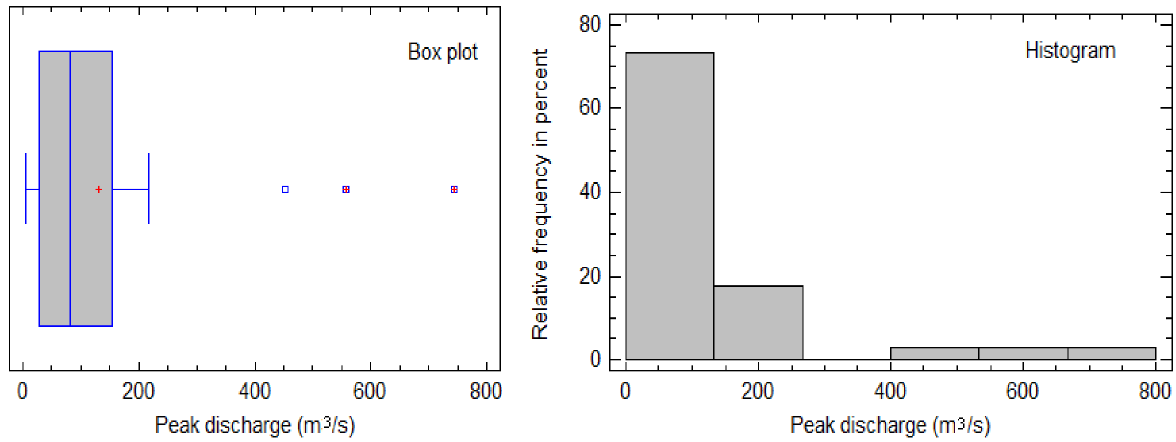

Fig. 3. Distribution of empirical peak discharge of the Saf-Saf wadi.

Frequency Analysis

From a descriptive statistics point of view, the histogram shape and the positive value of the asymmetry coefficient (Table 4), show that the empirical distribution of the maximum annual flows is skewed to the right. Therefore, probable flow rates might be estimated by theoretical probability distribution laws which have the same characteristics namely, the Gamma, Gumbel (EVI), Generalized Extreme Values (GEV), Log Pearson III, Fréchet and Log-normal distributions. Parameters that fully describe each probability law are estimated from observed data using the method of moments integrated in the Math wave Technologies Company *Easy Fit* software and are reported in Table 5.

Table 4. Saf-Saf wadi peak discharge at the Khemakhem gauging station.

Parameter	Mean	Median	Std. Deviation	Minimum	Maximum	Skewness	Kurtosis
$Q_p(m^3/s)$	139.69	80,535	160,93	5.48	745.1	2.53	6,92

Table 5. Adjusted probabilistic model parameters.

Distribution	Domain	Position	Scale	Shape
Fréchet	$0 < x < +\infty$	0	37,775	0,95963
Gamma	$-0 < x < +\infty$	0	198,17	0,6595
GEV	$1 + k\frac{(x-\mu)}{\sigma} > 0$; $k \neq 0$	55,341	60,187	0,41061
Gumbel (EVI)	$-\infty < x < +\infty$	58,264	125,48	0
Log-Pearson III	$0 < x \leq e^{\gamma}$; beta <0 $e^{\gamma} \leq x < +\infty$; beta >0	14,579	-0,13646	75,593
Log-normal	$0 < x < +\infty$	4,2643	1,1688	0

The goodness of fit (GOF) is appreciated by graphical techniques including the quantile-quantile (Q-Q) and probability-probability (P-P) plots and statistical tests such as the Kolmogorov-Smirnov (D), the Anderson-Darling, (W^2) and the Pearson X2 (Khi carré) tests integrated in the Easy fit software. Since graphical techniques provide a visual comparison of simulated and measured data and a first overview of model performance, the assessment of the probability distribution models is basically appreciated by the total GOF test score obtained from all the statistical tests. Test scores ranging from one to six (1-6) are attributed to each distribution model based on the criteria that the distribution with the lowest total score is chosen as the best distribution model for the data. That is, the distribution best supported by a test is attributed a score of one (1), the next best is awarded two (2), and so on in ascending order. The overall ranks of each distribution are obtained by summing up the individual test ranks (Table 6). Finally, a distribution is not taken into account if the test indicates that there is a significant difference between the predicted and observed discharge values at the 5% significant level.

Table 6. Goodness of fit test results

Distribution	D		W^2		X^2 (KHi2)		Total score
	Statistics	Score	Statistics	Score	Statistics	Score	
Fréchet	0,18835	5	1,1947	5	5,0093	6	16
Gamma	0,1195	4	0,824	4	2,8842	4	12
Gen. Extreme Value	0,07652	1	0,29874	2	0,58453	1	4
Gumbel (EVI)	0,21806	6	2,0432	6	4,9866	5	17
Log-Pearson 3	0,09575	2	0,27815	1	2,7278	3	6
Lognormal	0,11134	3	0,34964	3	2,0237	2	8

Since the peak flow time series is relatively short (Svensson and Jones, 2010) and the overall rank sum is minimum, the General Extreme Value distribution is preferred, over the log-Pearson III and log-normal models, to estimate the T-year peak discharge in the Saf-Saf wadi at the Khemakhem control station for 10 specified recurrence intervals (T) between 2 and 1000 years (Table 7).

Table 7. Probable maximum flood of the Saf-Saf wadi at Khemakhem (m^3/s)

(GEV model : k = 0,41061 s = 60,187 m = 55,341

Probability	0,999	0,998	0,995	0,99	0,98	0,96	0,95	0,90	0,80	0,50
T (years)	1000	500	200	100	50	25	20	10	5	2
Q_{max} (m^3/s)	2410	1790	1200	880	636	454	405	278	180	79

Results

Reference discharges for watercourses management and flood control plans in the Saf-Saf watershed

In the Saf-Saf watershed, historical data recorded during the 1968/69-2000/01period at Khemakhem station, the only hydrometric gauging site that controls the upper 322km² Saf-Saf sub-basin, are compared to the probable discharges presented above. It appears that the highest observed floods in the last four decades are:

- the 1969/70 flood: Qmax: 453m³/s , 25- year flood,
- the February 2nd to 5th, 1985 flood: Q_{max}: 745m³/s, volume: 29hm³, duration: 4 days, 70-year flood,
- the December 28th, 1984 to January 1st, 1985 flood: Qmax: 559m³/s, volume: 50.5hm³, duration: 5 days, 38-year flood.

At the Zardezas dam site, the December 28th, 1984 to January 1st, 1985 flood peak discharge, volume and return period are 754m³/s, 75.2Hm³ and 72 years, respectively. Qualified to be exceptionally high floods, the magnitude of these extreme events is less than the predicted 100-year flow (880m³/s).

Being the most devastating flood in the Saf-Saf basin with respect to duration, volume and human and property damages (11 deaths, severe damage to basic infrastructures, buildings collapses due to landslides, 400 hectares agriculture losses, etc.), the December 1984 flood may be considered as reference flood to formulate flood risk and watercourse management plans in the Saf-Saf wadi and its main tributaries. Such a reference random event is transposed to ungauged sub-basins in the Saf-Saf wadi watershed using the Francou-Rodier Regional Model (1967) which takes the form:

$$Q(T) = 10^6 \times \left(\frac{A}{10^8}\right)^{1-\frac{k(T)}{10}} \quad (1)$$

where Q(T)is maximum discharge of T-year return period (m^3/s); *A* is catchment area (km^2); *K* is the Francou-Rodier flood index coefficient to be estimated from observed data. Solving the above equation for K(T) yields:

$$k(T) = 10 \times \left[1 - \frac{logQ(T) - 6}{logA - 8}\right] \quad (2)$$

Introducing the values of the 72-year flood at the dam spillway (Q_{72yr} = 754m^3/s; A=345 km^2) and the 100-year flood at the Khemakhem station (Q_{100yr} = 880m^3/s; A=322 km^2) into equation 2, the estimated K_{72yr} and K_{100yr}values are 4,435 and 4,436, respectively. If the Francou-Rodier flood index coefficient is set to 4.44 and if the channel flood routing effects are taken into account, the reference design flood in the Saf-Saf watershed, rounded to nearest 10, are reported in Table 8 and fig. 4.

Field topographic surveys on historical flood that are memorized by riparian residents and high water marks will make it possible to make cross section and longitudinal profiles of the Saf-Saf wadi and its main tributaries in the areas affected by flooding.

These post-flood surveys data (geometry of specific cross-section, river slope) and the predicted reference design floods (100-year flood) for each ungauged river are used as inputs to validate a Manning-Strickler or any stage-discharge type hydraulic model to provide, for each profile, the submerged zone width, the submergence stages (depth of water) and the distribution of flow rates and velocities. These data are required for watercourses management and flood risk mapping as defined in major flood prevention strategies worldwide. The will to collaborate and the ability to reach consensus among all concerned actors are essential conditions for the success of such a regulatory and technical project.

Table 8. Adopted 100-year design flood in the Saf-Saf wadi basin
(*Francou-Rodier* flood index *coefficient k= 4.44)*

N°	Wadi and basin outlet names	Basin area (km^2)	Q_{100yr} (m^3/s)
1	Saf-Saf at Khemakhem	322	*880*
2	Nessa at the confluence with Saf –Saf	*106* *	*475*
3	Saf-Saf at Salah Bouchaour Bridge	*543*	*1180*
4	Ammeur at the confluence with Saf-Saf	*144*	*565*
5	Hadarat at Ramdane Djamel	*143*	*560*
6	Zerga at Ramdane Djamel	*17*	*170*
7	Saf-Saf at Ramdane Djamel (Gare SNTF)	*858*	*1525*
8	Gouhdi at Bountous	*31*	*240*
9	Zeramna at the Skikda bypass	*128*	*530*
10	Saf-Saf at the outlet (Mediterranean sea)	1158	*1800*

* *Values of basin area in italic bold are taken from Abdelli et al., 1991.*

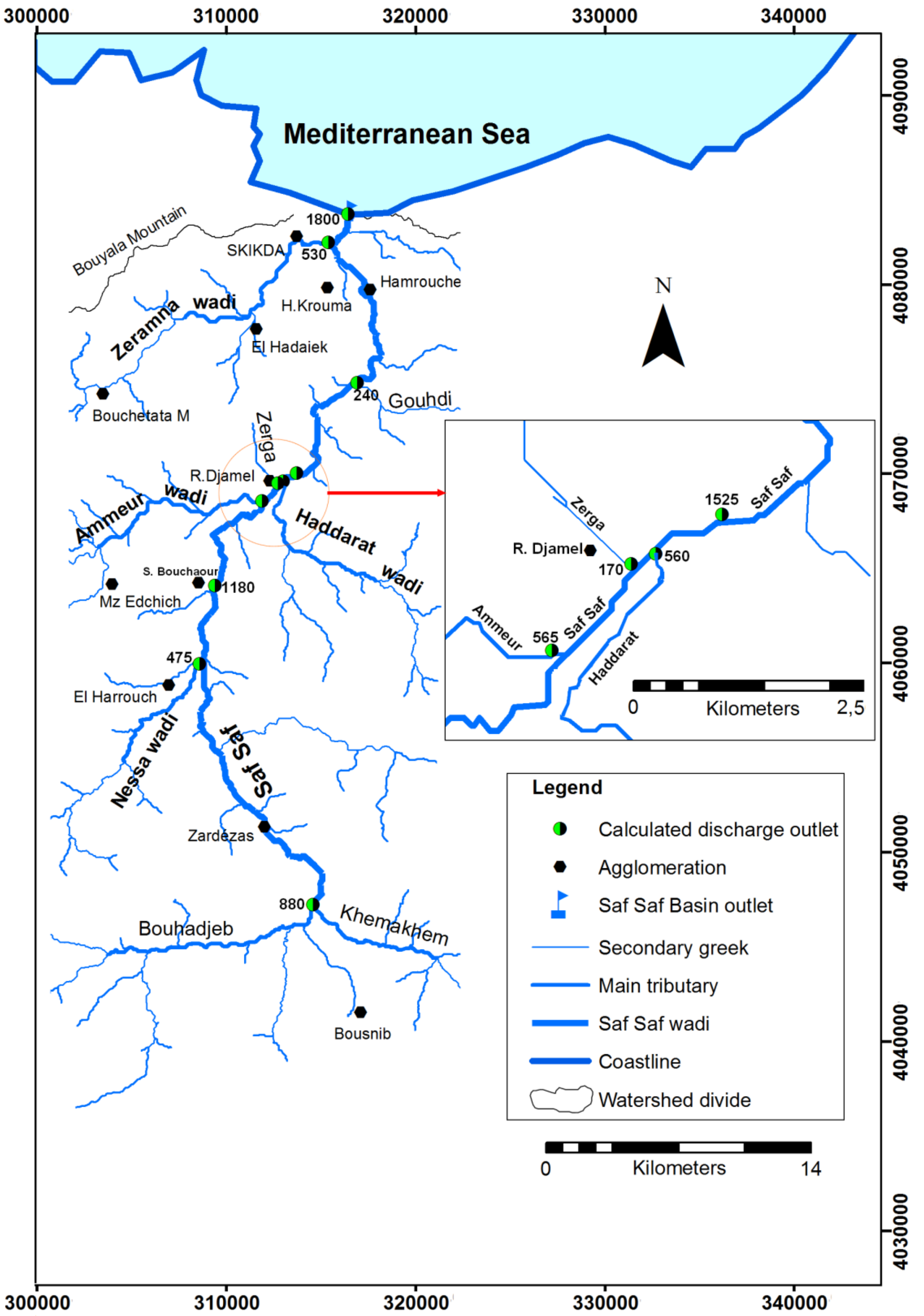

Fig. 4. 100-year design flood distribution in the Saf-Saf wadi basin.

Conclusion

At the end of this work, it should be noted that flood phenomena are a part of nature. They always exist and will continue to exist. Based on past years observed evolution and trends, the approach to deal with natural hazards requires a change of conception.

We have to move from a purely defensive action against random events to effective hazard management in order to reduce potential losses. Professionals involved in the implementation of prevention and protection policies, whether they are political or technical, must ensure that all efforts are made to fulfill these objectives. Whatever the measures taken to limit hazard magnitude and to regulate land use, the effectiveness of the long-term flood prevention policies depends on the development of information that encompasses the risk notification and facilitates public participation in the decision-making process. To this end, the identification of floodplain areas must be systematically and widely publicized through flood hazard maps. In the Saf-Saf wadi watershed, these maps are established by combining the predicted 100-year design flood, field surveys and hydraulic modeling.

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