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Quantification of total solid transport in a Mediterranean stream: case study of Wadi Bellah, Tipaza, Algeria

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ABSTRACT/RESUME

Abstract: *The study is to evaluate the total sediment transport (suspended and bed load) in a Mediterranean river (Bellah, Tipaza, Algeria).To understand this study, we based our analysis on hydrometric data related to the instantaneous discharge and to the concentration of suspended sediment, over a period of 33 years (from 1974/75 to 2006/07). The results show that a good correlation between the suspended sediments and water discharge. The exponent b of our model is equal to 1.38, a value close to those found by researchers who worked in semi-arid region. The suspended sediment transport is about 610 t* km^{-2} $year^{-1}$*. This value is comparable to those found in other regions with similar hydrologic regimes. The bed load is about 170 t* km^{-2} $year^{-1}$ *for* $\tau_0 = \gamma \times I \times R_h$ *t* km^{-2} $year^{-1}$ *and it is about 115 t* km^{-2} $year^{-}1$ *for* $\tau_0 = 0.7 \times \gamma \times I \times R_h$*. The total sediment transport is estimated at 725 t* km^{-2} $year^{-1}$ *if we take into account the corrective coefficient of roughness in the bed of the wadi and equal to 780 t* km^{-2} $year^{-1}$ *in other direction. To better judge our results, we compared them with those obtained by the relationship Tixeront which remains the most used for estimating the specific degradation in the basins of the Maghreb. The value obtained by the relation of Tixeront is slightly below our own values, but it is permissible to say that the results are of the same order of magnitude. This slight difference can be explained by the introduction of the amount of sediments carried in the determination of the specific erosion of the watershed rates.*

I. Introduction

The most drastic consequences of basin's erosion and sediment transport are certainly the silting of dams and water pollution. Research conducted in these fields shows that the specific degradation of basins in the Maghreb varies from 1000 to 5000 tons per square kilometer per year ([19]; [37]; [29]; [24]; [18]). As results of these degradations, the amount of sediment flowing into the Mediterranean Sea is estimated at 100 (one hundred) million tons per year [29].

Erosion and solid transport processes in the basins of Mediterranean semi-arid zones have interested a great number of hydrologists, whose studies have increased in the last ten years with the aim of understanding and explaining the mechanisms, their causes and their consequences. We can mention the works of: [11], [23], [31], [1], [13], [38], [14] and

[26] all of which highlight the relationships that may apply on areas where the measures of the basin effect are rare, incomplete or non-existent.

In Algeria, sediment transport is evaluated at hydrometric stations for almost all periods of flow [22]. Generally, only suspended sediments are evaluated. Bed load measurement is, in fact, a problem whose solution is still to be solved. According to the evaluation of suspended sediment transport, the bed load is estimated between 15% and 25% of the suspension ([11]; [22]; [6]). The case of the wadi Bellah is noted, in view of the importance of sediment transport that passes through the outlet of its watershed. These large volumes of sediment are discharged into the sea causing the pollution [29]. On this issue, we discussed this kind of work. The study site is located in the catchment of the wadi Bellah. The long records of hydrometric variables and sediment transport is highly relevant for studying erosion and solid transport on this semi arid catchment.

In this work, the hydrometric measures (water level, water discharge and suspended sediments concentration in the bridge of RN 11 station) were used for the quantification and modelling of total sediment transport. The first approach applied on the wadi Bellah (Algeria) is of a determinist type and uses simple regressive models whose aim is to find one or many relationships between water and sediment discharge. The second approach is utilized for estimating the bed load from the suspension to determine the total sediment transport in the study area.

II. Materials and methods

II.1. Presentation of the study area

The basin of wadi Bellah covers an area of 55 km^2 with a perimeter of 38 km. It's moderately elongated in shape (compactness coefficient K_c = 1.43). It is part of the Algeria's coastal basin, and part of it stretches to Tipaza province. It is situated between 2°9'33.84" and 2°16'1.2" degrees East longitude, and between 36°30'7.56" and 36°36'41.76" degrees North latitude (figure 1).

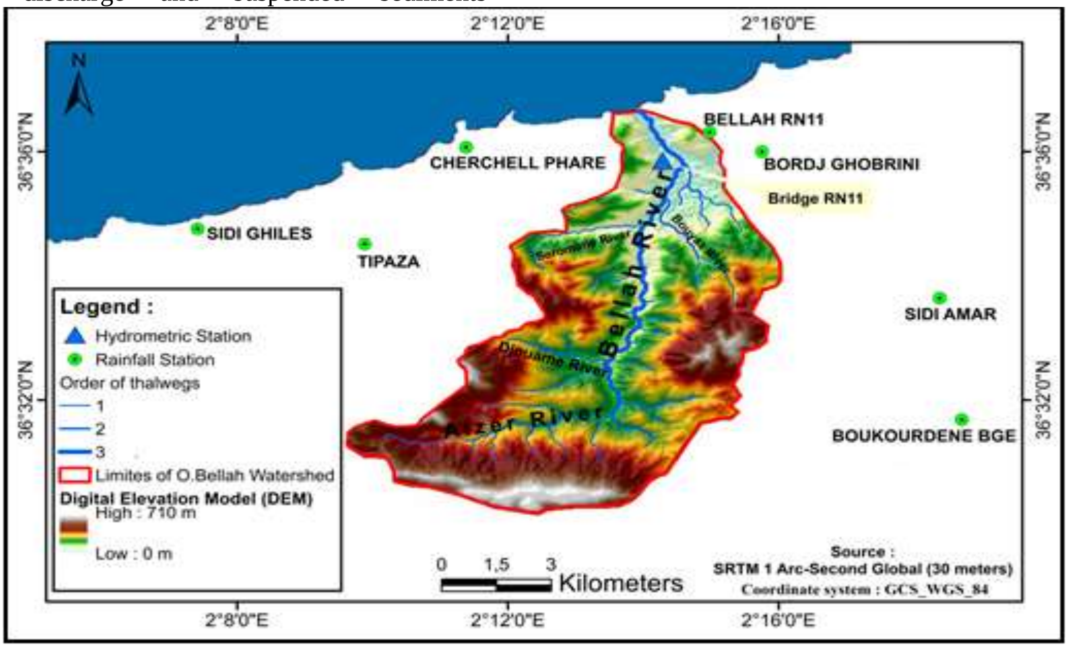

Figure 1. *Situation of the basin area of Bellah Wadi.*

The basin of Bellah wadi is of a mountainous nature. It is at an average altitude of 254 m. The altitude at the outlet where the hydrometric station Pont RN 11 is situated is 25 m. It is characterized by a maximum altitude of 736 m. The length of its equivalent rectangle is 10.39 km. Its drainage density is 3.6 km/km^2. The torrentiality coefficient in this basin is 32.76 and the length of its main Talweg is 16 km. The main soil types in Bellah wadi basin are alluvial soils and calcareous soils in the major part of the basin. The study zone consists in stable to unstable terrains despite the predominance of steep slopes greater than 12.5%. This is explained by the dominance of erosion resistant and medium resistant substrate. The climate of Bellah basin is semi-arid. It is wet and cold in winter and hot and dry in summer. The basin receives between 300 and 700 mm of rainfall per year with an inter-annual average of 519 mm for the period from 1974/75 to 2006/07 (figure 2).

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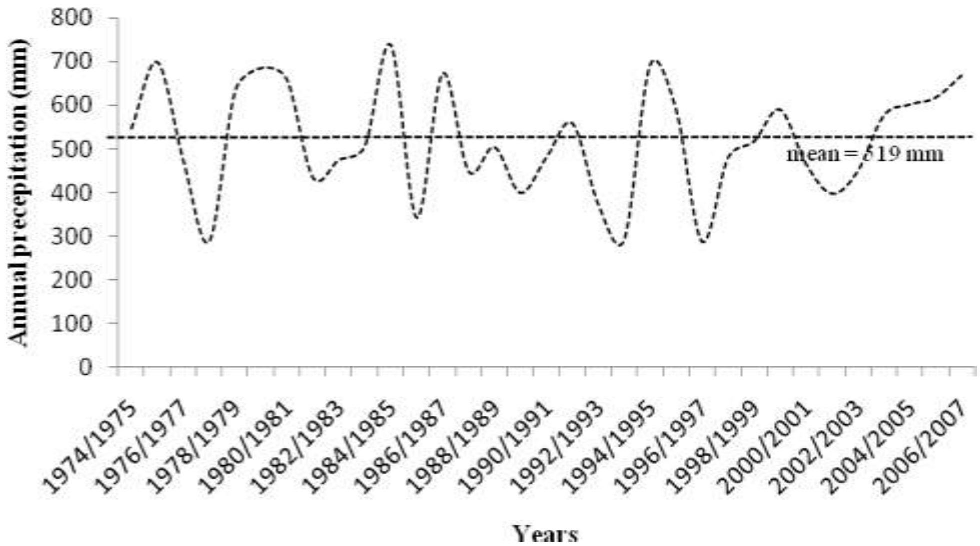

Figure 2. *Inter-annual variation in rainfall. Post RN Bellah 11 (1974/75 to 2006/07).*

II.2. Sampling site and methodology of measurement

The watershed of Bellah wadi is monitored by the Pont RN 11 hydrometric station. This station is located at Lambert in X = 458.65 km and Y = 367.50 km. The study was realized using the data collected during the period from 1974/75 to 2006/07 consisting of water discharge Q_l in m^3/s and of suspended load concentration C in g/l. The data are provided by the National Agency of Water Resources in Algeria. Water discharge measures are obtained by two ways: on the basis of curve rating according to the water level indicated by the limnimetric scale. The other way is by analyzing water level recorded on a float limnigraph.

The operating principle for measuring sediment suspended load is the following: water that is collected in flacons. This may lead to the underestimation of the solid flow. This way of sampling doesn't take into account neither the variations in suspended content from one point to another in the wet cross-sections nor does it consider the length of the vertical variation of sediment concentration [33]
. Many studies including those realized by Orstom in Africa showed, in fact, that suspended matter concentrations distributes uniformly into the gauging section and tend to increase with depth ([10]; [27]). However, measurements are generally simplified.

In this study, a number of sampling points are collected at a depth of about 30 cm under the surface of water and at about 50 cm above the bottom. At each sampling, the samples are transferred in plastic bottles, then stored in a cooler at a low temperature (t = 4 °C). After that, the samples are sent to the laboratory for analysis. To collect suspended matter, water filtration is realized on filter paper type Whatman (filter porosity equal to 10 µm, filtration time t = 10.5 s). After that, the suspended sediments are dried in the oven for an hour at a temperature of 105 °C and reduced to the unit of one liter. The suspended load is calculated then by the following relationship: $C = (P_2-P_1)/V$ where C is the concentration expressed in grams per liter. P_1 is the weight of filter paper (dry and empty) in grams before the weighing of the sample, P_2 is the weight of the filter paper with the suspended sediments expressed in grams and V is the sample volume. This measured suspended load is attributed to the instantaneous concentration in suspended sediments carried by the stream in grams per liter. The number of sampling has been adapted to a hydrologic regime. Samples are collected every other day. However, during flood periods, sampling frequency is intensified to intervals of one hour or even thirty minutes depending on the speed of water flow.

III. Results and discussion

III.1. Data and quantification methods

III.1. 1. Suspended sediment transport

The analysis focuses on the water discharge values in m^3/s and on sediment discharge in kg/s measured at the basin of Bellah Wadi from 1974/1975 to 2006/07 (instantaneous data for the complete series, figure 3).

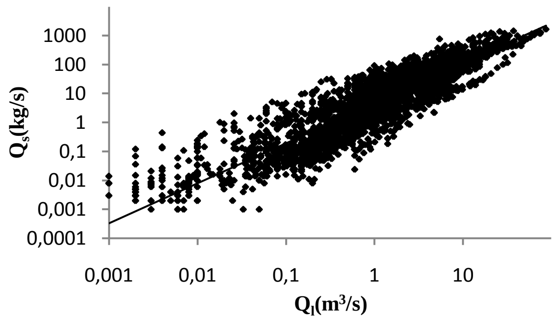

Figure 3. *Relationship between sediment discharge and water discharge for the complete series 1974/75 to 2006/07 (Bellah Wadi, hydrometric station Pont RN 11, $Q_s = 4.6162 \times Q_l^{1,3804}$, $R^2 = 0.8083$ and $R = 0.90$).*

The analysis of this figure shows a good correlation between the suspended sediments and water discharge. The scatter plots obtained are aligned around the regression line.

The power relationship [$Q_s = a \times Q_l^b$] was verified in most streams of the world ([15]; [5]; [7]). The exponent b, function of physical, climatic and hydrological characteristics of the basin ([8]; (34]; [28]; [4]) or hydraulic conditions of the flow in streams ([35]; [36]; [20]) generally vary between 1 and 2. It should be noted that the exponent b of our model is equal to 1.38, a value close to those found by researchers who worked in semi-arid regions ([31]; [2]; [3]; [25]; [38]).

It is also noticed, according to figure 3, that for low water discharges we can associate low sediment discharges around 0.001 m^3/s likewise, high values of water discharges engendered only a low sediment transport (less than 0.01 kg/s) due probably to ground water depletion following a major flood ([22]; [38]).

To estimate the suspended sediment transport, we used the relationship of complete series ($Q_s = 4.62 \times Q_l^{1.38}$) where Q_l is the monthly average water discharge.

The calculation is done over a period of thirty three years from 1974/75 to 2006/07. The obtained results are represented in the table 1.

Table 1 shows that the years 1975/76, 1978/79, 1990/91 and 1998/99 are characterized by important sediment yields. This can be explained by the occurrence of exceptional floods in volume and in duration. In this context, we may mention the flood of February 1976 (57895 tons) with an amount of water of 6.60 hm^3 and a concentration of 8.79 g/L, the flood of March 1979 (69025 tons) with an amount of water of 3.10 hm^3 and a concentration of 22.2 g/L, the flood of April 1995 (26862 tons) with an amount of water of 2.78 hm^3 and a concentration of 9.71 g/L, the flood of December 1998 (35535 tons) with an amount of water of 3.83 hm^3 and a concentration of 9.40 g/L and the flood of November 2001 (21106 tons) with an amount of water of 1.65 hm^3 and a concentration of 12.73 g/L.

The suspended sediments transported by Bellah Wadi are carried out during the period from November to April. The floods observed during this period are characterized by high concentrations in suspended sediments (22.2 g/L in the flood of March 1979) which favored an important sediment yield (of 69025 tons).

It is also observed that winter and spring floods (of 40 to 87 m^3/s) favor the transport of suspended sediments because they were characterized by severe turbulence due to extreme discharge. According to sediment yield A_s (t), we can determine the specific degradation $A_{ss} = A_s/S$ where S is the area of the basin.

Thus the specific degradation is highly variable from one year to another. It varies from 54 t/km^2/per year for the year 2000/01 to 1973 t km^{-2} $year^{-1}$ for the year 1978/79, for a ratio of 1 to 37.

It's noticed also that for two years receiving almost the same rainfall quantity, the suspended load can be different. During the year 1975/76, we calculated 0.11×10^6 tons for a precipitation of 698 mm, while in 1980/81, and for nearly the same quantity of precipitations (658 mm), only 0.016×10^6 tons of sediments were registered, for a ratio of 1 to 7.

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Table 1. *Monthly and annual distribution of sediment transport of suspended sediments in tons and specific degradation in tons per km² per year in the basin of Bellah Wadi (1974/75 to 2006/07).*

Année	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	$A_s[10^6t]$	A_{ss} [$t\ km^{-2}\ year^{-1}$]
74/75	45	7872	6719	469	447	3070	4640	4638	5002	280	156	354	**0,034**	**613**
75/76	213	191	14872	13744	5642	57895	6646	2295	4203	175	47	31	**0,110**	**1926**
76/77	268	1894	2847	3989	4991	733	3961	2614	605	63	24	19	**0,022**	**400**
77/78	671	1887	2875	13077	4962	13275	7365	2107	2205	1318	754	928	**0,051**	**935**
78/79	6	10926	353	4368	2743	18363	69025	2202	358	113	58	19	**0,110**	**1973**
79/80	88	211	3419	7907	15598	8389	9126	2043	852	168	84	106	**0,048**	**873**
80/81	134	199	315	2304	3907	1853	2506	981	3358	297	220	191	**0,016**	**296**
81/82	450	933	2672	10746	7199	5813	2586	1055	1521	240	116	118	**0,033**	**608**
82/83	515	466	3929	6358	1360	3168	941	279	363	89	115	7	**0,018**	**320**
83/84	34	52	277	5662	8139	1860	6914	676	905	382	66	6	**0,025**	**454**
84/85	53	8493	13664	1770	7308	6692	10615	1838	1776	207	8	17	**0,052**	**953**
85/86	157	21	1148	400	1061	4949	12607	3375	415	1302	1120	148	**0,027**	**486**
86/87	3198	437	15433	15382	7142	18439	13198	4779	3700	905	569	1515	**0,085**	**1540**
87/88	1864	459	1930	12418	5319	4130	12633	5189	3356	1472	501	6	**0,049**	**896**
88/89	97	505	4906	378	5127	1310	1711	19223	2055	850	198	50	**0,036**	**662**
89/90	2812	1545	4622	2019	6689	1347	1418	1829	1912	669	0	0	**0,025**	**452**
90/91	0	605	504	2289	25910	8508	15456	554	848	110	40	17	**0,055**	**997**
91/92	44	104	1073	4316	56	356	1705	2762	1893	558	93	23	**0,013**	**236**
92/93	192	749	2063	4613	1198	3843	988	660	360	77	74	20	**0,015**	**270**
93/94	633	16	84	1625	3441	2704	471	1015	4	5	0	6	**0,010**	**303**
94/95	445	145	1914	18	4465	720	8437	26862	290	52	12	16	**0,043**	**789**
95/96	10	5	3	51	283	741	53	993	2088	98	4	3	**0,004**	**79**
96/97	80	2331	7095	695	491	8990	1717	223	327	51	13	20	**0,022**	**401**
97/98	1	0	1107	1014	889	622	401	420	379	0	0	0	**0,005**	**88**
98/99	0	0	666	35535	1269	9315	12861	200	386	0	0	0	**0,060**	**1095**
99/00	56	251	29	257	7504	2032	612	156	995	0	0	0	**0,012**	**216**
00/01	85	102	627	120	1172	333	119	388	9	1	0	0	**0,003**	**54**
01/02	2	0	21106	100	203	111	2191	31	6	0	16	23	**0,024**	**433**
02/03	0	1	305	108	6958	1688	521	589	340	7	0	0	**0,011**	**191**
03/04	38	0	1818	1855	6272	5379	620	985	214	32	0	0	**0,017**	**313**
04/05	39	6	239	2223	4268	6930	7983	485	90	18	1	1	**0,022**	**405**
05/06	170	6	43	12615	2884	2801	1219	263	9747	968	4	2	**0,031**	**559**
06/07	3877	22	84	1633	4822	3358	1704	1348	12	6	3	3	**0,017**	**307**
Moy.	**493**	**1225**	**3598**	**5153**	**4840**	**6355**	**6756**	**2820**	**1533**	**319**	**130**	**111**	**0,033**	**610**

The annual average sediment flow recorded at Bellah Wadi outlet was evaluated at 33000 tons, which corresponds to a specific degradation of 610 $t\ km^{-2}\ year^{-1}$. This value is comparable to those registered in other regions with similar hydraulic regimes, like Mouilah basin (Algeria), with 126 $t\ km^{-2}\ year^{-1}$ [31], Sebdou basin (Algeria) with 937 $t\ km^{-2}\ year^{-1}$ [9], Saf Saf basin (Algeria) with 461 $t\ km^{-2} year^{-1}$ [21] and Sebdou basin (Algeria) with 1330 $t\ km^{-2}\ year^{-1}$ [17]. Works carried out in the Maghreb estimated that the specific degradations vary between 1000 and 5000 $t\ km^{-2}\ year^{-1}$. Other authors proposed higher values. Probst and Suchet, 1992 advanced values greater than 5000 $t\ km^{-2}\ year^{-1}$; these same authors estimated that the average specific degradation varies from 400 to 610 $t\ km^{-2}\ year^{-1}$ for streams that flow into seas and oceans [16].

III.1.2. Bed load sediment transport

The measures of bed load sediment transport in situ are very costly. For that, quantifying this type of transport is very difficult in the absence of databases. Studies are generally confined to small scale models to determine the bed load proportion in relation to the suspension or the total transport. Sediment transport in Algeria is evaluated in basin's hydrometric stations for almost all flow periods. Generally, only suspended sediment discharge is evaluated. Bed load measurement is, in fact, a problem whose solution is not complete. According to the evaluation of suspended sediment transport, bed load is estimated between 15% and 25% of the suspension, according to many authors ([11]; [22]; [6]).

At the Pont RN 11 station, we have a wide range of measurement. About 7510 water depth values (H in cm), of liquid flow (Q_l in m^3/s) and concentrations of suspended solids (C in g/l) were selected for the establishment of the relationship between the liquid flow and the flow rate solid. Given the total lack of measurement of the sediment carried along in the wadi Bellah, we established conventional measures of background material making materials levies along the wadi at downstream watershed. Particle size analysis in the laboratory to determine the average diameter carted revealed that the diameter d_{50} of granules is materialized by means of fine gravel (d_{50} = 9 mm). For evaluation of the sediment discharge by thrusting, we relied on the Meyer-Peter formula ([30]; [12]; [22]):

$$g_s = k(\tau - \tau_c)^{\frac{3}{2}} \qquad (1)$$

Where g_s is carted sediment discharge per unit width of the bed of the wadi, expressed in kg/s.m, τ is the actual average shear stress or strain friction, depending on the flow and expressed in kg/m^2, τ_c is the shear stress on the bed shear stress or critical start thrusting in kg/m^2, depending solely on the particular material carted its dimensional characteristics and its specific weight ρ. The parameters k, τ_c and τ are expressed respectively by:

$$k = 8\sqrt{\rho}\frac{\gamma_s}{\gamma_s - \gamma} \tag{2}$$

$$\tau_c = 0.047(\gamma_s - \gamma)d_{50} \tag{3}$$

$$\tau = aR_h I \tag{4}$$

In equations (2), (3) and (4), the variables γ, γ_s, d_{50}, a, R_h and I respectively designate the specific weight of the sediment, expressed in kg/m^3, the volume weight of the sediment, expressed in kg/m^3, the average diameter of sediments carried, expressed in mm, a correction factor taking into account the average roughness of the bed of the Wadi, the hydraulic radius, expressed in km and the average slope of the Wadi, expressed in %. For the case of the Wadi Bellah, we estimated the coefficient a equal to 0.70 [12].

In case we take into account the corrective coefficient of roughness in the bed of the wadi, the bed load is estimated at 19 % on average of the suspension and, it is equal to 28% otherwise [12]. The results of calculation are presented in the table 2 and the table 3.

That is a ratio of 1 à 37. The annual average bed load sediment arriving at the basin of Bellah wadi outlet is estimated at 9333 tons which corresponds to a specific erosion rate of 170 t/km^2/per year.

We notice according to table 3, in case where $\tau_0 = 0{,}7\times\gamma\times R_h\times I$, the specific erosion rate is highly variable from one year to another. It varies from 10 t/km^2/per year for the year 2000/01 to 375 t/km^2/per year for the year 1978/79, that is a ratio of 1 à 37.

The annual average bed load sediment yield up to the studied basin outlet is estimated at 6335 tons, which corresponds to a specific erosion rate of 115 t/km^2/per year. We notice also that the annual bed load sediment discharge is always less than the suspended sediment discharge. This can be explained by the existing floods where the flow becomes turbulent and the results found are well confirmed.

III.1. 3. Total sediment transport

The total sediment transport in Bellah Wadi is both the suspended and bed load sediment transport. The results of calculation for both are represented in the table 4 and the table 5.

We notice that the average specific degradation calculated, taking into consideration the total sediment transport is of 776 t/km^2/per year (table 4) in case where $\tau_0 = \gamma\times R_h\times I$ and it is of 721 t/km^2/per year in case where $\tau_0 = 0{,}7\times\gamma\times R_h\times I$. And, to better judge our results, we compared them with those obtained by the relationship Tixeront (1960) which remains the most used for estimating the specific degradation in the basins of the Maghreb. The relationship is:

$$T_a = a\times R^{0.15} \tag{5}$$

Were, T_a is the abrasion rate (t/km^2/per year), a coefficient which corresponds to soils of average permeability, R is the runoff curve number in mm/per year, $R = P_0 - D_m$, with, P_0 : the annual average pluviometry in mm. D_m is the annual flow deficit in mm from which $D_m = [P_0 / (0.9 + (P_0^2 / L))^{1/2}]$, where, $L = 300 + 25\times t + 0{,}05\times t^3$, with t : (the mean temperature).

According to the previous data, the specific erosion rate value of Tixeront formula is of 608 t/km^2/per year.

The specific erosion provided by Tixeront formula can be compared to that of the calculation (table 6).

It is interesting to note on Table 6 that the value obtained by the relation of Tixeront is slightly below our own values, but it is permissible to say that the results are of the same order of magnitude. This slight difference can be explained by the introduction of the amount of sediments carried in the determination of the specific erosion of the watershed rates.

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Table 2. *Monthly and annual distribution of bed load sediment yield in tons and specific degradation in tons per km² per year for $\tau_0 = \gamma \times I \times R_h$ in the basin of Bellah Wadi (1974/75 to 2006/07).*

year	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	A_s[t]	A_{ss}[t/km²/per year]
74/75	13	2204	1881	131	125	860	1299	1299	1401	78	44	99	**9434**	**172**
75/76	60	53	4164	3848	1580	16211	1861	643	1171	49	13	9	**29668**	**539**
76/77	75	530	797	1117	1397	205	1109	732	169	18	7	5	**6161**	**112**
77/78	188	528	805	3662	1389	3717	2062	590	617	369	211	260	**14398**	**262**
78/79	2	3059	99	1223	768	5142	19327	617	100	32	16	5	**30390**	**553**
79/80	25	59	957	2214	4367	2349	2555	572	239	47	24	30	**13438**	**244**
80/81	38	56	88	645	1094	519	702	275	940	83	62	53	**4555**	**83**
81/82	126	261	748	3009	2016	1628	724	295	426	67	32	33	**9365**	**170**
82/83	144	130	1100	1780	381	887	263	78	102	25	32	2	**4924**	**90**
83/84	10	15	78	1585	2279	521	1936	189	253	107	18	2	**6993**	**127**
84/85	15	2378	3826	496	2046	1874	2972	515	497	58	2	5	**14684**	**267**
85/86	44	6	321	112	297	1386	3530	945	116	365	314	41	**7477**	**136**
86/87	895	122	4321	4307	2000	5163	3695	1338	1036	253	159	424	**23713**	**431**
87/88	522	129	540	3477	1489	1156	3537	1453	940	412	140	2	**13797**	**251**
88/89	27	141	1374	106	1436	367	479	5382	575	238	55	14	**10194**	**185**
89/90	787	433	1294	565	1873	377	397	512	535	187	0	0	**6960**	**127**
90/91	0	169	141	641	7255	2382	4328	155	237	31	11	5	**15355**	**279**
91/92	12	29	300	1208	16	100	477	773	530	156	26	6	**3633**	**66**
92/93	54	210	578	1292	335	1076	277	185	101	22	21	6	**4157**	**76**
93/94	177	4	24	455	963	757	132	284	1	1	0	2	**2800**	**51**
94/95	125	41	536	5	1250	202	2362	7521	81	15	3	4	**12145**	**221**
95/96	3	1	1	14	79	207	15	278	585	27	1	1	**1212**	**22**
96/97	22	653	1987	195	137	2517	481	62	92	14	4	6	**6170**	**112**
97/98	0	0	310	284	249	174	112	118	106	0	0	0	**1353**	**25**
98/99	0	0	186	9950	355	2608	3601	56	108	0	0	0	**16864**	**307**
99/00	16	70	8	72	2101	569	171	44	279	0	0	0	**3330**	**61**
00/01	24	29	176	34	328	93	33	109	3	0	0	0	**829**	**15**
01/02	1	0	5910	28	57	31	613	9	2	0	4	6	**6661**	**121**
02/03	0	0	85	30	1948	473	146	165	95	2	0	0	**2944**	**54**
03/04	11	0	509	519	1756	1506	174	276	60	9	0	0	**4820**	**88**
04/05	11	2	67	622	1195	1940	2235	136	25	5	0	0	**6238**	**113**
05/06	48	2	12	3532	808	784	341	74	2729	271	1	1	**8603**	**156**
06/07	1086	6	24	457	1350	940	477	377	3	2	1	1	**4727**	**86**
Moy.	**138**	**343**	**1007**	**1443**	**1355**	**1779**	**1892**	**790**	**429**	**89**	**36**	**31**	**9333**	**170**

Table 3. *Monthly and annual distribution of bed load sediment yield in tons and specific degradation in tons per km² per year for $\tau_0 = 0.7 \times \gamma \times I \times R_h$ in the basin of Bellah wadi (1974/75 to 2006/07).*

year	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	A_s[t]	A_{ss}[t/km²/per year]
74/75	9	1496	1277	89	85	583	882	881	950	53	30	67	**6401**	**116**
75/76	40	36	2826	2611	1072	11000	1263	436	799	33	9	6	**20131**	**366**
76/77	51	360	541	758	948	139	753	497	115	12	5	4	**4182**	**76**
77/78	127	359	546	2485	943	2522	1399	400	419	250	143	176	**9771**	**178**
78/79	1	2076	67	830	521	3489	13115	418	68	21	11	4	**20621**	**375**
79/80	17	40	650	1502	2964	1594	1734	388	162	32	16	20	**9118**	**166**
80/81	25	38	60	438	742	352	476	186	638	56	42	36	**3090**	**56**
81/82	86	177	508	2042	1368	1104	491	200	289	46	22	22	**6355**	**116**
82/83	98	89	747	1208	258	602	179	53	69	17	22	1	**3342**	**61**
83/84	6	10	53	1076	1546	353	1314	128	172	73	13	1	**4745**	**86**
84/85	10	1614	2596	336	1389	1271	2017	349	337	39	2	3	**9964**	**181**
85/86	30	4	218	76	202	940	2395	641	79	247	213	28	**5074**	**92**
86/87	608	83	2932	2923	1357	3503	2508	908	703	172	108	288	**16092**	**293**
87/88	354	87	367	2359	1011	785	2400	986	638	280	95	1	**9363**	**170**
88/89	18	96	932	72	974	249	325	3652	390	162	38	10	**6918**	**126**
89/90	534	294	878	384	1271	256	269	348	363	127	0	0	**4724**	**86**
90/91	0	115	96	435	4923	1617	2937	105	161	21	8	3	**10420**	**189**
91/92	8	20	204	820	11	68	324	525	360	106	18	4	**2467**	**45**
92/93	36	142	392	876	228	730	188	125	68	15	14	4	**2819**	**51**
93/94	120	3	16	309	654	514	89	193	1	1	0	1	**1901**	**35**
94/95	85	28	364	3	848	137	1603	5104	55	10	2	3	**8241**	**150**
95/96	2	1	1	10	54	141	10	189	397	19	1	1	**823**	**15**
96/97	15	443	1348	132	93	1708	326	42	62	10	2	4	**4186**	**76**
97/98	0	0	210	193	169	118	76	80	72	0	0	0	**918**	**17**
98/99	0	0	127	6752	241	1770	2444	38	73	0	0	0	**11444**	**208**
99/00	11	48	6	49	1426	386	116	30	189	0	0	0	**2259**	**41**
00/01	16	19	119	23	223	63	23	74	2	0	0	0	**562**	**10**
01/02	0	0	4010	19	39	21	416	6	1	0	3	4	**4520**	**82**
02/03	0	0	58	21	1322	321	99	112	65	1	0	0	**1998**	**36**
03/04	7	0	345	352	1192	1022	118	187	41	6	0	0	**3270**	**59**
04/05	7	1	45	422	811	1317	1517	92	17	3	0	0	**4234**	**77**
05/06	32	1	8	2397	548	532	232	50	1852	184	1	0	**5837**	**106**
06/07	737	4	16	310	916	638	324	256	2	1	1	1	**3206**	**58**
Moy.	**94**	**233**	**684**	**979**	**920**	**1207**	**1284**	**536**	**291**	**61**	**25**	**21**	**6333**	**115**

Table 4. *Monthly and annual distribution of the total sediment yield in tons and specific degradation in tons per km² per year for $\tau_0 = \gamma \times I \times R_h$ in the basin of Bellah Wadi (1974/75 to 2006/07).*

year	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	A_s[t]	A_{ss}[t/km²/per year]
74/75	58	10076	8600	600	572	3930	5939	5937	6403	358	200	453	**43126**	**784**
75/76	273	244	19036	17592	7222	74106	8507	2938	5380	224	60	40	**135621**	**2466**
76/77	343	2424	3644	5106	6388	938	5070	3346	774	81	31	24	**28170**	**512**
77/78	859	2415	3680	16739	6351	16992	9427	2697	2822	1687	965	1188	**65823**	**1197**
78/79	8	13985	452	5591	3511	23505	88352	2819	458	145	74	24	**138924**	**2526**
79/80	113	270	4376	10121	19965	10738	11681	2615	1091	215	108	136	**61428**	**1117**
80/81	172	255	403	2949	5001	2372	3208	1256	4298	380	282	244	**20819**	**379**
81/82	576	1194	3420	13755	9215	7441	3310	1350	1947	307	148	151	**42815**	**778**
82/83	659	596	5029	8138	1741	4055	1204	357	465	114	147	9	**22515**	**409**
83/84	44	67	355	7247	10418	2381	8850	865	1158	489	84	8	**31965**	**581**
84/85	68	10871	17490	2266	9354	8566	13587	2353	2273	265	10	22	**67124**	**1220**
85/86	201	27	1469	512	1358	6335	16137	4320	531	1667	1434	189	**34180**	**621**
86/87	4093	559	19754	19689	9142	23602	16893	6117	4736	1158	728	1939	**108412**	**1971**
87/88	2386	588	2470	15895	6808	5286	16170	6642	4296	1884	641	8	**63075**	**1147**
88/89	124	646	6280	484	6563	1677	2190	24605	2630	1088	253	64	**46605**	**847**
89/90	3599	1978	5916	2584	8562	1724	1815	2341	2447	856	0	0	**31823**	**583**
90/91	0	774	645	2930	33165	10890	19784	709	1085	141	51	22	**70196**	**1276**
91/92	56	133	1373	5524	72	456	2182	3535	2423	714	119	29	**16618**	**302**
92/93	246	959	2641	5905	1533	4919	1265	845	461	99	95	26	**18991**	**345**
93/94	810	20	108	2080	4404	3461	603	1299	5	6	0	8	**12805**	**233**
94/95	570	186	2450	23	5715	922	10799	34383	371	67	15	20	**55521**	**1009**
95/96	13	6	4	65	362	948	68	1271	2673	125	5	4	**5545**	**101**
96/97	102	2984	9082	890	628	11507	2198	285	419	65	17	26	**28202**	**513**
97/98	1	0	1417	1298	1138	796	513	538	485	0	0	0	**6186**	**112**
98/99	0	0	852	45485	1624	11923	16462	256	494	0	0	0	**77097**	**1402**
99/00	72	321	37	329	9605	2601	783	200	1274	0	0	0	**15222**	**277**
00/01	109	131	803	154	1500	426	152	497	12	1	0	0	**3784**	**69**
01/02	3	0	27016	128	260	142	2804	40	8	0	20	29	**30450**	**554**
02/03	0	1	390	138	8906	2161	667	754	435	9	0	0	**13462**	**245**
03/04	49	0	2327	2374	8028	6885	794	1261	274	41	0	0	**22033**	**401**
04/05	50	8	306	2845	5463	8870	10218	621	115	23	1	1	**28522**	**519**
05/06	218	8	55	16147	3692	3585	1560	337	12476	1239	5	3	**39324**	**715**
06/07	4963	28	108	2090	6172	4298	2181	1725	15	8	4	4	**21596**	**393**
Moy.	**631**	**1568**	**4606**	**6596**	**6195**	**8134**	**8648**	**3609**	**1962**	**408**	**167**	**142**	**42666**	**780**

Table 5. *Monthly and annual distribution of the total sediment yields in tons and specific degradation in tons per km² per year for $\tau_0 = 0.7 \times \gamma \times I \times R_h$ in the catchment of Bellah Wadi (1974/75 to 2006/07).*

year	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	A_s[t]	A_{ss}[t/km²/per year]
74/75	54	9368	7996	558	532	3653	5522	5519	5952	333	186	421	**40093**	**729**
75/76	253	227	17698	16355	6714	68895	7909	2731	5002	208	56	37	**126085**	**2292**
76/77	319	2254	3388	4747	5939	872	4714	3111	720	75	29	23	**26190**	**476**
77/78	798	2246	3421	15562	5905	15797	8764	2507	2624	1568	897	1104	**61195**	**1113**
78/79	7	13002	420	5198	3264	21852	82140	2620	426	134	69	23	**129155**	**2348**
79/80	105	251	4069	9409	18562	9983	10860	2431	1014	200	100	126	**57109**	**1038**
80/81	159	237	375	2742	4649	2205	2982	1167	3996	353	262	227	**19355**	**352**
81/82	536	1110	3180	12788	8567	6917	3077	1255	1810	286	138	140	**39804**	**724**
82/83	613	555	4676	7566	1618	3770	1120	332	432	106	137	8	**20932**	**381**
83/84	40	62	330	6738	9685	2213	8228	804	1077	455	79	7	**29718**	**540**
84/85	63	10107	16260	2106	8697	7963	12632	2187	2113	246	10	20	**62405**	**1135**
85/86	187	25	1366	476	1263	5889	15002	4016	494	1549	1333	176	**31777**	**578**
86/87	3806	520	18365	18305	8499	21942	15706	5687	4403	1077	677	1803	**100789**	**1833**
87/88	2218	546	2297	14777	6330	4915	15033	6175	3994	1752	596	7	**58640**	**1066**
88/89	115	601	5838	450	6101	1559	2036	22875	2445	1012	236	60	**43328**	**788**
89/90	3346	1839	5500	2403	7960	1603	1687	2177	2275	796	0	0	**29586**	**538**
90/91	0	720	600	2724	30833	10125	18393	659	1009	131	48	20	**65261**	**1187**
91/92	52	124	1277	5136	67	424	2029	3287	2253	664	111	27	**15450**	**281**
92/93	228	891	2455	5489	1426	4573	1176	785	428	92	88	24	**17656**	**321**
93/94	753	19	100	1934	4095	3218	560	1208	5	6	0	7	**11905**	**216**
94/95	530	173	2278	21	5313	857	10040	31966	345	62	14	19	**51617**	**938**
95/96	12	6	4	61	337	882	63	1182	2485	117	5	4	**5155**	**94**
96/97	95	2774	8443	827	584	10698	2043	265	389	61	15	24	**26219**	**477**
97/98	1	0	1317	1207	1058	740	477	500	451	0	0	0	**5751**	**105**
98/99	0	0	793	42287	1510	11085	15305	238	459	0	0	0	**71676**	**1303**
99/00	67	299	35	306	8930	2418	728	186	1184	0	0	0	**14151**	**256**
00/01	101	121	746	143	1395	396	142	462	11	1	0	0	**3518**	**64**
01/02	2	0	25116	119	242	132	2607	37	7	0	19	27	**28309**	**515**
02/03	0	1	363	129	8280	2009	620	701	405	8	0	0	**12515**	**228**
03/04	45	0	2163	2207	7464	6401	738	1172	255	38	0	0	**20483**	**372**
04/05	46	7	284	2645	5079	8247	9500	577	107	21	1	1	**26517**	**482**
05/06	202	7	51	15012	3432	3333	1451	313	11599	1152	5	2	**36559**	**665**
06/07	4614	26	100	1943	5738	3996	2028	1604	14	7	4	4	**20078**	**365**
Moy.	**587**	**1458**	**4282**	**6132**	**5760**	**7563**	**8040**	**3356**	**1824**	**379**	**155**	**132**	**39666**	**725**

Table 6. Comparison between different values of specific erosion.

Erosion rates calculated (t/km^2/per year)		Erosion rates according to Tixeront (t/km^2/per year)
$\tau_0 = \gamma \times R_h \times I$	$\tau_0 = 0{,}7 \times \gamma \times R_h \times I$	T_a
780	**725**	**608**

IV. Conclusion

This study allowed the quantification of the total sediment yield transported in Bellah wadi. For this, we used the hydrometric data related to instantaneous discharge and to the suspended sediments' concentration on the right of Pont RN 11 station, over a period of 33 years, from 1974/75 to 2006/07.

During this study, we concluded that the relation is very significant (complete serie), relating the sediment discharge and the water discharge in suspension: $Q_s = 4.6162 \times Q_l^{1.3804}$, $R^2 = 0.8083$ and R = 0.90. The exponent b of the model found is equal to 1.38, a value close to that found by researchers who worked in regions with a hydroclimatic regime similar to that of the site under study.

We calculated the daily suspended sediment discharge using the established relationship and we deduced the annual tonnage of suspended sediment transported in Bellah wadi. The average annual yields of suspended sediments transported up to the basin of Bellah wadi is evaluated at 33000 tons, which corresponds to an average specific degradation of 610 t/km^2/per years. This value is comparable to those found in basins with similar climate and hydrology in Algeria and in the Maghreb.

We calculated the daily bed load sediment discharges, taking into consideration some hypotheses on stream roughness. We suppose that bed load, in the study zone, is estimated on average at 28% of the suspended sediment transport, if the roughness coefficient is not counted, and at 19% of the suspension if the roughness coefficient is counted, we calculated the daily bed load sediment discharges.

The average annual yield of bed load sediment transported in the basin outlet of Bellah wadi is evaluated at 9333 tons which corresponds to a specific degradation of 170 t/km^2/per year in case where $\tau_0 = \gamma \times R_h \times I$ while the average annual yield is estimated at 6335 tons, which corresponds to a specific erosion rate of 115 t/km^2/per year to $\tau_0 = 0.7 \times \gamma \times R_h \times I$.

The average specific degradation corresponding to the total solid transport is on average 780 t/km^2/per year (table 5) for $\tau_0 = \gamma \times R_h \times I$ and it is on average 725 t/km^2/per year for the second case, i.e. $\tau_0 = 0{,}7 \times \gamma \times R_h \times I$.

Therefore, the specific erosion rate was deduced according to Tixeront formula and the results obtained prove highly comparable to the average value calculated.

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