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Assessment of particulate matter fluxes in the Mazafran wadi (Algeria)

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Abstract
A model linking suspended solids to liquid flows was used in this study to estimate the particulate matter fluxes in the Mazafran wadi. We determined suspended solid fluxes and, for the first time in an Algerian wadi, organic and inorganic carbon fluxes. Based on the results of our study, the amount of suspended solids transported by the Mazafran wadi reaches 0.08 million tons per year, while the calculated flow of suspended solids is equal to 42t/km^2/year. This value is quite low compared to those previously recorded in other Algerian wadis. This phenomenon is probably linked to the low rainfall during the study period but also to the type of rocks upstream of the wadi that are mainly crystalline (eruptive and metamorphic). The particulate organic carbon flux is 415 t/year upstream, while the particulate inorganic carbon flux is 1629 t/year. In the downstream portion, the POC values are almost twice the upstream values (736 t/year). The PIC values are approximately the same upstream and downstream.

Keywords Suspended matter · Erosion balance · Particulate organic carbon · Mazafran wadi, Algeria

Introduction

Most of the flows from the continents to the marine environment are in particulate form. It is therefore important to quantify these suspended and dissolved solid (SS) flows. This provides insight into hydro-sedimentary phenomena and helps estimate erosion rates on continental surfaces (Meybeck 1985).

These flows of suspended solids can considerably modify the chemical composition of the wadi's waters and consequently contribute to their pollution by various organic and mineral compounds (Foster and Charlesworth 1996). Such results have been recorded in various studies carried out in Mediterranean rivers: Fiandino (2004), Launay (2019), Lefrancois (2007), and Bouguerra and Bouanani (2019).

The first works on the suspended sediment inputs in the Mazafran wadi were conducted by Pauc and Ait Kaci (1987) and Pauc (1989). The Mazafran wadi is a relatively small watercourse compared to large rivers and, therefore, presents unique small watershed characteristics. The Mazafran wadi watershed sometimes experience excessive sensitivity during severe climatic phenomena where most of the suspended solid transport occurs during flash floods, especially in autumn and even in spring.

The aim of the present study is the measurement of different flows of matter (suspended and dissolved) transported by the Mazafran wadi. The results are based on data recorded by the National Agency for Hydraulic Resources (ANRH) at a permanent measuring station located upstream of the wadi named "Fer à Cheval."

We used the model of Serrat et al. (1991) that relates the hydrological parameters (liquid flow and suspended solids) and subsequently determined the particulate matter fluxes. This study presents the first detailed analysis of particulate carbon fluxes in an Algerian wadi.

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Study area

The Mazafran wadi is one of Algiers' coastal wadis as defined by the ANRH. It is located at about 40 km west of Algiers, and its catchment area (including its tributaries: Oued Djer, Bou Roumi, and the Chiffa) covers 1900 km^2 (north latitude: 36° 15′/36° 45′ and east longitude: 2° 15′/3° 00′). It extends from SW to NE in the western part and curves northwards to reach the sea in Bou Ismail bay, along 24 km approximately (Fig. 1).

The Mazafran wadi watershed includes two geological entities:

The Blideen Atlas: it is composed of Jurassic and Cretaceous age formations formed by micaceous sandstones and metamorphosed limestones. The secondary age formations outcrop mainly in the northern parts and the western boundary of the Blideen Atlas (Ayme et al. 1953).

The Mitidja plain: it covers the central part of the basin, filled by detrital sediments of Pliocene and more recent ages. It contains quaternary alluvium and silty clays. It constitutes the deposition of the Mitidja basin and the Sahel of Algiers along the Bou Ismail bay coast. These deposits form the main source of solid load transported by the Mazafran wadi.

The Mazafran basin enjoys a typical two-season Mediterranean climate. During summer season, a mere stream of water flows in the wadi fed mainly by discharges of anthropic origin. However, during the winter season, the water inflow is quite high and sometimes very violent floods occur, particularly in early autumn.

The instantaneous liquid flow recorded in the Mazafran wadi varies from few m^3.s^{-1} to more than 750 m^3.s^{-1} during strong winter floods (Pauc 1989). The average annual liquid inflow is equal to 320.106 m^3, while the average annual liquid flow is 10.14 m^{3}s^{-1}(Messaoud Nacer et al. 2006)(Table 1).

Materials and methods

We collected 3 samples of surface water in the Mazafran wadi: the first one upstream at the Fer à Cheval station, the second one downstream near the river mouth, and the last one at the river exit in the sea.

The suspended solids were recovered from these samples by filtration on Whatman GF/F glass fiber filters (diameter 47 mm and porosity 0.7 µm) and then placed in a muffle furnace at 450 °C for 4 h to eliminate all organic particles. The suspended solids were then cooled in a dry atmosphere and weighed using a precision balance (1/100 of mg). The dried suspended solid filters are cooled and reweighed. The

Fig. 1 Geographical setting of the study area with the sampling station location

Table 1 Average annual flow of the Mazafran wadi and its tributaries

Wadis	The watershed area (km^2)	Average annual supplies and flows	
		$10^6 m^3$	$m^3.s^{-1}$
Djer	395	53.6	1.7
Bou Roumi	680	107.2	3.4
Chiffa	316	117	3.7
Mazafran	1893	320	10.14

concentration of suspended solids (SS) is calculated in mgl^{-1} for each sample by the weight of the filter, before and after filtration, referred to the filtered volume.

The liquid flow values are obtained from the Fer à Cheval station (ANRH). Total particulate carbon and particulate organic carbon were measured using the LECO CN-2000 analyzer equipped with an autosampler (Cauwet et al. 1990). This technique involves total combustion of the dry matter in a furnace heated to 1100°C under a stream of pure oxygen. Carbon values are expressed as a percentage per gram of sample. Inorganic carbon is calculated as the difference between total carbon and organic carbon.

Methods for calculating particulate matter fluxes (Serrat, 2001)

Several particulate matter flux calculation methods have been established by various authors (Balland 1983, 1984; Dupraz 1984; Walling and Webb 1981, Walling and Webb 1985). In this study, we used the deterministic or extrapolated method developed by Serrat et al. (2001) and applied by Terfous et al. (2001) and Tidjani et al. (2006). This method involves determining the relationships that may exist between concentrations and flows as follows:

$$flux = \sum C \times Q \quad Or \; C = f(Q) \qquad (1)$$

C is the concentration (mgl^{-1}), and Q is the liquid flow rate (m^3s^{-1}).

The flow transported during a given time interval is therefore expressed as a function of the flow rate only.

Other relations are obtained by taking into account the logarithmic values of the two parameters, especially in linear or polynomial relations as follows:

$$\log(C) = a \times \log(Q) + b \qquad (2)$$

$$\log(C) = a \times \log(Q)^2 + b \times \log(Q) + c \qquad (3)$$

According to Walling and Webb (1985), this method (2) is most applicable to components with concentration variability as important as flow variability and a good correlation between the two parameters. It is also suitable for a large number of flow-concentration data pairs covering the entire flow range. This equation was applied by Serrat et al. (2001) in the Agly river (South of France), and it is the one used in the Mazafran wadi.

Once the relations between concentrations and flows are established, the daily flows called Q_d yield theoretical daily concentrations called $C_{th\text{-}d}$ using Eqs. (2) and (3). The annual flux is then calculated as the sum of all products between the daily flow and the theoretical daily concentration calculated for the entire studied year.

Therefore, the calculation of the annual flow will be as follows:

$$Q_d \rightarrow C_i = f(Q_i) \rightarrow C_{th-d} \rightarrow Q_y = \sum C_{th-d} \times Q_d \qquad (4)$$

Results and discussion

Suspended matter flow

Based on the equations mentioned above, the Mazafran wadi transported during the studied period 0.08 million tons per year of suspended matter. It is during the flood periods that most of the detrital and suspended material transits through the wadi and reaches the sea forming a large and very dense turbid plume.

This calculated value is lower than those estimated by Leclaire (1972) or that of Benslama and Pauc (1988) in the Mazafran wadi which are respectively 3 million tons per year and 0.13 million tons per year. On the other hand, it is close to that recorded in the Isser wadi by Benslama and Pauc (1988) at 0.1 tons per year (Table 2). This could be due, on the one hand, to the amount of precipitation (434 mm) and, on the other hand, to the effect of the Bou Roumi dam, which captures a large volume of suspended solids. We note that the variations of low or high solid input amounts depend closely on the hydrological and rainfall pattern that can vary from one year to another (Lefrancois 2007). The liquid inputs estimated by ANRH Soumaa for the 2003–2004 periods and for the

Table 2 Comparison of solid inputs from the five major Algerian wadis (expressed in millions of tons per year)

Wadis	Leclaire (1972) (total inputs)	Benslama and Pauc (1988) (SS)	Foudil Bouras (2012) (SS)
Cheliff	–	0.6	
Mazafran	3	0.13	**0.08**
Isser	4.7	0.1	
Sebaou	1.2	0.27	
Soummam	4	0.3	

2004–2005 years are 56.5 Hm^3 and 79.5 Hm^3, respectively, while the liquid flow during 2005–2006 is estimated at 77.74 Hm^3.

The erosion rate in the Mazafran watershed is illustrated by the SS flux value which is equal to 42t/km^2/year based on the results of the study (Table 3). This value seems low compared to that established by Bourouba in 1998 or even those of other Algerian wadis. This could reflect a decrease in rainfall during these earlier periods compared to recent periods. This phenomenon could also be related to the type of geological formations composed of crystalline rocks (eruptive and metamorphic) upstream of the tributaries of the Mazafran wadi (Oued Djer, Bou Roumi, and Chiffa) (Moulfi et al. 2012). The flow is however almost equal to that found by Garcia Esteve (2005) in the river Têt (43t/km^2/year) (southwestern France). The author connects this phenomenon to the rocks' nature in the watershed upstream of the river, which are mostly crystalline, relatively resistant to erosion. Moreover, the climate in the Têt watershed is not favorable to strong erosion, particularly in its upper part, which is subject to low temperatures due to its altitude (Fiandino 2004; Garcia Esteve 2005).

Particulate carbon flux

Total particulate carbon (TPC) is the sum of particulate organic carbon (POC) and particulate inorganic carbon (PIC). The distribution of POC and PIC in Mazafran wadi can provide information on soil erosion in the watershed, especially the inorganic forms. The POC and PIC flows were determined using the same flow-concentration relation used to calculate the TSS flows. The downstream flow of particulate organic carbon is almost twice that of the upstream (736 t/year) (Table 4). This is attributed to the higher vegetation cover in lower areas of the wadi watershed responsible for a subsequent release of particulate organic carbon. However, the upstream inorganic carbon flux is slightly higher than that of the estuary (downstream), indicating a more pronounced mechanical erosion of carbonate rocks in the upstream part of the wadi watershed.

Table 3 Suspended solid flows of some Algerian wadis and the Têt river (South West France): (1) Bourouba: 1997, Bourouba 1998; (2) Foudil Bouras: 2006; (3) Terfous et al. 2001; and (4) Garcia Esteve 2005

Wadis and rivers	Annual flow of SS in t/km^2/year
Isser (1)	2300
Macta (1)	150
Mazafran (1)	1160
Mazafran (2)	**42**
Medjerda (1)	680
Soummam (1)	490
Mouilah (3)	126
Têt (4)	43

Table 4 Carbon flux values (in tons/year) in the Mazafran wadi

Carbon flow in tons/year	Upstream	Downstream
Total particulate carbon (TPC)	2044	2298
Particulate organic carbon (POC)	415	736
Particulate inorganic carbon (PIC)	1629	1562

The relative percentages of the two carbon types at the upstream and downstream stations and at the wadi's mouth (Fig. 2) indicate that the POC varies little between the downstream (65%) and upstream (61%), while its value is much higher (87%) at the wadi mouth. Similarly, the PIC varies little between upstream and downstream (39% for 35%) but unlike the POC, it is very low at the wadi's mouth (13%). Therefore, it is in the upstream that particulate inorganic carbon contributes most to the total particulate carbon fluxes. This is consistent with the concept of more intense mechanical erosion in the watershed and the relative abundance of carbonate rocks in this part of the wadi. These differences in carbon percentages indicate that the lower parts of the wadi (downstream and outlet) are areas of mainly organic carbon accumulation. These percentages are relative average monthly values between the two carbon forms. The high percentages of POC recorded at the wadi's mouth compared to PIC suggest organic matter richness in this area. Indeed, the lower parts of the Mazafran wadi watershed are mainly dominated by a Mediterranean climate characterized by severe flood events often in late autumn and early winter and even in spring. These events carry significant amounts of organic matter. The same phenomena have also been observed in the Têt river (southwestern France) by Ludwig et al. (2004), in the Sebou Wadi (Morocco) by Fekhaoui and Pattee (1993) and the Medjerda Wadi (Tunisia) by Arnould et al. (2003).

Comparison to other Algerian wadis and rivers in southern France

The coastal rivers that flow into the northwestern Mediterranean Sea present some similarities in SS and POC inputs (Table 5). However, due to the difference in climate between the northern part of the Mediterranean (southern France), more humid than the southern part, the SS concentrations of Agly and Têt rivers are slightly higher than those of the Tafna, Mazafran, Soummam, and Cheliff rivers, with the exception of the Têt river that features a SS value of 12 mgl^{-1} during low water periods and 1 gl^{-1} during flood period (2001).

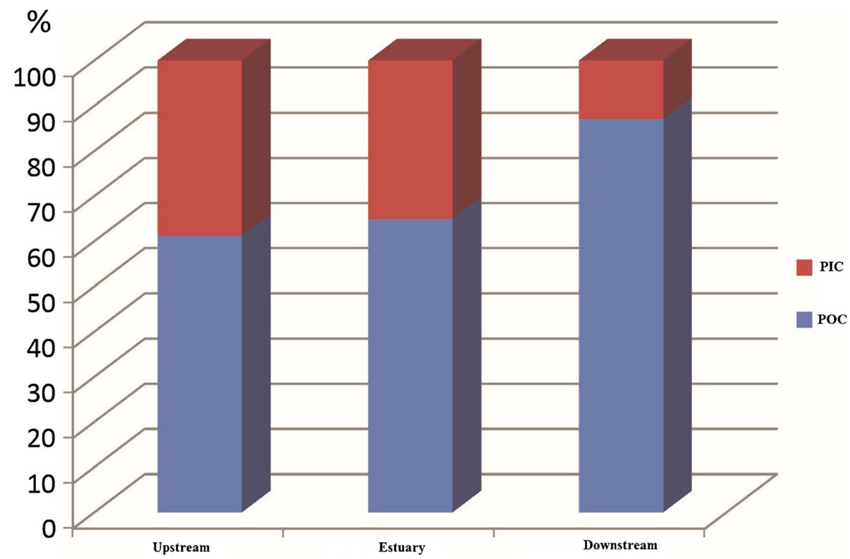

Fig. 2 Relative contribution of both carbon forms (COP particulate organic carbon, CIP particulate inorganic carbon) in Mazafran wadi surface waters and its estuary in the sea

On the other hand, the POC in Algerian wadis is significantly higher than those of French rivers, especially during the dry season. For the Mazafran wadi, according to previous works (1987), the concentrations of SS are largely higher than those of 2005–2006 both during low water or high-water periods. The POC, on the other hand, remains almost identical. The Mazafran estuary enclosure, for example, due to the absence of water supply and its pseudo-lagoon state, leads to the environment's eutrophication.

It is also important to emphasize that SS and POC concentrations vary from one year to another. There can be much rainier years in the southern Mediterranean basin, which sometimes results in higher SS concentrations, especially during autumn floods, which scour and mobilize detrital material in the absence of dense vegetation cover. In the northern part of the Western Mediterranean, a study conducted by Lespinas et al. (2010) shows that over the last 40 years, a decrease in rainfall has led to a 20% decrease in water resources.

Conclusion

Suspended solid fluxes are strongly related to the liquid flow variability. The empirical model developed by Serrat et al. (2001) has been used to calculate the TSS fluxes in the Mazafran wadi watershed.

The TSS fluxes depend on the flow rate period, which is the only phase of consequent contributions due to the Mazafran wadi hydrological pattern practically nonexistent during the low-water period. In this case, the modeling of inputs can be based on the relationships TSS/flow and POC/flow knowing that the concentrations of matter are significantly varying from 1 to 200 mg/l of TSS. Also, suspended solid fluxes decrease due to reduced rainfall. The fluxes of particulate organic carbon are higher (almost double) in the estuarine part of the Mazafran wadi. This phenomenon is linked to the denser vegetation in the lower part of the wadi and to water stagnation, which favors the development of organic matter. The water treatment plant of Kolea located upstream of the

Table 5 Suspended solid load and POC content of different wadis and rivers in the Mediterranean: (1) Benslama and Pauc, (2) Foudil Bouras, (3) Dahmani et al., (4) Garcia Esteve, (5) Serrat, and (6) Cotrida Cunha

Wadis and rivers	Low water period		High water period		Maximal high water period	
	Inputs	POC (%)	Inputs	POC (%)	Inputs	POC (%)
Cheliff (1988) (1)	7 à 10 mgl^{-1}	7 à 10	15 gl^{-1}	0.5	27 gl^{-1}	0.6
Soummam (1988) (1)	17 mgl^{-1}	3	1.8 gl^{-1}	0.7	12.7 gl^{-1}	0.6
Mazafran (1988) (1)	10 mgl^{-1}	29	3 à 6 mgl^{-1}	0.45	24 gl^{-1}	0.5
Mazafran (2005–2006) (2)	7.75 mgl^{-1}	10.87	1.58 gl^{-1}	0.66	1.71gl^{-1}	0.59
Tafna (2002) (3)	20 mgl^{-1}	7	33.2 gl^{-1}	0.5	12 gl^{-1}	0.6
Têt (France) (2005) (4)	11.57 mgl^{-1}	7.13	1 gl^{-1}	1.56	2.6 gl^{-1}	1.64
Agly (France) (1999) (5)	50 mgl^{-1}	–	4 gl^{-1}	–	–	–
Tech (France) (2000) (6)	28 mgl^{-1}	4	0.18 gl^{-1}	0.4	–	–

wadi could also be a potential source of POC that reaches the estuary. This contribution would occur as direct inputs or through aquatic primary production stimulated by excessive nutrient discharges.

Particulate inorganic carbon fluxes from upstream are slightly higher than those from downstream (estuary). This can be explained by the more pronounced mechanical erosion that occurs and provides more carbonaceous material in this part of the Mazafran wadi watershed.

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Code availability Not applicable.

Declarations

Conflict of interest The authors declare no competing interests.

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