VARIABLITY OF STREAMFLOW AND SEDIMENT YIELDS IN WADI TARIA (NORTHWEST ALGERIA)

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ABSTRACT

In this paper we are interesting to study the variability of stream flow and sediment yield in wadi Taria, a river of semi arid regions of Algeria. To do this, we adopt a methodology which consists to find a regressive model capable of explaining the sediment load as a function of the discharge measured at wadi Taria station, by studying this relation at various scales e.g., annual, seasonal etc. The results show that the power model explains the greatest part of the variance (80%). The analysis of the monthly sediment yields shows that the autumn season contributes in a large proportion of the annual sediment yield (60%).

Keywords: Erosion, Sediment, Water discharge, Modelling.

1. INTRODUCTION

Hydric erosion is a very widespread complex phenomenon in Mediterranean zone, concerning particularly the Maghreb countries from which it’s seriously threatens the potentialities out of water and soil (Achite. [1]). A large number of data on suspended sediment transport of the Algerian rivers were accumulated during the various decades (60, 70, 80, 90, 2000 and 2010) and made it possible to undertake a general study on erosion, sediment discharge and silting in dams. Many studies on erosion and its consequences were undertaken in different countries, but the complexity of the phenomenon, its irregular and random character did not make it possible to lead quickly to satisfactory results.

Slopes of the West Algerian catchment areas make the principal subject of the erosion study. They aroused the interest of a great number of researchers who tried to explain the complex mechanisms of sediment transport and to quantify volumes of the transported sediments. One will note old work of: MEDINGER (1960): who proceeded to the treatment of the first series of measures collected in Algeria on about thirty basins during the period 1946 - 1957; TIXERONT (1960): who based its work on the data of 32 basins of Algeria and 9 basins of Tunisia. CAPOLINI (1965 - 1969): undertook a regional geomorphologic study on the principal affluent of the Chelif (area physiographic, hypsometry, slope, geology formations, and vegetable cover). SOGREAH (1969) s: Studied the surfaces of irrigation basing on the data of observation collected at 9 dams and 18 hydrometric stations adding up 282 years. One will also note recent works of DEMMAK (1982), GACHI (1982), BOUROUBA (2003), MEDDI (1999-2004), TERFOUS (2001-2003), GHENIM (2001), BENKHALED and REMINI (2003), BOUANANI (2004), KHANCHOUL (2006) and ACHITE (2005, 2006), who have tried to quantify sediment transport and to explain hydric erosion in the basins of the Tafna, Seybouse and Chelif.

In consequence of the space-time discontinuity of the process erosion-transport-sedimentation, there exists only one remote relation and variable between the quantity of material torn off with the interfluves and that which is transported by the river. The irregularity of the phenomenon makes difficult the settling of a precise, reliable and operational measurement technique. The methods of direct and continuous recording are proved to be inapplicable on the rivers strongly charged. The sporadic taking away of samples carried out by an observer is insufficient and seldom correspond to the suitable periods. The high concentrations which constitute the major part of the annual solid contributions arrive during some brutal storms and are measured only on rare occasions (Khanchoul [2]).

This contribution focuses on a quantitative study of erosion, suspended sediment and siltation of dams and whose objective is to offer solutions to fight against this phenomenon. In this context, we attempt to show, by means of in situ measurement, the relationship between water discharge and sediment discharge in order to quantify the sediment transport and the ratio of silting, and the statistical models found, will be used also to fill the gaps due to lacking measurement data and extend the existing series.

2. STUDY AREA

The basin of the wadi Taria belongs to the catchment of Macta (figure 01), located at the North-West of Algeria. The two principal rivers, the Mekerra wadi in the west and the wadi El Hammam in the East, meet not far from the Mediterranean dimension to form Macta. The basin of the wadi el Hammam occupies a surface of 7862 km^2, is divided into 11 under basins (figure 02) (wadi louza, wadi melrhir, wadi mezoua, wadi Sefioun, wadi Berbour, wadi Hounet, wadi Saida, wadi Sahouat, wadi Ghriss, wadi El hammam, and wadi Taria which is the subject of our study).

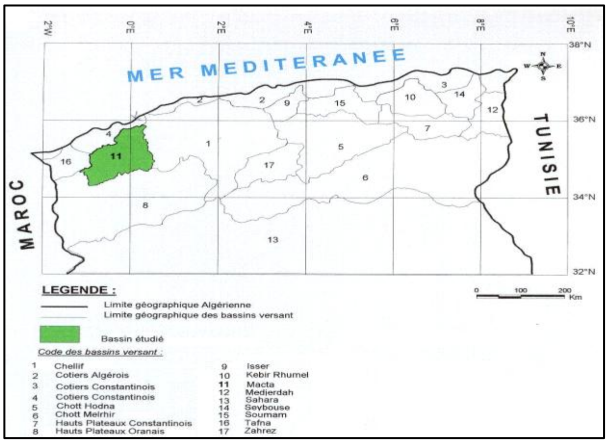


Fig. 1 Situation of Macta basin, Algeria

The catchment area of wadi Taria extends between longitudes 0°25' W - 0°50' E, and the latitudes 34°75' N - 35° 25 ' N, it is limited to north by the basin of the plain of Ghriss, in the south by the basin of Chott Chergui, in the east by the catchment area of Chellif Zehrez, and in the west by the basin of wadi Saida (figure 02). It is characterized by a semiarid climate with an interannual average pluviometry of 450 mm/an, with irregularities of rains and an annual average temperature of 17°C. The principal affluent of the studied area is wadi Taria with a 32 km length and an altitude of 600 m at the upstream and 450 m at the downstream. The station of study of wadi Taria is at the coordinates Lambert (X = 262.35, Y = 204.85), and controls a surface of 1365 km^2. It was brought into service in 1972, and has a battery of limnimetric scale, and a bridge where the gauging are done.

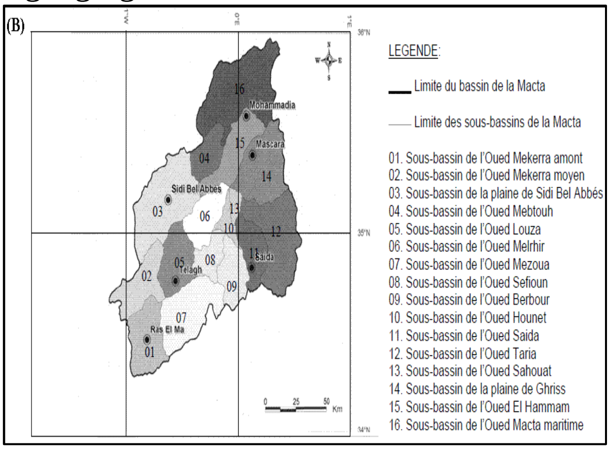


Fig. 2 basins of Macta catchment area

Ouizert dam, with a capacity of 100 million cubic meters and 58 meters height, was brought into service in 1985, for civil, industrial and agricultural uses. The prediction of sediment load will give information on the basin erosion that will serve to protect the reservoir from deposit of suspended sediment flux. The basin is principally formed by Oligocene sandstone and clay. The rest of the lithologic formations are Mio-Pliocene conglomerate and clay, marl and cretaceous limestone, and some Jurassic dolomitic limestone's outcrop Composed of. The presence of friable rocks in the study area associated with a semi-arid climate where rainfall is irregular and stormy promotes erosion and suspended sediment supply (ABH. [3]).

3. DATA AND METHODOLOGIES

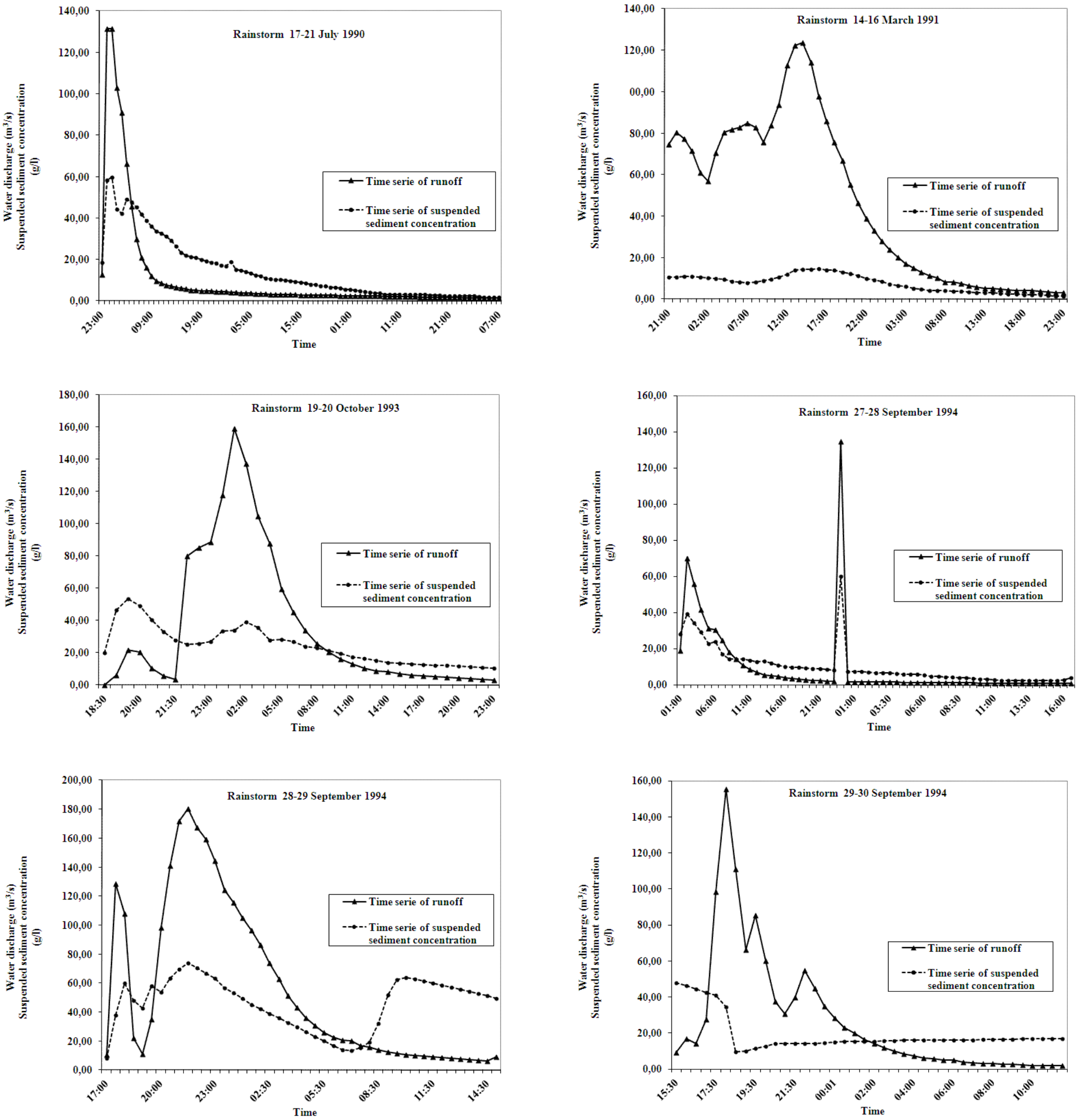
The study used instantaneous water discharge values (m^3/s) measured at the hydrometric station of wadi Taria from february 1987 to may 2007 (7657 observations), results obtained and furnished by the "Algerian National Agency of Hydric Resources" (ANRH). For measured values, sediment concentrations (g/l) were evaluated using samples taken from the river. The suspended sediment discharges were calculated by multiplying these concentrations the water discharges. The number of samples was adapted to the hydrological regime. They were taken every other day or during flood periods, as frequently as quarter-hourly. Thirty eight floods were selected and are illustrated on the (table 01) and (figure 03). The principle of the selection is based on the following criteria (Benkhaled et al. [4]):

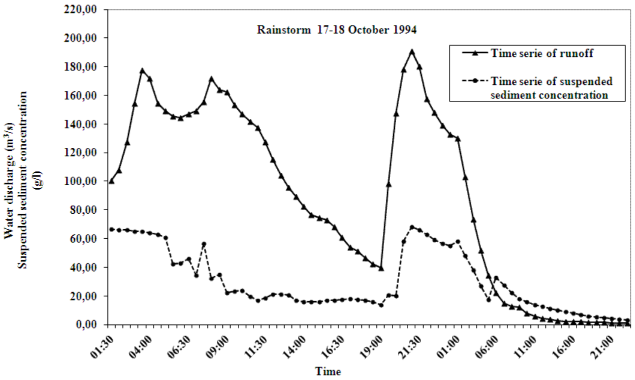
a. Has a realization of a complete and noncomplex hydrogramme;
b. A noncomplex rainstorm ;
c. A sampling rate sufficient in the event (well turbidigramme monitoring).

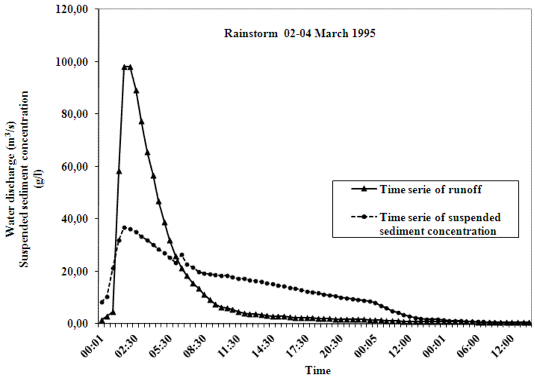
Table 1 Chronology of the important rainstorm selected

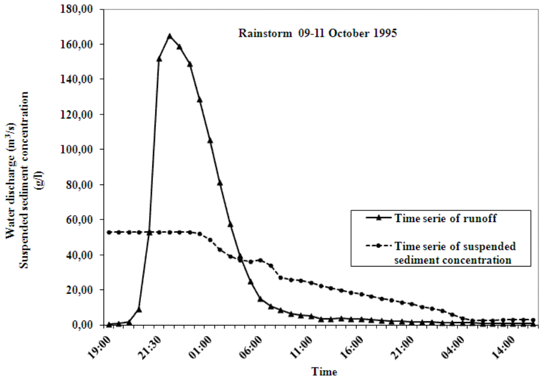
N°	Date	Number of observations	N°	Date	Number of observations
1	24-25/11/87	24	**20**	20-21/04/97	14
2	20-21/03/89	23	**21**	24/08/97	14
3	17- 21/07/90	81	**22**	25-26/08/97	40
4	11-13/11/90	48	**23**	15-16/09/97	51
5	14/03/91	19	**24**	22-24/10/97	37
6	14-16/03/91	51	**25**	22-25/11/97	53
7	08-10/04/92	39	**26**	23-24/04/98	29
8	31/08- 01/09/93	50	**27**	15-19/03/99	78
9	19-20/10/93	34	**28**	27-28/09/99	43
10	22-23/09/94	22	**29**	08-09/10/99	28
11	27-28/09/94	57	**30**	17/10/99	15
12	28-29/09/94	44	**31**	18-20/12/99	44
13	29-30/09/94	40	**32**	23-24/10/00	31
14	17-18/10/94	68	**33**	16-17/11/00	30
15	02-04/03/95	76	**34**	25-26/11/00	24
16	09-11/10/95	43	**35**	29-31/01/01	36
17	12-14/10/95	39	**36**	28/02- 02/03/01	53
18	05-07/12/95	73	**37**	07/05/02	24
19	03-06/02/96	71	**38**	25-26/11/02	43

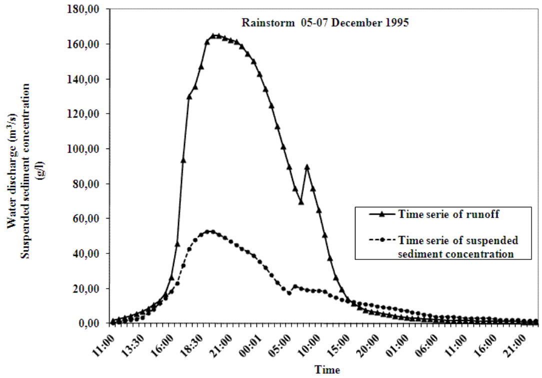
The systematic sampling procedure of the suspended sediments in Algerian wadis is simple and punctual. The sampling of the charged water is done using bottles from 0.5 to 1 liter capacity, and which either are launched in the current after being ballasted, or hung to a pole or a salmon, according to the conditions of current and of the variations of dimension of the wadi's bed. The samples collected are initially filtered on a millipore filter and the sediment load is measured by weighing the filters, then the filtered sediment are dried during 30 mn at a temperature of 110°C. Brought back to the unit of volume (1 liter), this load is allotted to the concentration in instantaneous suspension conveyed by the river in $g.l^{-1}$ (Ghenim et al. [5]). Concerning the evaluation of sediment transport during a rising, it is carried out in the same way that for the water flows, on the basis of examination of the recordings. Before the layout of the turbidgramme, the operation of carry forward on the limnigramme is necessary. The values of concentration in time and date are positioned on the limnigramme.

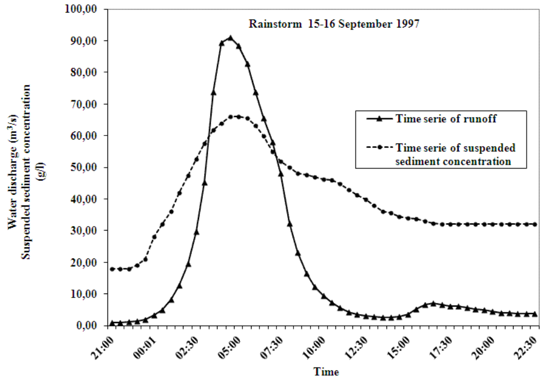


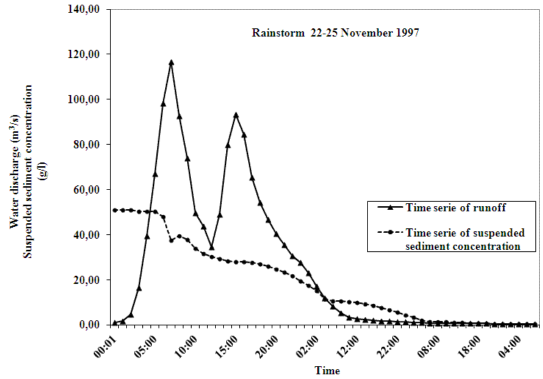

Rainstorm 17-18 October 1994
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time

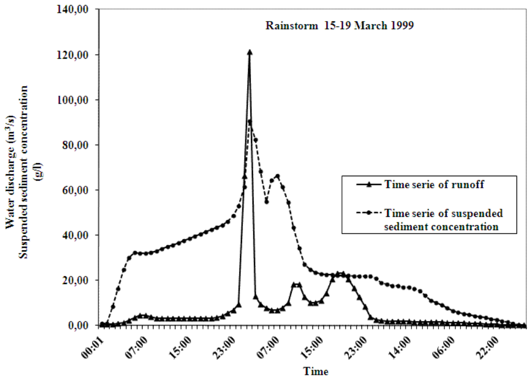

Rainstorm 02-04 March 1995
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time

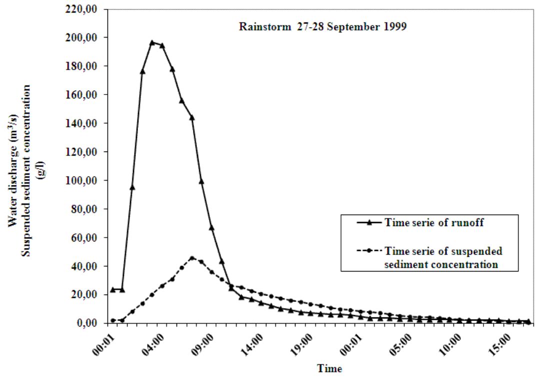

Rainstorm 09-11 October 1995
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time


Rainstorm 05-07 December 1995
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time


Rainstorm 15-16 September 1997
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time


Rainstorm 22-25 November 1997
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time


Rainstorm 15-19 March 1999
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time


Rainstorm 27-28 September 1999
Time serie of runoff
Time serie of suspended sediment concentration
Water discharge (m³/s)
Suspended sediment concentration (g/l)
Time

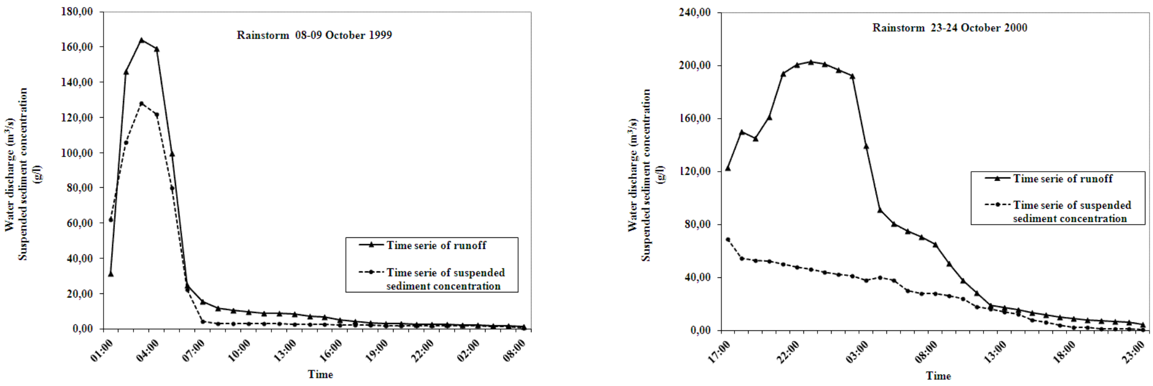


Fig. 3 Time series of water discharges and suspended sediment concentrations for the most important rainstorms selected.

3.1 Statistical parameters of rainstorms selected

The statistical parameters of the events (Table 2), confirms the irregularity of the hydrological mode of wadi Taria.

Table 2 Statistical parameters of the selected rainstorms

Rainstorm	Variables	values maximum	Standard deviation	Average	Mode	Median	C_v	Coefficient of asymmetry
1	C	18,70	5,15	7,73	4,00	6,10	0,67	0,66
	Q_L	39,20	9,71	12,68	6,86	7,64	0,77	1,77
2	C	12,70	3,81	5,73	0,68	6,80	0,66	-0,15
	Q_L	31,40	9,05	10,96	0,59	8,94	0,83	0,83
3	C	59,62	14,62	14,45	3,20	8,80	1,01	1,43
	Q_L	131,25	25,75	10,88	1,66	2,80	2,37	3,73
4	C	21,20	7,11	10,96	21,2	10,30	0,65	0,11
	Q_L	44,58	15,83	14,06	4,74	5,03	1,13	0,86
5	C	17,60	4,90	11,39	4,40	12,80	0,43	-0,42
	Q_L	128,00	44,53	62,53	13,56	72,50	0,71	0,11
6	C	14,50	4,20	7,57	10,4	8,10	0,55	0,05
	Q_L	123,80	39,08	46,06	82,7	38,90	0,85	0,35
7	C	12,35	3,60	5,17	1,00	4,00	0,70	0,73
	Q_L	33,84	9,58	6,56	0,74	2,33	1,46	1,90
8	C	48,50	13,82	18,02	7,50	12,60	0,77	0,92
	Q_L	52,00	15,01	8,14	50,5	1,80	1,84	2,21
9	C	53,50	11,80	24,47	28,00	23,55	0,48	0,78
	Q_L	159,00	44,28	35,67	20,25	11,70	1,24	1,42
10	C	50,40	20,86	20,22	12,00	11,80	1,03	0,49
	Q_L	123,00	39,39	48,76	98,5	47,65	0,81	0,24
11	C	60,00	10,63	10,09	2,40	6,70	1,05	2,68
	Q_L	134,52	21,77	9,44	1,00	1,55	2,31	4,15

Rainstorm	**Variables**	**values maximum**	**Standard deviation**	**Average**	**Mode**	**Median**	**C_v**	**Coefficient of asymmetry**
12	C	74,00	18,01	45,93	60,00	51,60	0,39	-0,58
	Q_L	180,12	56,13	55,81	10,75	24,20	1,01	0,92
13	C	48,00	10,28	19,27	14,2	16,00	0,53	2,02
	Q_L	155,40	34,61	26,93	14,3	13,05	1,29	2,07
14	C	68,00	20,89	30,30	17,00	20,75	0,69	0,64
	Q_L	191,00	62,92	88,68	127,3	97,00	0,71	-0,13
15	C	36,80	10,37	12,47	0,30	11,10	0,83	0,63
	Q_L	98,25	23,35	11,77	0,75	2,02	1,98	2,59
16	C	53,00	18,92	26,35	53,00	22,50	0,72	0,26
	Q_L	165,00	50,33	28,40	3,47	3,47	1,77	1,87
17	C	47,00	13,68	29,96	46,00	29,00	0,46	-0,29
	Q_L	78,38	15,68	23,47	13,32	19,54	0,67	1,86
18	C	52,50	15,99	16,32	2,00	10,50	0,98	1,08
	Q_L	165,00	60,11	47,05	1,26	8,70	1,28	0,97
19	C	25,80	8,22	13,79	3,10	15,00	0,60	-0,10
	Q_L	103,60	29,22	27,63	56,0	15,37	1,06	1,01
20	C	33,00	6,32	24,46	22,0	24,50	0,26	-0,53
	Q_L	163,43	63,32	73,42	-	48,13	0,86	0,52
21	C	54,00	20,29	26,50	0,48	32,30	0,77	-0,18
	Q_L	126,60	48,45	48,58	0,34	33,70	1,00	0,47
22	C	52,40	14,83	16,45	-	9,60	0,90	1,16
	Q_L	90,66	23,35	16,79	1,13	4,02	1,39	1,66
23	C	66,00	13,24	40,36	32,0	36,00	0,33	0,40
	Q_L	90,92	27,60	19,80	3,77	5,66	1,39	1,63
24	C	55,00	19,79	32,53	55,0	32,40	0,61	-0,16
	Q_L	94,93	26,87	17,69	0,68	5,39	1,52	1,79
25	C	51,00	17,29	18,64	0,40	11,60	0,93	0,60
	Q_L	116,58	32,57	25,22	0,42	4,58	1,29	1,20
26	C	38,00	10,63	16,07	32,0	14,50	0,66	0,57
	Q_L	41,88	10,41	6,77	0,62	1,58	1,54	2,10
27	C	90,50	20,34	26,90	22,0	22,45	0,76	0,86
	Q_L	121,40	15,88	7,70	3,26	3,26	2,06	5,59
28	C	46,00	12,52	13,52	2,00	9,00	0,93	1,05
	Q_L	197,00	60,69	37,10	2,36	6,86	1,64	1,78
29	C	128,00	39,36	20,28	3,00	2,50	1,94	2,02
	Q_L	164,12	49,52	26,64	9,00	6,88	1,86	2,23
30	C	52,00	17,67	20,41	-	16,50	0,87	0,60
	Q_L	53,26	16,80	19,09	-	13,26	0,88	1,13

Rainstorm	Variables	values maximum	Standard deviation	Average	Mode	Median	C_v	Coefficient of asymmetry
31	C	25,00	7,58	10,03	6,00	6,50	0,76	0,75
	Q_L	78,82	22,77	16,83	3,10	5,47	1,35	1,75
32	C	68,90	20,16	27,01	38,00	28,00	0,75	0,15
	Q_L	203,00	74,89	81,70	-	65,00	0,92	0,52
33	C	15,60	4,35	9,70	15,60	10,25	0,45	-0,39
	Q_L	67,51	16,77	15,20	9,29	9,29	1,10	2,18
34	C	31,50	9,40	14,29	5,00	13,90	0,66	0,42
	Q_L	62,00	15,25	13,08	2,10	8,77	1,17	2,1
35	C	30,20	7,83	15,67	15,00	15,00	0,50	0,34
	Q_L	55,00	14,01	17,9	21,60	18,03	0,78	1,25
36	C	32,70	8,61	9,38	5,80	5,80	0,92	1,17
	Q_L	126,50	33,28	22,94	1,19	6,27	1,45	1,86
37	C	58,00	14,27	36,01	29,00	29,00	0,40	0,39
	Q_L	196,40	72,90	118,4	155,40	152,88	0,62	-0,79
38	C	31,00	9,11	16,51	10,00	12,00	0,55	0,34
	Q_L	58,61	16,93	11,65	1,10	2,56	1,45	1,73

C: suspended sediment concentration g l^{-1}; Q_L: water discharge $m^3 s^{-1}$; C_v: coefficient of variation.

4. RESULTS AND DISCUSSION:

4.1 Using of the sediment rating curve:

Once sufficient data have been collected, attention must be given to deriving the rating relationship. In the absence of actual suspended sediment concentration measurements, hydrologists have used sediment rating curves to predict suspended sediment concentrations for subsequent flux calculations, determining long-term suspended sediment loads (Khanchoul et al. [6]).

A regression analysis is made between the instantaneous sediment discharges (Q_S) and the instantaneous water discharges (Q_L). The most commonly used sediment rating curve is a power function as in (1).

$$Q_S = a.Q_L^b \quad (1)$$

Where **a** and **b** are regression coefficients. Equation (1) covers both the effect of increased stream power at higher discharge and the extent to which sediment becomes available in weather conditions that cause high discharge. Water discharge and sediment discharge have been plotted on logarithmic co-ordinates. The data used to develop the sediment rating curves of the wadi Taria consists of 7657 values of suspended sediment concentrations and their discharges. High, medium and low flows were studied. The data set was also represented and gathered according to four seasons: Autumn, winter, spring and summer (figure 04).

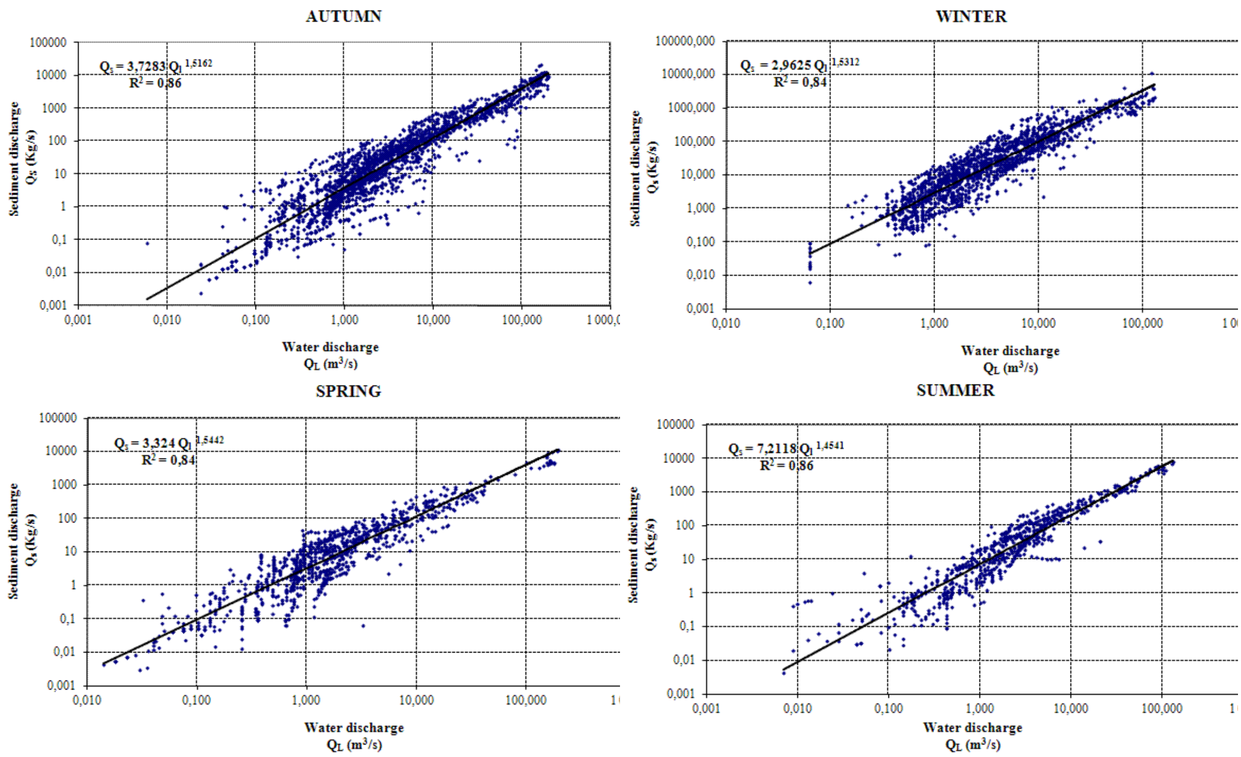


Fig. 4 Sediment rating curves developed on instantaneous water discharges and instantaneous sediment discharges according to seasonal scale.

After several tests with various types of adjustment, the model power seems to offer the best adjustment within sight of the value of the coefficient of determination R^2. The correlation coefficients, ranging between 0.84 and 0.86, are good, which makes it possible to conclude that these regressions give acceptable results.
Analysis of the seasonal regression parameters has shown that the constant ‘a’ is highly variable and differs significantly from season to season (figure 04). The winter season value of ‘a’ is lower than the corresponding dry and spring season value. The exponent ‘b’ is higher in the spring season than in autumn, winter and in the dry season. Since ‘b’ is a measure of the rate at which a change in the runoff is converted to geomorphic work and shows the sensivity of the system to carry out such work.

4.2 The seasonal and annual variations of the suspended sediment loads:

In this section, attempts will be made to explain the variations of the suspended sediment loads in the wadi Taria. The annual and seasonal budget of the suspended sediment load exported by wadi Taria is calculated as in (2)

$$A_S = \sum_{j=1}^{N} \frac{\left[(Q_{L(j+1)} \cdot C_{(j+1)}) + (Q_{Lj} \cdot C_j)\right]}{2} \cdot \left(t_{j+1} - t_j\right) \qquad (2)$$

Where: A_S: seasonal or annual sediment suspended load (Tonne/year); C_j: suspended sediment concentration measured (Kg/m^3); Q_{Lj}: water discharge (m^3/s); N: is the number of taking away carried out over the year and the season considered; and $(t_{j+1} - t_j)$ is the step of time separating two consecutive taking away (s). (Ghenim et al. [7]).
In the same way, the annual and seasonal water contribution A_L, corresponding to A_S is calculated as in (3)

$$A_L = \sum_{j=1}^{N} \frac{\left\lfloor Q_{L(j+1)} + Q_{Lj} \right\rfloor}{2} \cdot \left(t_{j+1} - t_j\right) \tag{3}$$

In addition, the sediment yield A_{SS} (tonnes/km^2/year) is calculated as in (4)

$$A_{SS} = \frac{A_S}{S} \tag{4}$$

S: area of the basin (km^2).

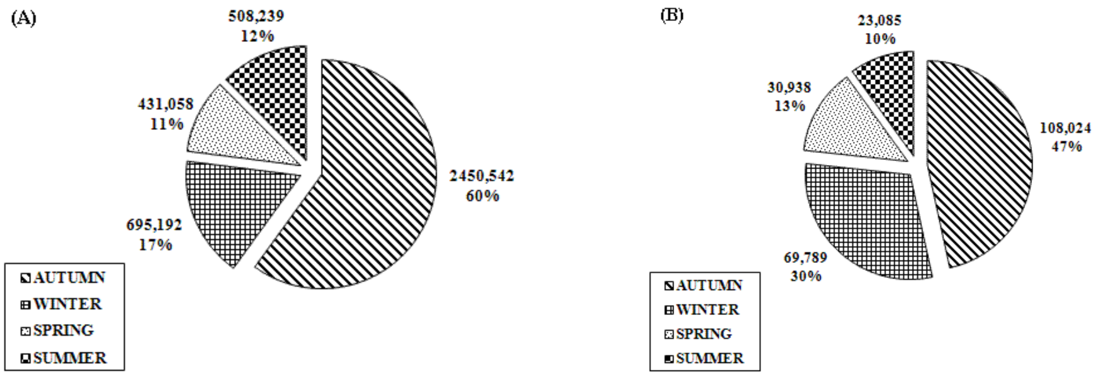


Fig. 5 (A). Seasonal sediment yield during 21 years (tonnes/km^2/year).
(B) Seasonal water contribution during 21 years (10^6 m^3/year)

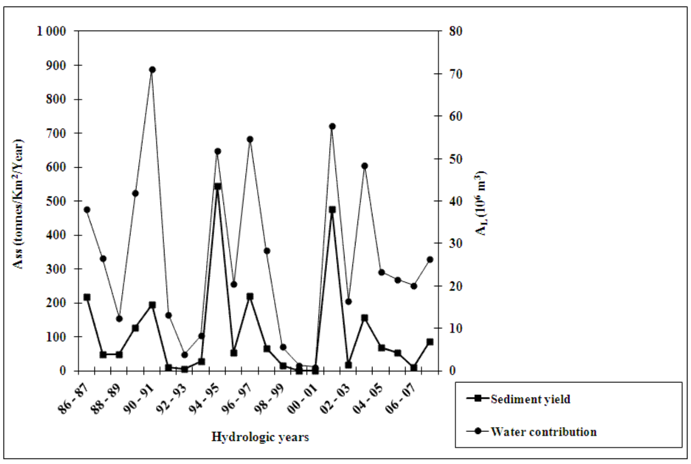


Fig. 6 Interannual variability of sediment yield (1986-2007) in wadi Taria gauging station

The study of seasonal distribution of sediment load indicates that 3 345000 tonnes were transported during the autumn. This quantity represent 60% of the total sediment yield (figure 5A) with a volume of water about 108 million m^3 (figure 5B). The second

highest sediment load occurred during the winter with a load reaching 949000 tonnes which represent 17% of the total load and 69 million m^3 of water contribution. This variability is explained by the variation of vegetation cover throughout the year and the nature of the rains in autumn (aggressiveness of the rains). These two factors allow the first rains of autumn to transport considerable quantities of sediments after a long dry season characterized by high temperatures and the destruction of the aggregates of the ground from these factors and energy developed by the first rains, also contributing is the weak vegetation cover rate in this season. The weak rate of erosion in winter is explained by the fact that most of the solid particles were transported by the first floods of autumn (Khanchoul and Jansson. [8]).
The annual suspended sediment yield varies significantly from one year to another (figure 06). For example, during the hydrologic year 1994-1995, stream flow, sediment concentration and sediment load were much higher than other hydrologic years due to exceptional rainstorms recorded in october 93, september 94 and march 95 (figure 03) and as a result, 30 million m^3 of water contribution was recorded, during which 1 048 535 tonnes of suspended sediment load what gives a suspended sediment yield of 768 tonnes/km^2/year, and hydrologic year 1988-1989 was the driest year with only 8744 tonnes observed corresponding to a suspended sediment yield equal to 6,4 tonnes km^{-2} $year^{-1}$.

5. CONCLUSION

The hydric erosion constitutes a major aspect of the degradation of the landscapes in the semiarid Mediterranean environments. So sediment yield from semiarid areas is very highly variable because precipitation and runoff are highly variable.
In this study we have estimate suspended sediment load in wadi Taria basin, using the sediment rating curve method. This gave a good correlation coefficients ranging between 0.84 and 0.86. A great number of data on the sediment transport in the wadi Taria basin have been explored in order to get a good estimation of the seasonal and annual suspended sediment yield. The results obtained indicate that the mean sediment yield for the catchment area is about 236 tonnes/km^2/year. Compared to the excessive erosion in other wadis of Algeria such as Sebdou wadi with 937 tonnes Km^{-2} $year^{-1}$ (Bouanani 2004), Ebda wadi with 1875 tonnes Km^{-2} $year^{-1}$, (Meddi 1999), Haddad wadi with 2.87 tonnes Km^{-2} $year^{-1}$, Abd wadi with 3.47 tonnes Km^{-2} $year^{-1}$ (Achit 2004, 2006), Mouilah wadi 165 tonnes Km^{-2} $year^{-1}$ (Ghenim 2008), Mellah wadi with 373 tonnes Km^{-2} $year^{-1}$ (Khanchoul 2008), the suspended sediment yield of the Taria wadi is considered moderate.

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