doi: 10.3304/JMES.2019.001

Journal of Mediterranean Earth Sciences 11 (2019), xx-xx

Journal of Mediterranean Earth Sciences

Analysis of the suspended sediment yield at different time scales in Mediterranean watershed, case of Wadi El Maleh (North-West of Algeria)

Oussama Benselama [1,*], Mohamed Mazour [1], Mahmoud Hasbaia [2], Omar Djoukbala [1],
Sakher Mokhtari [3]

[1] *LHYDENV Laboratory, University of Ain Temouchent Belhadj Bouchaib, Hydraulic Department, Algeria*
[2] *Hydraulic Department, University of M'sila, 166 Ichebilia, 28000 M'sila, Algeria*
[3] *Scientific and Technical Research Center on Arid Regions - Biophysical Environment Station, Touggourt-Algeria*
* *Corresponding author: benselama.oussama@gmail.com*

ABSTRACT - The present paper aims to estimate and analyse the variability of the suspended sediment transport in Wadi El Maleh watershed at different time scales. The used data sets consist of the measured instantaneous water flow discharge *QL* and suspended sediment concentration *C*, which have been recorded in the gauging station situated at the outlet of the watershed during 17 years.

The obtained results show that the sediment rating curve explains more than 74% of the variance for the whole pairs data (*QL*-*C*). The estimated specific soil erosion is about 294.29 10^3 kg/km^2/year. The analysis of the sediment yield and sedimentary quantification has shown that the major part of the sediment transport occurs mainly during extreme events, the floods contributes on average about 64% in the total annual sediment yields, a single flood in January 1988 generated more than 92% of the annual sediment yield rate. In wet season, we recorded 78% of the total soil loss rate, the most part of sedimentary dynamics for Wadi El Maleh is observed in winter with 45.41%. The suspended sediment transport in this season remains the highest, significantly exceeding the other seasons. These values are comparable to those reported in other regions with similar climate.

Keywords: Suspended Sediment; sediment rating curve; soil erosion; Wadi El Maleh; Algeria.

Submitted: 25 July 2018 - Accepted: 06 November 2018

1. INTRODUCTION

The determination of suspended sediment transport, especially in Wadis environment, has become a necessity in streams. Reasons for this interest include assessment of suspended sediment transport to the seas and oceans, estimation of erosion rate and soil loss, siltation prediction of reservoirs and dams. Erosion rates are related not only to geology, land use and relationships with biotic factors (plants and seeds) but also to climatic conditions (Giaccone et al., 2015). The total suspended sediment can be expressed as erosion rate, the spatial distribution of soil erosion is an important reference to the design of hydraulic installation and the strategies of preventing serious erosion for soil conservation in watersheds (Lin et al., 2014).

Soil degradation has been recognized as one of the most significant environmental problems across the world mainly in the Mediterranean environment where several areas are affected by accelerated erosion, largely favoured by the particular geological and climatic context and by anthropic land uses (Aucelli et al., 2012, 2014), several authors have treated this phenomenon in this region (Serrat et al., 2001; Rovira et al., 2005; Rovira and Batalla, 2006; Nadal-Romero et al., 2008; García-Ruiz et al., 2008, 2013; Della Seta et al., 2009; Del Monte et al., 2015; Del Monte, 2018; De Girolamo et al., 2015, 2018; Gamvroudis et al., 2015; Brandolini et al., 2018).

The occurrence of extremely intense and high volume rainstorms and the consequent floods have few parallels in other areas, and the erosion rates recorded in some bad land areas are well beyond those in other regions (García-Ruiz et al., 2013).

The North Africa region is under Mediterranean climate experiencing a very important erosive dynamics, It can be clearly observed by the high rate of water erosion and the fertile soil loss, the important suspended sediment transport and the silting of dams (Houghton et al., 1990; Kayser et al., 1990). The sedimentation in North Africa dams is very high in relation to what is known at international level (Hallouz et al., 2018). Algeria is among the most affected region by erosion worldwide (Probst and Suchet, 1992). Many of the interior Algerian's rivers are almost dry for most of the year, but periodically are subject to catastrophic floods that change the river morphology, destroy bridges, and cause heavy loss in terms of human lives, houses and infrastructure. Moreover, the coastal watersheds which are situated along the Algerian coast (about 1259 km) are characterized by the predominance of high amplitude floods, associated with a high spatial-temporal variability of suspended sediment transport.

The siltation in Algerian dams has caused an important loss of annual water storage rate that is ranging between 2% and 5%. Recently, a sediment inventory from 77 catchments in Algeria has shown that sediment yield ranges between 63 and $7273\cdot10^3$ kg/km^2/year (Vanmaercke et al., 2014).

The values of soil erosion in Algeria vary from one watershed to another. The north west is the most eroded, with 47% of the Algeria's total area: the rate of siltation of dams is about 15% (Achite and Ouillon, 2007). The specific soil erosion ranges from 111 to $3029\cdot10^3$ kg/km^2/year (Tab. 1), and even higher. It has reached $7200\cdot10^3$ kg/km^2/year as reported for Wadi Agrioun (Probst and Suchet, 1992).

The deposited suspended sediment in the Mediterranean littoral of the Algerian coasts are estimated at 47 million of tons (Probst and Suchet, 1992). Algerian's rivers carry a large amount of sediment which remains a serious problem for semi-arid regions, because of the high quantities of sediments and its spatial and temporal variability. Sediment transport varies quantitatively and qualitatively from one region to another. All these examples show the major challenge of this phenomenon, not only for Algeria, but also in other regions in the world. In China, about 1,79 million km^2 of land suffers from soil erosion, corresponding to 18.3% of China's total area (Hui et al., 2010).

The highest values are observed in the mountains bordering the margins of the Pacific in the large Chinese river, the Yellow River (Bravard and Magny, 2002). In Morocco, the soil degradation values are between 100 and $4620\cdot10^3$ kg/km^2/year in 38 catchments (Vanmaercke et al., 2014).

The first sediment transport measurement was carried out in Isser watershed in 1946 (Medinger, 1960; Demmak, 1982). Since the 1970s, several gauging stations have been installed in Algerian watersheds. Table 1 summarizes many studies which have used data from these gauging stations to model and estimate the soil erosion in divers watershed in Algeria using the sediment rating curve approach. This latter is represented by a power function linking water flow discharge Q_L and sediment discharge Q_S of the following form $Q_S=aQ_L^b$. It is one of the most commonly applied models to estimate soil erosion, (Asselman, 2000; Serrat et al., 2001; Horowitz, 2003; Rovira et al., 2005; Rovira and Batalla, 2006; Nadal-Romero et al., 2008; De Girolamo et al., 2015, 2018).

The present paper builds upon the study the suspended sediment transport in Wadi El Maleh watershed (North Western of Algeria). We quantify and investigate the variability of this phenomenon over time, mainly in flood events, during a period of 17 years (1981-1998). We have also tested the capacity of sediment rating curve approach to represent the suspended sediment variance, during the same study period.

Tab. 1 - Order of magnitude of soil erosion in Algerian watersheds.

Authors	Watersheds	S (km^2)	P (mm)	D_{SS} (10^3 kg/km^2/year)	a	b
Boudjadja et al., 2003	Wadi Messelmoun	218	-	3029	-	-
Achite and Meddi, 2004	Wadi Haddad	470	245	212	14.4	1.45
Ghenim et al., 2007	Wadi Sebdou	256	412.6	1330	0.26	1.64
Khanchoul and Jansson, 2008	Mellah	550	707	373	0.14	1.72
Khanchoul et al., 2012	Kebir	651	693	347	0.32	1.47
Elahcene et al., 2013	Wadi Bellah	55	519	610	4.61	1.38
Louamri et al., 2013	Bouhamdane	1105	589	237.5	0.16	1.49
Bouanani et al., 2013	Wadi Sikak	218	512	170	0.29	1.46
Boukhrissa et al., 2013	El Kebir	681	693	1410	0.43	1.41
Bouguerra et al., 2016	Boumessoud	118	396	518	1.59	1.64
Madani Cherif et al., 2017	Wadi Hammam	7440	400	111	5.85	1.32
Hasbaia et al., 2017	Wadi Soubella	183.5	288.5	126	11.5	1.29
Tourki et al., 2017	Kebir amont	1068	89	884	0.55	1.67
Hallouz et al., 2017	Wadi Mina	6000	305	211	-	-
This study	Wadi El Maleh	932.5	383	294.29	1.37	1.92

2. MATERIAL AND METHODS

2.1. The study area

The area belongs to the coastal-Oranian basin. Wadi El Maleh watershed drains a surface of 932.56 km^2 with a perimeter of 194.8 as shown in the table 2. It is located in the extreme north of Ain Temouchent, north-west of Algeria (Fig. 1), between 1°9'24" and 1°26'17"W of longitude and between 35°17'22" and 35°16'37"N of latitude, and it pours into the Mediterranean Sea. Its climate is typically Mediterranean semi-arid. The relief of Wadi El Maleh decreases from south to north, with altitudes varying from 808 at the summit to 0 at the outlet. The annual precipitation is very irregular, varying from 241 mm/year to 616 mm/year and the inter-annual average rainfall is about 382.68 mm associated with a variability (inter-annual coefficient of variation *Cv*= 28%) during 43 years. The maximum temperature in the watershed vary from 20 *C* degree to 26.9 *C* degree, in the same way, for the minimal temperatures, they range from 11.9 *C* degree and 16.4 *C* degree.

2.2. Sediment rating curve model

To determine the relationship between sediment discharge and water flow discharge, an approach at different time scales, based on regression models, is adopted.

The mobilization of solid materials on slopes and their transport by streams represent two distinct but interrelated phenomena. For a long time, researchers attempt to correlate the solid flows to the water flow discharge and to determine a relation which would make it possible to estimate soil loss rate. For this reason, we cite the works of (Jakuschoff, 1932) on the rivers of Turkey, (Straub, 1937) on the Missouri River USA and Einstein (1950).

Suspended sediment concentration *C* and the water flow discharge Q_L generally evolve according to a power model $Y=a\,X^b$ (Etchanchu and Probst, 1986; Walling and Webb, 1981; Wood, 1977):

$$C=aQ_L^{b-1} \tag{1}$$

Another empirical relationship, commonly referred as the sediment rating curve (Campbell and Bauder, 1940; Crawford, 1991), links the sediment discharge to water flow discharge:

$$Q_s=aQ_L^b \tag{2}$$

These last equations have been established by (Kennedy, 1895; Einstein, 1937). Since then, many authors have tried to identify the value of the exponent *b*. Leopold and Emmett (1976) propose for rivers in the western United States of America values of *b* varying between 2 and 3.

Others, such as (Müller and Forstner, 1968; Bruschin and Trau, 1977; Wood, 1977; Vivian, 1981; Walling and Webb, 1981, 1982; Meybeck, 1986; Kattan and Probst, 1987) limit them between 1 and 2, depending on the physical, climatic and hydrological characteristics of the watersheds and the hydraulic conditions of the flow in the rivers. This approach is widely used by researchers around the world, in France (Serrat et al., 2001), in Spain (Rovira et al., 2005; Rovira and Batalla, 2006; Nadal-Romero et al., 2008), in Italy (De Girolamo et al., 2015, 2018), in Taiwan (Tfwala and Wang, 2016), in China (Zheng, 2018), in Iran (Khaleghi and Varvani, 2018).

Tab. 2 - Hydro-morphometric characteristics for Wadi El Maleh watershed.

Parameters	Notation	Unit	Value
Area	S	km²	932.56
Perimeter	P	km	194.8
Circularity ratio	Kc	-	1.78
Maximum altitude	H_{max}	m	808
Minimum altitude	H_{min}	m	0
Average altitude	H_{moy}	m	283.11
Length of equivalent rectangle	L_{rec}	km	86.27
Width of equivalent rectangle	l_{rec}	km	10.81
Average slope	I_{bv}	%	152.7
Length of the main stream	L	km	67.4
Average slope of the main stream	I_{cp}	%	11.99
Time of concentration	Tc	H	9.37
Global slope index	Ig	%	0.82
Roche slope index	Ip	%	23.25
Drainage density	Dd	km.km^{-2}	1.21
Hydrographic density	F	km.km^{-2}	2.27
Streams frequency	Fr	km^{-1}	1.18

2.3. Hydrological data

The study is based on the instantaneous data of water flow discharge Q_L and the suspended sediment concentrations *C* managed by the National Agency of Hydraulic Resources ANRH. The Wadi El Maleh is controlled by a gauging station installed at the outlet of the watershed, called Turgot Nord, located at *X*=149.3 km *Y*=244.4 km (Lambert coordinated) and *Z*=18 m. The used data are 2017 couples of (Q_L-*C*), they cover a period of 17 years from 1981 to 1998, except the year of 1982, marked by the absence of data.

2.4. Sampling methodology

The water flow discharge is obtained from the rating curve of the gauging station using the measured water depth. At each reading, a sample of turbid water is taken from the Wadi by means of a 50 cl bottle, the filtered sediments on filter paper are then dried in oven for 30

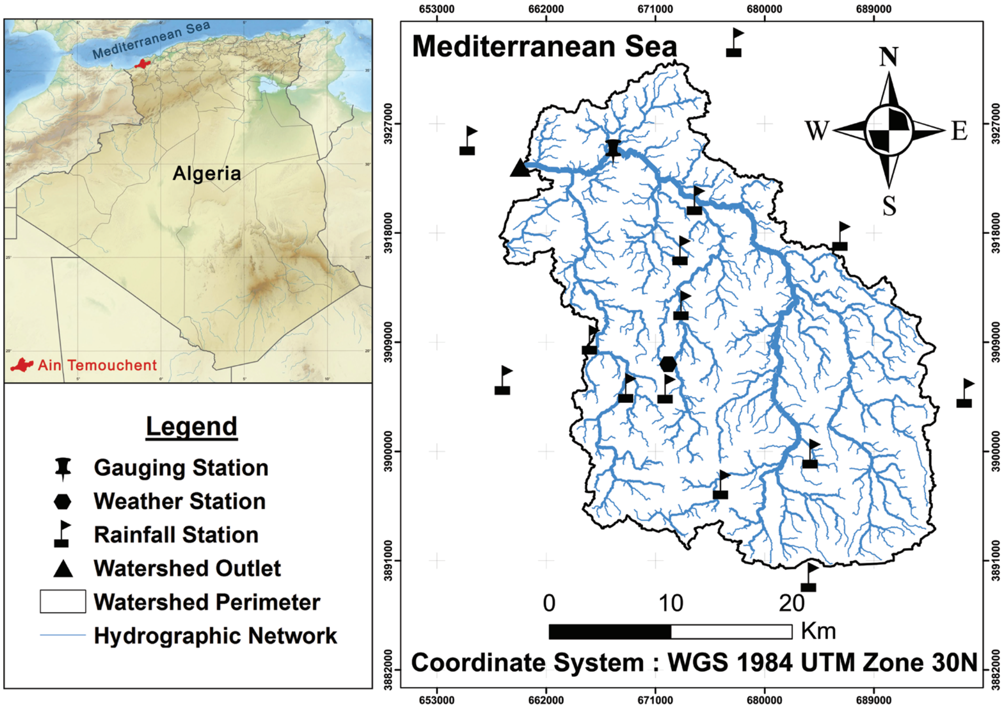

Fig. 1 - Location of Wadi El Maleh watershed.

minutes at a temperature of 105 *C* degree, reduced to a volume of one litre, this charge is attributed to the concentration of instantaneous suspension conveyed by the streams and its tributaries in g/l.

The sediment yield is defined as the total sediment outflow from a watershed measurable at a point of reference during a specified period of time. Sediment outflow from the watershed is induced by processes of detachment, transportation, and deposition of soil materials by rainfall and runoff (Boukhrissa et al., 2013). During the flood period, measurement are intensified up to 1 hour or even 30 minutes and sometimes up to 15 minutes, depending on the speed of the increase in water flow discharges. During normal runoff or low water yield periods, a daily measure is generally taken at noon. The sediment flow in suspension is then calculated by the conventional method:

$$Q=CQ_L \tag{3}$$

where
Q_S: Sediment discharge in (kg/s);
Q_L: Water flow discharge in (m^3/s);
C: Suspended sediment concentration (g/l).

2.5. Water, sediment yields, and specific soil erosion

The annual sediment yield transported during a time interval $(t_{i+1}-t_i)$ is calculated by the formula:

$$Y_s = \frac{(Q_{Li+1}C_{i+1}) + (Q_{Li}C_i)}{2}(t_{i+1} - t_i) \tag{4}$$

where: C_i and C_{i+1} are the concentrations observed at instants t_i and t_{i+1}; respectively corresponding to the water flow discharge Q_{Li} and Q_{Li+1}.

The arithmetic sum of these elementary contributions during the year will constitute the annual sediment yield. Similarly, the water yield is calculated as follows:

$$Y_W = \frac{Q_{Li+1} + Q_{Li}}{2}(t_{i+1} - t_i) \tag{5}$$

The specific soil erosion is calculated by dividing the annual sediment yield Y_s [t/year] by the area of the watershed S [km²] according to the following formula:

$$D_{ss}=Y_s/S \tag{6}$$

3. RESULTS AND DISCUSSION

3.1. At the global scale

The modeling of the entire instantaneous data (2017) of water flow discharge Q_L and suspended sediment concentration C using the sediment rating curve approach shows that the obtained relationship explains more than 74% of the sediment transport variance in Wadi El Maleh watershed (Fig. 2). The resulting loads estimated show that the specific soil erosion is about 294.29·10^3 kg/km^2/year.

Previous investigations reported by other studies conducted in Algeria, especially in the coastal watersheds that are affected by the Mediterranean climate, (Hallouz et al., 2017) recorded a specific soil erosion value of 373·10^3 kg/km^2/year in the north-eastern watershed of Wadi Mellah. Similarly, values of 212·10^3 kg/km^2/year and 211·10^3 kg/km^2/year were obtained in north-western of Wadi Haddad and in Wadi Mina by (Achite and Meddi, 2004; Khanchoul and Jansson, 2008) respectively.

The sediment rating curve coefficients (*a*, *b)* of Wadi El Maleh are of 1.37 and 1.92 respectively. These values are very close to those calculated on other Algerian watersheds (Achite and Meddi, 2004; Ghenim et al., 2007; Khanchoul and Jansson, 2008; Khanchoul et al., 2012; Elahcene et al., 2013; Louamri et al., 2013; Bouanani et al., 2013; Bouguerra et al., 2016; Madani Cherif et al., 2017; Hasbaia et al., 2017; Tourki et al., 2017; Hallouz et al., 2017).

These two parameters *a* and *b* varies from one region to another and they are very sensitive to the time scale (Hasbaia et al., 2017). On the main stream of the Yangtze River of China, the downstream changes in parameters *a* and *b*. These latter were closely associated with the river channel morphology using the sediment rating curve (Yang et al., 2007)

The Wadi El Maleh watershed has an elongated shape with a weak relief whereas the hydrographic network presents a medium hierarchy. It is also characterized by an almost permeable formation as well as a time of concentration and weak runoff witch influences on the time of infiltration.

3.2. At flood scale

In the semi-arid watersheds, the suspended sediment transport often occurs during extreme events.

The flood depends mainly on the quantity and the rain intensity, the rapid water flow discharge is largely influenced by the vegetation cover, the lithology and the morphometric parameters of the basin (Yles and Bouanani, 2016). Downpour is the most suitable temporal unit for hydrological analyses in relation to sediment yield (Guy, 1964). In this study, we observed that the floods are responsible for the most part of the suspended sediment transport. Wadi El Maleh transports 63.78 million m^3 of water and 2222 million kg of sediment at flood scale during the 17 years of the study period, while the total yields measured are 393.56 million m^3 of water and 4610 million kg sediment. These outcomes show that 16.21% of the total water yield and 48.15% of the total suspended sediment yield rate are observed during this period. More than 80%, 82% and 92% of the annual sediment yields are recorded during the extreme events period in 1985, 1986, and 1988 respectively as displayed in (Tab. 3). The flood contribution in the sediment transport of 92.95% recorded in 1988 (Tab. 4) is produced during a one flood noted in January.

This finding agrees with that observed in many watersheds of Algeria. A flood reported in the Upper Tafna watershed (North Western of Algeria) generated 98% of the suspended annual load (Megnounif et al., 2003). In Wadi Sikkak, one flood of March 1973 with a water flow discharge of 176 m^3/s drained 70% of the total annual water yield (Bouanani et al., 2013). In the upper Celone river basin (Italy), the most of the suspended sediment yield is transported during the high flow status, in particular the high flow is estimated to account for 94% of the total amount suspended material, another watershed located in the Puglia region in southern Italy, during the summer period (June and July), two flood events were recorded, each of these occurred over a period of a few hours during which water carried a huge amount of suspended material and debris. (De Girolamo et al., 2015).

Considering the sediment rating curve as black box model, the coefficients *a* and *b* have no physical meaning (Asselman, 2000); many studies contributed to link their variability to some physical and sediment transport parameters. The *b* coefficient is more depend to the flow parameters (water discharge and yield), a high values of *b* are attributed to high water discharge (Peters-Kümmerly,

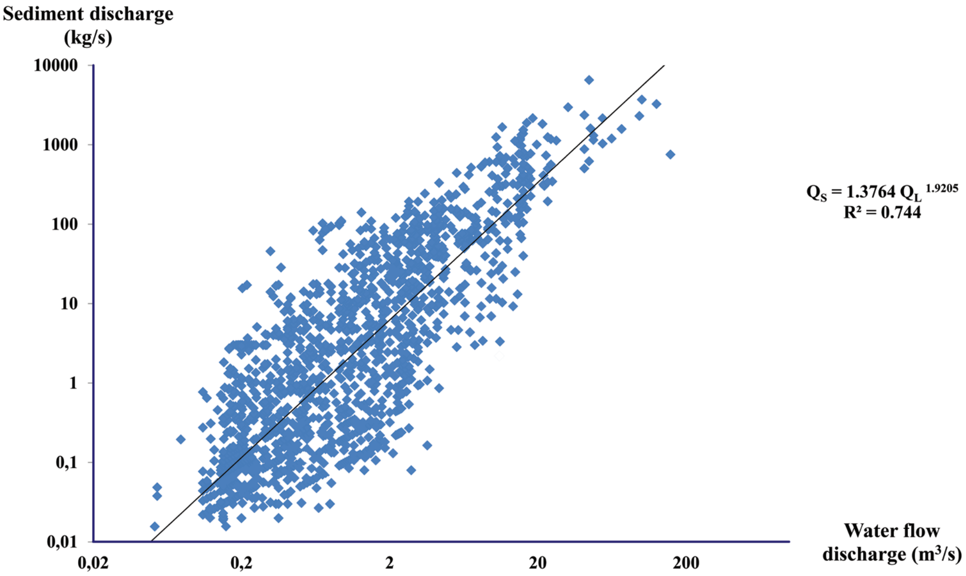

Fig. 2 - Sediment rating curve of Wadi El Maleh watershed.

Tab. 3 - Water yield (Y_W), sediment yield (Y_S), annual rainfall (P), and runoff depth (R_D) at the flood scale.

Years	Y_W (Mm³)	Y_S (Mkg)	Y_W flood (Mm³)	Y_S flood (Mkg)	Y_W flood %	Y_S flood %	P (mm)	R_D (mm)	a	b
November 1985	18.36	331	6.94	267	38.05	80.74	416	19.7	17.95	1.10
February 1986	37.92	407	13.99	338	36.90	82.93	418	40.7	3.94	1.44
January 1988	24.56	885	13.55	823	55.18	92.95	518	26.3	12.66	1.26
May 1992	51.45	200	6.45	114	12.54	57.14	248	55.2	9.2	1.22
March 1995	48.24	1153	13.24	381	27.45	33.06	361	51.8	1.47	1.73
December 1997	29.73	770	9.61	299	32.29	38.84	382	31.9	1.94	1.95

Tab. 4 - Flood characteristic of January 1988.

Flood	Values
Water flow discharge peak (m³/s)	54.65
Maximum concentration (g/l)	147.3
Water yield of flood (Mm³)	13.55
% of water yield of flood/annual water yield	55.18
Sediment yield of flood (Mkg)	823
% of sediment yield of food/annual sediment yield	92.95

1973), especially in flood scale (Tab. 3), the same outcome is obtained by Benkhaled and Remini (2003). The a-coefficient is more dependent on sediment transport parameters (sediment concentration and yield), it is considered as an erosion index (Peters-Kümmerly, 1973; Morgan, 1995; Asselman, 2000; Benkhaled and Remini, 2003). In this study, we cannot confirm this finding due to low number of recorded floods.

3.3. At monthly scale

As presented in table 5, the monthly water and sediment yield values show a high variability of the suspended sediment transport (Cv=105%). The results also show that more than 84% of the annual sediment load is observed in just five months: September (16.07%), November (13.11%), January (28.66%), February (12.91%) and in March (13.75%), which explain that the early rainfall intensity in autumn and those in winter are responsible of the most part of the sediment transport in Wadi El Maleh watershed. It is in January that the water and sediment yields are the most important as shown in (Tab. 6). Indeed, the month of January ensures nearly 28.66% of the solid contributions. It is noted that the high flood is recorded January 1988 in Wadi El Maleh watershed. This result differs slightly from other neighbouring basins (Achite and Meddi, 2004; Achite and Ouillon, 2007; Megnounif et al., 2003).

In common with results already done by other studies conducted in the Mediterranean region, it is observed in North-Est of Spain, that the total suspended load in the Lower Tordera Mediterranean basin, increases gradually from October to December and decreases considerably from December to September (Rovira et al., 2006). In the Celone river (Italy), more than 90% of the total annual suspended load is transported from November to May, while in June the suspended sediment yield is less than 100 t per month, and decreases from August to October when it reaches the minimum at less than 10 t per month (De Girolamo et al., 2015).

3.4. At seasonal scale

As far as the seasonal scale, the analysis of the suspended sediment transport phenomenon in Wadi El Maleh watershed is almost the same as previously concluded at the monthly scale.

Suspended sediment concentrations trend to be higher in winter (45,41%) than in autumn (33.26%), in spring (20.79%) and in summer (0.54%) (Tab. 6). The most part of the sediment transport ie 45,41% from the sediment load, is therefore transported in winter. In fact, this can explain that the temporal variability depends on the contribution of floods in the sedimentary activity. Indeed, the extreme events generate the most of the sediment suspended load. We note that during the winter season, three floods (February 1986, January 1988 and December 1997) have generated more than (82%, 92%, 38%) respectively. We have also observed that the wet season is responsible for more than 78% of soil degradation. The sediment yield in wet seasons can reach more than 4 times those in the dry season.

3.5. Annual and inter-annual variability

The suspended sediment load varies greatly from one year to another, the results show a wide range of values, $0.46 \cdot 10^3$ kg/km²/year (1998) to $1236.94 \cdot 10^3$ kg/km²/year (1995). The annual variation coefficient is almost 125% (Tab. 7). At the annual scale, there is no relationship between the suspended sediment load and the annual rainfall as well as the runoff volume. Indeed, for two years receiving almost the same amount of precipitation, the suspended sediment load can be very different. For almost close annual rainfall, observed in 1984 (485 mm) and in 1985 (416 mm), the measured soil loss are very different, ($355.08 \cdot 10^3$ kg/km²/year, $1.67 \cdot 10^3$ kg/km²/year), respectively); the same outcomes are observed in the upper

Tab. 5 - Water yield (Y_W), sediment yield (Y_S), specific soil degradation (D_{SS}), suspended sediment concentration (C), and runoff depth (R_D) at the monthly scale.

Months	Y_W (Mm^3)	Y_S (Mkg)	D_{SS} (10^3 kg/km^2/month)	D_{SS} %	C (g/l)	P (mm)	R_D (mm)
September	19.28	592	635.71	16.07	17.24	9.56	20.7
October	19.62	150	161.12	4.07	5.05	17.27	21.1
November	34.27	483	518.65	13.11	10.92	46.87	36.8
December	24.49	142	152.29	3.85	5.2	34.52	26.3
January	46.53	1056	1133.42	28.66	9.91	59.07	49.9
February	50.12	476	510.51	12.91	4.10	55.46	53.8
March	44.09	507	543.97	13.75	6.83	50.93	47.3
April	26.81	68	73.34	1.85	2.77	31.51	28.8
May	26.91	191	205.05	5.18	3.91	32.91	28.9
June	17.22	5	5.48	0.14	0.42	2.71	18.5
July	6.16	1.8	1.93	0.05	6.18	1.82	6.6
August	12.31	12.9	13.89	0.35	1	0.83	13.2
Cv	51%	105%					

Tab. 6 - Water yield (Y_W), sediment yield (Y_S), specific soil degradation (D_{SS}), suspended sediment concentration (C), and runoff depth (R_D) at the seasonal scale.

Seasons	Y_W (Mm^3)	Y_S (Mkg)	D_{SS} (10^3kg/km^2/season)	D_{SS} %	C (g/l)	P (mm)	R_D (mm)
Autumn	73.15	1226	1315.48	33.26	11.02	24.6	78.48
Winter	121.14	1674	1796.22	45.41	6.22	49.7	129.98
Spring	97.79	766	822.37	20.79	4.75	38.4	104.93
Summer	35.68	19.8	21.29	0.54	1.97	1.8	38.28
Cv	38%	66%	-				
Wet Season	194.2*	2900	3111.70	78.67	8.62	37.1	208.46
Dry Season	133.47	786.3	843.66	21.33	3.36	20.1	143.21

Tafna watershed (Megnounif et al., 2003). This scatter of values is due to the periodicity and duration of violent floods responsible on erosion throughout the year.

The highest value for a water yield is marked in 1992 by 5144 million of m^3 and a transport of 200 million kg of sediment and by a soil loss of about 214.58·10^3 kg/km^2/year. On the other hand, the lowest annual value is observed in 1998 and represents 72000 m^3 of water yield and 500000 kg of sediment yield equivalent to 0.54·10^3 kg/km^2/year of water erosion.

The suspended sediment concentration observed in Wadi El Maleh watershed varies between 0.1 g/l and 147.3 g/l with an average of 6.39 g/l. The suspended sediments in streams originate either from the channel of the stream or from the surface of the soil in the watershed, the production and delivery of these particles are affected by physical and human factors (Sadeghi et al., 2012).

A recent review of European sediment yields demonstrated that Mediterranean rivers have higher yields than those in the rest of Europe, which has been attributed to climate, topography, lithology and land use (Vanmaercke et al., 2011; García-Ruiz et al., 2013). In Algeria, the soil loss rates are variable, this disparity is due to the difference in lithology, vegetation cover, slope, and size of basins (Walling, 1984).

5. CONCLUSION

Wadi El Maleh watershed with an area of 932.56 km^2 losses annually 294.29·10^3 kg/km^2/year, equivalent to an average of 23 million m^3 of water yield per year with a high variability (*Cv*=65%) and 274 million kg of sediment, with a high variability (*Cv*=125%). The most part of the suspended sediment transport in Wadi El Maleh watershed occurs mainly during floods. In the study period, the floods contributes from 33% to 92% (with an average of 64%) in the total annual sediment yields. The most important percentage (92%) is observed in only one extreme event, case of flood of January 1988.

The temporal dynamic of suspended sediment transport in Wadi El Maleh watershed showed a high variability at different time scales. On a monthly basis, the most

Tab. 7 - Water yield (Y_W), sediment yield (Y_S), specific soil degradation (D_{SS}), suspended sediment concentration (C), and runoff depth (R_D) at the annual scale.

Years	Y_W (Mm^3)	Y_S (Mkg)	D_{SS} (10^3 kg/km²/year)	D_{SS} %	C (g/l)	P (mm)	R_D (mm)
1981	18.69	24	25.63	0.51	0.83	244	20.1
1983	8.23	11	12.18	0.24	1.36	315	8.83
1984	7.74	2	1.67	0.03	0.23	483	8.3
1985	18.35	331	355.08	7.09	9.75	416	19.7
1986	37.92	407	436.01	8.71	2.72	418	40.7
1987	18.24	43	45.67	0.91	1.43	262	19.6
1988	24.56	885	948.95	18.97	7.13	518	26.3
1989	9.29	2	2.24	0.045	0.3	351	10
1990	23.46	222	237.93	4.76	7.49	446	25.2
1991	31.25	153	163.74	3.27	5.1	295	33.5
1992	51.45	200	214.48	4.29	6.52	248	55.2
1993	42.61	200	214.48	4.29	6.95	291	45.7
1994	13.87	101	108.83	2.17	8.46	299	14.9
1995	48.23	1153	1236.94	24.72	24.71	361	51.8
1996	9.21	161	172.73	3.45	8.59	242	9.9
1997	29.73	770	825.96	16.51	16.39	382	31.9
1998	0.72	5	0.46	0.11	0.72	268	0.8
Cv	65%	125%					

important sedimentary activity is recorded in January with more than 28%, the sediment transport in this month remains the highest, significantly exceeding the other months. At the seasonal scale, suspended sediment load is mainly transported in winter and autumn, when floods with high magnitude occurred. Winter ensures almost half of the total soil degradation with 45.41%.

ACKNOWLEDGEMENTS - The authors gratefully acknowledge Maurizio Del Monte (Sapienza University of Rome) and Christian Conoscenti (University of Palermo) for their careful and meticulous reading of the paper and providing an opportunity to improve his quality. We also thank Sylvain Ouillon, Research Director at the Research Institute for Development IRD, Toulouse, France, for his help to write this paper.

Notation

Y_W: Water yield (m^3);
Y_S: Sediment yield (ton);
D_{SS}: Specific soil degradation (10^3kg/km²/year);
C : Suspended sediment concentration (g/l);
C_V: Coefficient of variation;
P : Average annual rainfall (mm);
Q_L : Water flow discharge (m^3/s);
Q_S: Sediment discharge (kg/s);
R^2: Coefficient of determination;
P : Rainfall (mm); **R_D**: Runoff depth (mm);
S : Surface (km^2);
a, b : Sediment rating curve coefficients.

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