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Hydro-sedimentological modeling in wadi Labiod watershed during extreme floods by hec-hms model

BERGHOUT Ali [1], MEDDI Mohamed [2]

[1] Department of Hydraulics, Faculty of Technology, Msila University 28000 Algeria; E-mail : berghoutali@gmail.com

[2]National School of Hydraulics, Blida, Algeria; E-mail: mmeddi@yahoo.fr

Highlights: *Using seasonal remotely sensed data, flood flow data recorded at the hydrometric station controlling the watershed and using the HEC-HMS model to predict the watershed 's hydrological and sedimentological responses.*

Keywords: Wadi Labiod Watershed, Extreme Floods, Hec-Hms, Modeling, Solid Transport.

Abstract. The study includes the simulation of the hydrological behavior of the watershed during extreme precipitation in the first place using Hec-Hms, which takes into account the losses (infiltration losses, retention or evapotranspiration), the flow rate that takes into account surface runoff, storage, pressure drop and water behavior when it is in the bed of a watercourse. Secondly, its sedimentological behaviour with the aim of estimating solid inputs reaching the outlet of this watershed during the same precipitations.

Keywords:watershed, Labiodwadi, Extreme floods, Hec-Hms, Modelling, Rainfall-Runoff, Solid transport.

1 Introduction

Basin of LabiodWadi (Aurès Algeria), is characterized by a Mediterranean semi-arid climate (winter rain, summer drought), semi-permeable geological conditions, favourable morphological conditions to run-off and degraded vegetation cover. These factors have widely contributed to speed up erosive process.(BERGHOUT, 2017).

The examination of the solid transport values of the flood events shows that the high quantitative contribution of sediments is conditioned by the importance of the liquid flow: For example, the flood of 02/09/79 transported 1,024,137 tons sediment; which represents 48% of the load of the year and which exceeds the average annual load (ANRH).

In this context, and in order to estimate solid inputs produced by extreme floods of different frequencies, we have relied on teledetection data at seasonal time scales, data of rainfall and flood flows recorded in rainfall and hydrometric stations located in the basin by using HEC-HMS model.

2Materials and methods

2.1 Presentation of study area

Labiodwadi is located in the Aurès massif (eastern part of the Saharan Atlas). It is composed of five main wadis: Labiodwadi, Ichmoulwadi, Bachawadi, T'koutwadi, Isliwadi and BouSahbanewadi forming by their confluence Labiodwadi. All of these wadis go south and flow into ChottMelghir (-24 m). The Labiodwadiformed by the meeting of descending torrents of the steep slopes of Chelia (2328m), Ichemoul (2100m), BouTlaghmine (2178m), El-hara (1972m), Taghda (1899m) and Ich Aziza (1937m).

The Labiodwadi basin totals an area of 1317 km^2, delimited by a perimeter of 870 km (at the Foum El-Gherza dam site) and a dominant north-east exposure (DjZellatou), southwest (DjTaghenechrirt) and whose watershed waters gives it an elongated shape(BERGHOUT, 2017).

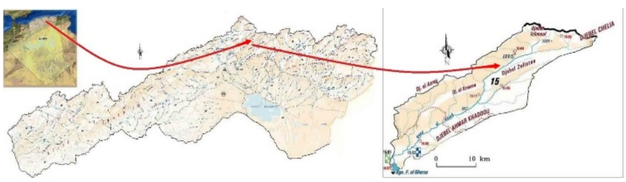

Figure 01 :Situation of watershed of Labiodwadi (ANRH 2005)

2.2Methodology

2.2.1 Hydrological simulation

In order to simulate hydrological behavior of the basin, the model HEC-HMS takes into account rainfall, losses (by infiltration, seepage or evapotranspiration), direct runoff which takes into account surface flows, storage, load losses and water behaviour when it is found into the river bed. The selected combination to modelling these different parameters dictated mainly by available data is as follows(USAD, 2013) :

* The meteorological module adopted is:**Natural Resources Conservation Service** (**NRCS**), this latter allowed overcoming problem of the lack rainfall data(Musy etHigy, 1998).

* The method NRCS CN (curve number) selected for production function is simple and faithful not in the need to use large quantities of data, and depends directly on a single parameter which retains three basic factors in rainfall-runoff modelling (land uses, soils and antecedent moisture), according to the following equation (USACE, 2013) :

$$Pe = \frac{(P - Ia)^2}{P - Ia + S}, \quad (1)$$

With: Pe : Net rainfall at time t ; P : brut rainfall at time t ; Ia: Original abstraction ; S ; Retention maximum potential.

NRCS proposed additional empirical relationship linking original abstraction of watershed to maximum potential retention(USACE, 2013):

$$Ia = 0{,}2 \text{ x } S, \quad (2)$$

Influence of the two first sub-mentioned factors is estimated by CN parameter which is linked to S by equation (USACE, 2013) :

$$S = \frac{25400 - 254CN}{CN}, \quad (3)$$

* The selected transfer function is **unithydrograph of NRCS**, this function does not require too much data, and shows satisfactory results. This function expresses Up flow as proportional to peak flow Up, for each time t, fraction of the peak time Tp (Laborde, 2007):

$$Up = C\frac{A}{Tp}, \quad (4)$$

With, A : surface of the watershed ; C : Conversion constant (2.08 for international system).

The peak time Tplinked to duration of the net rain by formula:

$$Tp = Tlag\frac{\Delta t}{2}, \quad (5)$$

Where; Δt : duration of the net rain (it is the time step of simulation) ; $T_{Lag}$the Lag of basin (difference between the net peak rain and peak of hydrograph) The $T_{Lag}$is calculated by formula NRCS defined as follows(USACE, 2013) :

$$Tlag = L^{0.8} \text{ x } \left(\left(\left(\frac{1000}{CN}\right) - \right) + 1\right)^{0.7} \frac{1}{1900 \, x \, \sqrt{Y}}, \quad (6)$$

With T_{Lag} : the lag in hours : L: length from outlet until upstream of the largest watercourse CN: curve number basin composite ;Y :basin slope in %.

* Module of basic flow selected is the **exponential recession**; this latter is well adapted to semi-arid context. (USACE, 2013) :

$$Qt = Q0\ x\ k^{t}, \quad (7)$$

Where, Q_t: flow to time t : Q_o : original flow : K : constant of exponential decay.

2.2.2 Sedimentological simulation

For simulation of watershed's sedimentologicalbehavior we have used:

a/ Approach of Williams [1976] "Modified Universal Soil Loss Equation (MUSLE)" offered by HEC HMS is used to estimate slope erosion:

$$SY = 11{,}8\ x\ \ (Q\ x\ qp)^{0{,}56}\ x\ K\ x\ C\ x\ P\ x\ LSx\ Lv, \quad (8)$$

SY : Production of sediments from particular event (tons) ; Q: volume of consecutive runoff conversely (m^3) at level of the watershed : Qp: peak flow (m^3/s) : Lv : length of the watershed : K = soils erodibilityindice to water erosion (ton, hour / Newton. hectare) : LS = topographic factor depending of the slope and its length : C = culture factor, including vegetal cover (land use) : P = factor of conservation and development.

b/In streams, one of the seven transport functions (Ackers-White, 1973;Engelund-Hansen, 1967; Laursen-Copeland, 1958 ; Meyer-Peter Muller, 1948;Toffaleti, 1968; Wilcock, 2003; Yang,1984) and one of the four fall speed calculation methods (Report 12, 1957; Rubey, 1933;Toffaleti, 1968; Van Rijn, 1993)available in the model are used to estimate the quantities of sediment transported during floods.

2.3 Data preparation

In this model, watershed is divided into twelve sub-basins in order having homogenous units as far as possible of point of view lithological and hydrological. These sub-basins are drained by a hydrographic network formed by eleven wadis. In order to evaluate factors quoted previously, we have drawn maps of slope lengths, soils type NRCS (Cane, 1985), land cover and vegetation cover (made from satellite image), curve number (made from soils maps type NRCS and maps of land cover), soilserodibilityindice to water erosion (made from lithological map)and anti-erosive practices.

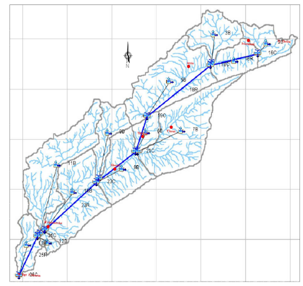

Figure 02 : Basin cutting

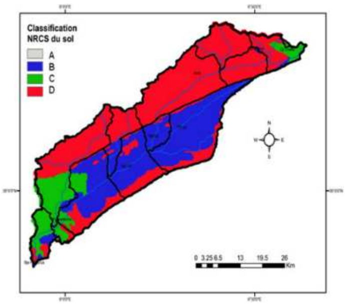

Figure 03 : The soils mapNRCS

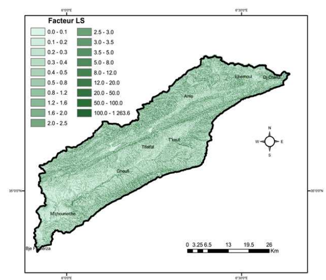

Figure 04 Factor map LS

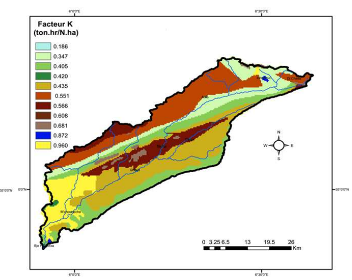

Figure 05 : Factor map K (SI)

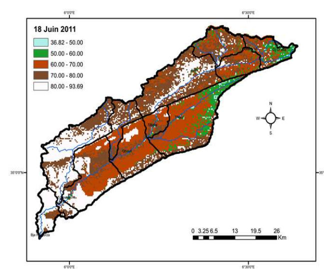

Figure 06 : Factor map CN (June)

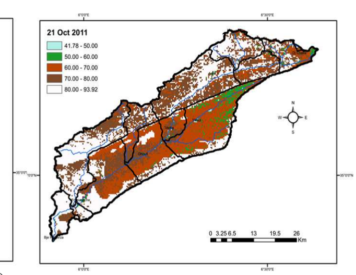

Figure 07 :Factor map CN (Oct)

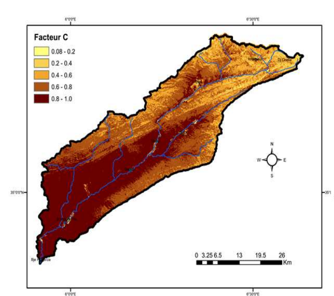

Figure 08 : Factor map C (June)

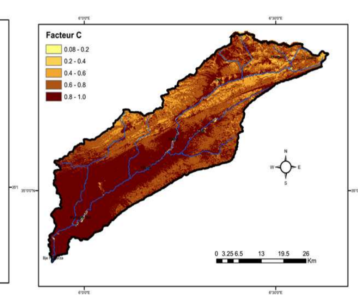

Figure 09 : Factor map C (Oct)

Indices corresponding to plotted maps vary as follow:

LS varies from 0 to 1264: with average of 0.20 in the whole of the watershed ; K varies from 0,17 to 0,96 with average of 0.43 ; CN varies from 36 to 94 with average varying of 73,62 in October to 75,89 in June ; C varies from 0.08 to 1.0 with average varying from 0.47 in October to 0.63 in June and value of P (varying from 0 to 1) is considered as constant and equal to 1 for all the study area.

After the scanning of flows and maximal daily rains supplied by NAWR(ANRH 2005), number of events, which we have selected, is of three(03) for which monthly rains equal to maximal daily rains of the same month. The selected floods are as follow: 02 September 1979 (1), 10 November 1982 (2) and 19 June 1989 (3). For each event, rain should be taken under height form fallen on each sub-basin during the day where this event occurred. This latter is estimating for each sub-basin by the weighted average of rainfall recorded at level of rainfall stations of the total basin

Table 01: Rains values estimated to different sub basins

S/B	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B	12B	13B
(1)	50.1	50.1	50.1	29.6	27.5	17.8	15.0	15.0	11.1	11.3	7.0	7.0
(2)	67.2	67.2	67.2	26.0	21.6	22.4	24.0	24.0	23.0	23.1	22.0	22.0
(3)	58.1	58.1	58.1	29.9	26.7	18.7	15.5	15.5	17.8	17.7	20.2	20.2

2.4 Models calibration

Before starting calibration of hydrological model, we have prepared all files of simulations of the two events previously selected for each sub-basin in taking into account the four types of the precipitations NRCS and to analyse the sensitivity of model successively to this types. Therefore, we have 08 simulation files.

As for sedimentological model, in taking into account the seven formulas of solid transport and the four methods of velocity calculation used by Hec-Hms in order to analyse sensitivity of the model to different combinations. Therefore, we have 28 simulation files.

By comparing peak flow simulated with that one measured at level of hydrometric station of M'chouneche, we note that precipitations type 1A are the highest ranked in restitution of hydrograph characteristics. Also by comparing results of each combination of transport formula and falling velocity with hydrometric station measures, and finally combination of equation TOFFALETI with method of speed calculation of TOFFALETI with an active layer of wadis beds average of 50 cm was more compatible with natural conditions of the basin. After calibration, validation made on the third event. By applying, the data play result to calibration events; we reach the following results. :

Crue du 02 /09/1979

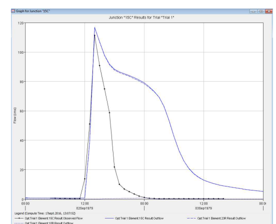

Figure 10 : Hydrograph of the flood simulated and the flood observed

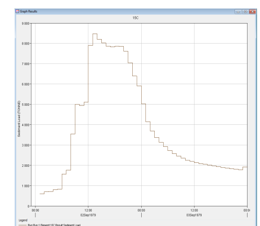

Figure 11 : Histogram of solid inputs of the flood simulated

Crue du 10/11/1982

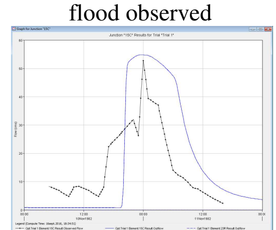

Figure 12 : Hydrograph of the flood simulated and the flood observed

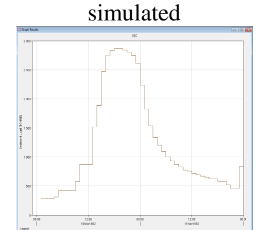

Figure 13 : Histogram of solid inputs of the flood simulated

Crue du 19 /06/1989

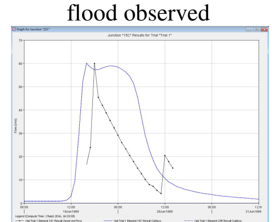

Figure 14 : Hydrograph of the flood simulated and the flood observed

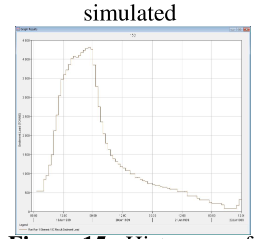

Figure 15 : Histogram of solid inputs of the flood simulated

Table 02: calibration results and validation of hydrological model

Evénement	$Q_p$obs (m^3/s)	$Q_p$sim (m^3/s)	DiffErence %
02/09/1979	111,3	116,8	4,94

10/11/1982	52,7	54,8	3,98
19/06/1989	60,0	60,1	0,17

Table 03: Calibration results and validation of sedimentological model

Evénement	Sol. inpobs(Tons)	Sol. inpsim(Tons)	Difference %
02/09/1979	189583.4	177083.9	-6.59
10/11/1982	59971.8	56349.1	-6.04
19/06/1989	141551.10	115499.3	-18.40

Results judged favourable, and application of this model shows that the formulation adopted may lead to good results, as soon as we have representative data.

2.5 Estimation of solid and liquid flows from different return period showers by HEC-HMS

After calibration and validation of the two models, we have simulated effect of precipitations of different return periods on hydrograph of solid and liquid flow in hydrometric station controlling the basin and in the site of Foum El-Ghuerza dam.

2.5.1 Inputs data

The following table summarizes values estimated of the rain for different return periods (data's statistical treatment), which will be used in the simulations and so average values of CN and C (average of the four seasons). Each height of rain will be added to parameter play optimized defined in hydrological model validation to setting up a file of distinct simulation for each sub-basin with combination of transport equation, the calculation method of the speed and so the thicknesses of the active layer results of calibration and validation of sedimentological model of the basin.

Table 04: Maximum daily precipitation values of different frequencies, average CN and C.

S/water-shed	maximum rain of a day				CN average	C average
	10	50	100	1000		
2B	80.4	112.1	125.6	171.2	71.5	0.6
3B	79.0	111.5	125.8	175.6	78.4	0.7
4B	85.2	124.9	143.5	208.5	74.7	0.6
5B	71.46	105.80	122.34	181.37	78.50	0.69
6B	79.2	128.4	152.7	244.8	66.0	0.8
7B	60.1	90.6	104.0	150.4	68.3	0.9
8B	53.5	75.3	84.2	112.7	75.3	0.7
9B	58.9	89.5	103.0	149.7	71.5	0.8
10B	52.51	73.11	81.26	106.28	80.89	0.83
11B	56.7	83.8	95.3	133.4	75.1	0.7
12B	59.3	88.8	101.3	142.6	82.3	0.9
13B	58.8	87.2	99.0	137.2	81.8	1.0

Extreme flows values of frequency floods estimated by hydrological model Hec-Hms are close of those found by statistical treatmentof liquid flow data.

During floods of return period 50 years to 1000 years, average specific degradation varies from 840 to 1560 tons / km². It is greater than the annual specific degradation, which is in the order of 700 tons / km².

2.5.2 Simulation results

The graphs from 16 to 23 present the results in term of hydrogramof the flood and Histogram of solid inputs at the site of the Foum El-Gheurza damfor different return periods:

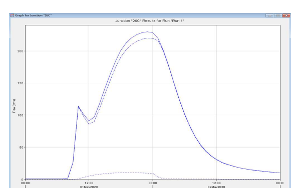

Fig. 16 : Hydrograph of the flood return period 10 years simulated

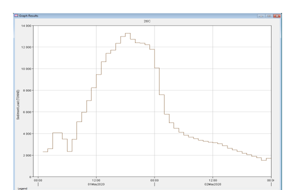

Fig. 17 : Histogram of solid inputs of return period flood 10 years simulated

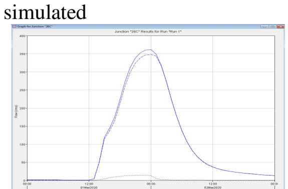

Fig. 18 : Hydrograph of the flood return period 50 years simulated

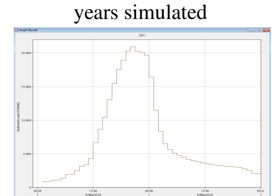

Fig. 19: Histogram of solid inputs of return period flood 50 years simulated

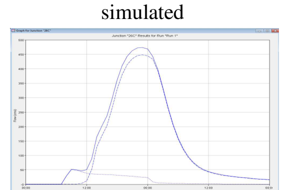

Fig. 20 : Hydrograph of the flood return period 100 years

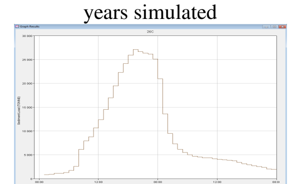

Fig. 21 : Histogram of solid inputs of return period flood 100

simulated

years simulated

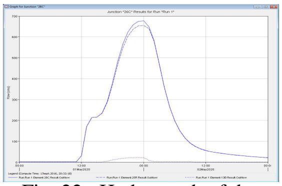

Fig. 22 : Hydrograph of the flood return period 1000 years simulated

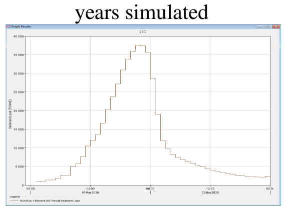

Fig. 23: Histogram of solid inputs of return period flood 1000 years simulated

Results summarized in the table 05 present values estimated by the HEC-HMS model to the basin in term of hydrogram peak, of run-off volume and solid inputs quantities transported until hydrometric station of M'chouneche and to the dam site of Foum El-Ghuerzafor different return periods.

Table 05: values predicted of peak flow, of water volume and solid inputs quantities to the M'chouneche station and to dam site of Foum El-Gherza.

T (ans)	T = 10	T = 50	T = 100	T = 1000
Basin of LabiodWadi (to station of M'chouneche) S= 1051 km²				
Q_p(m^3/s)	191,2	310,7	396,4	597,8
V (10^3 m^3)	12995,3	15959,0	20555,3	29578,6
A.S. (10^3 Tonnes)	605,0	881,5	1264,1	1644,3
Ass (T/km^2)	575,6	838,8	1202,8	1564,5
Basin of LabiodWadi (to dam Foum El-Ghuerza) S= 1317 km²				
Q_p(m^3/s)	229,7	361,4	473,4	677,2
V (10^3 m^3)	14642,9	17400,2	24770,4	31330,6
A.S. (10^3 Tonnes)	805,6	1081,6	1701,3	1943,6
Ass (T/km^2)	611,7	821,3	1291,8	1475,8

3 Conclusion

Finally, this study confirmed that essential of solid transport comes from wadis and during flood, and that annual average solid inputs reach outlet of the watershed are are much lower than the solid inputs carried by floods of return period 50 years and over.

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