The role of sediment pore waters in the fertility of Abu Qir Bay, Egypt

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Abstract

Due to the construction of Aswan High Dam at 1964, the annual means of discharged Nile water through Damietta and Rosetta Estuaries, into the Mediterranean Sea was sharply decreased from 42.9 x10^9 to lesser than 1.00 x 10^9 m^3 before and after the damming construction, leading to a considerable drop in the amount of nutrients, fish production in addition to the change in the hydrographical features of the Mediterranean waters off the Egyptian Coast. Recently, a noticeable increase in the amount of fish production in spite of lacking the discharged Nile water into the sea was observed. Such increase in the fertility was suggested to be as a result of the anthropogenic effects from land based sources which replaced the nutrients of fresh Nile waters. Such condition attracted the attention of scientists to follow up the changes in water quality of the Abu Qir Bay and adjoining Mediterranean waters from one side and to evaluate the impacts of these changes on the fertility of water column from the other side. Accordingly, the present investigation was undertaken to study the concentrations of dissolved nitrogen, phosphorus and silicate in both bottom sediment pore waters and corresponding overlying water column at different sites of Abu Qir Bay and adjoining Mediterranean waters during seasonal cruises. In order to evaluate the consequently, see to what extent it may contribute in the fertility of eutrophic water layers of these regions. The present study demonstrated that, the benthic fluxes lead to a considerable increase in fluxes of nitrate (53µg/m^2.dayNO_3-N), ammonium (10.50mg/m^2.dayNH_4-N), phosphate (445 µg/m^2.dayPO_4-P) and silicate (1.76950mg/m^2.daySiO_4-Si) in the corresponding overlying water column. This could be responsible for the increasing fertility of the investigated regions rather than those of the anthropogenic effects. Factors affecting the mechanism of nutrient diffusion were investigated.

Keywords: pore water, eutrophic, anthropogenic, benthic fluxes

1. Introduction

The exchange of dissolved substances across the sediment-water interface is an important process affecting the chemical composition of coastal marine environments, where nutrients regeneration in benthic sediments can supply a significant part of the requirements of primary producers in the overlying waters (Brossard and Jankowska, 2001). Noel (1999) signified that, the sediments can act as a sink or a source according to the conditions at the sediment-water interface. Processes involved in the nutrients transfer are reversible and quick, and differ with season and sediment type. The flux of nutrients released to the water column through the interstitial water of the sediment could be enough to increase the dissolved concentration of the water body to induce a phytoplankton bloom. It is becoming increasingly clear that the solute exchange across the sediment-water interface is an important process in regulating the water column distribution and global cycles of many elements (Andersen and Malahoff, 1977; Nixon *et al*., 1980; Zeitzschel, 1980; Codispoti and Christensen, 1985; Jones and Murray, 1985). Biogeochemical processes in sediments and sediment-water/air interactions are driven by the mineralization of organic matter which can be adequately described by so called "early digenetic" models (Berner, 1980).

Molecular diffusion within interstitial waters is of a fundamental importance in affecting the exchange of dissolved constituents across the sediment-water interface. Some other processes may enhance the flow of dissolved nitrogen at the sediment –water interface. These processes include physical mixing of sediments by currents, benthic biota, bioturbation of sediments by the macrobenthos, and transport through bubble tubes; disregarding them leads to the underestimation of benthic fluxes (Callender and Hammond, 1982). They added that, these processes could increase the nutrient flux even twenty fold, although opinions concerning dissimilarities between the real and diffusive (estimated from concentration gradients) ammonium fluxes considerably differ. Also they pointed out that, advective fluxes in coastal zone (connected with transport of dissolved constitutes by water and sediment transport induced by organisms) are almost as important as diffusive fluxes, and therefore, fluxes calculated on the basis of Fick's low are seriously underestimated. However, some other authors have shown that in the case of ammonium the main process responsible for the flow at the sediment- water interface is molecular diffusion.

Bolalek and Graca, (1996) stated that, the calculations of ammonium fluxes based on concentration gradients and *in situ* ammonium fluxes measured using benthic chambers yield similar results. Bearing the conclusions of these authors in mind, the present study was estimated the diffusive ammonium fluxes on the assumption that they approximately reflect the real fluxes at the sediment-water interface. Moreover, it is necessary to have accurate quantitative calculations of the nitrogen transformation processes in the sediments, with special regard to ammonification, nitrification and denitrification.

The present study was focused on the role of pore waters (interstitial waters) contribution in the productivity of overlying water, therefore, is an attempt to cover this gap of information in Abu-Qir Bay as one of the hot spots of the Mediterranean Sea.

2. Material and methods

Abu Qir Bay lies between 30º 05́ and 30º 20́ E and 31º16́ and 31º28́ N and extends for about 63Km from El-Montazah in the west to Rosetta mouth in the east.

The three main opening waste sources to Abu Qir Bay are:

1- Tabia- pumping station.
2- Outlet of Lake Edku.
3- Rosetta mouth of the River Nile

Bottom water samples were collected from nine stations on a seasonal basis during four successive cruises to represent the different sites of southwestern side of Abu-Qir Bay. Water samples for ammonium concentrations were fixed immediately after sampling (IOC, 1983). Water samples for other measurements (nitrite, nitrate, reactive phosphate and silicate) were kept frozen until analysis following the Techniques of Strickland and Parsons (1972).

Grab sediments from each of nine stations were collected using a grab sampler on a same seasonal cruises. The choice of the techniques used for extracting the interstitial water from sediments is usually governed by the nature of sediments and available facilities as the following: in case of muddy sediments fractions, the squeezer technique was used, centrifugation for finer sediments at 20.000 r.p.m for about 10 minutes and by filtration on a glass fibers filter, in case of coarse sediments. The interstitial water was collected in small polythene bottles, and ammonium was directly determined after extraction of interstitial water, by the same method as was used for near bottom waters, whereas the samples for other analyses (nitrite, nitrate, reactive phosphate and silicate) were stored at -20 ºC and analyzed within one week following Strickland and Parsons (1972). The diffusive fluxes of ammonium nitrogen at the sediment-water interface were calculated using Fick's first law from concentration gradients in the interstitial waters and near-bottom waters (Bolalek and Graca, 1996; Feuillet-Girard *et al*., 1997) as the following:

$$\mathbf{J_x = -D_s \Phi_0 (C_x - C_0) x'^{-1}},$$

Where

J_x = diffusion flux at depth x (□mol cm^{-2} s^{-1}),
D_s = total sediment diffusion coefficient,
Φ_0 = sediment porosity,
$C_{x'}$ = concentration [□mol dm^{-3}] for X = x,'
C_0 = concentration [□mol dm^{-3}] for $X = 0$,
X = sediment depth (5 cm) (the negative sense towards the sediment).

Values of the total sediment diffusion coefficient were calculated using the equation (Krom and Berner 1980)

$$\mathbf{D_s^{sed} = D_s^0 / \Phi_0 F'},$$

Where

D_s^0 – water diffusion coefficient at infinite dilution [cm^{2}s^{-1}]
F' – the modified Krom and Berner (1980) ``formation factor, corrected for viscosity and deviation from the Archie relation $F' = \Phi^{-2.5}$
$D_s^0 = D_i^0 + 0.16\ (T\text{-}25^0C)$ (Li and Gregory, 1974).

3. Results and Discussion

The calculated flux values of nutrients (NH_4, NO_2, NO_3, PO_4; and SiO_4) in the grab sediment PW of Abu-Qir Bay were recorded in Table 2 and illustrated in Figure 2.

The nutrient flux (mg/m^2.day) estimated across all regions were followed, the concentration gradients. The negative sign means that the direction of fluxes occurred from sediment to the overlying bottom water and the most flux of nutrients occurred in one direction from sediment pore water (pw) to the overlying layer.

The absolute minimum and maximum values of fluxes were ranged from -0.147 to -42.533 mg/m^2.day NH_4-N in spring at stations 9 and 2 respectively for ammonium, from -0.002 mg/m^2.day NO_2-N in summer at stations 1 and 8, in autumn at stations 5 and 9 in winter at station 1 to 1.224 mg/m^2.day NO_2-N in winter at station 3 for nitrite, from 0.00 to 1.853 mg/m^2.day NO_3-N in winter at stations 6 and 3, respectively for nitrate, from -0.001 to -1.885 mg/m^2.day PO_4-P in spring and winter at stations 9 and 2, respectively for phosphate and from -0.062 to -7.912 mg/m^2.day SiO_4-Si in winter and spring at stations 1 and 2, respectively for silicate (Table 1).

The seasonal average values of nutrient fluxes were fluctuated between -9.507 to -12.177 mg/m^2.day NH_4-N in spring and winter for ammonium, -0.014 to 0.095 mg/m^2.day NO_2-N in summer and winter for nitrite, -0.007 to 0.204 mg/m^2.day NO_3-N in summer and winter for nitrate, -0.292 mg/m^2.day PO_4-P in spring and autumn to -0.445 mg/m^2.day PO_4-P in winter for

Table 1: Calculated diffusive fluxes of nutrient (mg/m^2.day) in Abu Qir Bay during 2004-2005

	NH4					NO2					NO3					PO4					SiO4				
Stations	Spring	Summer	Autumn	Winter	Regional	Spring	Summer	Autumn	Winter	Regional	Spring	Summer	Autumn	Winter	Regional	Spring	Summer	Autumn	Winter	Regional	Spring	Summer	Autumn	Winter	Regional
	2004			2005	average	2004			2005	average	2004			2005	average	2004			2005	average	2004			2005	average
1	-7.369	-3.444	-2.872	-2.828	-4.128	-0.019	-0.002	-0.010	-0.002	-0.008	0.023	-0.004	-0.026	-0.004	-0.003	-0.029	-0.095	-0.031	-0.062	-0.054	-0.859	-0.544	-0.603	0.062	-0.486
2	-42.533	-21.184	-37.847	-39.046	-35.152	-0.045	-0.015	-0.103	-0.154	-0.079	0.004	-0.024	-0.059	-0.017	-0.024	-0.564	-1.271	-0.770	-1.885	-1.122	-7.912	-6.175	-6.170	-4.033	-6.073
3	-11.345	-27.114	-29.876	-28.010	-24.086	-0.065	0.002	-0.065	1.224	0.274	-0.048	-0.020	-0.082	1.853	0.426	-1.595	-0.381	-1.266	-1.169	-1.103	-4.412	-5.621	-3.344	-6.110	-4.872
4	-12.161	-18.476	-13.840	-19.468	-15.986	-0.058	-0.027	-0.055	-0.123	-0.066	0.231	0.077	-0.012	0.075	0.093	-0.295	-0.628	-0.431	-0.728	-0.521	-1.392	-2.880	-1.515	-2.893	-2.170
5	-4.041	-6.071	-2.912	-1.828	-3.713	-0.050	-0.027	-0.002	-0.005	-0.021	0.079	-0.022	0.034	-0.009	0.020	-0.119	-0.366	-0.088	-0.045	-0.155	-0.347	-1.110	-0.936	-0.100	-0.623
6	-0.965	-1.775	-1.459	-4.625	-2.206	-0.023	-0.026	-0.011	-0.038	-0.024	0.010	0.005	0.002	0.000	0.004	-0.019	-0.051	-0.019	-0.081	-0.043	-0.403	-1.925	-0.398	-0.624	-0.837
7	-3.277	-2.895	-2.512	-5.401	-3.521	-0.027	-0.004	-0.009	-0.023	-0.016	-0.006	-0.013	0.001	-0.045	-0.016	-0.008	-0.024	-0.014	-0.005	-0.013	-0.495	-0.412	-0.301	0.226	-0.245
8	-3.724	-3.647	-2.769	-3.797	-3.484	-0.005	-0.002	-0.004	-0.005	-0.004	-0.012	-0.020	-0.004	-0.012	-0.012	-0.002	-0.004	-0.003	-0.002	-0.003	-0.167	-0.246	-0.356	-0.220	-0.247
9	-0.147	-2.660	-1.531	-4.590	-2.232	-0.012	-0.025	-0.002	-0.023	-0.016	-0.004	-0.042	0.007	-0.001	-0.010	-0.001	-0.017	-0.006	-0.026	-0.012	-0.145	-0.497	-0.233	-0.608	-0.370
Average	-9.507	-9.696	-10.624	-12.177	-10.501	-0.034	-0.014	-0.029	0.095	0.004	0.031	-0.007	-0.015	0.204	0.053	-0.292	-0.315	-0.292	-0.445	-0.336	-1.793	-2.157	-1.539	-1.589	-1.769

Table 2: Correlation matrix between diffusion fluxes of nutrient salts and properties of sediment in Abu Qir Bay during 2004-2005

	porosity	*Eh*	*WC*	*NH4*	*NO2*	*NO3*	*PO4*	*SiO4*
porosity	1							
Eh	-0.4948	1						
WC	0.909656	-0.65118	1					
NH4	-0.84342	0.406583	-0.83384	1				
NO2	0.163445	-0.19786	0.243817	-0.13525	1			
NO3	0.256884	-0.29409	0.321749	-0.22823	0.969722	1		
PO4	-0.78242	0.465125	-0.79935	0.766771	-0.16039	-0.25076	1	
SiO4	-0.88357	0.414212	-0.89204	0.900185	-0.25462	-0.31071	0.749872	1

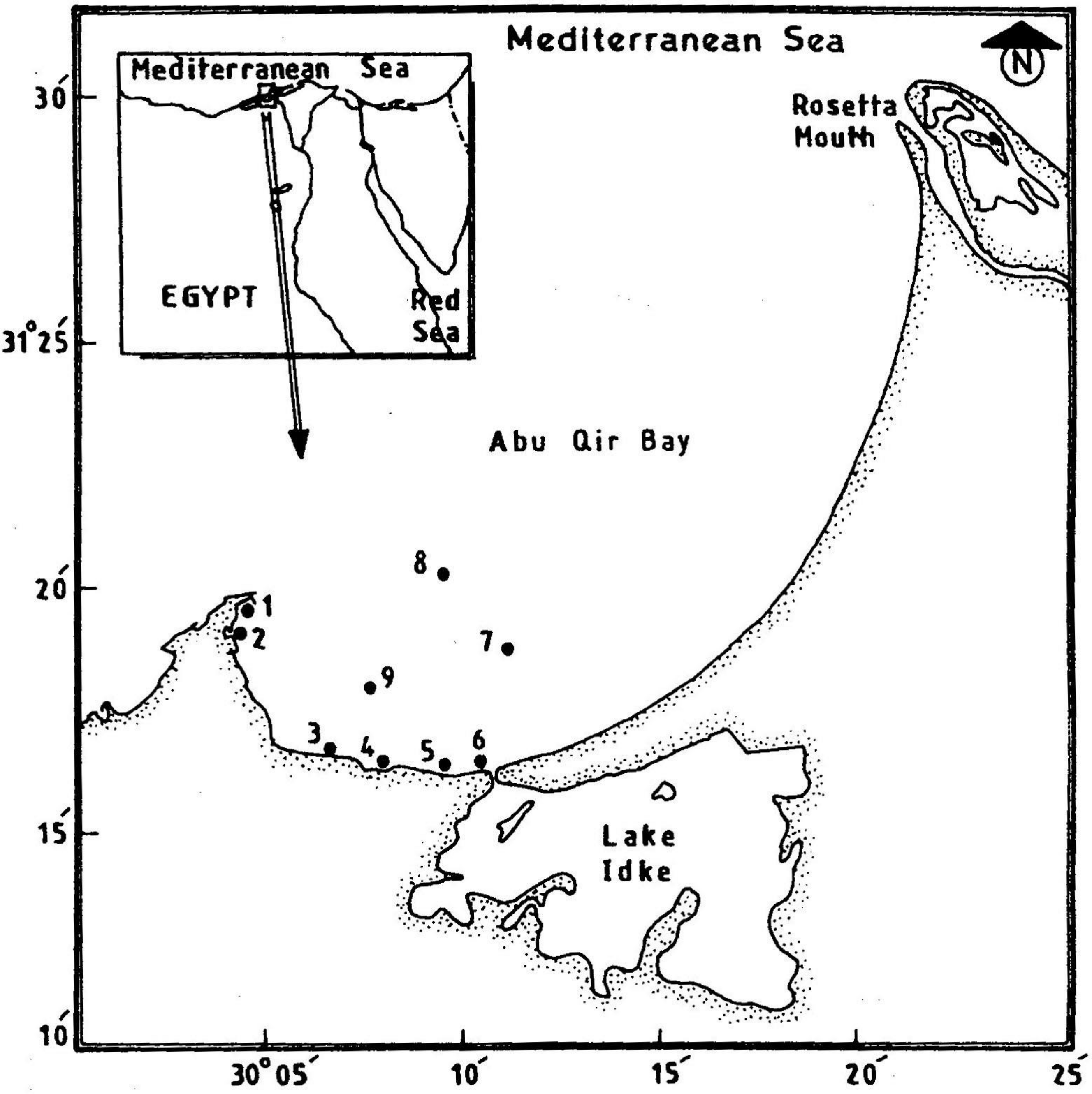

Figure 1: Map showing the sampling sites of Abu-Qir Bay southwestern area collected during 2004-2005.

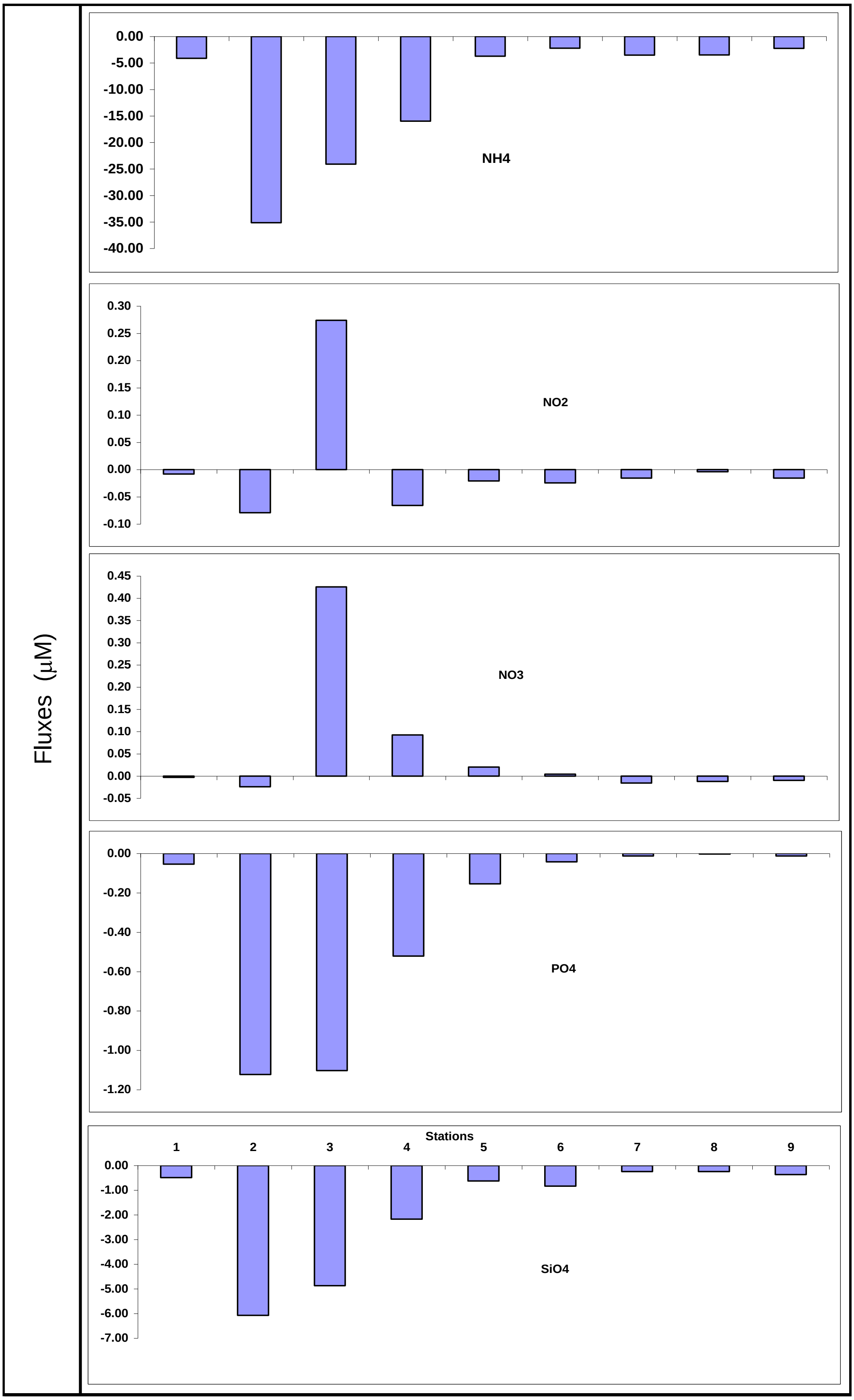

Figure 2: Regional average values of nutrient fluxes in Abu Qir Bay during 2004-2005

phosphate and -1.539 to -2.157 mg/m^2.day SiO_4-Si in autumn and summer for silicate.

The regional average values of flux in the grab sediment PW fluctuated between -2.206 and -35.152 mg/m^2.day NH_4-N at stations 6 and 2, for ammonium, -0.004 and 0.274 mg/m^2.day NO_2-N at stations 8 and 3 for nitrite, -0.003 and 0.426 mg/m^2.day NO_3-N at stations 3 and 1 for nitrate, -0.003 and -1.122 mg/m^2.day PO_4-P at stations 8 and 2 for phosphate, and -0.245 and -6.073 mg/m^2.day SiO_4-Si at stations 7 and 2 for silicate.

Based on the absolute maximum values and regional average values of all nutrient fluxes, it is easy to noticeable that stations 2 and 3 are highly polluted in consistence with their sediment type (silty –clay), their depth and stagnant conditions of water.

Generally, low NH_4 concentrations and low values of ammonium fluxes from sandy sediments may suggest that the ammonification in this type of sediments is negligible. However, low ammonium concentrations and fluxes may have been caused by the fact that part of the NH_4 produced in sandy sediments was immediately oxidized to nitrates during nitrification. Canfield *et al.* (1993) emphasized that, even if ammonium concentrations are low, ammonification and nitrate reduction are relatively intense in sandy sediments. They added that, the factors affecting nutrient diffusion across sediment / water interface include bioterbation, nitrification, denitrification, adsorption, dissolution and sediment porosity. Phosphate registered an increased with depth in PW.

Diffusive fluxes of the nutrients always move in the direction from the sediment into the water column and it was significantly different in relation to sampling station and sediment type. Their values were the highest in sediment of high silty-clay fraction. Brossard and Jankowska (2001) pointed out that NH_4 released, intensified in all sediments simultaneously as the temperature of the near-bottom water increased as a result of intensified ammonification and nitrate reduction. Lerat *et al*. (1990) registered a strong negative correlation between ammonium fluxes and DO concentration in the near-bottom waters. It seems therefore, that released ammonium may not indicate only intensifying ammonification of organic matter in the sediments, but may also reflect the less important role of nitrification, which results from a decreasing oxygen concentration.

The rapid decrease of phosphate at the sediment / water interface could be a result of redox- dependent retention and accumulation of phosphate by sorption onto ferric oxyhydroxides and carbonates **(**Liu *et al.*, 2003) or a formation of insoluble Fe/Al-phosphate complexes, pore water silicate concentrations at the sediment /water interface indicate diffusion of silicate from sediment to the overlying seawater. The PO_4 flux may affect by authentic mineral precipitation and the SiO_4 flux may also be affected by dissolution rate constant. The regeneration rate of phosphate is relatively slower to that DIN and silicate coincided with the adsorption of phosphate in the oxic environment. The diagenetic model calculation demonstrates that bioturbation and porosity obviously influenced the benthic nutrient fluxes. The relatively decreased in fluxes of silica and particles due to dam construction has changed the structure of aquatic ecosystems and accelerated coastal erosion (Billen *et al.*, 1991; Jorgensen & Richardson, 1996 and Humborg *et al.*, 1997). The construction of Aswan High Dam has decreased the transport of sediment and dissolved silica from river into the sea . As a result, the silicon to nitrogen ratio has changed. This change in the nutrient supply has shifted the composition of phytoplankton from diatom communities (silicious algae) towards nanoplanktonic species for the benefit of dinoflagellates and coccolithophores (Bodeanu, 1992; Humborg *et al.*, 1997).They lead to severe changes in the structure and functioning of the planktonic food-web, with an explosive development of opportunistic gelatinous organisms (jelly fishes, dinofllagellates) that are of negligible food value (Mee, 1992).

Moreover all nutrient fluxes were correlated with porosity, Eh and water content of the sediment (Table 2).

4. Conclusion

The benthic fluxes lead to a considerable increase in the concentrations of nitrate, ammonium, phosphate and silicate in the corresponding overlying water column. This could be responsible for the increasing fertility of the investigated regions rather than those of the anthropogenic effects. Factors affecting the mechanism of nutrient diffusion were concentration gradients, bioturbation and porosity obviously influenced the benthic nutrient fluxes. Processes involved in the nutrients transfer are reversible quick, and differ with season and sediment type.

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