# Study of the relationship between sediment transport and rainfall extremes in the watershed of the wadi Mina (northwest Algeria)

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**Abstract** Arid and semi-arid areas are characterized, in particular, by the great irregularity of their climate. This irregularity comes out as sporadic, sometimes very important, showers. They can be responsible for erosion and for exceptional sediment transport. The spatial variability of erosion and sediment transport phenomena in North Africa is very high, either because of the intensity of the phenomena or for their consistency. The main factor of these phenomena is the water. Langbein & Schumm (1958) showed how erosion varies according to the annual rainfall. Two factors act antagonistically on erosion: rain and vegetation. To have erosion, it is necessary to have rain. Erosion is an increasing function of the height of annual rainfall. This article aims to analyse and describe the relationships between sediment transport and rainfall extremes. The study was conducted on Mina, a sub-watershed of 6000 km$^2$ on the left bank of the River Cheliff. The wadi Mina feeds Dam Sidi M'hamed Ben Aouda (SMBA), for agriculture and drinking water supply in the region. This watershed is facing a serious problem of soil degradation, as reported by almost all Western Algerians. This problem causes the rapid siltation of dam Sidi M'hamed Ben Aouda, which has a capacity of 160 million m$^3$. This also affects local agriculture, causing huge losses to cropland, forcing farmers to migrate to urban areas. It is interesting to note that before the 1980s, the dam was experiencing the lowest siltation rates in Algeria. Currently, sediment deposits in the reservoir of the dam are very high, and they have doubled in two years. This dam is classified among the most silted dams in Algeria. The study of the basin covers a period of 33 years (1968/69–2000/01).

**Key words** climate; Algeria; Oued Mina watershed; sediment transport; extreme rainfall; silting

## INTRODUCTION

Sediment transport is influenced by several parameters including: climatology, geology of the site, slope, rain and its intensity. In Algeria, physical conditions, geomorphological, hydro- and socio-economic factors are particularly favourable to the launching and acceleration of the phenomenon of erosion and sediment transport. The average amount of basin sediments discharged into the sea every year by the tributaries of the Mediterranean, is estimated at 120 million tonnes. One of the serious consequences of this phenomenon is the siltation of reservoirs. Due to silting, Algeria's water infrastructure is decreased annually from a potential water reserve equivalent of 20 million m$^3$.

In semi-arid regions, characterized by erratic rainfall which is often very intense, climatic factors have a significant influence on soil loss. Negev (1967) developed a model based on the fact that the amount of soil removed by the effect of "splash" is a function of the height of hourly rainfall. Williams (1978) has developed an instant unit turbidigramme for ungauged basins, in which the suspended load varies linearly with the volume drained away. Bergaoui *et al.* (1998) has developed from hydropluviometric data a non-constant relationship for the micro basin of Tebaga, in central Tunisia. He concluded that 84% of the solid linear transport model is explained by the maximum flow. This work focuses on the use of parameters representing the intensity of the rain (rainfall and Pjmax) and other factors resulting in extreme runoff (maximum flood flow) to estimate the contributed suspended solids. The concentration of suspended materials depends on changes in flow. Values of concentration, actually observed, depend on the intensity of rainfall and the type of soil, the erosion forces due to topography (Benkhaled & Remini, 2003).

The objective of this work is to find a relationship which allows the estimation of major contributions based on one or more hydro meteorological parameters.

## DATA AND METHODS

### Overview of the study area

The watershed of the wadi Mina, which covers 6000 km$^2$ in the western part of the Tell Atlas is part of the largest watersheds in northern Algeria, Wadi Cheliff, which has an area of 43 750 km$^2$ (Fig. 1). It is located about 300 km west of Algiers, between 0°20′ and 1°10′ East longitude and 34°40′ and 35°40′ North latitude (Hubert *et al.*, 1989).
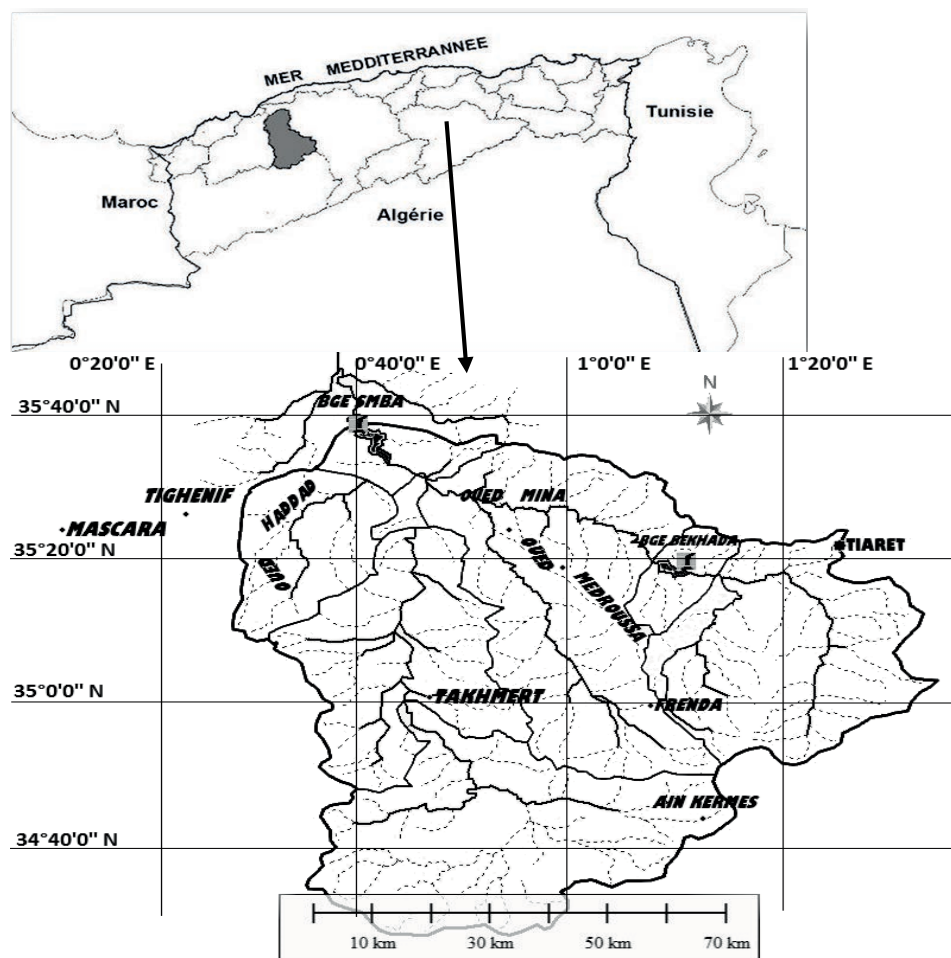


**Fig. 1** The watershed of wadi Mina.

Wadi Mina and the last main tributary of the left bank of Cheliff has its source in the mountains of Frenda, reaching the wadi Cheliff after a journey of 125 km, and travelling a distance of 135 km between dams and Bekhadda Sidi M'hamed Ben Aouda, with an orientation southeast, northwest.

The topographic survey (Meddi, 1992) has allocated the studied basins in the class of high landscape, according to the classification of ORSTOM/IRD (Dubreuil *et al.*, 1971). The basin of the wadi Mina spans two dissimilar natural units:

– In the South, the Plateaus Telliens, also including the Frenda mountains and Saida, have an altitude of 900 to 1300 m, where there is often limestone outcrops;
– In the North, a set of mountain ranges and basins, generally below 900 m altitude, in a complex geological structure of individual blocks in which Ouarsenis is one of the elements. They are characterized by the abundance of marls and are very sensitive to erosion.

The climate of the region is semi-arid Mediterranean (rainy in winter, drought in summer), with a total annual average of about 305 mm (Meddi, 1992).

## METHODS

The study was conducted using data collected during the period from October 1976 to September 2000 on five sub-basins of the watershed of the wadi Mina. The results of processing the raw data are shown in Table 1. The rainfall was obtained from the raingauges installed at the five sub-basins studied. The flow rates and concentrations are obtained by gauging with a reel, by the use of calibration and sampling rates, respectively. Quantities of major contributions are calculated from the data recorded during different floods. The maximum flood flow is determined from the gauging and the limnigraphic records.

**Table 1** Values of the variables involved in the regression of the five sub-basins.

| Sub basins | Stations | Flood | $Q_{max}(m^3s^{-1})$ | As (Tkm$^{-2}$) | Total rain (mm) | $R_{dmax}$ (mm) |
|---|---|---|---|---|---|---|
| Wadi Mina | Wadi Abtal | 21/10/1985 | 65.26 | 377.94 | 32.7 | 29.9 |
| | | 08/03/1986 | 364 | 3041.93 | 57.4 | 48.7 |
| | | 04/02/1996 | 184.5 | 3548.85 | 53.8 | 43.2 |
| | | 09/03/1996 | 322.8 | 5064.83 | 68.7 | 45.3 |
| | | 17/07/1996 | 260 | 2102.70 | 17.4 | 13.9 |
| | | 22/08/1997 | 632.5 | 3684.13 | 43.9 | 23.2 |
| | | 18/09/1997 | 249.4 | 2464.60 | 57 | 30.9 |
| Wadi Mina Haddad | Sidi Aek Djillali | 28/11/1982 | 52.52 | 2143.15 | 26.3 | 25.7 |
| | | 10–11/03/86 | 19.14 | 1684.15 | 34.1 | 14 |
| | | 03/10/1987 | 40.02 | 2017.90 | 31.9 | 11.4 |
| | | 01/01/1988 | 43.5 | 1656.36 | 38.9 | 35.3 |
| | | 17/10/1994 | 73.16 | 4932.10 | 27 | 27.6 |
| | | 23–24/08/97 | 113.25 | 3371.37 | 22.1 | 10.3 |
| Wadi Abd downstream | Ain Hamara | 01/10/1976 | 83.64 | 161.06 | 57.1 | 43.2 |
| | | 29/01/1978 | 26.4 | 98.92 | 32.9 | 26.9 |
| | | 6–7/3/86 | 117.3 | 633.77 | 46.4 | 37.4 |
| | | 28/09/1994 | 392.7 | 5767.43 | 65.1 | 49.6 |
| | | 25/08/1997 | 560.54 | 9735.17 | 31 | 30.5 |
| | | 29/03/1999 | 42.75 | 827.14 | 56.7 | 30.8 |
| | Takhmert | 06/03/1986 | 76.22 | 490.7 | 53.5 | 17 |
| | | 04/10/1986 | 62.4 | 373.2 | 40.1 | 10 |
| | | 11/07/1987 | 219 | 1674 | 18 | 17.5 |
| | | 08/06/1988 | 81 | 242.94 | 22.2 | 11.7 |
| | | 03/10/1988 | 213.6 | 997.88 | 44.3 | 26 |
| | | 08/05/1990 | 203.2 | 1092.75 | 48.8 | 35.1 |
| | | 28/09/2000 | 132.32 | 1595.27 | 24 | 22.6 |
| Wadi Mina upstream | Sidi Ali Ben Amar | 06/03/1986 | 90.2 | 375.32 | 69.4 | 12.5 |
| | | 19/08/1989 | 123 | 1900.9 | 41.6 | 13.4 |
| | | 03/08/1992 | 114.76 | 270.7 | 20.4 | 10.9 |
| | | 05/05/1993 | 58.06 | 473.24 | 35.8 | 24.4 |
| | | 23/09/1993 | 189.6 | 5162.97 | 35 | 34.2 |

These selected events, which created flow, were used to determine the parameters explaining the solid contribution, and propose a simple model, based on a reliable statistical approach. The approach relies on simple regression analysis with the explanation variable being the solids contribution for each event. The validation criterion considered is the correlation coefficient.

## RESULTS AND INTERPRETATIONS

### Event features

In general, in the rain–flood events, it is very important to note that during the years 1994, 1996 and 1997, sediment transport is high in all sub-basins. In 1993 Sidi Ali Ben Amar station has recorded the highest rainfall of the observation period, the largest peak flow and also the most runoff.

The analysis of the data table showed the following:

–   The months of autumn are characterized by the large amounts of rain and thus a relatively large hydro-sedimentary activity.
–   The months of January and February are characterized by less rainfall, but have very important sediment transport.
–   The spring season is characterized by heavy rain over the months of rainfall activity and heavy runoff inducing a high solids contribution.
–   In the river sub-basin downstream of the Abd Ain Hamara station, the flood of August 1997 generated a very high sediment transport; this is due to vegetation characterized by overgrazing and an extended discontinuity.

### Analysis of regressions

Data from strong contributions were correlated with those of the maximum flow rate ($Q_{max}$) of rain as well as those of maximal daily rain ($R_{dmax}$). The analysis is performed on 4 variables and 31 observations recorded on the five sub-basins studied.

The correlation matrix is given in Table 2.

**Table2** Correlation matrix.

|  | Parameters | As (T.km$^{-2}$) | Qmax (m$^3$.s$^{-1}$) | Total rain (mm) | R$_{dmax}$ (mm) |
|---|---|---|---|---|---|
| Wadi Abtal | As (T/km$^2$) | 1 | 0.77 | 0.56 | 0.28 |
|  | Qmax (m$^3$/s) | 0.77 | 1 | 0.16 | –0.17 |
|  | Total rain (mm) | 0.56 | 0.16 | 1 | 0.85 |
|  | R$_{dmax}$ (mm) | 0.28 | –0.17 | 0.85 | 1 |
| Sidi Aek Djillali | As (T/km$^2$) | 1 | 0.71 | –0.2 | 0.55 |
|  | Qmax (m$^3$/s) | 0.71 | 1 | –0.8 | –0.17 |
|  | Total rain (mm) | –0.2 | –0.8 | 1 | 0.41 |
|  | R$_{dmax}$ (mm) | 0.55 | –0.17 | 0.41 | 1 |
| Ain  Hamara | As (T/km$^2$) | 1 | 0.98 | –0.23 | 0.24 |
|  | Qmax (m$^3$/s) | 0.98 | 1 | –0.16 | 0.47 |
|  | Total rain (mm) | –0.23 | –0.16 | 1 | 0.8 |
|  | R$_{dmax}$ (mm) | 0.24 | 0.47 | 0.8 | 1 |
| Takhmert | As (T/km$^2$) | 1 | 0.75 | –0.4 | 0.51 |
|  | Qmax (m$^3$/s) | 0.75 | 1 | –0.08 | 0.72 |
|  | Total rain (mm) | –0.4 | –0.08 | 1 | 0.37 |
|  | Rdmax (mm) | 0.51 | 0.72 | 0.37 | 1 |
| Sidi Ali Ben Amar | As (T/km$^2$) | 1 | 0.9 | –0.14 | 0.78 |
|  | Qmax (m$^3$/s) | 0.9 | 1 | –0.24 | 0.5 |
|  | Total rain (mm) | –0.14 | –0.24 | 1 | –0.2 |
|  | R$_{dmax}$ (mm) | 0.78 | 0.5 | –0.2 | 1 |

The most significant contribution of the solid may vary over the entire sub-basins, is the maximum flow rate ($Q_{max}$). This parameter which characterizes the violence of the phenomenon explains the variability of sediment production.

Figure 2 shows the established relationship for the observations recorded at the wadi Abtal station, and only a power model with a correlation coefficient R = 0.84.

$$A_s = 8.31 Q_{max}^{1.02} \qquad (1)$$

With As: solid intake in Tonnes.km$^{-2}$ and $Q_{max}$ in m$^3$.s$^{-1}$

The maximum flow rate alone explains more than 80% of the variation of solids contribution.
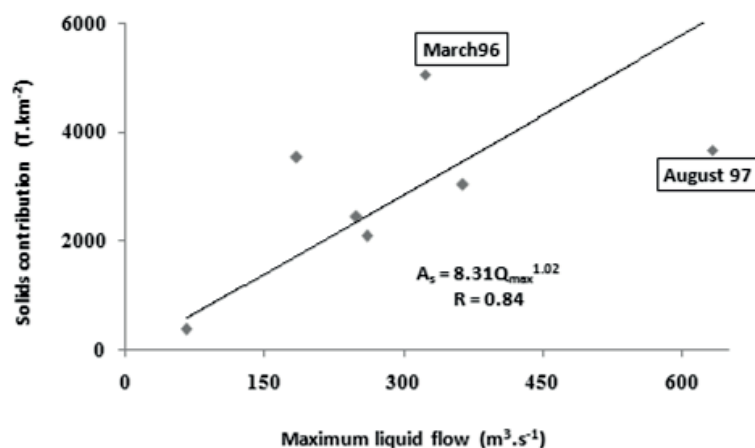


**Fig. 2** Relationship between solids contribution and maximum liquid flow in the wadi Abtal station

The data points follow the power relationship for the majority of observations (Fig. 2). This model is applicable to the sub basin of wadi Mina at the wadi Abtal station, the model shows the amount of sediment mobilized from different parts of the sub-basin, and it reaches the outlet during storm events where the quantity is dependent on the maximum flow and a stock of sediment available for transport.

It should be noted that in a study of sediment transport in four tributaries of the wadi Mina Meddi (1992) concluded that the scale of flooding, the flow peak discharge was the main factor in the sediment transport.

**CONCLUSION**

Quantification of sediment yield is often difficult because of the large number of parameters involved. We concluded that the explanatory and significant factor in the variation of sediment yield is the maximum flow for all events.

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