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Temporal variability of liquid and solid flow in the basin of Wadi Allalah (north-central Algeria)

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ABSTRACT - Soil erosion and sediment transport have been modeled at several time scales. In this study, we propose a power-type model (Q_s=a.Q_l^b) with (R^2=0.77) linking the fluvial discharge rate to the suspended solid flow rate that was tested at different time scales to quantify the specific erosion at the basin scale. Oued Allalah (293 km^2). The results of this test show that the average specific degradation is of the order of 11.08 t·ha·year^{-1}. This modeling will be applied to the rebuilding of missing data at the hydrometric station of the basin.

Keywords: specific erosion; sediment transport; modeling; fluvial discharge; sediment load.

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1. INTRODUCTION

Soil erosion is a major obstacle to the development of agricultural and rural areas and the preservation of the natural environment in the Mediterranean basin. It is the main cause of soil degradation. Water erosion results from the synergistic effects of natural conditions and inadequate human activities. It degrades the ecosystem services provided by soils due to multiple negative impacts, such as loss of soil fertility and worsen productivity, particularly watersheds, thus limiting the potential of arable land, silting up of reservoirs dams and reduction of water quality. Erosion is manifested by the degradation of the soil, the run off and other external agents, including processes such as ablation, suspension transport (Tahiri et al., 2017). At the global, the rate of loss of volume of dams by sedimentation has been estimated at 1% per year and the cost of recovery of mobilizable volumes of water thus lost to 130 x US \$ 10^9 (Mahmoud, 1987). This rate is 3% to 10% in the Mediterranean region (Gazzolo and Bassi, 1969). Algeria has more than 120 small and large dams in operation, with a capacity of about 7 billion m^3 of water, with a regularized volume of 3 billion m^3 per year. A cumulative sludge of about one billion m^3 was deposited at the bottom of these dams (Meguenni and Remini, 2008). These high values are only the consequence of the degradation of the surface states of all basin in Northern Algeria. In the Mediterranean environment, some areas have reached the maximum of degradation and erosion. We have to give more importance to this field. The transport of suspended solids is a phenomenon that has generated enormous strengths from nations in combating the degradation of arable land, siltation of dams and the devastating effect of flood cycles and of desertification, which it is capable of generating (Deploey et al., 1991; Shaban and Khawlie, 1998). Preservation of the environment has long encouraged the scientific community to highlight the results of research in this area by promoting projects and programs for the management and control of soil erosion. In Algeria, during extreme events, the order of magnitude of average concentrations varies from 50 to 150g/l and can sometimes reach 600g/l (Medjber, 2011).

The problem of water erosion related to the evaluation of specific degradation and sediment transport motivated many researchers to work on this problem in order to quantify the volumes of sediments thus transported. Several authors have published studies on this phenomenon (Sogreah, 1967; Probst and Amiotte Suchet, 1992; Meddi, 1992; Kouri, 1993; Bourouba,1998; Touibia, 2000; Terfous et al., 2001; Achite, 2002; Achite and Meddi, 2004; Bouanani, 2004; Megnounif, 2007; Ghenim, 2008; Elahcene et al., 2012; Bouguerra et al., 2016; Hallouz et al., 2017; Madani Cherif et al., 2017). 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, 2017; De Girolamo et al., 2015, 2018; Gamvroudis et al., 2015; Brandolini et al., 2018). 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). One of their priorities has been the search for statistical models highlighting the relationship between liquid flow and the transport of suspended solids. These models are applicable to watersheds where measurements are rare or non-existent (Achite; 2002; Elahcene and Remini 2009; Lupia Palmieri et al., 1998). The objective of our study falls within the scope of this theme and has two parts: the first is to evaluate the rate of specific degradation within the Wadi Allalah watershed by developing an explanatory expression of the solid transport by liquid flow, the second will involve a statistical analysis at different time scales of the pairs of values (QL, QS) of the series of measurements available in order to find the best modeling.

2. THE STUDY AREA

The coastal Algerois basin with a drainage area of 11972 km² is a very important basin of Algeria although it represents only 0.5% of the total area of Algeria; it extends over nearly 500 km, from Bejaia to Mostaganem, on the coast mediterranean for an average width of 24 km.

In this study, we are focusing on the Wadi Allalah watershed, which is one sub-basin of the basin of Sidi Akkacha, that is located west the Algerois basin. Wadi Allalah watershed is located between 36°40' and 35°50' north latitude and between 1°40' and 0°50' east longitude. It drains an area of 293 km^2 (with a perimeter of 96.60 km) to the gauging station Rocade-Sud installed at the outlet of the basin (Fig. 1).

The hypsometric study of the basin shows the dominance of the altitude class 200 to 400 m with 48.16% (141.11 km²) of the total area and a minor class between 800 and 986 m. The average altitude is 326 m.The concentration time, defined by Roche (1963) as the time that a water particle comes from the furthest part of the basin to reach its outlet, and calculated following Giandotti (1937), is 10.61 h (Tab. 1).

The land use of the Wadi Allalah basin is characterized by bare soil occupying more than 52% of the total basin area which further promotes water erosion. The area of cultivated land that plays an important role in land stabilization and energy dissipation is about 13% (Tab. 2).

The Wadi Allalah basin is made up of different geological formations (Fig. 2). Marine Miocene formations occupy the center and the southwest of the basin with a percentage of 48%. To the north-center are the Quaternary, a series of clays and formations of the Upper Cretaceous. Lower Miocene and Oligocene occupy the northeast basin (Tab. 3).

3. MATERIALS AND METHODS

3.1. DATA

Systematic measurements of instantaneous water flow rate Q_l (m^3.s^{-1}), solid flow rates Q_S (kg.s^{-1}) and suspended sediment concentration were conducted by the National Water Resources Agency (NWRA) at the Sidi Akkacha hydrometric station located on the axis of the main wadi of the basin (latitude = 36°48'69"N, longitude=1°31'28" W, elevation=79 m). This study covers a 30 years period from September 1983 to August 2013 and is based on 5137 instantaneous measurements of suspended sediment flow and concentration measurements at the gauging station.

The annual precipitation of the rainfall station which is extended over the basin in a period of 30 years (1983/84-2012/13) was provided by the National Water Resources Agency NWRA. The liquid flow rates are obtained from the calibration curve and that the solid flows are the product of the liquid flow by the concentration of sediments in suspension (CS).

These concentrations are the result of a procedure commonly adapted to all hydrometric stations owned by NWRA: 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 fitered sediments on fiter paper are then dried in oven for 30 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 (Bouguerra et al., 2016).

Water treatment to collect materials in suspension is carried out on Whatman type paper. The filters are then dried in an oven. Brought back to the unit of volume (one liter) this calculated solid charge is attributed to the instantaneous concentration of suspended solids conveyed by the river in (g/l).

4. RESULTS AND DISCUSSION

A regression analysis is done between solid sediment flow (Q_s) and liquid water flow (Q_L). The most used sediment evaluation curve is a power function as in (1).

$$Q_s = aQ_L^b \quad (1)$$

Where a and b are regression coefficients. Equation (1) covers both the effect of increased flow and suspended sediment load in weather conditions that cause runoff (Madani Cherif et al., 2017).

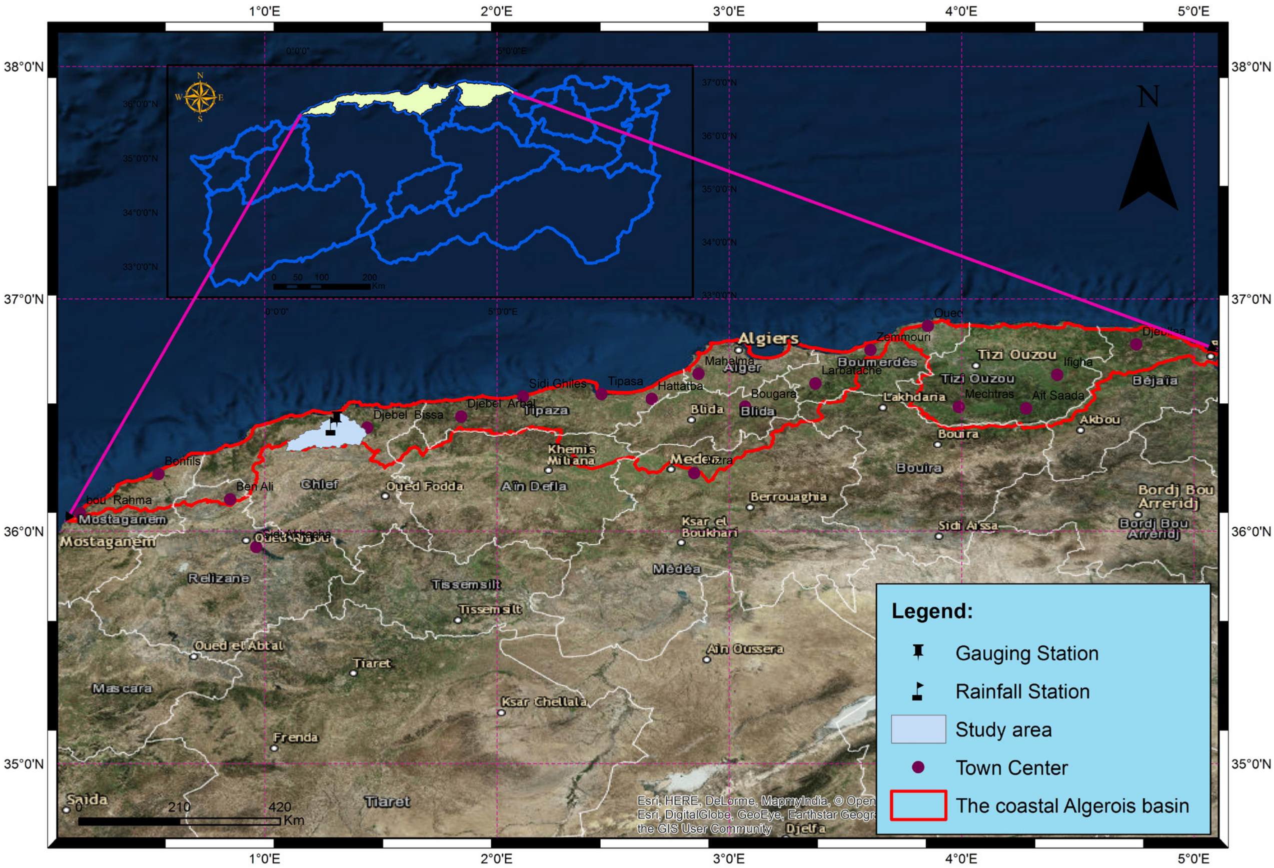

Fig. 1 - Location of study area.

Tab. 1 - Morphometric characteristics of Allalah basin.

Parameters	Notation	Unit	Value
Area	S	km²	293
Perimeter	P	km	96.60
Circularity ratio	Kc	-	1.58
Maximum altitude	Hmax	m	986
Minimum altitude	Hmin	m	79
Average altitude	Hmoy	m	326
Altitude to 95%	H95%	m	666
Altitude to 50%	H50%	m	294.7
Altitude to 5%	H5%	m	109
Length of equivalent rectangle	Lrec	km	41.30
Width of equivalent rectangle	lrec	km	7.00
Index of drainage basin	DS	m	230.95
Global slope index	Ig	%	1.35
Time of concentration	Tc	h	10.61

4.1. ANNUAL VARIABILITY OF LIQUID AND SOLID INPUTS

The average annual fluid intake conveyed by the Wadi Allalah was evaluated at 16.56 hm^3; it generated a mean annuel erosion of 324.69·10^6 t, is a specific solid discharge of 1108 t·km^{-2}·year^{-1}.The year 1999/00 and 2001/02 were those which carried the greatest solid contribution of all the series of study (Fig. 3), that is to say 26.38% of the global load. The specific erosion is 8768 t·km^{-2}·year^{-1}, eight times the annual average value of the period September

Tab. 2 - Classes of occupation of the soil.

Classes	Area (km²)	Area (%)
Vegetal cover	38.15	13.02
Water	22.30	7.61
Building	16.76	5.72
Arid Soil	154.39	52.69
Plowed Soil	42.00	14.33
Roads	19.40	6.62
Total	293	100

1983-August 2013. In fact, during these hydrological years, the fallen rainfall and the geology of the Wadi Allalah basin as well as the absence of the vegetation cover lead to the recording of these values. The solid contribution generated during these years was $2569.26 \cdot 10^6$ t. However, it should be noted that the 1992/93 hydrological year, judged by its considerable solid contribution of $21.64 \cdot 10^6$ t, recorded a low liquid input 3.96 hm^3.This result seems to be due to a set of hydroclimatic factors which generate the effect erosion of floods and their period of occurrence.

The value of the specific degradation found for our basin is close to those estimated by many authors who have worked on basins in the southern Mediterranean, in this case erosion rates ranging from 269 to 2569 $t \cdot km^{-2} \cdot year^{-1}$ proposed for the Maghreb (Heusch and Millies-Lacroix, 1971), degradation values ranging from 240 to 5900 $t \cdot km^{-2} \cdot year^{-1}$ (Lahlou, 1994) at the basin level Morocco, or estimates between 165 and 938 $t \cdot km^{-2} \cdot year^{-1}$ in the Mouillah, Sebdou, Isser and Sikak basins of western Algeria (Bouanani, 2004).

4.2. MONTHLY AND SEASONAL VARIABILITY OF LIQUID AND SOLID INPUTS

The variations in monthly mean liquid inputs and corresponding suspended solid loads provide insight into the overall trend in basin susceptibility to sediment production (Fig. 4). Two phases are to be distinguished: a phase of large mobilization and sediment entrainment that runs from November to May is a contribution that amounts to 96% of the annual average load. Another poor phase in loss of soil during the hot and dry summer season whose hydromorphological and climatic effects extend until October. Indeed, in the first phase there is a significant rainfall during winter and spring.

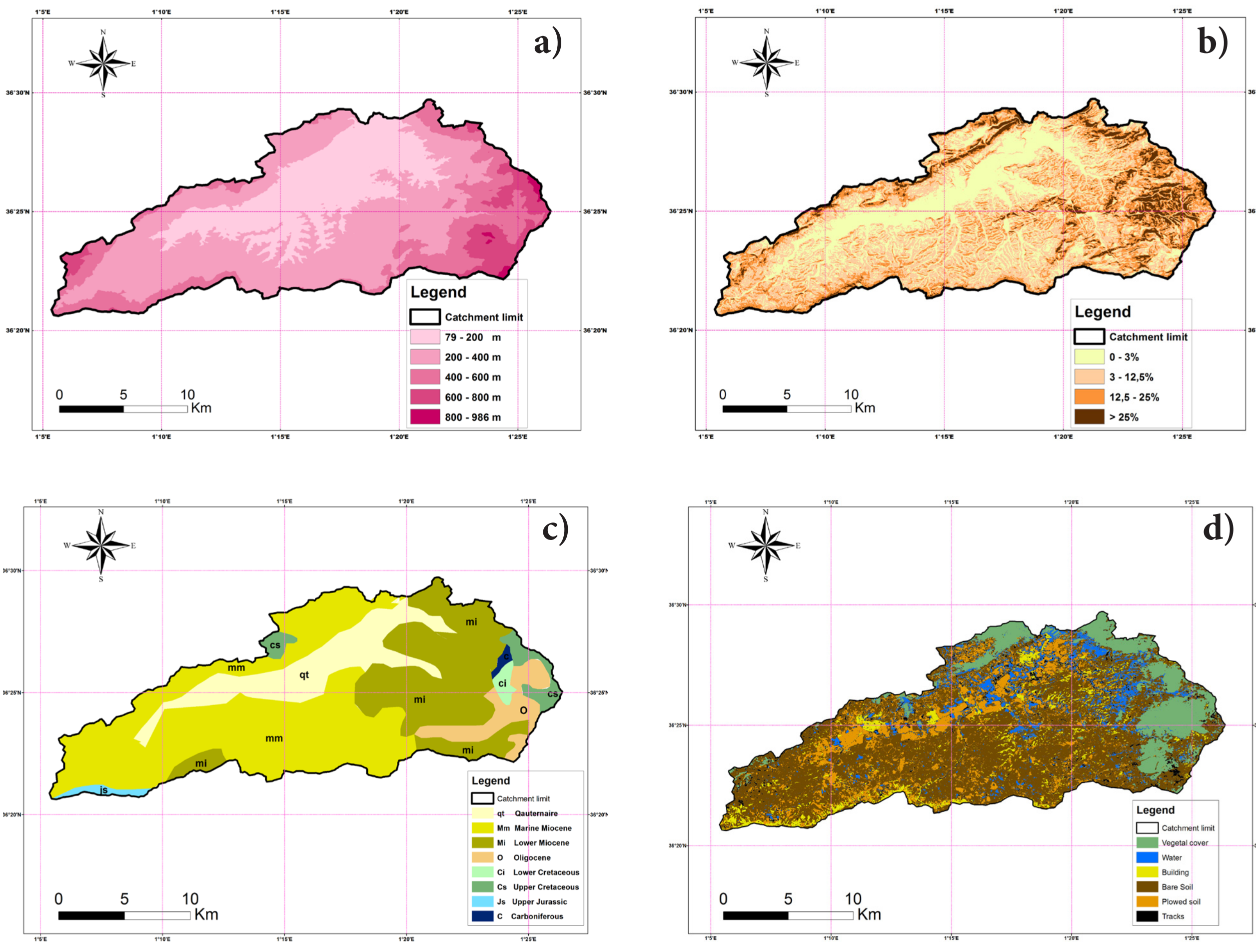

Fig. 2 - Thematic map of Wadi Allalah basin. a) Altitude map. b) Slope map. c) Geological map. d) Occupation map.

Tab. 3 - Lithology of the watershed of Oued Allalah.

Description	Area (km²)	Percentage (%)
Qauternaire	40.20	13.72
Marine Miocene	140.64	48.00
Lower Miocene	78.03	26.63
Oligocene	17.66	6.03
Lower Cretaceous	2.69	0.92
Upper Cretaceous	9.57	3.27
Upper Jurassic	2.96	1.01
Carboniferous	1.25	0.43

Through our analysis of figure 5, winter is the first season of erosion in the study catchment with a solid contribution of 194.12·10^6 t or 60% of the overall load, for such a large cash inflow 9.10 hm^3 or 55% of the total annual volume. Indeed, the spring rains, quite abundant, after a cold rainy winter with a succession of gels and thaws favoring the destabilization of the soil structure and making it more vulnerable to erosion, find a soft soil and then trigger highly charged flows with a contribution of 18% of the total charge is a liquid contribution of 27%. Bank failures and the different mass movements of the watersheds that reach liquidity limits in late spring are the main cause. In the fall the values recorded during this season due to heavy rains after a very hot summer, with 22% of solid transport. The quantities of sediments discharged by the flow of Wadi Allalah at this time of the year are influenced by the icing and splash phenomena caused by the first violent rain of autumn. Winter floods do not have an erosive impact comparable to that of the other two seasons spring and autumn , this is explained by the fact that large quantities of sediments were transported by the first fall floods (Achite and Meddi, 2005; Stephen, 2000). On the other hand, they contribute much more to the recovery of aquifers and participate in the support of surface flows until June. Summer remains a dry season with a solid load transport of 1%.

It is noted that this scale gives better results in terms of coefficient of determination, because each season with a quite different hydrological behavior (Tab. 4), the autumn is characterized by showers on a rather dry soil, which facilitates the erosion and gives solid concentrations quite important. During the winter, the soil is humid enough, so it is more resistant to erosion, except that the fairly high

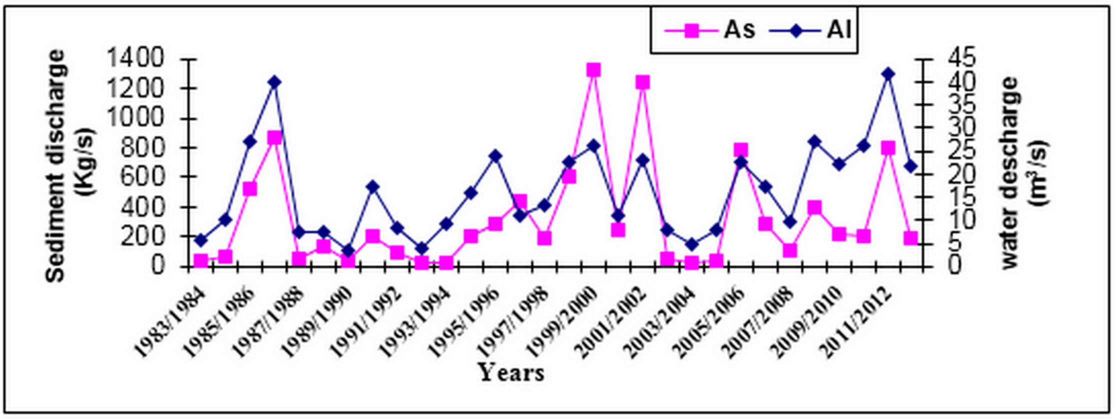

Fig. 3 - Interannual variability of solid and liquid inputs in the watershed area of wadi Allalah basin.

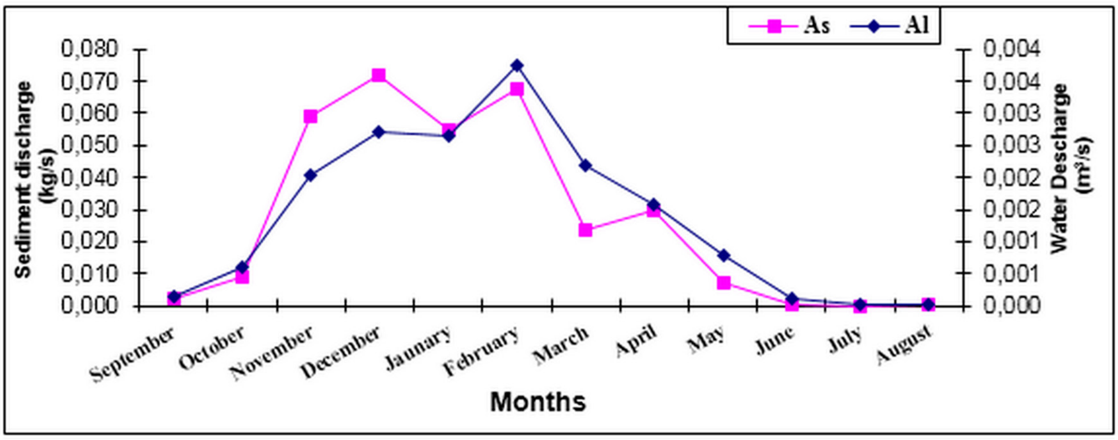

Fig. 4 - Variability of monthly liquid and solid intakes in the catchment area of wadi Allalah basin.

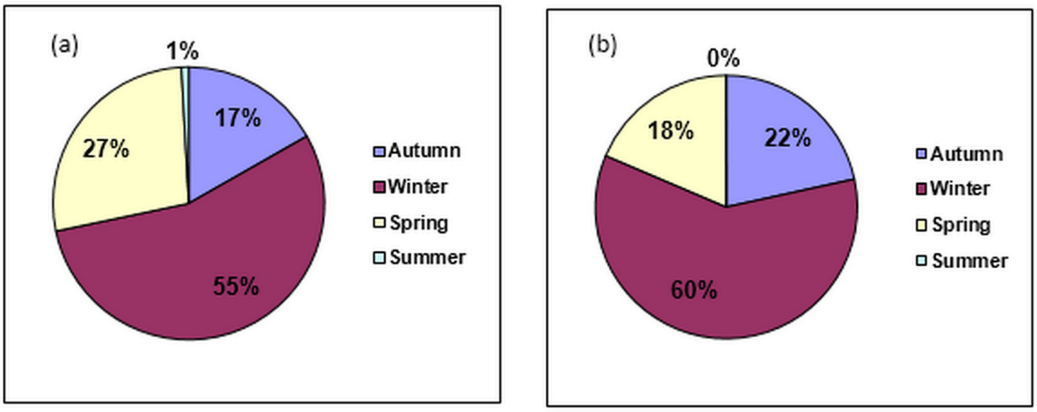

Fig. 5 - Seasonal contribution of the wadi Allalah basin. a. Seasonal liquid contribution. b. Solid seasonal contribution.

Tab. 4 - Rating curve parameters.

Temporal scale	Number of observations	a	b	R^2	Relationship
All events	2240	2.53	1.72	0.77	Qs = 2.53.Ql1.72
Autumn	304	9.07	1.76	0.84	Qs = 9.07.Ql1.76
Winter	1069	2.59	1.75	0.80	Qs = 2.59.Ql1.75
Spring	835	1.90	1.73	0.72	Qs = 1.90.Ql1.73
Summer	32	8.03	1.83	0.75	Qs = 8.03.Ql1.83

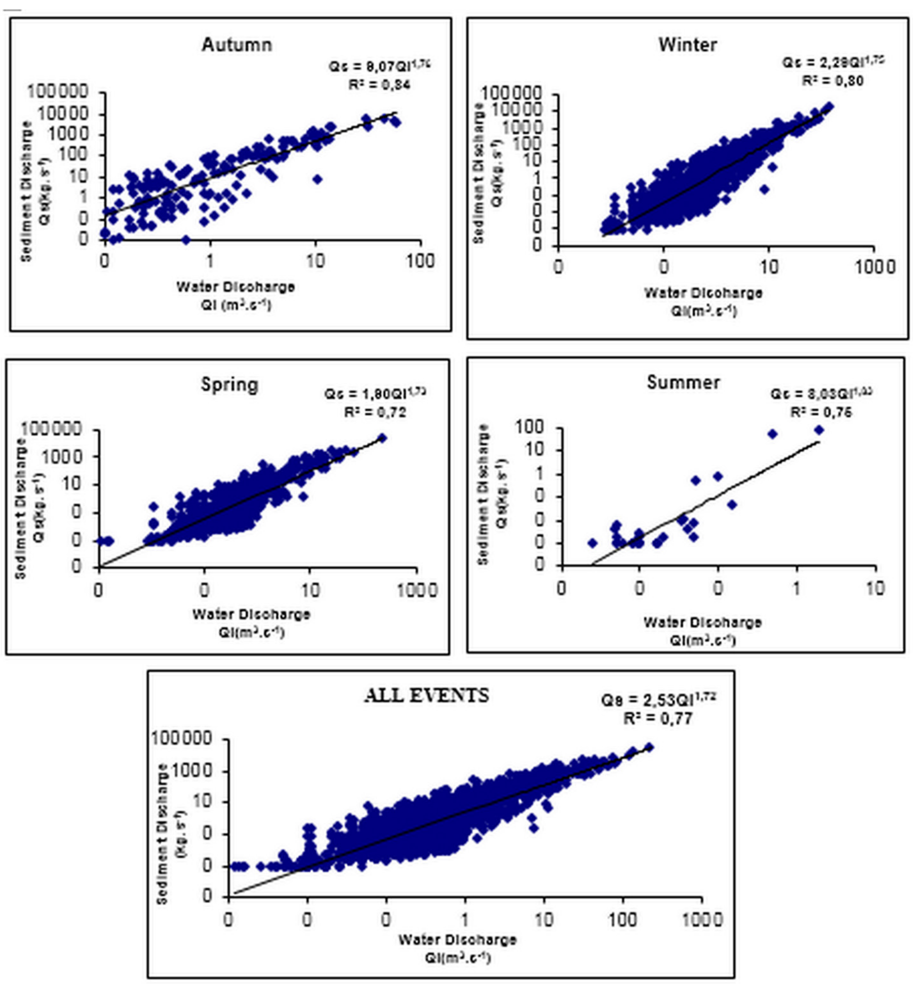

Fig. 6 - Relationship between instantaneous sediment yield and water discharges at different temporal scales.

liquid flows make it possible to obtain considerable solid input in winter. During the spring, vegetation enhances the ability to resist soil erosion and often reduces solid concentrations. Finally, summer is a dry season when usually wadi is dry, but solid concentrations can be impressive during summer floods (Fig. 6).

5. CONCLUSION

The objective of this study is to make a statistical approach to the assessment of solid suspended solids based on the calibration curve method (SRC). This statistical approach makes it possible to quantify the specific degradation of our watershed from the data observed at the hydrometric station levels. Snapshot data files are used to search for highly significant models that can relate liquid flow to solid flow. The developed models can be used for solid transport prediction. Measurements and prediction of suspended solids concentration are of great interest because they allow reliable quantification of solid inputs. For the Allalah Wadi, a rather poor vegetation cover, and a soil not very resistant to the erosive action which to give the results recorded at the level of the station of Sidi Akkacha. The estimated specific degradation for the Allalah wadi basin, controlled by the SIDIAKKACHA gauging station, was 1108 $t \cdot km^{-2} \cdot year^{-1}$. It is high compared to that of the Algerian watersheds (Boudjadja et al., 2003 in Wadi Messelmoun the specific erosion 3029 $t \cdot km^{-2} \cdot year^{-1}$, Ghenim et al., 2007, the specific erosion is 1330 $t \cdot km^{-2} \cdot year^{-1}$ in wadi Sebdou; Boukhrissa et al., 2013 in wadi El Kebir the specific erosion is 1410 $t \cdot km^{-2} \cdot year^{-1}$; Tourki et al., 2017 in wadi Kebir amont the specific erosion is 884 $t \cdot km^{-2} \cdot year^{-1}$). It is in the range of 269 to 2569 $t \cdot km^{-2} \cdot year^{-1}$ proposed for the Maghreb (Heusch and Millies-Lacroix, 1971). The erosive potential is relatively high during the winter because of bank collapses and mass movements often triggered in this season.

Based on the results obtained, we recommend a quantitative aspect of solid transport in this basin, a reflection at the scale of the watershed is essential and essential to significantly reduce the risks of water erosion. To increase soil infiltration and facilitate sedimentation or rolling of floods or manage flow, the combination of certain cultural practices (stubble cultivation, hoeing and peeling) and other management techniques (reforestation, grass strips, embankments, hedges, ditches, etc.) is therefore necessary to effectively combat surface runoff and soil erosion, especially for agricultural purposes. Some cons, siltation of dams, lowering of soil fertility and shortage of surface water volumes. In order to reduce these cons of the phenomenon we use afforestation as an inexpensive solution.

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