Influence of Mafragh and Seybouse inputs (sediment and salts) on the productivity of Annaba Bay

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Abstract. This study assesses the transfer of water, sediment and salts from the Mafragh and Seybouse river outlets into Annaba Bay. The Bay receives freshwater inputs from the two rivers' estuaries, which are atypical estuaries stretching several kilometers inland. The Mafragh estuary (3200 km^2) is a unique near-pristine, wild and virgin area in the region. The upper catchment areas include several dams that retain a large fraction of the surface water yield. The Mafragh catchment area is weakly populated, and the human activities around the lower estuary are limited to small food processing factories and some intensive farming. In contrast, because of high population density (200 inhab km^{-2}), intensive farm land and industrial areas, the Seybouse (6500 km^2) is one of the most polluted rivers in Algeria. The Total Suspended Solids (TSS) and Total Disolved Solids (TDS) were measured twice a month during the wet season, from January to May 2014, at the outlets of both rivers. During the study period, sediments and salts transported by the two rivers had tended to decrease. This problem is directly linked to the decrease in river discharge. The recent addition of dams and changes in rainfall patterns has significantly reduced the sediment load and water discharges. These biogeochemical modifications are responsible for many negative impacts: increased proliferation of harmful phytoplankton species, eutrophication, reduction of fisheries stocks, disappearance and extinction of fish species. The two rivers outlets delivered 1x10^9 m^3 of freshwater into Annaba Bay and about 500 t km^2 yr^{-1} of total solids (TS). At the Mafragh outlet TSS is about 24 t km^{-2} yr^{-1}, which is about 4 times higher than the Seybouse river outlet. Both rivers transported 500 t km^{-2} yr^{-1} of salts into the bay, out of which the Mafragh estuary was responsible for the transport of 4/5 of those salts.

Key Words: Mafragh River, Seybouse River, TSS, TDS, water flow.

Introduction. Because of their unique location at the interface between terrestrial freshwater and the sea (Toublanc et al 2016), estuaries are dynamic transition zones (Bazin et al 2014) acting as important geochemical and biological filters and transformers of materials passing from catchments to the sea (Church 1986; Teuchies et al 2013). Estuaries are among the most productive and precious ecosystems in the world with high ecological value (migration routes and reproduction zones, biodiversity, habitats and wetlands of conservation importance, nutrient regulation, trapper, filter and recycler of suspended particulate matter, detoxification of polluted waters) and economic value (breeding areas for terrestrial populations, preferential sites for commercial fishes, tourism and recreation, transportation, supply of food and energy resources) (Edgar et al 2000; Beaumont et al 2007).

Nevertheless, estuaries are facing severe anthropogenic pressures, being under intense demographic, economic and ecological pressures (Turner et al 2000; Hood 2004). They are particularly sensitive to human various alterations including nutrient enrichment, organic carbon loading, chemical contamination, fisheries overexploitation, introduced species, freshwater diversions, shoreline development, and habitat loss and alteration (Kennish 2002).

Total Solids (TS), are the total of all solids in a water sample, they include the total suspended solids (TSS) and total dissolved solids (TDS). The TDS is the fraction of total material that passes through a membrane filter with a nominal pore size of (0.45

μm). In contrast, the TSS or suspend particulate matter (SPM) is solids retained by the filter of (0.45 μm). Dissolved solids (TDS) consist of sodium (Na^+), calcium (Ca^{2+}), potassium (K^+), chlorides (Cl^-), nitrate (NO_3^-), phosphorus (PO_4^{3-}), silicates (SiO_4^{2-}), and other ions. Suspended solids include silt and clay particles, plankton, algae, fine organic debris, and other particulate matter: biogenic silica (BSi), particulate organic phosphorus (POP), particulate organic nitrogen (PON), particulate organic carbon (POC) and chlorophyll (chl *a*). Total solids in coastal water result from erosion from urban runoff and agricultural land, industrial wastes, bank erosion, bottom feeders (such as carp), algae growth or wastewater discharges and atmospheric transport (Taamalah et al 2016). TSS regulate transparency of water, depth of the photic zone, and regulate primary and secondary production. They also regulate the production of bacterioplankton and the mineralization and consumption of the oxygen content (Håkanson 2005). Soil erosion constitutes a serious danger for Mediterranean soils (UNEP/MAP/MED POL 2003), when the action of water was intensive, the solid charge becomes important (5-130 g L^{-1}) and erosion becomes significant (Roose 1991). Water erosion causes soil degradation, which is closely related to nutrient losses either in the soluble form or adsorbed to soil particles (Bertol et al 2007). The loss of nutrients by water erosion in catchments contributes to soil degradation (Bertol 1994; Schick et al 2000). Nutrients (N, P, K Ca, and Mg) are the main nutrients that restore soil fertility and are subject to losses by water erosion (Schick et al 2000). In contrary, the superabundant concentrations of nutrients in water resulting from water erosion are leading to salinisation, acidification, eutrophication or pollution by toxic substances.

Because global climatic change, many researchers have tried to assess the changes in runoff and sediment transport by rivers. In last 50 years existing research results (Ludwig et al 2009) show that sediment transport by rivers has tended to decrease, because of increases in dam construction, demographic growth, intensification of agricultural practices. A reduction of the river freshwater discharge implies a reduction of total solids fluxes. These biogeochemical modifications are responsible for many negative impacts: loss of habitat and biodiversity, increased proliferation of harmful phytoplankton species, eutrophication, and hypoxia (Howarth et al 1996; Ragueneau et al 2006; Billen et Garnier 2007; Eero et al 2016). In the same context, Turner et al (2003) reported that the decrease in the dissolved solids cause severe changes in the coastal food web including fisheries stokes. In the Mediterranean, it is admitted that the dissolved silica (Si) can not only reduce productivity, but also induce changes in phytoplankton communities with dominance of non-siliceous harmful species. Similarly, Turner et al (1998, 2003), and Cloern (2001) demonstrate that the decrease in the abundance of diatoms and copepods in coastal areas is linked to the reduction of Si rivers inputs. Development of plankton is linked to dissolved solids, when dams are building on upstream rivers they directly block the flow of total solids originating from the catchment basin and they negatively affect fisheries production and diversity in estuaries and marine environments (Marmulla 2001).

The cascading effects of changes in dissolved solids and primary productivity on fish biomasses are often not apparent in empirical data or are difficult to demonstrate (Micheli 1999). However, several studies comparing nutrient levels or primary production with fish production or fisheries yields suggest that such relation may exist (e.g. Ware & Thomson 2005; Chassot et al 2007, 2010).

Dams placed in the midst of rivers have a negative impact on natural fish populations and may contribute, along with other factors, to reduction of fisheries stocks, disappearance and extinction of the species (Marmulla 2001). The best example of this extinction is that of the salmon (*Salmo salar*) in the Rhine River, a stock that supported a thriving fishery in the first half of the twentieth century. Dams menace many aquatic species in Europe and North America, as well as on other continents where much less is known about the biology, behavior, catches and population dynamics of the fish species concerned (Marmulla 2001).

According to Phillips & Slattery (2006) rivers are the major source of marine sediment and marine basin are the ultimate sink for most river borne sediment. Rivers annually deliver about 35 000 km^3 of freshwater and 20-22 x 10^9 tonnes of solid and dissolved sediment to the global ocean (Milliman 2001). Walling & Fang (2003) and Walling (2006) showed that rivers with an increasing annual sediment load, a decreasing annual sediment load and a stable annual sediment load accounted for 2.8%, 47.9% and 49.3% of the total solids, respectively. Many rivers in the world have sediment trapping problems, in China Gorges Dam traps 34 million tons of sediment (Hu et al 2009). In Colorado and Nile catchments, sediments is trapped completely due to large size of the reservoirs and flow diversion (Vörösmarty et al 2003; Walling & Fang 2003). Continental freshwater declining of sediment load coincides with declining trends of TDS (Zhang et al 2007).

The main objective of this work is to assess transfer of water, sediments and salts from Mafragh and Seybouse rivers into Annaba Bay.

Material and Method

Description of the study sites. Annaba Bay receives continental inputs from the Mafragh and Seybouse rivers estuaries (10,000 km^2) and from direct industrial and household wastes (Ounissi et al 2014) of about 2 million people (Figure 1). Seybouse and Mafragh lower parts function as atypical estuaries with hydrologic cycle comprising river phase, estuarine core phase and lagoon phase (Khélifi-Touhami et al 2006). The salt wedge reaches up to 8 and 15 km in Seybouse and Mafragh Rivers, respectively (Khélifi-Touhami et al 2006). Mafragh catchment (3200 km^2) is weakly populated (90 inhab km^{-2}), the intensive agricultural practices is being invading the most middle and lower catchment. The catchment has been recently (UNEP/MAP/MED POL 2013) described as the most source of agricultural nitrogen and phosphorus emissions, mainly originating from irrigated area (5%, UNEP/MAP/MED POL 2013) cow rearing and transportation (mainly to and from the contiguous Tunisian cities). The catchment is largely forested in the upper part, but includes large marshland and floodplain (130 km^2) in the lower part. During the dry season of the year 2014 and under low river flow, the Mafragh estuary was closed from the sea connection for about 7 months, as can be seen in the (Figure 2).

Even if Seybouse River (Figure 1) is among the largest and developed river systems in Algeria (165 km length, 6500 km^2), with a population of about 1.5 million inhabitants, intensive agriculture is extending (3-4%, UNEP/MAP/MED POL 2013) over the middle and the lower Seybouse catchment, which is maintained by large reservoir retention (400 million m^3). This amount is approximately equivalent to half the total annual runoff.

Analytical method. Surface water samplings were taken monthly from January 2014 to May 2014 at the outlets of Mafragh and Seybouse rivers estuaries, and the hydrological variables (flow and TDS) were simultaneously measured. To assess the estuary's freshwater discharge (m^3 s^{-1}), flow velocity at the estuary's outlet was determined with the current meter CM-2 (Toho Dentan Co., Ltd., Tokyo), and calculated by multiplying the water velocity by the total surface area (m^2) of the estuary wet section. The TDS were measured (mg L^{-1}) in situ with a multi-parameter probe WTW Cond 1970i.

In the laboratory the SPM was measured following the method described in Aminot & Chaussepied (1983). Two water subsamples of 250-500 mL (depending on the water turbidity) were filtered on pre-combusted (450°C for 1 h) and pre-weighed Whatman GF/C glass filters. The filters were dried at 110°C for 1 hour by an oven dryer and then weighed with a Mettle microbalance (precision of 0.10 mg). For each filter, the SPM was obtained by subtracting the final filter weight (filter + TSS) from the initial weight of the filter, and the results were expressed in mg L^{-1}. The instantaneous flux of materials was calculated by multiplying their levels by the estuary flow. The annual loads for materials were estimated using the method of average instantaneous loads (Preston et al 1989).

Figure 1. Map of the Seybouse river (SR) and Mafragh river (MR) outlets.

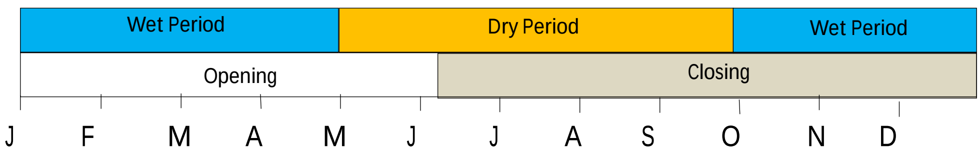

Figure 2. Diagram showing the coincidence of wet and dry periods to the closing and opening periods over the year 2014 in Mafragh river oulet.

Statistical analysis. The data were statistically analyzed using SPSS statistics software version 17.0. The relationships between all parameters measured from samples at each site (SR and MR) were also assessed via the correlation coefficient *r*. For the all samples, the significance threshold values at p = 0.001, 0.01 and 0.05 are $|r| > 0.79$, $|r| > 0.60$ and $|r| > 0.48$, respectively (Scherrer 1984).

Results

Fresh water TSS and TDS level at Mafragh and Seybouse rivers outlets. Precipitation data from Annaba meteorological station over the year 2014 showed monthly precipitation varied between 0.1-170 mm (Figure 3). The total annual rainfall in the year 2014 is about 596 mm, maximum precipitation levels were occured during March and December and very low occured during the dry season.

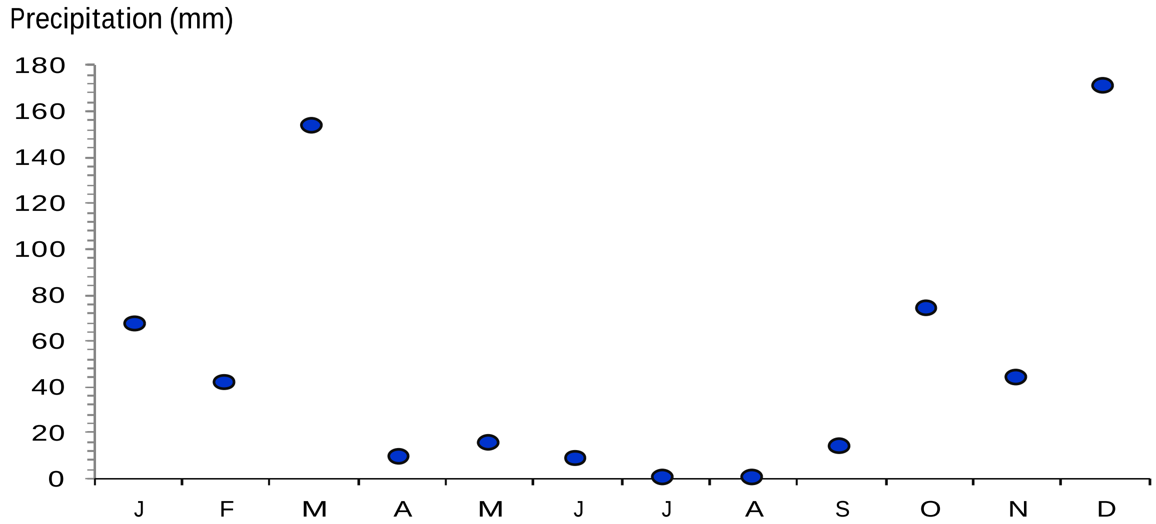

Figure 3. Mounthly precipitation at Annaba region during the year 2014.

The freshwater discharges varied between 0-63 m^3 s^{-1} at the SR and varied between 0-97 m^3 s^{-1} (Figure 4). The mean annual discharge is 13 and 18 m^3 s^{-1} at SR and MR respectively. During the dry period (May-September) and under low river discharge, Mafragh estuary is closed from the sea connection for 7 months (Figure 4). The two rivers delivered together 1 x 10^9 m^3 of freshwater into Annaba Bay. As showing in Figure 4, the high river flow coincide with high precipitation levels (Figure 3).

The TSS mean concentration was about 51-75 mg L^{-1} in Seybouse and Mafragh rivers outlets respectively. The high levels of TSS were occurred during January and February (Figure 4) which coincided with high river discharge. The minimum levels of TSS were occurred during the dry period (Figure 4).

There were significant correlations between the SPM levels and the water flows (r = 0.78, p < 0.001) at MR outlets and r = 0.57, p < 0.05 at SR outlets.

Salts in Seybouse River outlet varied between 477-4728 mg L^{-1} (Figure 4) with average value of 2518 mg L^{-1}. In Mafragh river salts varied between 641-22896 mg L^{-1} with a mean value of 14345 mg L^{-1} (Figure 4). There were negative correlations between the TSS levels and water in Seybouse river (r = -0.60, p < 0.01).

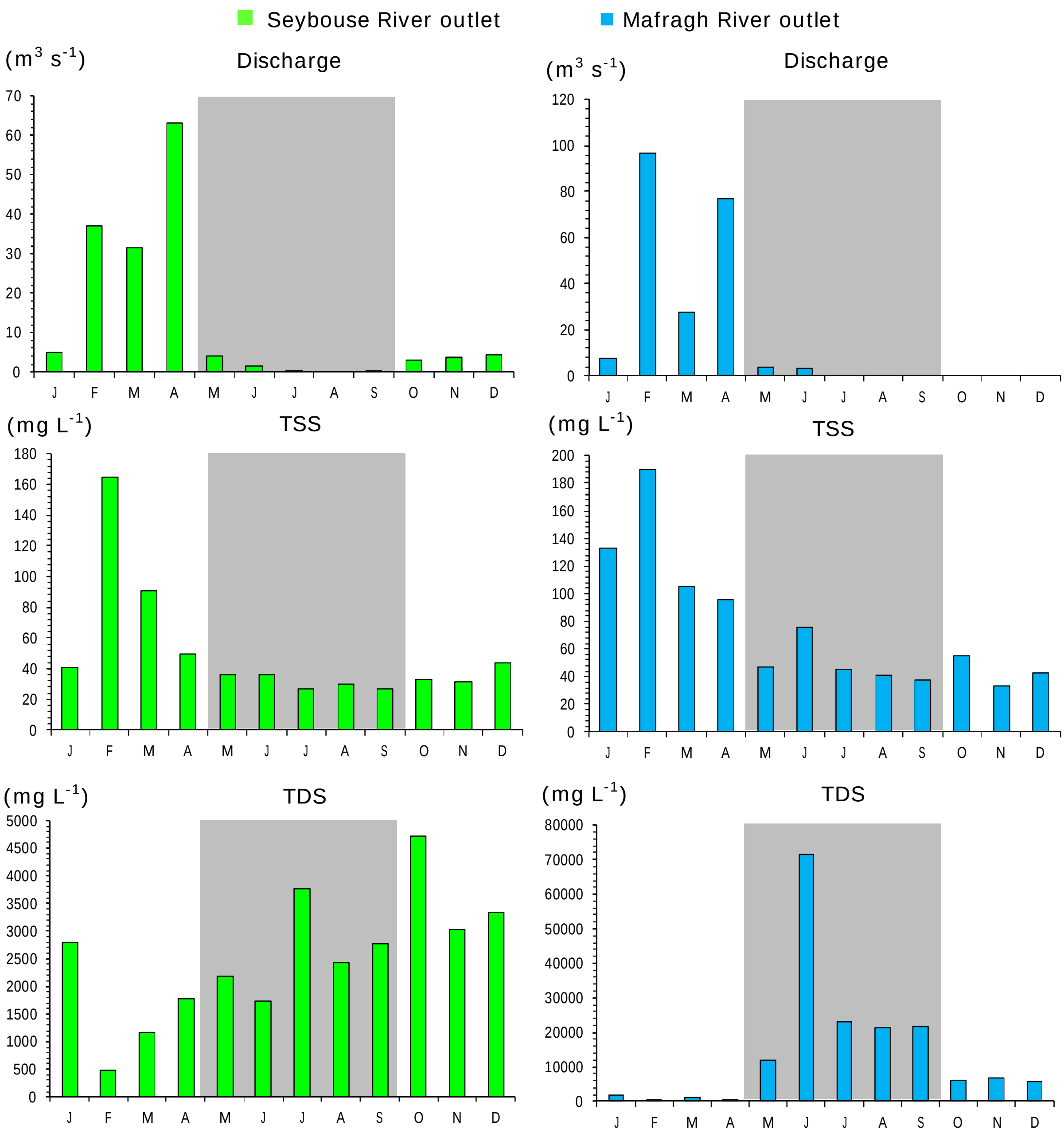

Figure 4. Discharge (m^3 s^{-1}), TSS and TDS levels (mg L^{-1}) at Mafragh and Seybouse rivers outlets during the year 2014. The grey area represents the dry season.

Specific flux of TSS, TDS and delivered from Mafragh and Seybouse rivers outlets into Annaba Bay. Mafragh and Seybouse rivers delivered together $1x10^9$ m^3 of freshwater into Annaba Bay. Which 60% of freshwater was delivered by MR during the wet season (Table 1). The two rivers transported about 500 t km^{-2} yr^{-1} of TS, which MR transported 400 t km^{-2} yr^{-1} of TS.

The TSS introduced to the Bay Mafragh and Seybouse rivers is a 30 t km^{-2} yr^{-1}, only MR is responsible to 80% of TSS delivered to the sea (Table 1). Mafragh and Seybouse rivers outlet delivered together 470 t km^2 yr^{-1} of TDS, which Mafragh River dominate with 79% (Table 1).

Table 1

Specific flux (t km^{-2} yr^{-1}) of TSS, TDS and TSS delivered from Mafragh and Seybouse Rivers to Annaba Bay

River	*Catchment (km^2)*	*Discharge (m^3 s^{-1})*	*TSS (t km^{-2} yr^{-1})*	*TDS (t km^{-2} yr^{-1})*	*TS (t km^{-2} yr^{-1})*
Seybouse (SR)	6500	0.40	5.00	95	100
Mafragh (MR)	3200	0.60	24.8	373	400
MR + SR		1	30	470	500

Discussion. This study aims to assess transfer of water, sediments and salt fluxes from Mafragh and Seybouse rivers into Annaba Bay. During the study period (January-December 2014) Annaba Bay receive 1 x 10^9 m^3 of freshwater. Compared to volume water discharge delivered by some Mediterranean rivers (UNEP/MAP/MED POL 2013; Ludwig et al 2009) this volume is very low. Due to biogeochemical factors and climatic conditions, Algerian surface waters are more salty than those of northern Mediterranean countries (Aubert 1976). Because of low river discharge during the study period TSS was significantly reduced 5-24.8 t km^{-2} yr^{-1} in Seybouse and Mafragh rivers respectively.

Not only the low river flow of both rivers but dams trapped a large amount of TSS (Ounissi & Bouchareb 2013; Taamalah et al 2016; Bougdah & Amira 2017; Sadaoui et al 2017; Youcef & Amira 2017). In Mafragh and Seybouse catchments sediment loss reached a value of 30 t km^{-2} yr^{-1}. In Mediterranean and Algerian coastal casements sediment yields are very variable (Table 2). Meybeck & Moatar (2012) has been reported mean sediment yield of 61 t Km^{-2} yr^{-1} for 86 rivers catchments in the world, which were daily surveyed for a long term. The Mediterranean river catchments (including Algerian coastal catchments) can be ranked among the most eroded areas, considering this world river catchment value (Bougdah & Amira 2017). UNEP/MAP/MED POL (2003) reported that the sediment yield for Mediterranean Rivers is about 580 t km^{-2} yr^{-1}, because of dam construction the actual sediment flux is reduced to about 251 t km^{-2} yr^{-1}. Because of very low discharge during the study period sediment loading (TSS) is still very low compared to the all Mediterranean rivers (Table 2). In Mediterranean and other coastal catchments (Table 3), the TDS yields are highly variable (Milliman 2001; Bouchareb 2013; Taamalah et al 2016; Bougdah & Amira 2017), ranging between 3 to 415 t km^{-2} yr^{-1} depending on the river as shown in Table 2. The TSD specific flux in the Mafragh river was 4 times higher than Seybouse river. But these levels are still comparable to those of Mediterranean and Algerian rivers (Table 3).

As shown in Figure 5, reduction of river freshwater discharge implies a reduction of total solids (TS). Decreases on total solids (TSS + TDS) can affect marine food chain and cause many negatives impacts: proliferation of harmful phytoplankton species (Dinoflagellates), eutrophication, hypoxia and declining in fish stokes (Billen & Garnier 2007). Plankton growth is linked to dissolved solids availability in water, when dams are building on upstream rivers they directly reduce the flow of total solids originating from the catchment basin and they negatively affect phytoplankton production (Figure 5). In this crucial situation stimulate the proliferation of harmful phytoplankton and it directly affects the zooplankton development and fisheries production and diversity in estuaries and marine environments (Figure 5).

Table 2

Sediment loading TSS (t km^{-2} yr^{-1}) for Mediterranean rivers

River/dam opening	*t km^{-2} yr^{-1}*	*References*
Maghreb catchments	397	Probst et al (1992)
North African catchments	800	Fox et al (1997)
Asi, Turkey	826	Milliman & Syvitski (1992)
Evros, Greece	160	Milliman & Syvitski (1992)
Ebre, Spain	214	Milliman & Syvitski (1992)
Gediz, Turkey	524	Milliman & Syvitski (1992)
Têt stream, France	40	Serrat et al (2001)
Rhône River, France	324	Pont et al (2002)
Jucar, Sapin	36	Milliman & Syvitski (1992)
Ishem, Albania	2985	Poulos & Collins (2002)
Mazafran, Algeria	1579	Milliman & Syvitski (1992)
Miliane	450	Milliman & Syvitski (1992)
Var, France	3571	Milliman & Syvitski (1992)
Têt stream, France	40	Serrat et al (2001)
Seman, Albania	4000	Poulos & Collins (2002)
Rhône River, France	324	Pont et al (2002)
Crati, Italy	901	Ludwig et al (2003)
Tet, France	40	Ludwig et al (2003)
Herault, France	72	Ludwig et al (2003)
Axios, Greece	1220	Ludwig et al (2003)
Mediterranean rivers	251	UNEP/MAP/MED POL (2003)
Italian rivers	780	UNEP/MAP/MED POL (2003)
Greece rivers	1140	UNEP/MAP/MED POL (2003)
Majrda, Tunisia	963	UNEP/MAP/MED POL (2003)
Ebro River, Spain	214	UNEP/MAP/MED POL (2003)
Italian rivers	780	UNEP/MAP/MED POL (2003)
Moulouya, Morocco	250	UNEP/MAP/MED POL (2003)
Nile, Egypt	42	UNEP/MAP/MED POL (2003)
Cheliff, Algeria	78	UNEP/MAP/MED POL (2003)
Isser, Algeria	193	UNEP/MAP/MED POL (2003)
Kebir west, Algeria	200	UNEP/MAP/MED POL (2003)
Seybouse, Algeria	333	UNEP/MAP/MED POL (2003)
Tafna, Algeria	143	UNEP/MAP/MED POL (2003)
Cheffia dam, Algeria	2700	Touaibia (2010)
Charf dam, Algeria	300	Touaibia (2010)
Beni-Haroun dam, Algeria	64	Bouchareb (2013)
Zit El-Amba dam, Algeria	374	Bouchareb (2013)
Zerdaza dam, Algeria	192	Bouchareb (2013)
Chaffia dam, Algeria	143	Taamalah et al (2016)
Mexa dam, Algeria	371	Taamalah et al (2016)
Mafragh catchment' outlet,	1974	Taamalah et al (2016)
Kebir Ouest Rivers, Algeria	4	Bougdah & Amira (2017)
Soummam River, Algeria	28	Youcef & Amira (2017)
Isser River, Algeria	52	Youcef & Amira (2017)
Sebaou River, Algeria	59	Youcef & Amira (2017)
Mafragh River, Algeria	24.8	This study
Seybouse River, Algeria	5	This study

Table 3

Total dissolved solids loading (TDS, t km^{-2} yr^{-1}) for some Mediterranean and Algerian rivers and dams

River/dam opening	*t km^2 yr^{-1}*	*References*
World average value	61	Meybeck & Moatar (2012)
Ebro River, Spain	104	Milliman (2001)
Evros Rivers, Greece	50	Milliman (2001)
Rhone River, France	175	Milliman (2001)
PO Rivers, Italy	228	Milliman (2001)
Amazon, Brazil	43	Milliman (2001)
Yangtze, China	100	Milliman (2001)
Ganges, India	91	Milliman (2001)
Mississippi, US	42	Milliman (2001)
Parana/Uruguay	22	Milliman (2001)
St Lawrence	52	Milliman (2001)
Rhine	270	Milliman (2001)
Cunene, Angola	3	Milliman (2001)
Torne, Norway	9	Milliman (2001)
Ems, Germany	42	Milliman (2001)
Citandy, Indonesia	79	Milliman (2001)
Beni-Haroun dam, Algeria	8.6	Bouchareb (2013)
Zit El-Amba dam, Algeria	6.3	Bouchareb (2013)
Zerdaza dam, Algeria	40	Bouchareb (2013)
Chaffia dam, Algeria	82	Taamalah et al (2016)
Mexa dam, Algeria	218	Taamalah et al (2016)
Mafragh catchment' outlet	224	Taamalah et al (2016)
Kebir Ouest River	325	Bougdah & Amira (2017)
Seybouse, Algeria	95	This study
Mafragh, Algeria	373	This study

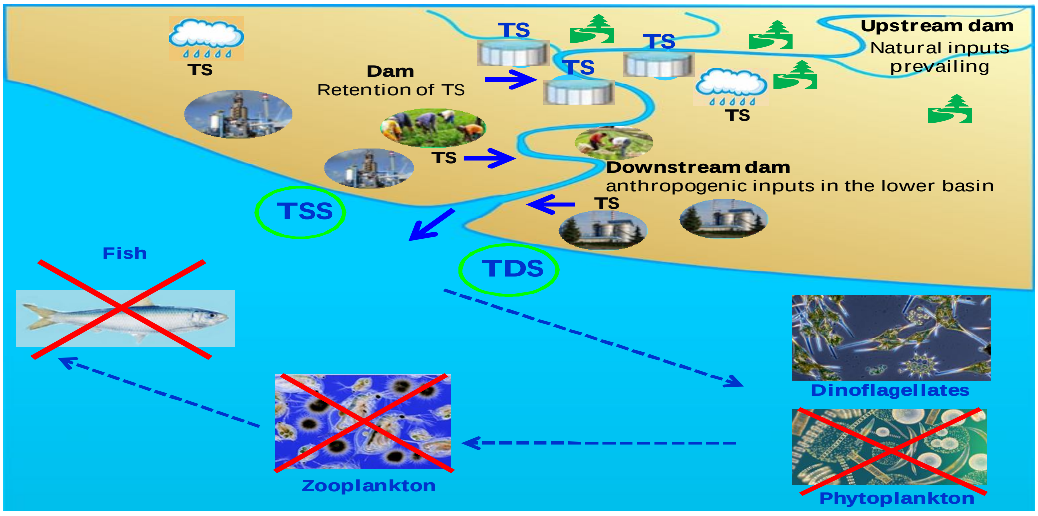

Figure 5. Diagram of the impacts of human activities on the chemistry of continental waters and on the coastal functioning and productivity.

Conclusions. This study assesses the transfer of water, sediments and salt fluxes from Mafragh and Seybouse rivers into Annaba Bay during the year 2014 (from January to December 2014).

This study highlights the following points:

- the decrease in rainfall events during the year 2014, has led to a reduction in river discharge in Mafragh (MR) and Seybouse (SR) rivers outlets;

- the very low flow during the study led to a reduction in TSS flux in Mafragh (MR) and Seybouse (SR) Rivers;

- waters delivered from Mafragh and Seybouse Rivers have high contents of total dissolved solids (TDS);

- because Mafrgh and Seybouse Rivers are the most important source of nutrient enriching Annaba Bay, the decrease in freshwater and total solids can affect primary production and disrupts the food web especially the fish stock.

References

Aminot A., Chaussepied M., 1983 Manuel des analyses chimiques en milieu marin. CNEXO, Brest, 395 pp.

Aubert G., 1976 Les sols sodiques en Afrique du Nord. Annales de l'Institut National Agronomique-El Harrach 7(1):185-196.

Bazin P., Jouenn F., Friedl T., Deton-Cabanillas A. F., Le Roy B., Véron B., 2014 Phytoplankton diversity and community composition along the estuarine gradient of a temperate macrotidal ecosystem: combined morphological and molecular approaches. PLoS ONE 9(4):e94110.

Beaumont N. J., Austen M. C., Atkins J. P., Burdon D., Degraer,S., Dentinho T. P., Derous S., Holm P., Horton T., van Ierland E., Marboe A. H., Starkey D. J., Townsend M., Zarzycki T., 2007 Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. Marine Pollution Bulletin 54(3):253-265.

Bertol I., 1994 [Water erosion in dystrophic humic cambisol under different soil tillage and crop rotation]. Revista Brasileira de Ciência do Solo 18(2):267-271. [in Portuguese]

Bertol I., Engel F. L., Mafra A. L., Bertol O. J., Ritter S. R., 2007 Phosphorus, potassium and organic carbon concentrations in runoff water and sediments under different soil tillage systems during soybean growth. Soil and Tillage Research 94(1):142-150.

Billen G., Garnier J., 2007 River basin nutrient delivery to the coastal sea: assessing its potential to sustain new production of non-siliceous algae. Marine Chemistry 106(1-2):148-160.

Bouchareb N., 2013 Transferts et géochimie de l'azote, du phosphore et du silicium des bassins des oueds Kebir-Rhumel, Kebir ouest et Saf-saf au littoral. PhD thesis, Univertsity of Annaba, Algeria, 111 pp.

Bougdah M., Amira A. B., 2017 Water and sediment retention in a reservoir (Zit Amba, Algeria). AACL Bioflux 10(3):534-542.

Chassot E., Mélin F., Le Pape O., Gascuel D., 2007 Bottom-up control regulates fisheries production at the scale of eco-regions in European seas. Marine Ecology Progress Series 343:45-55.

Chassot E., Bonhommeau S., Dulvy N. K., Mélin F., Watson R., Gascuel D., Le Pape O., 2010 Global marine primary production constrains fisheries catches. Ecology Letters 13:495-505.

Church T. M., 1986 Biogeochemical factors influencing the residence time of microconstituents in a large tidal estuary, Delaware Bay. Marine Chemistry 18(2-4): 393-406.

Cloern J. E., 2001 Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series 210:223-253.

Edgar G. J., Barrett N. S., Graddon D. J., Last P. R., 2000 The conservation significance of estuaries: a classification of Tasmanian estuaries using ecological, physical and demographic attributes as a case study. Biological Conservation 92(3):383-397.

Eero M., Andersson H. C., Almroth-Rosell E., MacKenzie B. R., 2016 Has eutrophication promoted forage fish production in the Baltic Sea? Ambio 45(6):649-660.

Fox H. R., Moore H. M., Newell Price J. P., El Kasri M., 1997 Soil erosion and reservoir sedimentation in the high Atlas Mountains, Southern Morocco. IAHS Publications - Series of Proceedings and Reports 245:233-240.
Håkanson L., 2005 Suspended particulate matter in lakes, rivers and coastal areas. The Blackburn Press, New Jersey, 410 pp.
Hood W. G., 2004 Indirect environmental effects of dikes on estuarine tidal channels: thinking outside of the dike for habitat restoration and monitoring. Estuaries 27(2): 273-282.
Howarth R. W., Billen G., Swaney D., Townsend D., Jaworski N., Lajtha K., Downing J. A., Elmgren R., Caraco N., Jordan T., Berendse F., Freney J., Kudeyarov V., Murdoch P., Zhu Z., 1996 Regional nitrogen budgets and riverine N and P fluxes for the drainages to the North Atlantic Ocean: natural and human influences. Biogeochemistry 35:75-139.
Hu B., Yang Z., Wang H., Sun X., Bi N., Li G., 2009 Sedimentation in the Three Gorges Dam and the future trend of Changjiang (Yangtze River) sediment flux to the sea. Hydrology and Earth System Sciences 13:2253-2264.
Kennish M. J., 2002 Environmental threats and environmental future of estuaries. Environmental Conservation 29(1):78-107.
Khélifi-Touhami M., Ounissi M., Saker I., Haridi A., Djorfi S., Abdenour C., 2006 The hydrology of the Mafragh estuary (Algeria): transport of inorganic nitrogen and phosphorus to the adjacent coast. Journal of Food, Agriculture and Environment 4(2):340-346.
Ludwig W., Meybeck M., Abousamra F., 2003 Riverine transport of water, sediments, and pollutants to the Mediterranean Sea. Medit. Action Technical Report Series #141, UNEP/MAP Athens, 111 pp.
Ludwig W., Dumont E., Meybeck M., Heussner S., 2009 River discharges of water and nutrients to the Mediterranean and Black Sea: major drivers for ecosystem changes during past and future decades? Progress in Oceanography 80(3-4):199-217.
Marmulla G., 2001 Dams, fish and fisheries: opportunities, challenges and conflict resolution. FAO Fisheries Technical Paper, No. 419, Rome, FAO, 166 pp.
Meybeck M., Moatar F., 2012 Daily variability of river concentrations and fluxes: indicators based on the segmentation of the rating curve. Hydrological Processes 26(8):1188-1207.
Micheli F., 1999 Eutrophication, fisheries, and consumer-resource dynamics in marine pelagic ecosystems. Science 285:1396-1398.
Milliman J. D., 2001 Delivery and fate of fluvial water and sediment to the sea: a marine geologist's view of European rivers. Scientia Marina 65(2):121-132.
Milliman J. D., Syvitski J. P., 1992 Geomorphic/tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. The Journal of Geology 100(5):525-544.
Ounissi M., Bouchareb N., 2013 Nutrient distribution and fluxes from three Mediterranean coastal rivers (NE Algeria) under large damming. Comptes Rendus Geoscience 345:81-92.
Ounissi M., Ziouch O. R., Aounallah O., 2014 Variability of the dissolved nutrient (N, P, Si) concentrations in the Bay of Annaba in relation to the inputs of the Seybouse and Mafragh estuaries. Marine Pollution Bulletin 80(1):234-244.
Phillips J. D., Slattery M. C., 2006 Sediment storage, sea level, and sediment delivery to the ocean by coastal plain rivers. Progress in Physical Geography: Earth and Environment 30(4):513-530.
Pont D., Simonnet J. P., Walter A. V., 2002 Medium-term changes in suspended sediment delivery to the ocean: consequences of catchment heterogeneity and river management (Rhône River, France). Estuarine, Coastal and Shelf Science 54(1):1-18.
Poulos S. E., Collins M. B., 2002 Fluviatile sediment fluxes to the Mediterranean Sea: a quantitative approach and the influence of dams. Geological Society, London, Special Publications 191(1):227-245.

Preston S. D., Bierman J. R. V. J., Silliman S. E., 1989 An evaluation of methods for the estimation of tributary mass loads. Water Resources Research 25(6):1379-1389.
Probst J. L., 1992 Géochimie et hydrochimie de l'érosion continentale. Mécanismes, bilan global actuel et fluctuations au cours des 500 derniers millions d'années. Sciences Géologiques Mémoires 94, 167 pp.
Ragueneau O., Conley D. J., Leynaert A., Longphuirt S. N., Slomp C. P., 2006 Role of diatoms in silicon cycling and coastal marine food webs. In: The silicon cycle: human perturbations and impacts on aquatic systems. Ittekot V., Unger D., Humborg C., Ann N. T. (eds), Island Press, Washington, D.C., pp. 163-195.
Roose E., 1991 Conservation des sols en zones méditerranéennes. Synthèse et proposition d'une nouvelle stratégie de lutte antiérosive: la GCES. Cah Orstom sér Pédol 26:145-181.
Sadaoui M., Ludwig W., Bourrin F., Romero E., 2017 The impact of reservoir construction on riverine sediment and carbon fluxes to the Mediterranean Sea. Progress in Oceanography, https://doi.org/10.1016/j.pocean.2017.08.003.
Scherrer B., 1984 Biostatistique. Boucherville, Gaëtan Morin.
Schick J., Bertol I., Batistela O., Balbinot Júnior A. A., 2000 [Water erosion in Cambisol. Humic alumina submitted to different systems of soil preparation and cultivation: I. Soil and water losses]. Brazilian Journal of Soil Science 24(2):427-436. [in Portuguese]
Serrat P., Ludwig W., Navarro B., Blazi J. L., 2001 Variabilité spatio-temporelle des flux de matières en suspension d'un fleuve côtier méditerranéen: la Têt (France). Comptes Rendus de l'Académie des Sciences 333(7):389-397.
Taamallah F. Z., Laskri H., Amira A. B., 2016 Transport and retention of dissolved and suspended solids across the Mafragh catchment (Algeria). Advances in Environmental Biology 10(5):177-185.
Teuchies J., Vandenbruwaene W., Carpentier R., Bervoets L., Temmerman S., Wang C., Maris T., Cox T. J. S., van Braeckel A., Meire P., 2013 Estuaries as filters: the role of tidal marshes in trace metal removal. PLoS ONE 8(8):e70381.
Touaibia B., 2010 Problématique de l'érosion et du transport solide en Algérie septentrionale. Sécheresse 21(4):333-335.
Toublanc F., Brenon I., Coulombier T., 2016 Formation and structure of the turbidity maximum in the macrotidal Charente estuary (France): influence of fluvial and tidal forcing. Estuarine, Coastal and Shelf Science 169:1-14.
Turner R. E., Qureshi N., Rabalais N. N., Dortch Q., Justic D., Shaw R. F., Cope J., 1998 Fluctuating silicate: nitrate ratios and coastal plankton food webs. Proceedings of the National Academy of Sciences of the USA 95(22):13048-13051.
Turner R. E., Rabalais N. N., Justic D., Dortch Q., 2003 Global patterns of dissolved N, P and Si in large rivers. Biogeochemistry 64:297-317.
Turner R. K., Van Den Bergh J. C. J. M., Söderqvist T., Barendregt A., Van Der Straaten J., Maltby E., Van Ierland E. C., 2000 Ecological-economic analysis of wetlands: scientific integration for management and policy. Ecological Economics 35(1):7-23.
UNEP/MAP/MED POL, 2003 Riverine transport of water, sediments and pollutants to the Mediterranean Sea. MAP Technical Reports Series No. 141, UNEP/MAP, Athens, pp. 1-118.
UNEP/MAP/MED POL, 2003 Riverine transport of water, sediments and pollutants to the Mediterranean Sea. MAP Technical Reports Series No. 141, UNEP/MAP, Athens, pp. 1-118.
Vörösmarty C. J., Meybeck M., Fekete B., Sharma K., Green P., Syvitski J. P. M., 2003 Anthropogenic sediment retention: major global impact from registered river impoundments. Global and Planetary Change 39(1-2):169-190.
Walling D. E., 2006 Human impact on land-ocean sediment transfer by the world's rivers. Geomorphology 79(3-4):192-216.
Walling D. E., Fang D., 2003 Recent trends in the suspended sediment loads of the world's rivers. Global and Planetary Change 39(1-2):111-126.
Ware D. M., Thomson R. E., 2005 Bottom-up ecosystem trophic dynamics determine fish production in the Northeast Pacific. Science 308(5726):1280-1284.

Youcef B., Amira A. B., 2017 Transport of dissolved and suspended solids from three coastal rivers (North Central Algeria). AACL Bioflux 10(6):1404-1412.
Zhang S. R., Lu X. X., Higgitt D. L., Chen C. T. A., Sun H. G., Han J. T., 2007 Water chemistry of the Zhujiang (Pearl River): natural processes and anthropogenic influences. Journal of Geophysical Research: Earth Surface (2003–2012) 112(F1).

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