The Effects of a Dry Stone Anti-Erosive Management on the Strength and Shape of Floods: Example of the Zioud Wadi Watershed in Central Tunisia

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Abstract: The study of the water balance of this small experimental shows us the different behaviour patterns which result from the modifications made on the slopes and in the hydrographic network.

The lands of the dry Mediterranean zone have suffered serious degradation and widespread deforestation since ancient times. In the mountainous regions, large scale efforts at reforestation seem to be insufficient to rehabilitate the area, and to reduce the sever flooding which is responsible for serious damage downstream. The hill slopes management with dry stone terraces and the treatment of the gullies by filling them with stones, were recommended in order to stabilise the head waters and reduce runoff. At the level of the wadi catchment (area: 780 ha) an integrated management in the forested area of Djebal Semama in the center of Tunisia was tested. This included defensive measures, barriers of isohypse stones and the treatment of the gullies. The criteria of efficiency were limited to the hydrologic parameters measured at the outlet: surface runoff, erosion and flood shape. In order to do this we compared the annual water balance and the shape and the intensity of the flood before and after management in the river basin. (1987—1989). To compare the floods for both periods, their hydrographs were divided into 5 minutes time steps, and superimposed . The peak flow is taken as the time reference for all hydrographs. We distinguished several typical floods for each period: the average, the envelope and the centile floods of 0.1 and 0.9. The study of the evolution in time of the discharge hydrographs shows that the global reduction of the runoff is accompanied by a stifling of the peak flow and a lengthening of the flood base time.

Keywords: Tunisia, catchment, integrated management, runoff, erosion

1 Introduction

The catchment slopes in south Mediterranean countries have suffered widespread deforestation since antiquity, and the spread of agriculture and breeding has further damaged the environment. Fertile soil has disappeared under the effect of water erosion (10,000 ha per year according to the Ministry of Agriculture).

The natural vegetation has thinned out "Pontanier R., M'Hiri A. *et al*. (1995)". In order to protect the soil and increase the efficiency of the rainfall, numerous measures have been taken, according to relief, climate and land use "El Amami S. 1983 & Prinz D. (1995, 1996)".

The most recent research on the small experimental catchments tries to better understand the water cycle and the sediment load "Dieter G. (1994)" in order to work out methods for the best use of the soil, taking into consideration methods of preserving it and limiting the risk of runoff and erosion "Rémy J.C. & Le Bissonnais Y. (1998)". In central Tunisia large areas of agricultural and pastoral land are located on slopes. Their percentage of organic matter is low, sometimes less than 1%. High rain intensities can exceed 100 mm/h during 5 minutes. This rain aggression on the soil can have catastrophic results "Albergel J. & Rejeb N. (1997)".

In the semi-arid zones, an austere soil and water use is necessary, and the Tunisian government has implemented a 10 year plan for the harvesting of surface water and the protection of sloping land, constructing water reservoirs (dams, hillside lakes, etc.) and setting up an integrated management of the catchments.

The construction of anti erosive works (earth banks, stone barriers) on the steep slopes, and measures to treat the gullies have been adopted. In the mountainous zone of the Ezioud experimental catchment, a system of stone walls has been put in place with the aim of slowing down surface runoff and reducing water erosion.

This paper presents a simple method to test the efficiency of the catchment management. The aim is to quantify the effects of these measures on the catchment hydrologic behaviour. The method consisted in observing the river flow at the catchment outlet and in doing the statistical comparison of the flood hydrologic parameters before and after management. On a catchment of 7,8 square km, the rainfall-runoff relationships are difficult to establish (spatial heterogeneity of the rain). There is also an experimental problem of adjustment in time between the rainfall pattern recordings and the river water level recordings. On this site the consequences of the catchment management on the rainfall-runoff relation were studied on micro basins (area of 1 ha) further upstream “Bergaoui M. & Camus H. (1995)”.

2 Methods and data

2.1 Comparison of the flood parameters before and after the intervention

2.1.1 Analysis and choice of the floods

All the floods observed at the catchment outlet were represented graphically after interpretation and computation of the limnigraphs. According to the hydrograph curve, the floods were classified in two groups:

- Group 1: floods with a single peak resulting from a short heavy storm
- Group 2: flooding with multiple peaks from multiple peak or separated storms

For our study we chose floods from the first group, that is 71 out of 235 floods carefully observed. These were generated by rainfalls which had affected the whole catchment.

The hydrographs of the chosen floods present the shape of a dissymmetric curve which can be divided as follows:

- The rising curve (water concentration curve)
- The peak of the flood
- The flood recession curve

The shape of the rising curve depends on several factors: the extent of the spatial heterogeneity and the duration of the rain, the catchment area, the pre-existing soil moisture (case of the rain sequences). This curve is characterised by the rising time and the maximum flow “Chow V.T. *et al*. (1988)”.

The rising time for the hydrographs varied considerably between 10 and 70 min. These time values are typical for these stormy floods.

The area stretching from the inflexion point of the rising curve and that of the recession curve is referred as the flood peak, or flood crest.

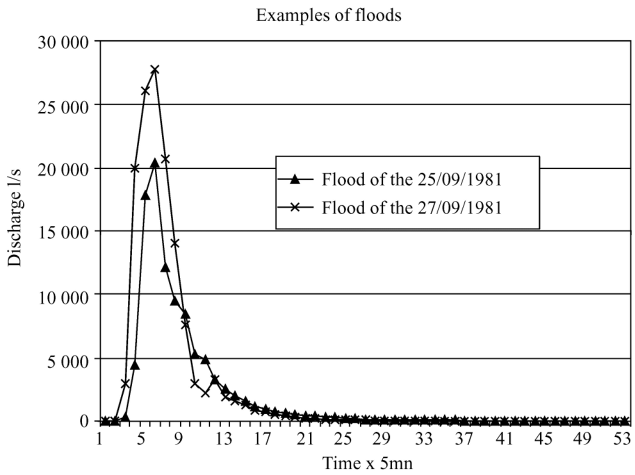
The flood peak occurs soon after the end of the storm with a delay depending on both the hydric characteristics of the basin and the duration of the storm. The maximum flow for these floods varies between 708 l/s and 35,600 l/s (the flood of the 24.10.84).

The recession curve shows the draining of the water accumulated in the basin after the reduction or the end of the rain. Its appearance depends only on the physical characteristics of the hydrographic network. This curve defines the base time which varies between 40 / 265 minutes in our watershed.

2.1.2 Establishment of characteristic hydrographs for a given period of time

The hydrometric data was collected and processed at irregular intervals. The peak of the flood was precisely picked out on the limnigraph.

From the peak of the flood (qm) the rising and the recession curves were divided into regular intervals of 5 minutes. For a given period, all the selected flood data are superimposed on the same graph, representing the flow in time, taking the flood maximum as the time reference. Figure 1 represents the data analysis for 2 floods of 1981.



Flood examples flow in l/s time × 5mm

Fig. 1 The analysis of various floods during 1981

At each time step the average flow, the maximum flow and different quantiles were calculated for the whole selected rain events. The average hydrograph for the chosen period was drawn by joining up all the average flow points and the enveloping hydrograph by joining all then points of the maximum flow. In the same way it is possible to define a characteristic hydrograph for a chosen quantile. In our study we have chosen the following characteristic hydrographs: the envelope hydrograph, average and those of quantiles 10, 50 and 90%.

2.1.3 The choice of the periods of comparison to show the impact of the management

On each type of hydrograph (envelope, average, and the three chosen quantiles) the following parameters were calculated , the peak flow (qm), the volume of the flood (Vr), the rising time (tm) and the base time(tb). We can say that the typical hydrograph is different for two periods if one of the parameters has significantly changed, with a standard deviation higher than 10%. Four periods were defined:

- Two blue periods of equal duration, before the management began: 1976—1981 with 17 floods selected according to the criteria defined above, 1982—1986 with 26 floods
- A white period corresponding to the setting up of the management (1987—1989) with 11 floods
- A red period after the work had been done, 1990—1994 with 14 floods

We will consider that the changes had an effect on a parameter of the flood if there was no significant variation on this parameter between the two blue periods but a clear difference in the red period.

2.1.4 Geographical data

The Ez-zioud catchment is a sub basin of the largest basin of the wadi El Hissiane in Jebel Semmama in central Tunisia, not far from Sbeitla. Figure 2 is a map of the site.

The general landscape is that of the high steppes of central Tunisia, represented by a mountainous mass dominating a system of slopes and alluvial plains formed in the quaternary era. The range of the jebel Semmama (1,314 m), like many other jebels of the region, is affected by a very strong water erosion, which tends to give the wadis a characteristic shape by their embankments and complex ramifications.

They open onto a glacis of foothills into which they cut deeply until they spread out onto the low plains. The limestone outcrops of the cretaceous (lower and middle) era form the basins water divide and cover a large area upstream. They rise above rough detritus formations. Quaternary formations are to be found in the lower part (down stream) of the valley. They are made up of continental deposits of sands, silts and clays covered by a solid limestone crust (old quaternary era) by crusts of varying limestone deposits (middle quaternary era) and of aeolian and alluvial deposits. (recent quaternary age) "Riaucourt H. (1979)". The dominant climate is semi-arid Mediterranean with an yearly rainfall of 350 mm. Precipitation

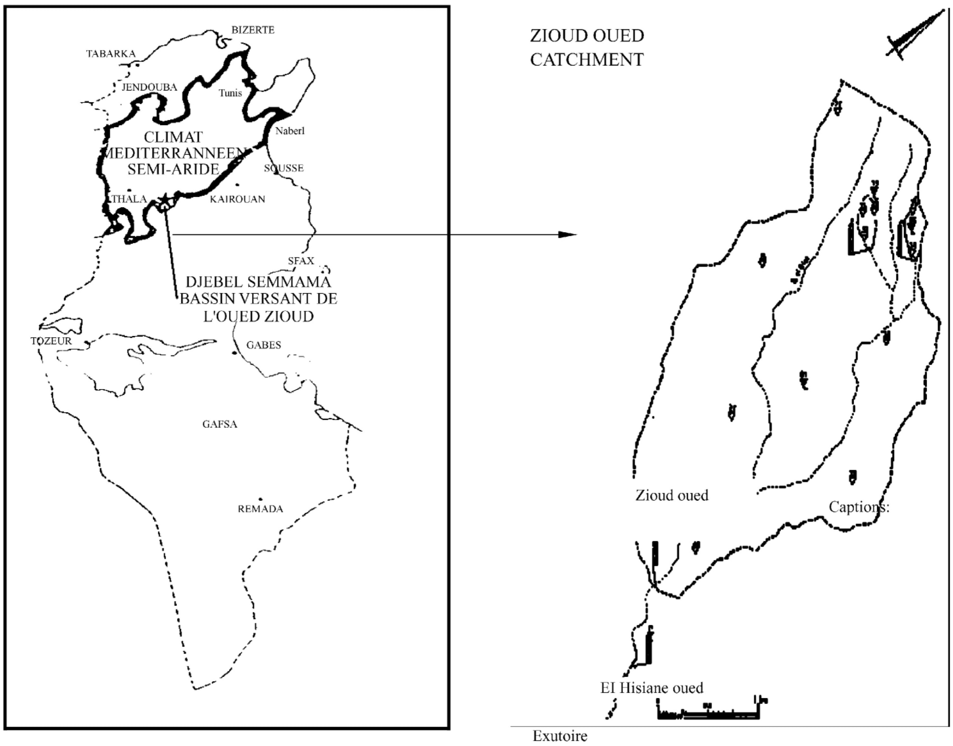


Fig. 2 Map of the site

are essentially made up by the autumn and spring storms and some winter rain. The seasonal temperature contrasts are large, with a very hot summer (average max. temperature in August in Sbeitla reaches 34°C) and cold winters (average minimal temperature in Sbeitla falls to 3.4°C). The winds are generally dictated by the Saharian anticyclone movements (the Sirocco is the dry hot sand laden wind of the summer) by the anti cyclones of the Azores over the Atlantic and the movements of cold air masses from Europe.

The land has suffered very strong water erosion, the soils are of 2 types, depending on the geomorphology and the bedrock “Delhoume J.P. (1981, 1985)”.

- The structural surface soils. Over the cretaceous limestone's, which form the south-east flank of the anticline constituting the jebel Semama, we observe a limestone / magnesium soil of the rendzine type.
- The soils of the mountain slopes. As a result of progressive subsiding of the hydrographic network, the surface structure has been carved out by wadis and deeply steep- sided valleys are the result.. Their sides are covered with a layer of colluvions resulting from the erosion of the surface soils, and within which has developed the brown limestone type of magnesic soils.

The distribution of plant groups of the Jebel Semama is the result of a bioclimate and human intervention “Joffre R. (1978)”. In each group, we find several stages of degradation (reduction of the covering arboreal strata, and patches without vegetation appear). The natural cover is principally made up of Aleppo pine forest or juniper scrub.

2.1.5 The physical characteristics of the watershed of the Ez Zioud wadi

It is a oval watershed, between an altitude of 772 and 1,250 m. with an uneven surface and a steep incline between 1,250 and 1,100 m. It reaches an altitude of 900 m, with long concave banks and then the outlet at 772 m by a series of topographical variations and steep convex slopes deeply cut out by gully erosion.

The runoff is quick and forceful and appears at a very low rainfall value. The minimal rainfall heights generating runoff (partial or generalised) are in the order of 1 mm—1.5 mm. within 5 min, that corresponds to an intensity of 12 mm/hr—15 mm/hr. with a minimal rain peak of 7 mm. This threshold can be appreciably lowered in the case of several consecutive days of rain, taking into account the preliminary soil moisture. An extension in time or space of such storms can generate a considerable volume of water. The rain event generating the ten-year return period flood, calculated before catchment management, would last 320 min and have a 5-min intensity of 129 mm/hr "Bergaoui M. & Camus H. (1994)".

2.1.6 Hydrologic data

The station of the Ez Zioud known also as the east station, controls a catchment of 7.74 km^2 and is located some 860 m. north west of the station of El Hissiane wadi. It consists in:

- A ladder system made up of 5 elements of 1 m intervals installed on the left bank.
- A water level recorder OTT type x, set on a socket with a diameter of 400 mm on the left bank and to the right of the ladders.

A stabilising concrete ground socket was built. The discharge was measured with a propeller currentmeter and the measures were taken for practically each serious flood.

Between November 1976 and October 1994, 235 floods were recorded on 2 hydrographs and analysed. On each hydrograph the following parameters were calculated:

- The volume of the flood (*Vr* (m^3)), depth of surface runoff (*Lr* (mm)) and the ratio between runoff volume and the catchment area.
- The max. flow of the flood (*Q* max (m^3s))
- The specific flow (*q* (l/km^2/s) or (mm/hr)
- The rising time (*Tm* (min))
- The base time (*Tb* (min))

The 235 events recorded over 20 years of measuring, correspond to 207 days of rain. The distribution of floods year by year is very variable. It ranges from 7 floods / year in 1980—1981 to 19 floods in 1981—1982 (Table 2).

The depths of surface runoff vary from *Lr* 0.01 mm to *Lr* 8.5 mm (the flood of 15.09.85).

During the period of this study, the average depth of surface runoff was 0.64 mm. The median depth of runoff was 0.16 mm. The average yearly depth was 8.3 mm, that is a coefficient of an average yearly storm runoff coefficient of about 3%. We made the calculations of characteristic hydrographs over a period of 5 yrs: 2 periods before the development management (blue periods) and 1 after (red periods).

We can distinguish the 2-year period corresponding to the setting-up of the catchment management works (1987—1989). We checked in the 2 first periods that the natural climatic variation had no significant effect on the shape of the flood and we determined the influence of the management measures.

2.1.7 The management works

The anti-erosive measures taken for the Zioud catchment began in 1987, and most of the work was completed in 1989. The consolidation and completion were carried out until October 1993.

The catchment process began by the construction of small banks on the slopes and dry stone dams in the bed of the wadi on the median and downstream part of the catchment. The flood waters of July 1989 were caught by the first dams which overflowed, and then broke one after the other. The water then broke through in a rush. After this incident the water and soil conservation technicians changed their approach. The work on the watersheds preceded that of the bed of the wadi.The management with dry stone walls stretch over 60% of the total catchment area. They are located on the steepest slopes of the rugged topography. Stone works forming micro dams were constructed across all the active gullies. The whole catchment area, situated in a region of a natural forest reserve was protected in 1987, at the beginning of the work.

The objective of this management using dry stone is to slow down the surface runoff and thus permit the retention of sediment load The walls are constructed following the contour lines and act as an hydraulic brake by increasing the roughness of the slopes . The terraces formed in the gullies are designed to stabilise the slopes and the crumbling edges. They slow down the flow of water without stopping it. They are porous and let through a part of the runoff , thus reducing the dynamic and hydrostatic strength .

This management on the small mountain catchments has been implemented according to the standards defined in the guide for the conservation of water and soil "Chérif B. *et al*. (1986)".

3 Results

3.1 The hydrologic regime observed on the Zioud catchment

Graph 3 shows the depth of surface runoff recorded during this study.
Distribution of the depth of surface runoff for the stated hydrological years

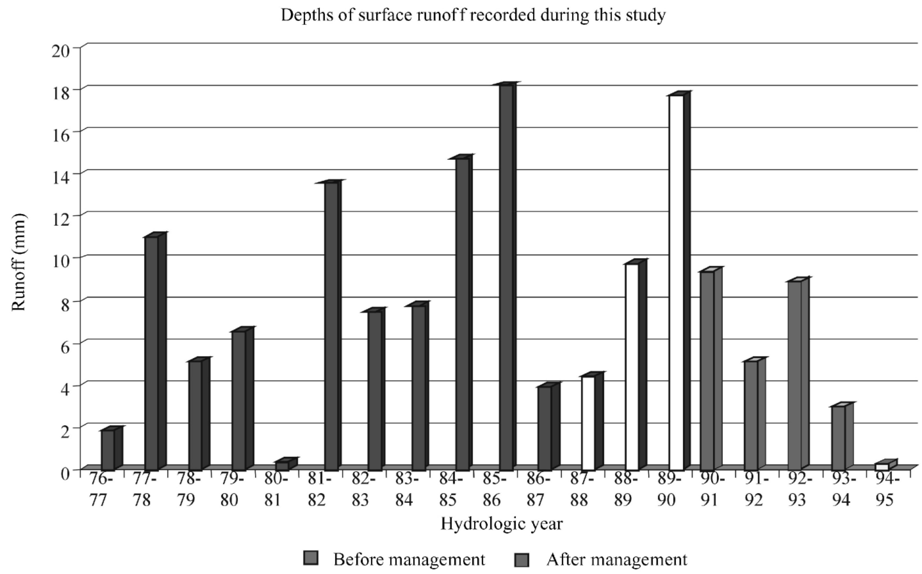


Fig. 3 Annual depths of surface runoff

Depths of surface runoff after management (mm) Depths of surface runoff before management (mm)

The distribution of the depth of surface runoff year by year is very variable (it ranges from 18.2mm in 1985—1986 to 3.9 mm the following year). In the year of maximum runoff the flood of 15/09/85 accounted for 46.7 % of the total .

A rapid examination of the annual depth of surface runoff does not show much difference between the periods before, during or after the management. The climatic variability appear to have more effect .

The monthly, like the yearly, depth of surface runoff presents great variability.

The same month may contribute to the maximum runoff for one year, and generate no runoff the following year. (December 1988-a depth of 3.21mm; December 1989- a depth of 0mm) Table 3 shows the distribution of monthly floods and classes them according to the intensities of the storms which produced them. "Bergaoui et Camus (1994)".

- 60% of the floods recorded were due to rain showers with an 5 min intensity lower than 12mm/h and a global depth of surface runoff of 47.4mm that is 30% of the total depth of surface runoff for this period.
- 53% of the depth of surface runoff occurred in the months of September, June, August and March.
- 75% of the floods recorded in the months of June and August were erosive (15>30 mm/h) and 25% were insignificant.
- The month of September had a depth of surface runoff of 27.5mm , 3 of the 34 floods had a total depth of runoff of 16.8 mm, ie. 61% of the total for the month.

These results show that :

- The surface runoff in the catchment is very slight, and influenced by a few generally significant storm floods.
- In the case of the Ez Zioud catchment, the larger floods occur generally in the autumn and summer. They are caused by violent storms of high intensity, sometimes affecting quite large

areas. These storms only occur on practically bare ground, which encourage runoff in the first place.

- For each month there are some distinct floods which contribute with a large percentage to the depth of surface runoff.
- The effect of the management is not obvious at this stage of the observation of the runoff.

3.2 Comparison of characteristic floods

3.2.1 Results for the envelope floods

The peaks are very much reduced and flattened and the volume of the flood significantly decreased. The time parameters of the floods are modified by the work, the rising and the base times have almost doubled. Fig. 4 compares these floods for different periods.

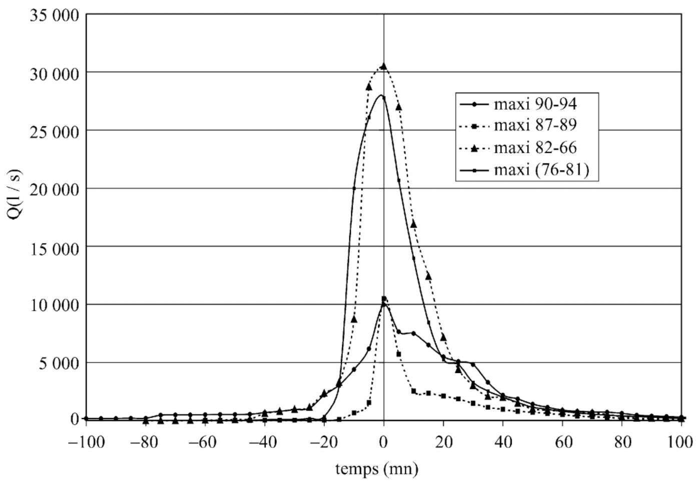


Fig. 4 Superposition of the hydrograph envelope

3.2.2 Results for the centile 0.9 floods

Table 5 gives the values of the parameters (maximum flow in l/s, hydrograph volume in million m^3, rising time and base time in minutes), as well as the percentage (Rap.)ratio between values of the red period and each of the other periods. Below each parameter the ratio between the red period and the period under consideration is expressed as a percentage. We notice (Table 5) that the maximum flow has been reduced for the centile 0.9 floods which can be classed as heavy floods: 60% if we compare it to the first blue period or 15% compared to the second. The flood volume has not significantly changed, whereas the characteristic time spans are longer.

3.2.3 Results on the average floods

The flood peaks are weaker in the red period while they are equal in the two blue periods, the volumes of this characteristic flood are not affected by the management . The rising and base times are clearly longer in the red period.

3.2.4 Results on the centile 0.1 flood

In the red period the number of small floods decreased significantly. The red period was characterised by centile 0.1 floods, stronger than in the blue periods. Low precipitation no larger results in widespread surface runoff;

4 Conclusion

In conclusion, this study shows that over a period of 5 years, a complete management project does not have an effect on the volume of yearly runoff. The climatic variability covers up the impact of the work. Perhaps we need observations over a longer period to obtain more representative averages of the catchment.

On the other hand the work affects the floods individually when analysed separately. We notice the disappearance of generalised runoff in the watershed during low rain, whereas before the work, 5mm of rain was enough to give rise to an exutoire flood. The lowest floods observed (those of around centile 0.1) were greater in both volume and peak flow after management but corresponded to rains which caused heavy flooding before the management in the catchment.

The average floods and above all the heaviest were clearly modified. The volume and the flood peaks were significantly reduced (by about 50%). The characteristic times were lengthened, as a result of the increase of the roughness on the slopes. This increase in roughness is induced by the dry stone walls and by the use of gabi in the gullies. These act as hydraulic brakes on the flood spread.

The shape of the floods and the storm runoff coefficients were affected by the works. The hydrographs were flattened and lengthened after the management This phenomena can be put forward by a stochastic analysis of the observed floods. These modifications can be brought out through a rainfall-runoff modelling, in which the parameters of the production and transfer function must be adjusted to the different periods.

In spite of a dense rain recorders network, it is not yet possible to analyse the rainfall- runoff relation. The homogenisation of the rainfall data is long and difficult. Numerous time gaps between the different rain recorders and water level recorders are difficult to correct. The first statistical study of the flood shapes based on the runoff database is a preliminary work before the modelling, and enable us to appreciate and quantify the modifications to the hydrologic regime. At a time when catchment management projects are increasing, it is possible to implement these methods to assess their efficiency. On larger catchments monitored by the national hydrographic network, it would be useful to assess the viability of this method through the use of hourly time steps for the flood.

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Table 1 Flood distribution in terms of the depth of surface run- off

Lr (mm)	>0	>1.0	>2.0	>3.0	>4.0	>5.0	>10.0
Number of events	235	45	20	10	5	3	0
% of the total	100	19.15	8.5	4.25	2.12	1.27	0

Table 2 The distribution of monthly floods

			I5>=12mm/h		I5>=35mm/h	
Month	Number of flood	*Lr*(mm)	Number of flood	*Lr*(mm)	Number of flood	*Lr*(mm)
S	34	27.5	19	20.8	12	11.1
O	26	13.2	14	9.8	8	7.2
N	22	10.5	7	1.9	2	0.0
D	13	8.7	5	5.3	2	3.0
J	6	9.4	2	4.4	1	3.8
F	8	2.0	4	0.8	1	0.1
M	22	14.5	17	12.8	3	4.0
A	23	9.6	15	5.5	7	3.1
M	24	13.4	15	7.8	10	7.3
J	27	22.1	21	15.5	18	14.2
J	6	3.5	4	3.5	3	3.5
A	24	14.7	18	14.0	18	14.0
Total	235	149.2	141	101.8	85	72.4

Table 3 Comparison of the parameters of hydrograph centile 0.9

	Blue period		While period	Red period
	76—81	82—86	87—89	90—94
Qmax (l/s)	10,488	7,400	1,700	6,432
Rapport(%)	163	115	26	100
Vr (Mm^3)	16.5	13.38	2.14	17.29
Rapport(%)	95	77	12	100
Tm(mn)	60	60	50	75
Rapport(%)	80	80	67	100
Tb(mn)	275	250	290	360
Rapport(%)	76	69	81	100