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

F. HALLOUZ[1], M. MEDDI[1] & G. MAHE[2]
1 LGEE, ENSH, Blida, Algeria
a-fouzette71@yahoo.fr
2 IRD, Mohamed V University, Rabat, Morocco

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).

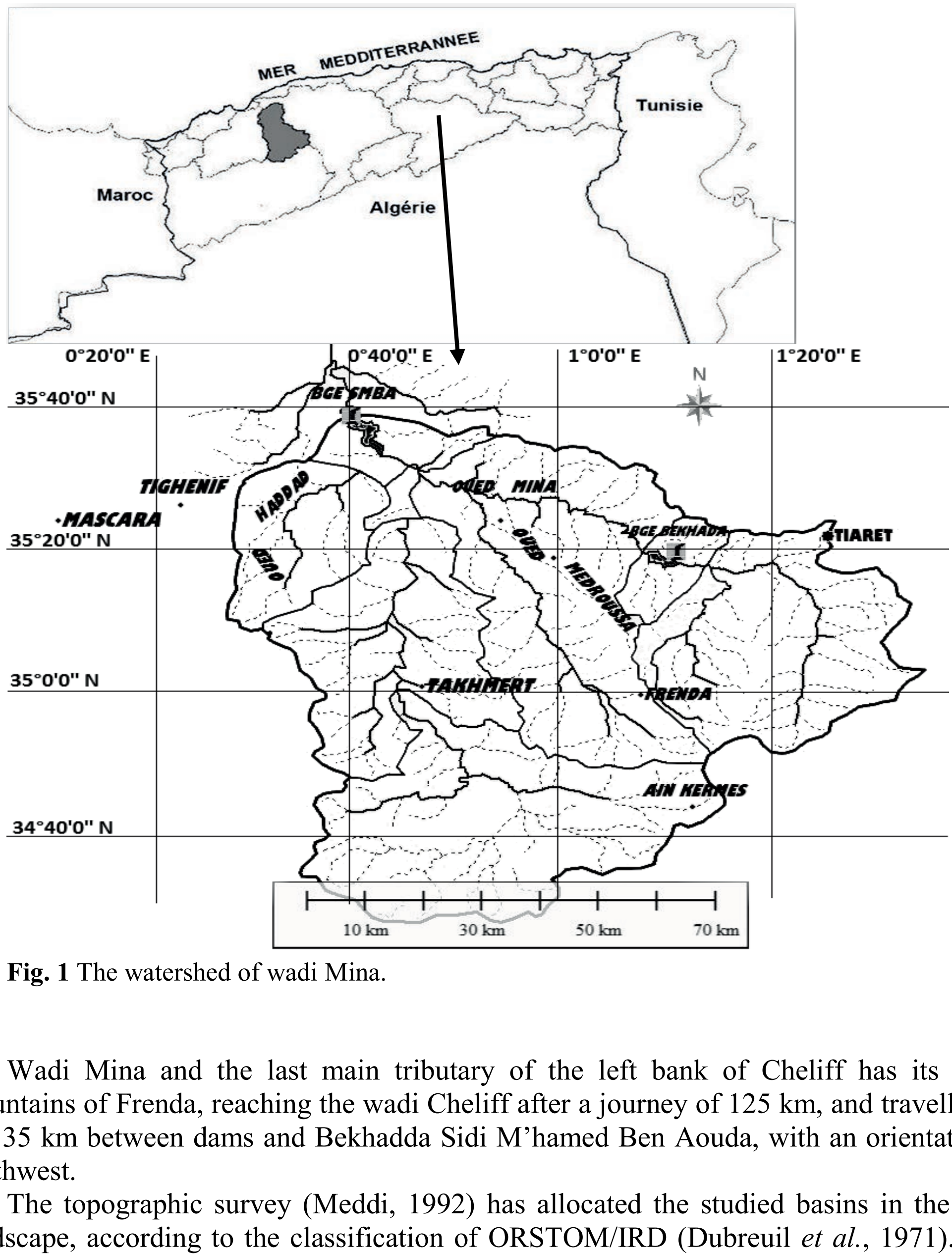

Fig. 1 The watershed of wadi Mina.

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.

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

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.

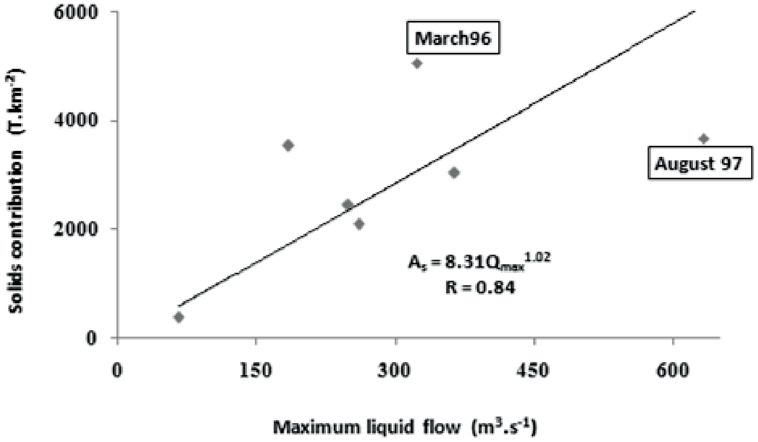

Fig. 2 Relationship between solids contribution and maximum liquid flow in the wadi Abtal station

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.

REFERENCES

Benkhaled, A. & Remini, B. (2003) Influence des paramètres hydrométéorologiques sur l'estimation des apports solides dans un bassin versant de zone semi aride. L'oued Ouahrane. Colloque International Oasis, Eau et Population. Biskra. 22–23 et 24 Septembre.

Bergaoui, M., Camus, H. & Nouvelot, J-F. (1998) Essai de modélisation du transport solide sur les micro bassins versants de Tebaga (Tunisie centrale). *Cahiers Sècheresse* 9(1), 51–57.

Bourouba, M. (1997) Les variations de la turbidité et leurs relations avec les précipitations et les débits des oueds semi arides de l'Algérie orientale. *Bulletin ORSTOM* 17, 345–360.

Dubreuil, P. & Guiscafre, J. (1971) La planification du réseau hydrométrique minimal. *Cahiers ORSTOM, Série Hydrologie* VIIII(2), 3–38.

Demmak, A. (1982) Contribution à l'étude de l'érosion et des transports solides en Algérie septentrionale. Thèse de docteur-ingénieur, Paris, 323 p.

El Mahi, A. (2002) Déficit pluviométrique des dernières décennies en Algérie du Nord et son impact sur les ressources en eau. *Mémoire de Magister*, Centre universitaire de Mascara, 120 p.

Hallouz, F., Meddi, M. & Mahe, G. (2013) Modification du régime hydroclimatique dans le bassin de l'oued Mina (Nord Ouest d'Algérie). *Revue des Sciences de l'Eau* 26(1), 33–38.

Hubert, P., Carbonnel, J. P. & Chaouche, A. (1989) Segmentation des séries hydrométéorologiques. Application à des séries de précipitations et de débits de l'Afrique de l'Ouest. *Journal of Hydrology* 110, 349–367.

Khanchoul, K. (2006) Quantification de l'érosion et des transports solides dans certains basins versants du nord-est algérien. Unpublished PhD Thesis, Department of Geology, University of Annaba, Algeria.

Meddi, M. (1992) Hydro-pluviométrie et transport solide dans le basin versant de l'oued Mina (Algérie). Thèse de doctorat, Univ. Louis Pasteur, Strasbourg, France, 285.

Meddi, M. & Hubert, P. (2003) Impact de la modification du régime pluviométrique sur les ressources en eau du Nord-ouest de l'Algérie *Hydrology of die Mediterranean and Semiarid Regions* (Proceedings of an international symposium held at Montpellier, April 2003). IAHS Publ. 278. IAHS Press, Wallingford, UK.

Meddi, M. & Humbert, J. (2000) Etude des potentialités de l'écoulement fluvial dans le Nord de l'Algérie en vue d'une réalimentation des aquifères. In: *Eaux sauvages, eaux domestiquées, Hommage à L. DAVY*, Publications de l'Université de Provence, 177–190.

Negev, M. (1967) A sediment model on a digital computer. Stanford Univ. Dept. Civ. Eng. Tech. Rep. 76.

Probst, J. L. & Amiotte Suchet, P. (1992) Fluvial suspended sediment transport and mechanical erosion in the Maghreb (North Africa). *Hydrological Sciences Journal* 37(6, 12), 621–637.