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Damming Effects of Spatial and Seasonal Distribution of Dissolved Nutrients and Fluxes from A Mediterranean River (North-Ouest Algeria)

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ABSTRACT

This present study investigated the spatio-temporal variation of nutrients and fluxes from Chlef river, and the examination of the results showed that the Sub basin of Chlef river, upstream waters, and downstream salty waters are controlled by the tidal process. In terms of nutrients, it was noticed that the basin especially holds more reduced mineral nutrients, and generates oxidized forms. High levels of ammonium were observed in times of floods with a 54% upstream annual percentage, which in these fractions were converted to nitrate during the summer, and 66% of these fractions were eliminated by the metabolism growth in reservoirs. For the P mineral, our results indicated high levels in dry period, and low amounts in wet period. These concentrations were generated by the hydro-geochemical comporting phosphorus. For silicates forms, we observed a decrease between upstream and downstream with a high retention by the dam. For nutrients flux, we observed that our estuary contributed less charge of ammonia but high charge of nitrite, while this element generated more charge of dissolved inorganic nitrogen. The N/P ratio indicated the dissolved nitrogen as the generator of eutrophication in the catchment.

Keywords: *Nutrients, Fluxes, Chellif Dam, Mediterranean River, Algeria.*

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1. INTRODUCTION

More than 70,000 large dams have been built worldwide. With growing water stress and demand for energy, this number will continue to increase in the conceivable future. Damming greatly modifies the ecological functioning of river systems. In particular, dam reservoirs sequester nutrient elements and, hence, reduce downstream transfer of nutrients to floodplains, lakes, wetlands, and coastal marine environments. Homogenization of river flow systems resulting from damming is a growing worldwide phenomenon, and was found to be one of the reasons for the decline in freshwater biodiversity (Poff, 2007). Another major global driver of environmental change of river systems is the enrichment by the anthropogenic nutrients, in particular phosphorus (P) (Correll, 1998; Smil, 2000). Fertilizers which cause soil erosion by discharging wastewater have more than doubled the global nutrients in catchment compared with the inferred natural baseline (Compton, 2000). Here, we quantified the global impacts of dams on the riverine fluxes and speciation of the limiting nutrients. In Maghreb (North Africa), problems are essentially related to the salting of the dams, which reduces the water storage capacity and the hydraulic potentials by 2–5% per year (Kassoul et al., 1997; Achite, 2007). Dams may have a strong impact on the water and nutrient river discharge due to Silicate and Phosphorus retention within sediments and, but not always, due to nitrogen removing (Avilés et al., 2007). Also, for specific irrigation dams, the river nutrient discharge decreases with the increasing rate of water and nutrient uptake by crops (Wahby et al., 1980). Urban and agricultural nutrient inputs and water residence time within dams also lead to a change on the nutrients ratios, as well as the Redfield's (1963) ratio (Ludwig et al., 2009; Ludwing et al, 2010). Considering the severe lack of geochemical data for coastal rivers, a number of recent studies have addressed global nutrients' retention by river damming. This study aimed to evaluate the nutrients' distribution in the catchment between upstream and downstream dam, and examine the effects of construction of dams on the (N, P, Si) nutrients dynamics by retention and release, and finally estimate the final fluxes of nutrients exported to Mostaganem coast in the Mediterranean Sea.

2. MATERIEL AND METHODS

Study area

Chelf river in the longest permanent river of Algeria with the length of about 700 km, the catchment surface of about 56400 km2, the number of inhabitants of about 3 million people. Chlef river receives household and agricultural wastes without treatment plans. The 64 dams implanted in the upstream of the catchment, retain the precipitation used for drinking and irrigation in this semiarid zone with low precipitation. The Chlef dam is the latest dam planned in the downstream of the maritime catchment (0136) with a surface of about 431.41 Km2, and heavily managed by several dams that retain about half of the precipitation's wealth. Chlef dam (50 million m3 storage capacity) built on Chlef River is mainly used for the water transfer to meet drinking water demands for the cities of

Oran and Mostaganem to supply irrigation water to the local agricultual activities.

The stations were chosen far from the mouth of the river estuary, and three station areas were sampled: the first in the upstream (ST1), the second station in the downstream of the dam (ST2) and the latest station present in the estuary outlet (ST3) (Fig. 1; Table 1).

Table 1. Geographical coordinates of the sampling stations

Stations	Geographical coordinates (Latitude; longitude)
ST1	0°31'17.87"E; 35°58'3.13"N
ST2	0°24'3.14"E; 35°59'53.49"N
ST3	0° 8'5.90"E; 36° 2'18.33"N

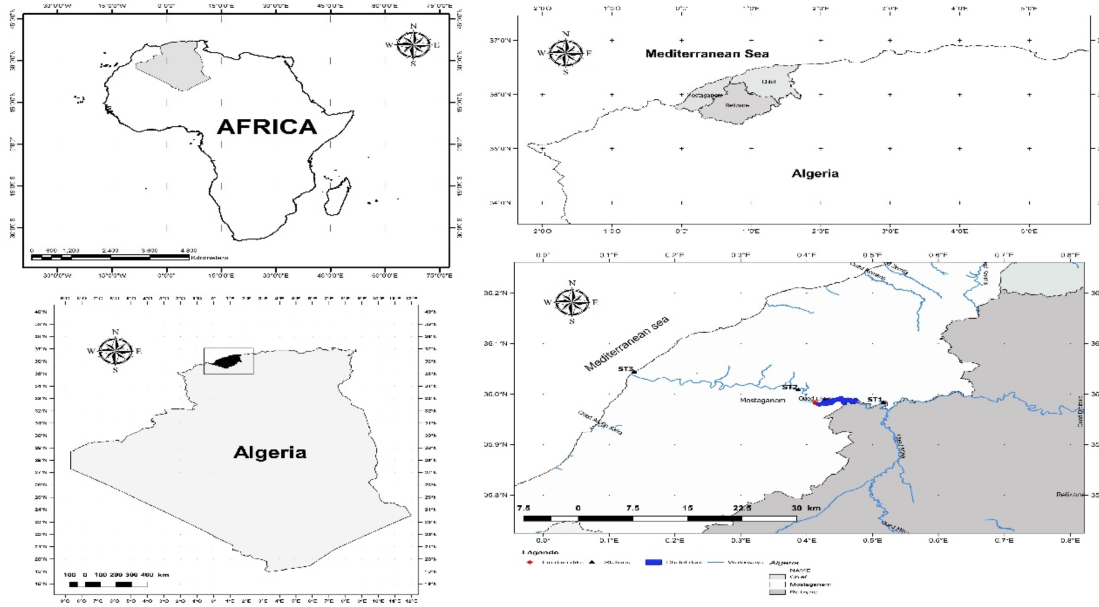

Figure 1: Sampling station and study area of Chlef river

While collecting water samples, some hydrological parameters were also measured. The flows' velocity of three stations (ST1, ST2, ST2) (Fig. 1; Table 1) was measured by a CM-2 current meter, Toho Dentan Co, td, Tokyo. Water salinity, temperature, pH, and dissolved oxygen were estimated by a multi-parameter, WTW 340i, as mentioned by the manufacturer, the precisions of the physic parameters were ±0.5 % for salinity, the temperature and the dissolved oxygen measurements, and ±0.1 % for the temperature and pH. The flow rate (m3. s-1) was calculated by multiplying the water velocity (m3. s-1) by the total of the surface area (m2).

Water sampling and analytical methods

The water samples collected from the river surface in a polyethylene bottles were transported to the university laboratory. Surface water samples were taken twice per month from January 2009 to December 2011. The analysis was processed in the laboratory after filtration of the sample through Wathman GFS/C glass filters (0,45µM porosity with 47 diameter). All dissolvable nutrients dissolved inorganic nitrogen DIN (ammonia: NH4+ nitrate: NO3; nitrite: NO2-), phosphates PO43- and silicates(SiOH4) which were determined by means of the standard colorimetric methods described in Parsons et al. (1989). Polyphosphate (P2O5) was measured following the standard colorimetric method of Rodier (1996). The dissolved inorganic phosphorus (DIP) was calculated as the sum of the two phosphorus fractions (PO4 and P2O5). Their precisions were: ± 5% (NH4), ± 2.5% (NO2), ± 3% (NO3), ± 3% (PO4, P2O5), ± 2.5% (Si(OH)4).

To understand the fluxes' distributions in our catchment study area, the fluxes in the three stations were estimated. The instantaneous fluxes of all the nutrients were calculated by multiplying their concertation by the river flow. The annual load of nutrients was estimated using the method of average instantaneous loads described by (Preston et al., 1989).

$$F = K\sum_{i=1}^{n}\frac{C_iQ_i}{n}$$

Where:

F is the annual load (t.y-1), C_i is the concentration of nutrients (µM converted to kg m^{-3}), Q_i is the concomitant instantaneous flow (m^3. s^{-1} converted into m^3. Day^{-1}), n is the number of days for concentration and flow data, and K is the conversion factor needed to consider the period (365 days) and the unit of estimation.

Nutrient fluxes into and from dams were also computed in order to assess their budgets from the rates of retention or production. The flows' measures at the entrances and exits were calculated during the period of the study (January 2009 to December 2011). To modulate the results, and understand the fluxes' dynamic in the catchment, two scenarios calculated the retention and the release of the nutrients as follows in the equation:

Retention = inflow flux [mainstream + wet atmospheric deposition] – outflow flux from dam storage. The atmospheric deposition to dams was neglected,

$$R = \left(\frac{\text{In flux} - \text{Out flux}}{\text{In flux}}\right) * 100$$

If the result of R is negative, there is a retention of nutrients in the dam reservoir, and if the result of R is positive, there is a release (contribution or production).

3. RESULTS

hydrological parameters

Salinity varied between [0.20–31.80] µM. For the potential of hydrogen, it was observed that the waters examined showed enough pH which is important based on the gradient of the contents of the Middle H. Overall results capitalized at the end of this study showed that the pH of the waters of River Chlef did not exceed the standards, and revealed the acceptable values of natural waters. The pH varied between [6.28–9.60] with the average value of 7.80. As it was noticed, the salinities' indications showed that the waters of sub basin of Chlef river are characterized by fresh water in upstream and salty water downstream that fluctuate based on the dynamics of the tides in the station mouth. In the periods of floods, the River presented homogeneous water masses which were soft. The stratification of salinity was based on the micro tidal waters' activities, or the maximum values which were observed in the mouth with a value resort, and minimum values which were observed in the station upstream according to the salinity gradient (Fig. 2).

For the electrical conductivity, it was observed that fluctuations were the same as that of salinity varied between [0.77-49.40] ms/Cm with the value average of 6.25 ms/Cm (Fig. 2)

In terms of potential of hydrogen, it was noticed that in the examined waters, pH was enough based on the gradients of the contents of the H+. Overall, the results capitalized at the end of this study showed that the pH of the Chlef river did not exceed the standards, and revealed the acceptable values of natural waters (Fig. 2).

Oxygen in surface water levels was based on the atmospheric levels of CO2 solubility. We noticed that the high values were observed downstream, which were moderated by hydrodynamic effects. Also, the flow of the surface water factor had a direct influence on the solubility of CO2. It was noticed that the conditions of Anoxia upstream in low flow period, the levels increased by water entering to the reservoir and in upstream, and their saturation level were very important (Fig. 2).

Q varied between [0.21– 113.2] m3. s-1 (Fig.2) with the average value of 16.87(m3. s-1) throughput. It was observed that the flow of the waters of Chlef river was very important in upstream and downstream translates, in a way that the construction of the dam had a direct effect on the reduction of the flow through water retention, and ensured an ecological flow for the watershed. And high values were observed in the period of floods, and low values were saved in the low-flow period. It was also recorded in the peaks of the dry period directly due to the accidental showers and the released dams in some periods of the year for irrigation to agricultural activities.

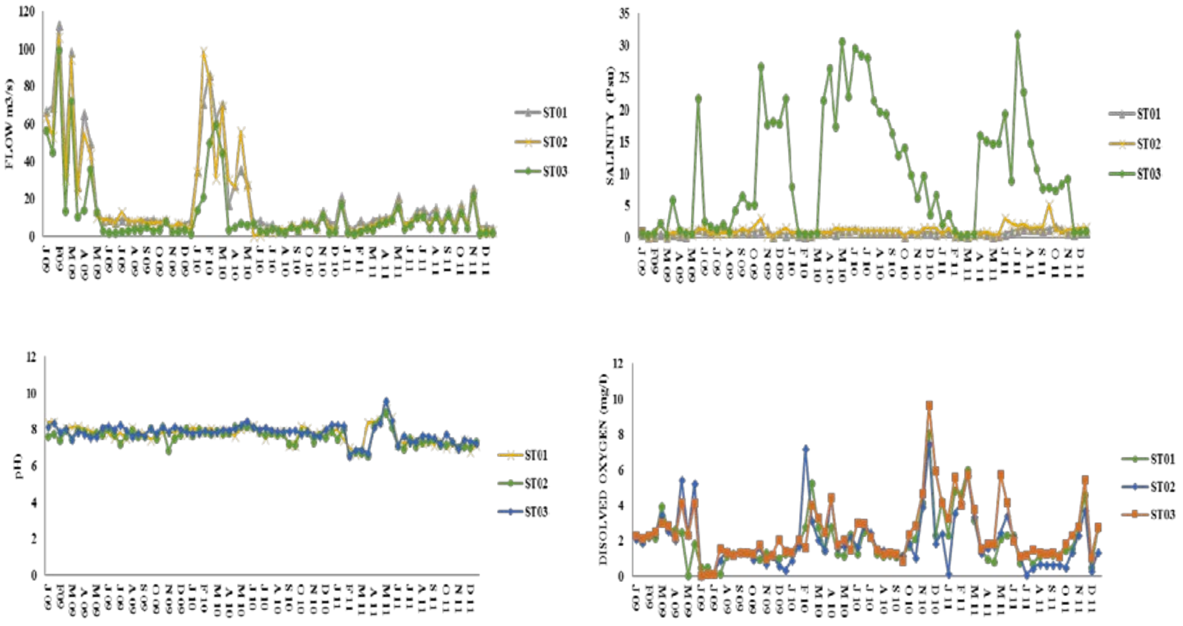

Figure 2. Distribution of hydrological parameters in the three studied stations of Chlef river.ST01: Upstream dam; ST02: Downstream dam; ST03: Estuary outlet

Nutriments' distribution

It was noticed that the high levels of ammonium were observed in times of the floods with a 54% upstream annual percentage or the load of nutrients through the strong pressure of the tributaries of River Chlef, and the low values were observed in summer, and the major rite of these contents was oxidized to nitrate, or the percentage of ammonium was about 37% during this period of study. The makers were regressed from upstream to downstream which implied the direct effects of the dams on the levels of ammoniacal nitrogen retention, and during their time in the dams, the fractions were converted to form oxidized according to the factors of nitrification (Fig. 3 and Table 2). For intermediate forms of nitrite, we noticed that the makers fluctuate between 0 and 82 µM with an average value of 16 µM. The results of the analysis showed that the low percentages did not exceed 21% upstream and 12% downstream at the mouth. For more oxidized forms, we noticed that the basin of Chlef river was characterized by the high levels that fluctuated between 0.03 and 154 µM, and the strong concentrations were saved in the summer, the condition of oxidation was seen in the winter. We also noticed a reduction in a Mount downstream of the dam, and nitric nitrogen was about 94% above the fraction of mineral nitrogen. After the passage through the dam, the fraction reduced up to 40% of the dissolved nitrogen at the outlet of the sub basin, Table 2 expresses a trapping of 54% by the dam during the period of the study.

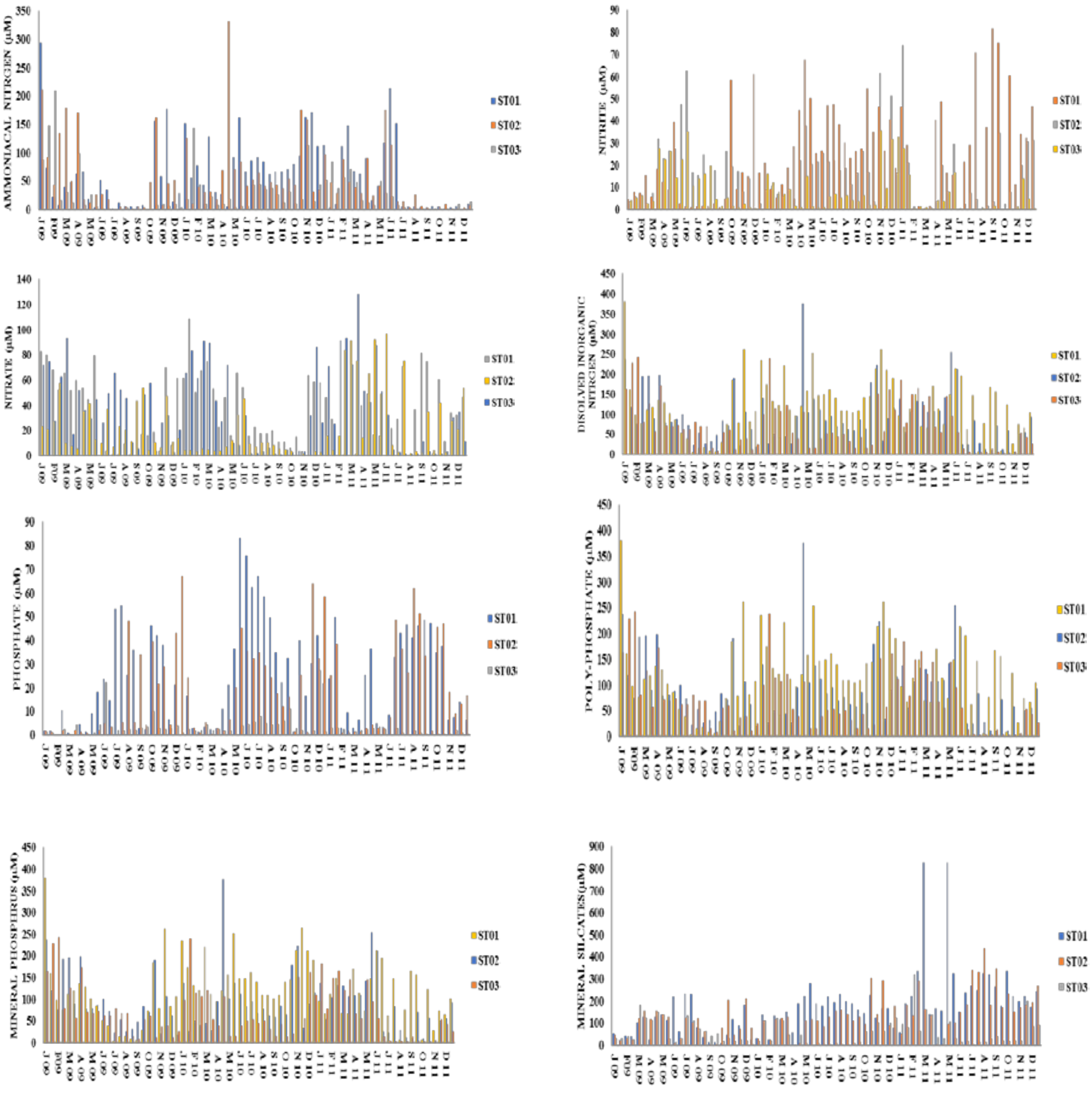

Figure 3. Spatio-temporal variation in nutrients (µM) in the three studied stations of Chlef river.ST01: Upstream dam; ST02: Downstream dam; ST03: Estuary outlet

For the ortho phosphate, it was noticed that the makers in Ortho phosphate were quite low in times of flood and most importantly in low-flow period. This explained the behavior of the fraction of forms of phosphorus adsorption with the materials in suspensions and precipitation in winter (sedimentation) which decreased the concentrations of the dissolved forms, and increased the particulate forms in the summer, and desorbed the PO4 of the contents in the suspensions. And then, the dissolution increased the levels of the phosphorus amounts which fluctuated between 0.04 and 83 µM. There was also a regression between upstream and downstream. In terms of percentage, it was signed that phosphates represented about (47%) of mineral forms of phosphorus upstream, and (46%) and (40%) in the estuary mouth. This implied a reduction between the upstream dam and downstream dam (Fig. 3, Table 2). Regarding the water-soluble phosphates (polyphosphates), the high levels of polyphosphates were observed in low-flow period, and the low levels were recorded in the flood period. This expressed the phenomenon of behavior of phosphorus. The P2O5 fluctuated between 0 and 78 µM with an average value of 16 µM during this follow-up period (Fig. 3). This fluctuation showed a significant difference between upstream and downstream at the mouth. The levels were still low compared to the upstream. For the mineral form of phosphorus, the high levels in low-flow period and low levels of raw period which increased the particulate phosphorus forms were observed (Fig. 3).

For silicates forms, a decrease between upstream and downstream was observed. The recorded levels varied between 0.71 and 830 µM with an average value of 124 µM. These contents were trapped by the dams, which increased the mineral silicates. The high levels of nitrogen and phosphate were observed (Table 2). The Reyfield ratio N/P was very important that was 16/1 which implied that nitrogen generated the eutrophication in Chlef water. Si/DIN indicated low values which expressed strong levels of mineral nitrogen produced by the waters upstream, and the dam waters showed signs of eutrophication, and promoted the growth of diatoms (Table 2 and 3).

Table 2: The total annual flow of the nutrients

		P (mm)	Q $(m^3. s^{-1})$	NH_4 $(t. yr^{-1})$	NO_2 $(t. yr^{-1})$	NO_3 $(t. yr^{-1})$	DIN $(t. yr^{-1})$	PO_4 $(t. yr^{-1})$	P_2O_5 $(t. yr^{-1})$	MIP $(t. yr^{-1})$	SiOH4 $(t. yr^{-1})$	N: P[a] (g/g)	Si: N [a] (g/g)	Si: Pa (g/g)
2009	Upstream dam	267.5	27.82	1070.25	400.70	3136.09	4607.04	553.59	732.30	12.85.89	6033.97	68.85	4.03	6.76
	Downstream dam	267.5	24.87	1384.86	467.63	1063.44	2915.93	306.95	364.11	671.06	6086.37	100.05	1.51	14.61
	R/P (%)	-	-10.60	29.40	16.70	-66.09	-36.71	-44.55	-50.28	-47.81	0.87	-	-	-
	Estuary Outlet	267.5	17.03	879.43	467.63	1772.00	3119.06	62.37	130.64	193.01	4180.19	89.59	1.30	20.29
	Speciphic flux (Kg/km2/y)	-	-	(2.04)	(1.08)	(4.11)	(7.23)	(0.14)	(0.30)	(0.44)	(9.69)	-	-	-
2010	Upstream dam	429	22.97	1047.73	802.98	2550.20	4400.91	992.47	1154.79	2147.26	8397.07	21.89	1.10	6.69
	Downstream dam	429	22.29	967.73	486.09	218.50	1972.32	592.17	564.40	1156.57	5826.07	22.84	1.92	8.15
	R/P (%)	-	-2.96	-7.64	-39.46	-91.43	-62.00	-40.33	-51.13	-46.14	-30.62	-	-	-
	Estuary Outlet	429	12.05	250.73	486.09	1385.14	2121.96	11.86	174.72	186.58	2663.89	34.87	0.75	8.94
	Speciphic flux (kg/km2/y)			(0.58)	(1.13)	(3.21)	(4.92)	(0.03)	(0.40)	(0.43)	(6.17)	-	-	-
2011	Upstream dam	429	10.19	239.47	391.96	530.60	1162.03	763.27	693.14	1456.41	9481.96	10.11	6.84	10.09
	Downstream dam	429	7.93	136.72	802.989	523.59	1463.30	553.05	591.30	1144.35	4712.60	29.52	7.28	9.54
	R/P (%)	-	-22.18	-42.91	104.87	-1.32	25.93	-27.54	-14.69	-21.43	-50.30	-	-	-
	Estuary Outlet	429	6.71	56.42	91.65	394.67	542.74	31.32	68.08	99.4	981.59	45.54	2.37	16.64
	Speciphic flux (kg/km2/y)			(0.13)	(0.21)	(0.91)	(1.26)	(0.07)	(0.16)	(0.23)	(2.28)	-	-	-

For the flows, it was noticed that the year 2009 presented the high loads of nutrients than other years. The total annual flow of the nutrients (Table 2) in terms of the flow was measured, which showed that our catchment exported a strong charge of ammonical nitrogen. During the three years of follow-up, it was represented by five, as the charges were exported by Syboyse (Ounissi, 2013).

Table 3: Total annual flux dissolved nutrients from some Algerian estuaries in the same period of study (*) present study. Experimented by (t.y-1).

Years	Estuaries	NH4 (t. yr-1)	NO2 (t. yr-1)	NO3 (t. yr-1)	DIN (t. yr-1)	PO4 (t. yr-1)	SiOH4 (t. yr-1)	N: Pa (g/g)	Si: N a (g/g)	Si: Pa (g/g)
2009	Sybouse estuary	3666	93	539	4299	194	4918	44	-	2,2
	Mafrag estuary	211	95	242	549	88	1895	12	-	6,9
	Chlef estuary (*)	879,43	467,63	1772	3119,06	62,37	4180,19	89,59	1.30	20,29
2010	Sybouse estuary	649	44	255	948	96	897	21	-	1,9
	Mafrag estuary	200	72	214	486	94	1889	10	-	7,7
	Chlef estuary (*)	250,73	486,09	1385,14	2121,96	11,86	2663,89	34,87	0.75	8,94
2011	Sybouse estuary	533	54	281	868	118	1010	14	-	2,3
	Mafrag estuary	138	34	154	326	51	1653	13	-	10
	Chlef estuary (*)	56,42	91,65	394,67	542,74	31,32	981,58	45,56	2.37	16,64

4. DISCUSSION

Our results showed that the dams affect the biogeochemical transformations of nutrients, which bring along transformations of organic nutrients released by the plankton metabolism. The implantation of dams has direct effects on the elimination of inorganic nutrients, because the dams produced a large dissolved organic matter, and caused the retention of particulate nutrients, and finally changed the N/P Reyfieds ratio (Table 3). In the outlets of the estuaries, the salinity was controlled by the river inputs, and taken to a lesser degree by the tidal intrusion. In the wet period which extends approximately from November to April, continental inputs dominated the entire estuary, driving the salt wedge back towards the sea (Ounissi, 2014; kebabsa, 2016) (Table 3). The examination of the results showed that the Chlef dam trapped 66% of nitrate, which was affected by the augmentation temperature that favored the nitrification comparing to the results of Garnier et al. (2007). In the temperate reservoirs of Marne, Seine, and Aube, the relative low retention of N–NO3 (40%) and more elevated rates (50%) for Si and (60%) for P–PO4 were reported. In the other temperate reservoirs of Iron Gate, I built on the Rhine River, Humborg et al. (2000) demonstrated that over 80% of dissolved Si reduction could be related to the retention by Iron Gate I. This in-stream elimination may be explained by the bacterial consummation as reported by numerous works (Bustillo et al., 2011; Purvina et al., 2010; Wiegner et al., 2006; Wolfe et al., 1999).In terms of load of nutrients, it was noticed that Chéliff had pretty low charge in ammonium, but high load of oxid forms which increased the mineral forms in estuary mouth represented only in two estuaries which were studied (Ziouch, 2014; Kebabsa,2016) during the same period of follow-up (Table 2 and 3). Also in terms of phosphate, strong polyphosphates, in the three-year study got a charge of significant amounts of silicates which gave importance to these nutrients assimilated by the group phytoplanktons in the adjacent coast which were shown by the ratio of Si/P (Table 3). These two continental nutrient sources also stood in contrast to the DIN:PO4 ratio, which was lower in Mafragh estuarine inputs. The second factor was explained mainly by the levels of Si(OH)4 and the Si(OH)4: DIN ratio as distributed in Mafragh estuary and in the Bay. In the same area, Chlef estuary exported from 1.26 to 7 kg NID km2 yr1 , comparing to Seybouse outlet was high, ranging from 77 to 640 kg N km2 yr1 depending on the year. From these amounts, it can be considered that Seybouse had the highest amounts among the Mediterranean Rivers (EEA, 2007; Ludwig et al., 2009; Ounissi and Bouchareb, 2013)and the Chlef is very lower than Seybouse and Mafrag outlets where DIN specific loadings were rather low (34–154 kg N km2 yr-1 in average), and P– PO4 specific loadings were elevated as (3–28 kg P km2 yr-1 in average). These masses may also be considered important comparing to the Mediterranean Rivers (e.g., EEA, 1999; Ludwig et al., 2009; Sadaoui,2016). For the phosphate, in our study, the catchment exported an amount of specific flux (0.07 to 0.14) kg P km2 yr-1 in average. These amounts were very lower than the amounts of Seybouse outlet waters, and the specific loadings in the catchment which were (2–15 kg P km2 yr-1), were paradoxically low. The low loadings of DIN of Mafragh estuary compared to Seybouse one, is not only because of the smaller human population in the watershed but may also be linked to the buffering effects of Mafragh marshland (Ounissi et al, 2018), which provides nutrient sinks. The loadings of Si–Si(OH)4 were remarkably comparable between the two estuaries in both wet and dry years in all Algerian estuaries. In addition to the heavy nutrient loads introduced into the Bay, especially via Seybouse, (Aounallah, 2015) the loading ratios of DIN:PO4 (>30) and Si(OH)4: DIN (<1), were also unbalanced, suggesting that P and Si may be the limiting factors for coastal phytoplankton growth.

5. CONCLUSION

In conclusion, it can be retained that the major characteristics of Chlef estuary is the low values of NH4 and PO4, unlike NO2 and NO3 charges which were very high, and SiO4 levels that were remarkably lowered because of its retention in the dams. It was noticed that all inorganic nutrients experienced a large removal in the dams, and the reified ratio was very moderate by the construction dam. Our study showed that the DIN was the generator of eutrophication.

6. ACKNOWLEDGEMENTS

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