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Suspended Solid Transport and Specific Degradation of the Oued El-Hammam Catchment Area

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Abstract:
Solid transport has a big importance and can be a major problem in Algeria at the same time (degradation of agricultural soils, alluvial reservoir).
The study of solid transport makes it possible to evaluate the quantities of sediment transported by the wadis and specify the erosive dynamics of the basin with understanding the functioning of the watersheds in the production of sediments.
In this work we will highlight the solid transport of the Oued El-Hammam watershed, so we used make a series of precipitations (monthly and daily maximum) of the Oued El-Hammam watershed collected at the pluviometric station of Bouhanifia (1962 to 2019), as well as data on solid and liquid flows collected at the hydrometric station of Bouhenifia (1985-2004) and we sought an estimation curve by applying a power model ($Qs = a\ Q^{b}$)*, the latter showed that the parameter* ***(b)*** *remains linear, which means that the dynamics of erosion is constant, on the other side, regarding to parameter* ***(a)*** *we notice a variation in the morphology and vegetation cover of the basin.*
Key words*: solid transport, watershed of the El-Hammam wadi, rainfall study, power model, estimation curves*

1. INTRODUCTION

Soil erosion is one of the main causes of soil degradation, this situation characterized by a drop in yields due to the loss of fine soil elements and topsoil, soil drying, infrastructure degradation and flood risks (Melalih, 2012).
Arid and semi-arid zones are characterized by irregular rainfall and runoff patterns, which can cause a serious problem like: water erosion, solid transport and flooding. (Alexandrov et Laronne, 2003 ; Castillo et al., 2003, Bouguerra S., Bouanani A.2019).
Solid transport in rivers is one of the major problems in river hydraulics. (Zoubir A , 2007)
Semi-arid Mediterranean regions are characterized by much more irregular inter-annual variability in solid inputs than in liquid inputs. Concerning to the Algerian basins, some authors have noted specific degradations varying between 200 and 5,000 t/km2/year. (Heusch et Millies-Lacroix, 1971 ; Lahlou, 1994 ; Bouanani, 2004 ; El Mahi et al., 2012).
In the semi-arid zones of northern Algeria, water erosion usually causes many problems relating to the assessment of specific degradation and solid transport. This problem has pushed many researchers to study the mechanisms of slope morphogenesis and the hydrodynamics of wadis in an attempt to quantify the volumes of sediment transported. Many authors have published studies about this phenomenon (Achite and Meddi, 2004; Bouanani, 2004; Bourouba, 1998; Elahcene et al., 2012; Ghenim, 2008; Sorgeah, 1967). So one of their objectives is to develop statistical models and establish a relationship between hydroclimatic and geomorphological parameters and the transport of solid materials. These models are applicable to regions or catchments where measurements are rare or non-existent (Achite, 2002; Elahcen, Remini, 2009).
In this work, we will focus on Oued El-Hammam catchment, which is a large sub-catchment of the Macta

and a good hydrological behavior.

Our objective is to study the transport of suspended solids in this catchment specifically at the hydrometric station of the Bouhanifia dam.

2 DATA AND METHODS

2.1 The study region

Our study area is part of Algeria's north-western hydrographic basin, exactly Oued El Hammam catchment area. This is located in the north-west of the country.

It forms part of the greater Macta basin (Fig1), approximately between longitudes (0° 14‘23’’ E and 0° 21’ 23’’ W) and a latitude between (35° 9‘55’‘N and 35° 34’ 38’’ N) which is located in the wilaya of Mascara.

This area is bounded by the Macta reservoir to the north, the Atlas Tellien to the south, the Beni Chougrane mountains to the east and the Tessala mountains to the west. The catchment area contains two artificial reservoirs: the Bouhanifia dam and the Fergoug dam, which are located in series.

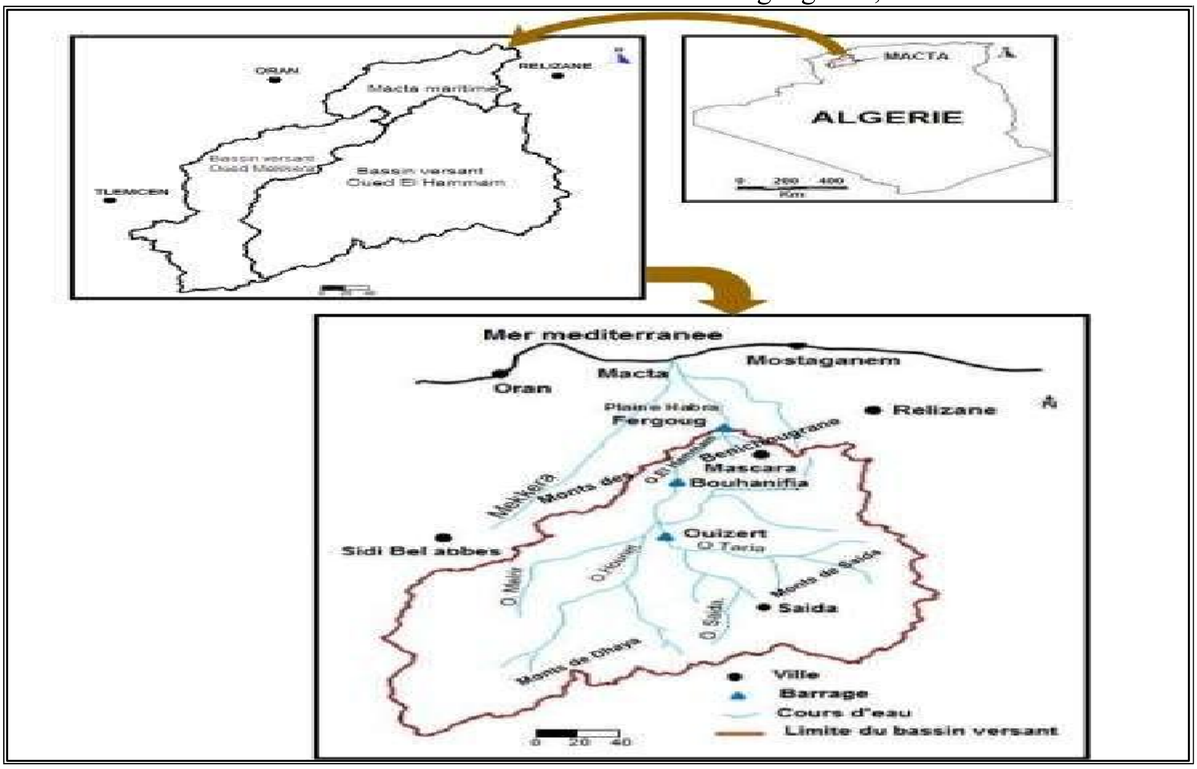

Figure 1. Geographical location of the Wadi El Hammam catchment area (Gliz, 2015).

2.2 Data

The Study of hydrological regime need to analyze the runoff recorded in the watercourse; all runoff in Oued El-Hammam catchment is monitored and controlled by the Bouhanifia hydrometric station.

Rainfall data, as well as liquid and suspended solid flows, and even more so the average liquid flow, come mainly from the data base of the Agence national des resources hydrauliques (ANRH) in Algiers. Suspended sediments measured at the Bouhanifia station correspond to kg/s. We have a series of measurements covering the period 1985-2004, with a sample size of 4,258 data. The data on liquid and solid inputs of suspended sediment cover a period of 21 years (1962-1983).

3 RESULTS AND DISCUSSION

3.1 Monthly rainfall pattern

According to Fig 2, the monthly rainfall pattern in the Bouhanifia region reached 445.16 mm during the period (1962-2019).

The highest rainfall was 76.69 mm in December, while the lowest rainfall, 0.95 mm in July.

The most important for agropastoral, farmer and stockbreeder is not the total rainfall, but its distribution over the year.

The Analysis of some results shows that the average monthly rainfall at the station studied is 445.2mm, with a maximum in December (76.69 mm). However, the amount of rainfall in July and August is very low (Fig 2).

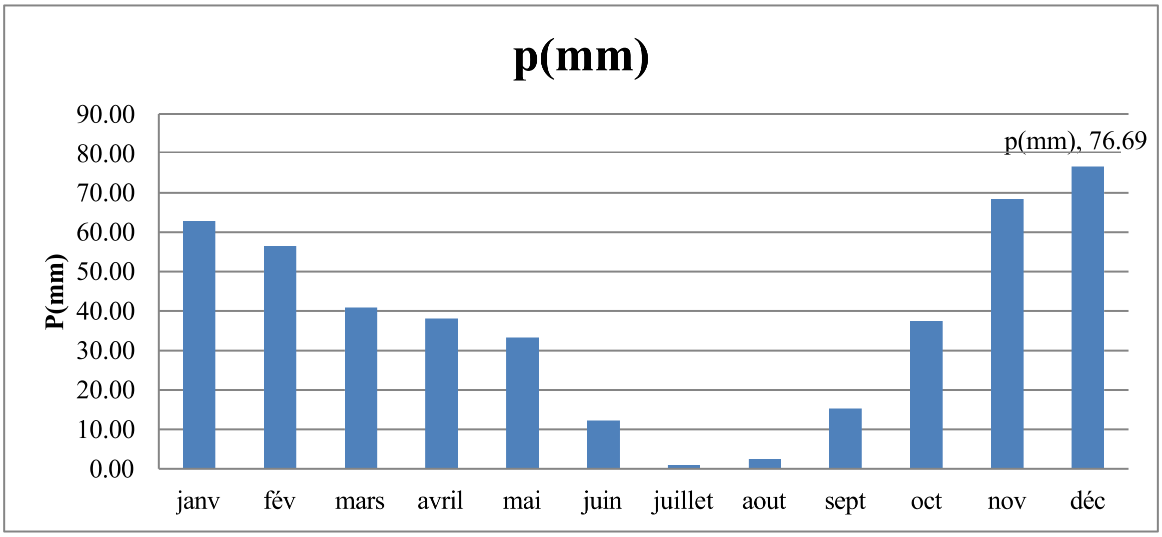

Figure 2. Distribution of average monthly rainfall in mm (1962-2019).

3.1.1 Climatic index

The aridity of a region can be expressed by various indices, based mainly on average rainfall and temperature values. The most famous are those of Martonne (1926); E. Emberger (1932); C.W. Thornthwaite (1948); J. Dubief (1950); R. Capot-Rey (1951); H. Gaussen; F. Bagnouls (1952) and P. Birot (1953).

- **De Martonne aridity index**

This index determines the aridity of the climate of the region studied by combining temperature and precipitation, and is expressed as follows:

$$I = \frac{P}{(T+1)}$$

with:
I: De Martonne aridity index;
P: mean annual precipitation in (mm);
T: mean annual temperature in (C°).
For:
20< I <30: temperate climate;
10< I <20: semi-arid climate;
7.5< I <10: steppe climate;
5< I <7.5: desert climate;
I < 5: hyper-arid climate.
The aridity index is around 16.02 at the Bouhanifia station, which corresponds to a semi-arid climate.

3.1.2 Solid-liquid flow model

- **Solid flow-liquid flow model on an instantaneous scale**

The study focuses on instantaneous liquid flows in m*/s and solid flows.

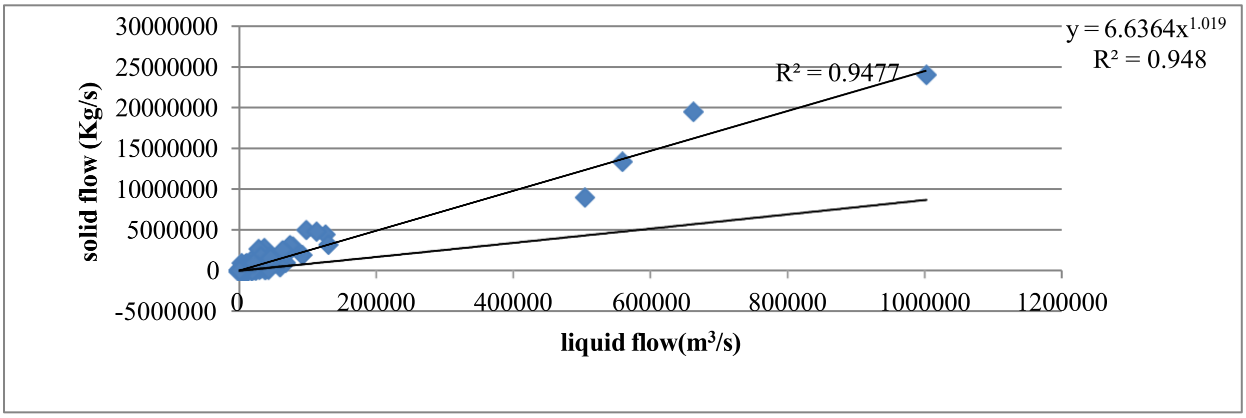

Figure 3. The relationship between solid flow and instantaneous liquid flow (Oued El-Hammam). (1985-2004).

The previous fig (fig 3) clearly shows that the variation in solid flow rates as a function of liquid flow rates can be expressed by the power law $Qs = a\ Ql^b$, such that a = 6.636 and b = 1.019 with a coefficient of determination R2 = 0.84 and a correlation coefficient r = 0,97.

-Daily solid-liquid flow model

The study of this model consists of developing a power law between the average daily liquid and solid flows. The average daily flows were determined from the instantaneous flows recorded at several times during the day. After processing the data, we obtained a sample of 759 data points. The results of applying the power law to this sample are summarized in the following table:

Table 1: Parameters of the daily power model (Oued El-Hammam)

Scale	Relationship	Coefficient of determination R2	correlation coefficient r	Sample size
Daily	$Q_s = 1{,}953 Q_l^{1{,}128}$	0,87	0,96	759

Examination of the results shows that the exponent b = 1,12 and the scale a = 1.95, which explains the low suspended sediment load. The coefficient of determination R^2 is 0,87 and the correlation coefficient r is 0,96.

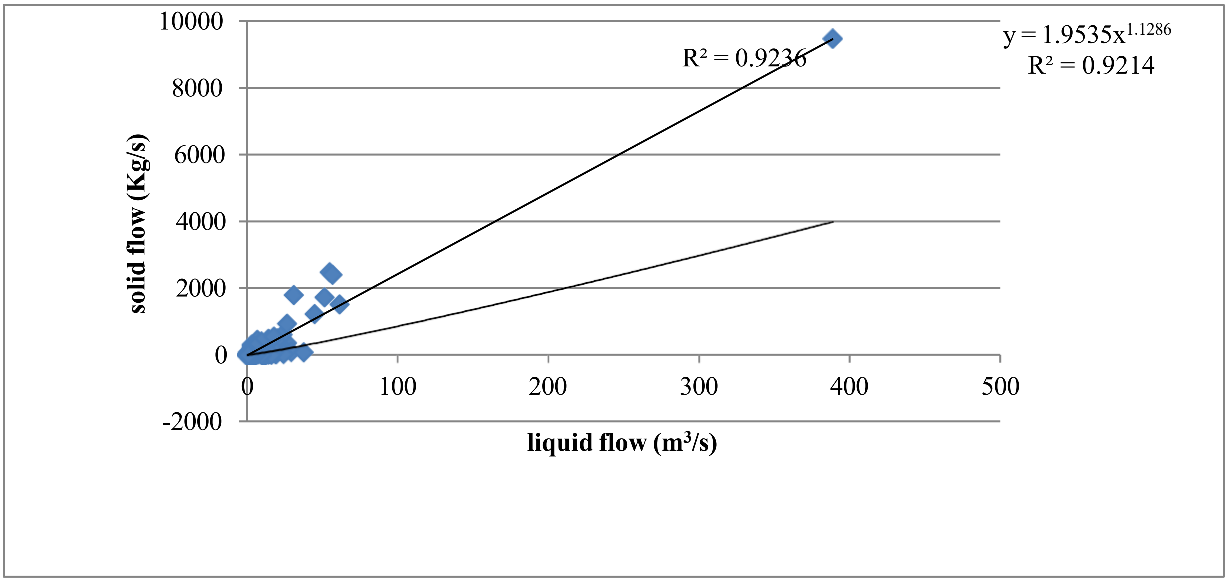

Figure 4. Solid flow-liquid flow relationship on a daily scale (Oued El-hammam).(1985-2004)

3.1.3 Seasonal solid-liquid flow model

In this section we classify all the data by season. As before, we apply the model to these data samples and summarize the results in Table 2 and the fig below (5: A.B.C.D).

Table 2: The power model on a seasonal scale (Oued El-hammam) (1985-2004).

Season	**Relationship**	**Coefficient of determination R²**	**Correlation coefficient r**
Autumn	$Qs = 3{,}924 Q_l^{1{,}152}$	0,96	0,81
Winter	$Qs = 2{,}064 Q_l^{1{,}107}$	0,99	0,72
Spring	$Qs = 1{,}496 Q_l^{1{,}197}$	0,93	0,91
Summer	$Qs = 3{,}864 Q_l^{1{,}123}$	0,96	0,50

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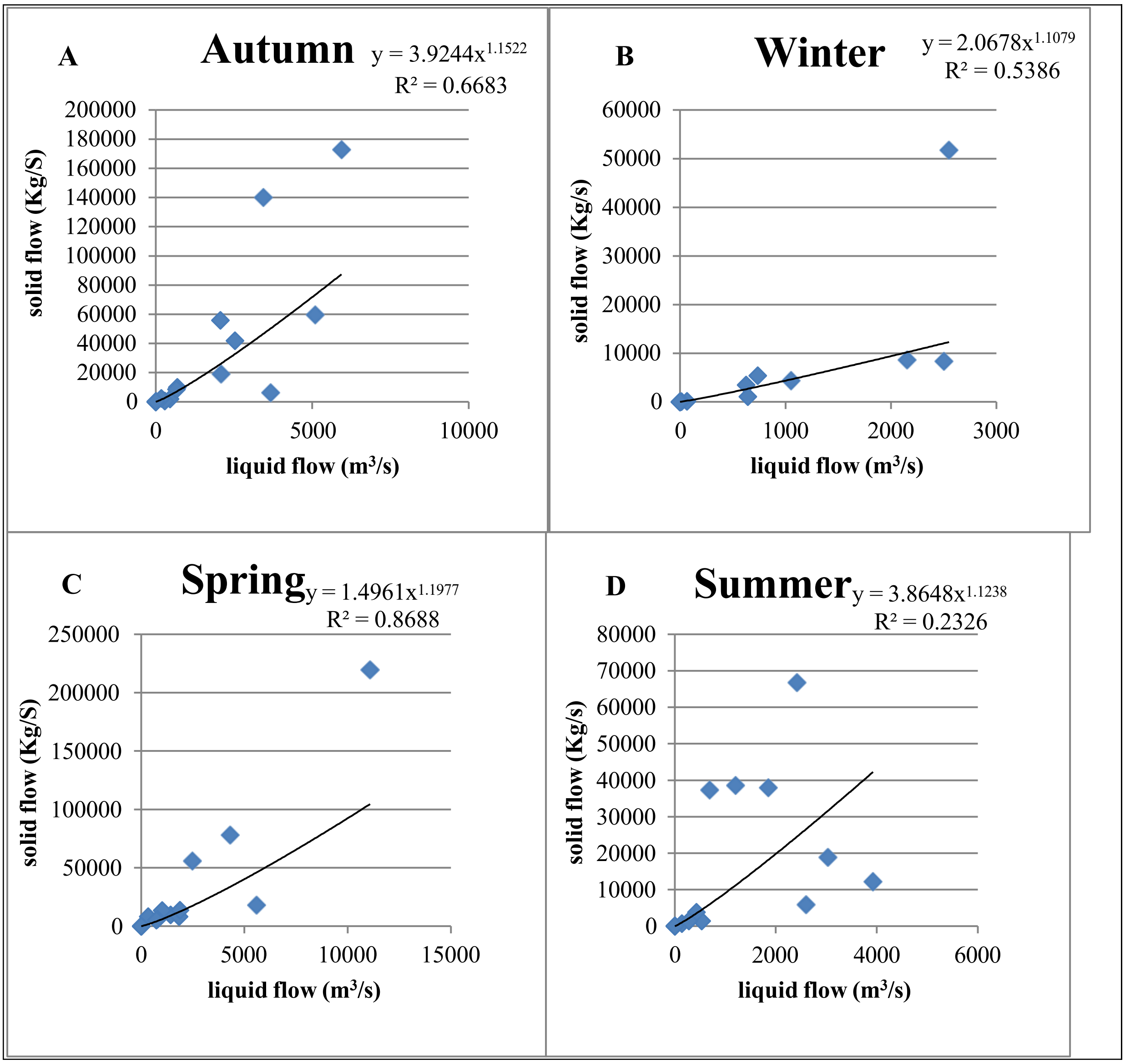

Figure 5. Solid flow-liquid flow relationship on a seasonal scale (Oued El-hammam). (1985-2004)

Through the Analysis of these results, we observe that parameter (a) varies from a minimum value of 1.49 to a maximum value of 6.63, while parameter (b) ranges from 1.01 to 1.19. This model explains the correlation coefficients varying between 0.50 and 0.97, the variation in solid flow as a function of liquid flow on this scale.

The results of this section show that the power model provides a good explanation of the variation in liquid flow and solid flow in the Oued El-Hammam basin. The parameters of this regressive model (a, b, r) varies from one scale to another, but the monthly and seasonal scales are among the best time scales, since the correlation coefficients obtained are satisfactory.

3.2 Estimation of solid and liquid inputs

In this section, we evaluate the liquid and solid inputs of suspended sediment for a period of 21 years (1962-1983), then deduce these solid inputs from the specific degradation of Wadi El-Hammam.

So, we use all the instantaneous liquid and solid flow data from the Bouhanifia station, which we classify on several time scales: interannual, seasonal and monthly.

Study of solid inputs

Sediments entering a reservoir are transported to it by the minor beds of the river systems. This solid input is extremely varied in granulometry, ranging from gravels and pebbles to silt and clay particles.

Determination of solid flows

Qs = Q1.C

With:

Qs: suspended solids flow rate (kg/m*/s).

Q1: liquid flow rate (m*/s).
C: suspension concentration (kg/m*).

-Annual variability of inputs

The results of the calculation of liquid and solid inputs of suspended sediment over the period (1962-1983), together with their statistical characteristics, are summarized in Table 3 and presented in Figs 6, 7 and 8.

Table 3: Liquid and solid inputs and specific soil degradation (Oued El-Hammam).

Years	Liquid intake (Li) (Hm^3)	Solid intake (Si) (T)	Ssi	Si (%)	Years	Liquid intake (Li) (Hm^3)	Solid intake (Si) (T)	Ssi	Si (%)
1962	40,83	281,93	0,05	1,50	**1973**	184,29	1269,08	0,23	6,77
1963	156,82	1080,17	0,19	5,77	**1974**	154,96	1062,57	0,19	5,67
1964	108,5	743,28	0,13	3,97	**1975**	111,21	759,03	0,14	4,05
1965	215,64	1488,74	0,27	7,95	**1976**	91,1	619,53	0,11	3,31
1966	254,47	1793,37	0,32	9,57	**1977**	80,07	542,43	0,1	2,90
1967	96,28	654,88	0,12	3,50	**1978**	57,42	387,82	0,07	2,07
1968	125,76	858,97	0,15	4,58	**1979**	70,92	478,95	0,09	2,56
1969	117,74	804,02	0,14	4,29	**1980**	80,92	548,64	0,1	2,93
1970	119,98	818,98	0,15	4,37	**1981**	69,52	470,32	0,08	2,51
1971	204,94	1425,88	0,26	7,61	**1982**	83,56	567,27	0,1	3,03
1972	256,74	1789,81	0,32	9,55	**1983**	43,26	289,6	0,05	1,55
					Average	123,86	851,60	0,15	
					Standard deviation	64,24	452,41	0,08	
					CV	0,6	0,7	0,5	
					Totals	2724,93	18735,27	3,36	100

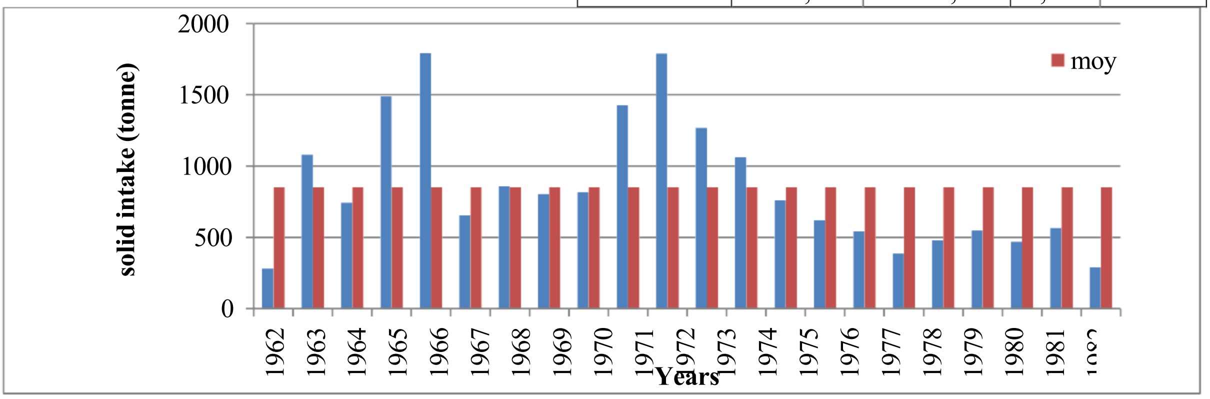

Figure 6. Annual solid input (Oued El- Hammam) (1962-1983)

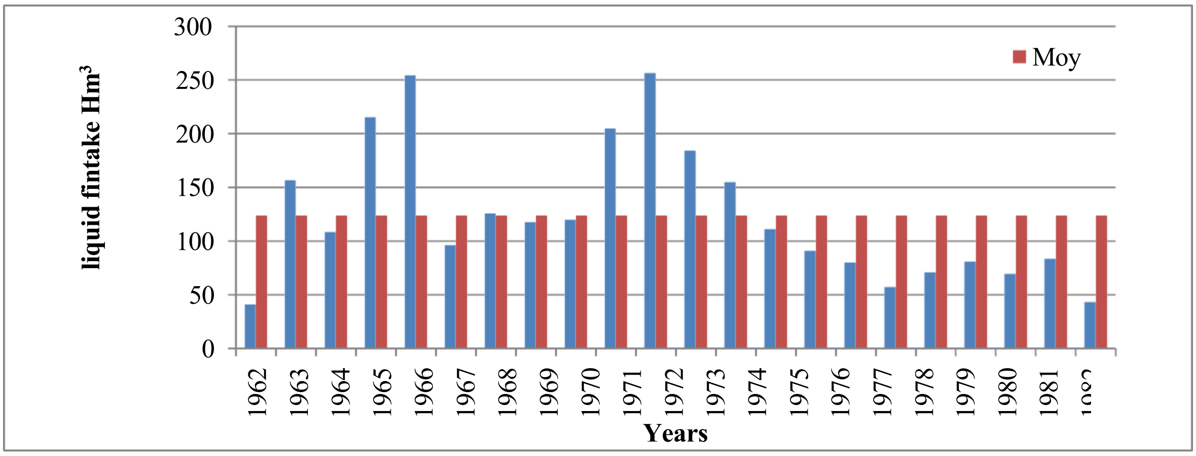

Figure 7. Annual liquid input (Oued El-Hammam) (1962-1983).

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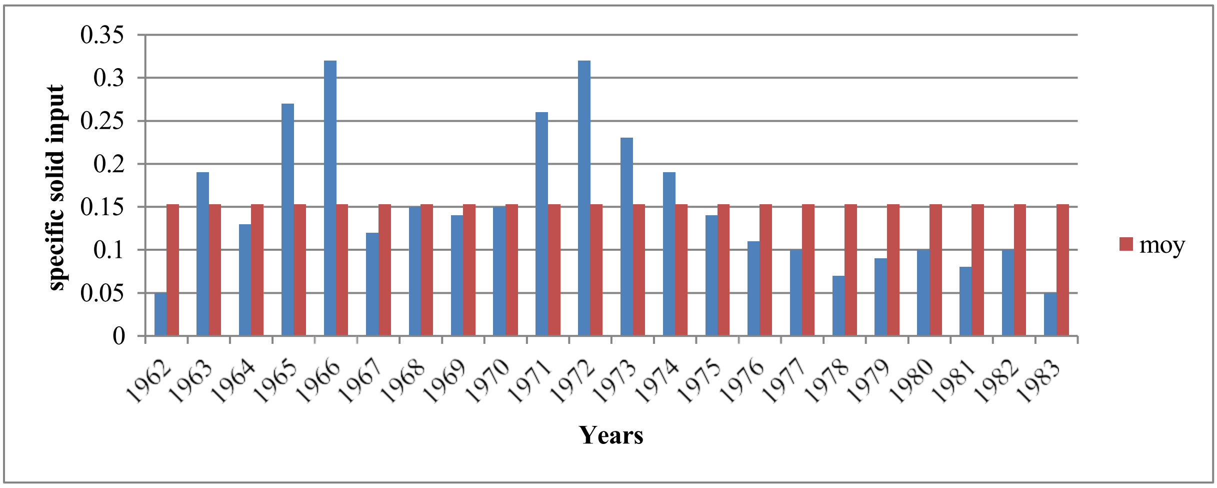


Figure 8. Specific annual solid input (Oued El-Hammam) (1962-1983).

Analysis of these results shows a degree of harmony in the general pattern of variation in liquid and solid inputs, but with varying orders of magnitude. On an interannual scale (1962-1983), there is a very high variability in liquid and solid inputs, with coefficients of variation of 0.5 and 0.7 respectively. Over these 21 years, solid inputs exceeded the interannual average in only 6 years, compared with 6 years for liquid inputs. This shows the high variability on this scale (see Fig 6).

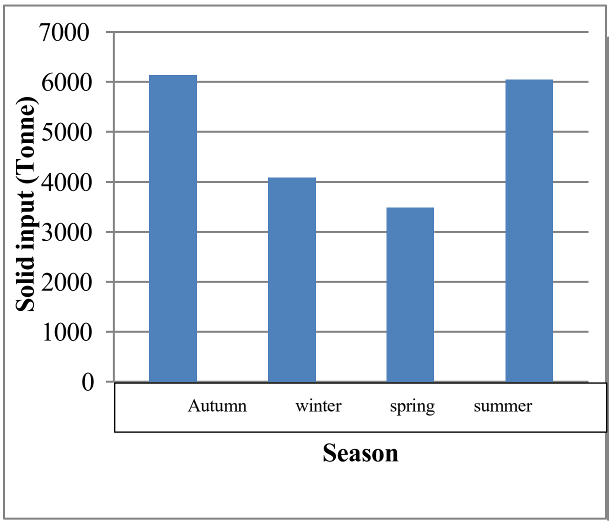
The high levels of suspended sediment input during the period (1971-1974) can be explained by the relatively dry period between (1962-1963). The other peaks in solid input follows the same pattern: each liquid inputs following a relatively dry period is always associated with a substantial solid input. Over the study period, the maximum value (the peak) of solid inputs is 1793.37 tones, observed in 1966-1967, and the inter-annual average is 851.60 tones. In the end of the period from 1973 to 1983, the solid input of suspended sediment amounted to 18735.27 tones and the liquid input to 2724.93 hm^3.

-Seasonal variability of inputs

The study of this variability offers another perspective: how do suspended solids transport and liquid and solid inputs behave from one season to another? Which season records the highest liquid and solid inputs?

Table 4: Seasonal variability of liquid and solid inputs (Oued El-hammam) (1962-1983).

Season	Liquid input (Hm^3)	Solid input (T)	Liquid input %	Solid input %
autumn	885,57	6146,09	30,45	31,08
winter	946,54	4084,54	32,55	20,65
spring	573,29	3493,81	19,71	17,66
Summer	502,94	6053,76	17,29	30,61



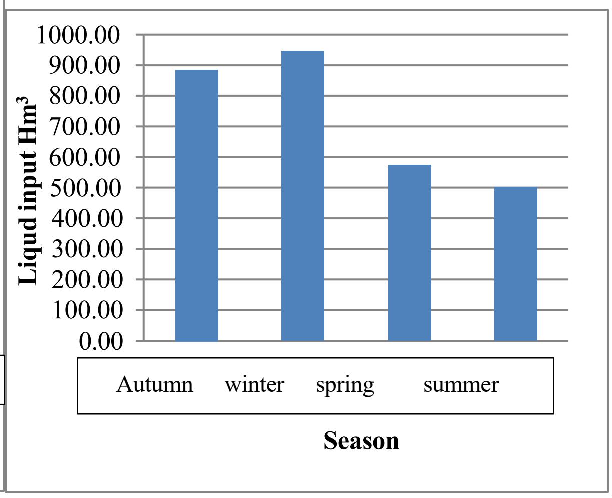


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Table 9. Seasonal variation in solid input Hammam (1962-1983).

Table 10. Seasonal variation in liquid input to Oued El-Hammam (1962-1983).

From the figs above (9.10), it is clear that winter transports the greatest quantity of suspended sediment, i.e. 31.04% of the total input during the period studied. As for liquid inputs, it is during winter that the highest values are recorded, with 32.55% of the total liquid input during the same period.

-Monthly variability of inputs

To study the variability of solid transport on a finer scale, we classify all solid inputs month by month. The results of this classification are summarized in table 5.

Table 5: Monthly variability of liquid and solid inputs (Wadi El-Hammam) (1962-1983).

Month	Liquid intake	Solid intake	Liquid intake %	Solid intake %	Month	Liquid intake	Solid intake	Liquid intake %	Solid intake %
September	33943,03	3611,24	21,22	18,26	May	13330,21	1618,50	8,33	8,18
October	8440,83	1201,21	5,28	6,07	June	12043,92	1585,16	7,53	8,01
November	9675,69	1333,64	6,05	6,74	July	24273,16	2766,01	15,17	13,99
December	5333,30	809,58	3,33	4,09	August	12389,26	1702,59	7,75	8,61
January	10444,80	1421,21	6,53	7,19	average	13329,91	1648,18	100	100
February	15752,98	1853,75	9,85	9,37	standard deviation	8269,41	820,92		
March	9776,64	1251,16	6,11	6,33	CV	1,61	2,01		
April	4555,06	624,15	2,85	3,16					

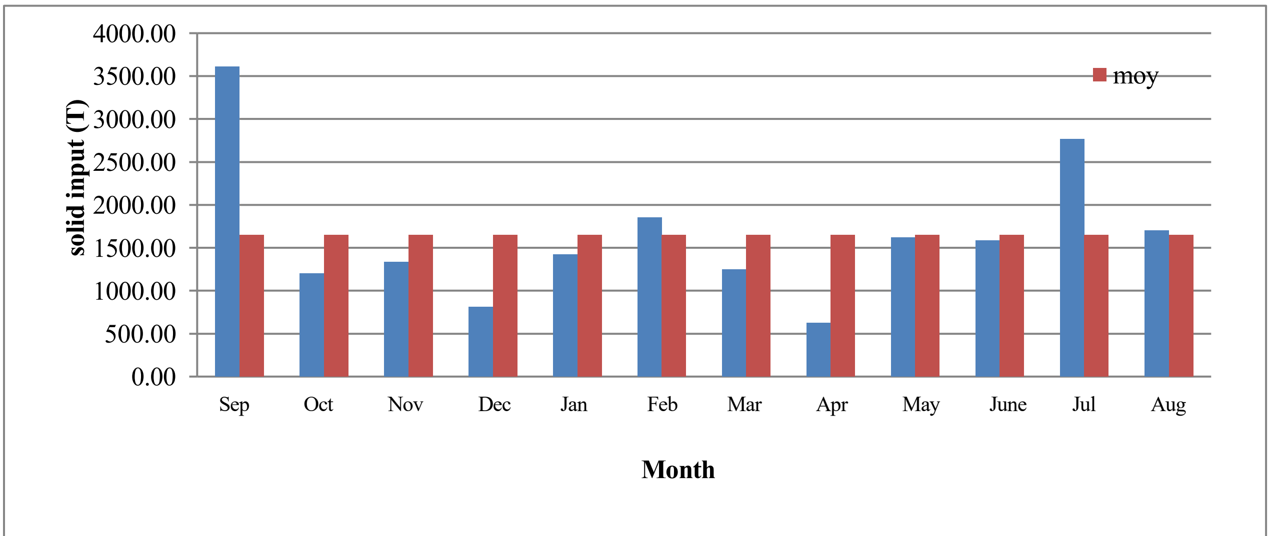

Figure 11. Monthly variability of solid inputs to Oued El-Hammam (1962-1983).

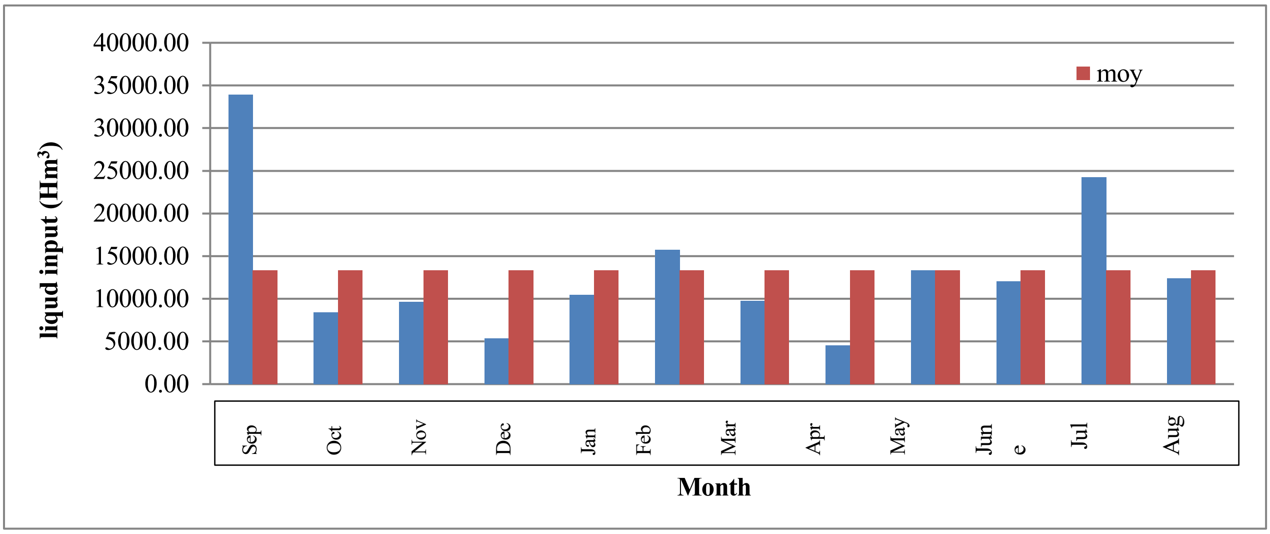

Figure 12. Monthly variability of liquid inputs (wadi El-Hammam) (1962-1983).

The analysis of the precedent table (Table 5) can be interpreted as follows: The average monthly solid input over the entire period (1962-1983) is 1 648.18 tones, corresponding to an average liquid input of 13,329.91 hm^3. Most months were below average, with the exception of September, February and July. First The maximum solid input of suspended sediment was observed in September, with a value of 3 611.24 tones, or 18.26% of the total input. In the same month, the liquid input was 339 430.3 hm^3, or 21.22% of the annual input.
Second, the month of February contributed 2 766.01 tons of sediment, or 13.99% of the total, and 24,273.16 hm^3, or 15.17% of the liquid contribution.
Third, the month of February contributed 1 853.75 tons of sediment, or 9.37% of the total.
We can conclude that it is the exceptional floods that are responsible for most of the solid transport, given the state of the soil (dry and cracked soil), which is essentially due to the high temperatures of the previous season.

4. CONCLUSION

Solid transport in wadis is a major problem in Algeria. The process of transporting suspended solids in catchment areas is complex. It occurs mainly during flood periods and is closely linked to the intensity of rainfall, the configuration of the catchment area and the hydraulic characteristics of the watercourse.
The Oued El-Hammam catchment area is located in the wilaya of Mascara. It extends over 8,314 km^2 with a perimeter of 572 km.
The rainfall data recorded at the stations studied shows a considerable change, with a clear drop in monthly rainfall, accentuated during the 1980s. The climate in this basin is typically semi-arid, with an average rainfall of 445.2 mm.
When we talk about the relationship between liquid flow and solid flow, we tested the power model generally used in this type of study, and the results are satisfactory with acceptable coefficients of determination.
Concerning the liquid input, we chose the variant based on seasonal data, with an annual mean of 123.86 km^3. On a seasonal scale, this rises to 946.54 km^3, or 32.55% of the total input. This trend is observed in September, with 25.22% of total input.
For the solid input, we chose the same time variant as for the liquid input, which gives a specific annual solid input of 780.07 T/km2/year, making this basin one of the most erodible in the world. The large amount of solid input in autumn (6 146.09 T/km2/year, or 31.08% of the total input) is due to the unfavorable soil conditions (dry, cracked soil) caused by high temperatures and drought.
This study makes us aware about the extent of the phenomenon studied; it means the high variability of liquid and solid inputs at all scales. This is a particularly serious problem in arid and semi-arid zones, particularly in terms of the quantification, management and design of hydrotechnical structures. Even this problem is natural, there is nothing we can do to change it. Nevertheless, controlling it is very important to fight its qualitative and quantitative consequences for the network. As far as solid inputs are

concerned, reforestation is an effective way of combating erosion. The development of the basin can be by building reservoirs in the most vulnerable areas that contribute to this result.

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