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Changes in Sedimentary Biogenic Elements in the Burullus Wetland, Egypt: Impact of Human Activities Over a Century

Alaa Salem[1*], Maotian Li[2], Liu Yan[2], Xiaoshuang Zhao[2], Abd El-Mohsen S. El Daba[3], Aziz M. Abu Shama[1], Mohamed M. Elhossainy[1], Chen Zhongyuan[2]
[1]Faculty of Science, Kafrelsheikh University, 33516 Kafrelsheikh, Egypt
[2]State Key Laboratory of Estuarine Coastal Science, East China Normal University, Shanghai 200062, China
[3]National Institute of Oceanography and Fisheries, Red Sea Branch, Egypt
***Corresponding Author: alaa.salem@sci.kfs.edu.eg**

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ABSTRACT
Burullus, a highly enclosed wetland at the mouth of the River Nile, receives biogenic elements primarily from the Nile River and serves as an ideal area for studying how changes in the watershed, particularly since the construction of the Aswan Dam, have impacted the estuarine lakes' environment. This study aimed to reveal the differences in nutrient salt levels in the estuarine lakes before and after the Aswan Dam's construction, as well as addressing the effects of these changes on the ecological environment through ^{210}Pb dating of Burullus Lagoon B1 cores, combined with testing and analyzing the total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), and biogenic silica (BSi), alongside the historical data. Theresults showed that sedimentary TOC, TN, and TP contents generally increased from bottom to top. This indicatesthat despite the significant reduction in nutrient fluxes due to the Aswan Dam, nitrogen (N) and phosphorus (P) concentrations in downstream lakes did not decrease owing to the substantial increase in N and P inputs from human discharges downstream, and that sedimentary TN/TP ratios were all below 16, suggesting that the lakes remained phosphorus-limited. While, the biogenic silica (BSi) and the BSi/TOC ratio both showed a decreasing trend from bottom to top, indicating that the reduction of water and sediment caused by the Aswan Dam has led to a decline in diatom biomass and their overall contribution to primary productivity in the wetland, suggesting that the ecological environment may deteriorate over time.

INTRODUCTION

The impact of changes in fluxes and proportions of land-derived materials from rivers on estuarine and offshore ecosystems has been one of the hot spots in global change research **(Ran *et al*., 2009)**. Nutrients such as nitrogen (N), phosphorus (P) and silicon (Si) are essential biogenic elements in estuarine and marine ecosystem **(Gong *et al*., 2011)**, and riverine inputs are the most important source. However, the filter effect of dam construction in the basin has increasingly interfered with the transport of biogenic substances to the sea over the past 100 years **(Li *et al*., 2014)**, e.g., the three reservoirs in the upper Seine River trapped upstream (**Jossette *et al*., 1999**); the DSi flux from the Danube to the Black Sea was reduced by 80% after the completion of the Iron Gate Dam (**Humborg *et al*., 2000**), and the dissolved silicon (DSi) content in the Yangtze estuary was reduced by about 63.37% after the Three Gorges Project impoundment **(Li *et al*., 2014)**. In addition, although the filter effect of reservoirs retains a large amount of N and P, the dramatic increase of agricultural fertilization and domestic sewage discharge in the basin, especially downstream of the dams, has led to a rapid increase of N and P fluxes in the middle and lower reaches of many basins instead of reducing them. For example, the N and P fluxes into the sea of the Yangtze River have increased 5-6 times in the past 60 years, leading to the increasing eutrophication of estuarine and offshore water bodies and the increasing red tide disasters (**Li *et al*., 2015; Liu, 2017**).

The reduction of water, sediment and nutrient fluxes brought by this reservoir retention effect and the increase of nutrient fluxes caused by human discharges in the basin have led to dramatic changes in nutrient fluxes and ratios, profoundly altering the nutrient concentration levels and natural structure of the downstream and estuarine offshore, causing increased ecological variability and vulnerability, and seriously endangering the sustainable development of regional resources and environment **(Li *et al*., 2014; Zhou *et al*., 2018)**. Therefore, the study of the effects of reservoirization and human discharge on watershed-estuarine resources and environment and their mechanisms has become one of the scientific problems that are researched and urgently needed to be solved at home and abroad. Most of the current studies generally focus on the characteristics of basin-estuary impacts of changes in basin-inlet material fluxes **(Chen & Chen, 2002; Meng *et al*., 2005)**, but changes in inlet material fluxes are the common result of reservoirization and human discharge, and such changes vary greatly from basin to basin, and how to screen the impacts and mechanisms of reservoirization and human discharge on basin-estuary ecology and environment, respectively, is a difficult problem in current studies of basin-estuary environmental changes.

Burullus is a highly enclosed lagoon at the mouth of the Nile River, with its biogenic elements primarily derived from the Nile. Following the completion of the Aswan Dam in 1965, 90% of water, 98% of sand, and 95% of dissolved silica (DSi) fluxes were reduced **(Ye *et al.*, 2003; Marin *et al.*, 2007; Li *et al.*, 2016)**, while agricultural and domestic wastewater discharges around the lagoon increased significantly **(Herelier *et al.*, 2010; Ji *et al.*, 2018)**.

Therefore, the Burullus Lagoon is the best area to screen the impact of reservoirization and human discharge on the estuarine ecosystem, respectively. In this paper, we used total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP) and biogenic silica (BSi) indicators from a shallow sediment column in the Burullus Lagoon, together with a chronological framework constructed from ^{210}Pb dating, to study the impact of reservoirization and human discharge on the estuary. The chronological framework was used to study the changes in nutrient content before and after the construction of Aswan Dam and to further reveal the anthropogenic influences behind the changes.

MATERIALS AND METHODS

Sample collection: An 85-cm-long column sample was collected using a gravity piston sampling tube at point B1 (31°26′N, 30°43′E) in Burullus Lagoon, Egypt, in October 2017 (Fig. 1), and the column samples were divided at 1-cm intervals in the laboratory of the Faculty of Geosciences, Kafresheikh University, and then stored in self-sealing bags under refrigeration. The samples were then brought back to the Institute of Estuarine and Coastal Sciences of East China Normal University for freezing.

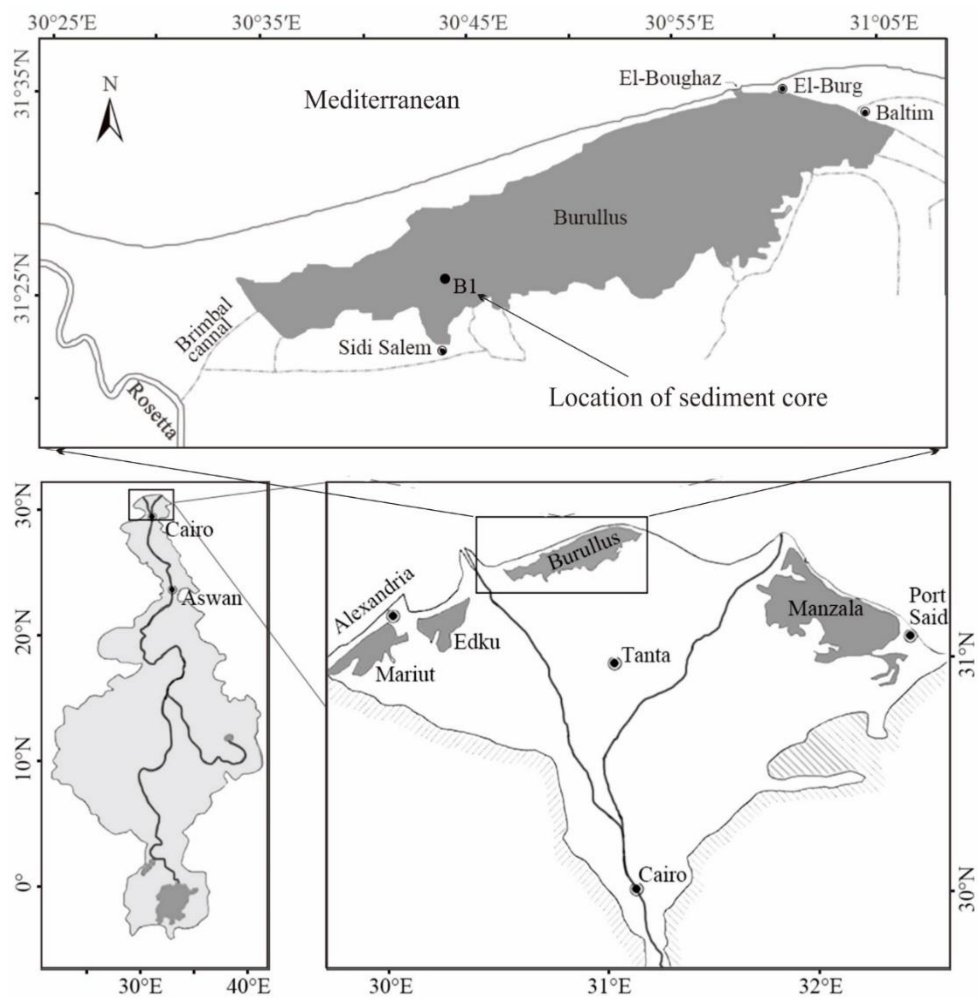

Fig. 1. Study area and sampling location map

Sample analysis: ^{210}Pb dating: According to the dating requirements of continuous deposition, homogeneous lithology, fine grains and low bioturbation **(Shaltout & Khalil,**

2005; Zalat & Vildary, 2005), we selected 28 samples from different depths for testing and analysis. The samples were dried at low temperature, ground and sieved through 100 mesh, then weighed 5g into test tubes and the openings were treated with sealing wax and left for 3 weeks to allow the radiometric energy to reach equilibrium. Subsequently, the samples were sent to the State Key Laboratory of Lake and Environment, Nanjing Institute of Geography and Lakes, Chinese Academy of Sciences, for determination using a high-purity germanium well detector (Ortec HPGe GWL) γ-spectrometer. The ^{210}Pb standard sample was provided by the University of Liverpool, UK, as a comparison standard, and the ^{226}Ra standard sample was provided by the China Institute of Atomic Energy. The CRS model was chosen to calculate the sediment ages of different layers in this study **(Coutellie & Stanley, 1987; El-shinnawy 2003)**.

TOC and TN analysis: Approximately 1g of each sample was weighed, dried at 40℃, and passed through an 80-mesh sieve. The samples were then soaked in 10% HCl to remove carbonates, rinsed with ultrapure water until neutral, and dried again at 40℃. A subsample weighing 0.03–0.04g was wrapped in tin foil and analyzed using a Vario Macro CNS elemental analyzer. The standard deviation of the test was less than 0.1%, and the recovery rate was above 99.5%. The detection limits were 0.0004mg for carbon (C) and 0.0001mg for nitrogen (N).

BSi analysis: Approximately 45mg of each sample was weighed, dried at 40℃, and passed through an 80-mesh sieve. The sample was placed in a 50mL round-bottom plastic centrifuge tube, treated with 10% H_2O_2 and 10% HCl to remove organic matter and carbonates, rinsed with ultrapure water until nearly neutral, and dried in a 60℃ oven for 12 hours. The sample was then treated with 30mL of 1mol/ L Na_2CO_3 solution and incubated at 85℃. The centrifuge tube was then wrapped with insulation cotton, and centrifuged at 4000r/ min for 5 minutes. From the supernatant, 0.2mL was taken and diluted with ultrapure water to 25mL in a separate 50mL centrifuge tube. The concentration of biogenic silica (BSi) was determined using the silicomolybdenum blue method, and the BSi content in the sample was calculated.

TP analysis: Samples were sent to the State Key Laboratory of Loess and Quaternary Geology at the Xi'an Institute of Earth Environment, Chinese Academy of Sciences, for testing using an Axios Advanced PW4400 X-ray fluorescence spectrometer. The relative deviation of the test was less than 2%, and the recovery rate exceeded 98%.

RESULTS

1. ^{210}Pb dating

The excess of B1 core sediment ^{210}Pb (^{210}Pbex) shows a significant exponential decay with increasing depth and reaches equilibrium at the bottom. CRS model calculations indicate that the sediment age is approximately 1932 at 74cm, 1964 at 57cm, the year of Aswan Dam closure, and 2008 at 13cm (Fig. 2).

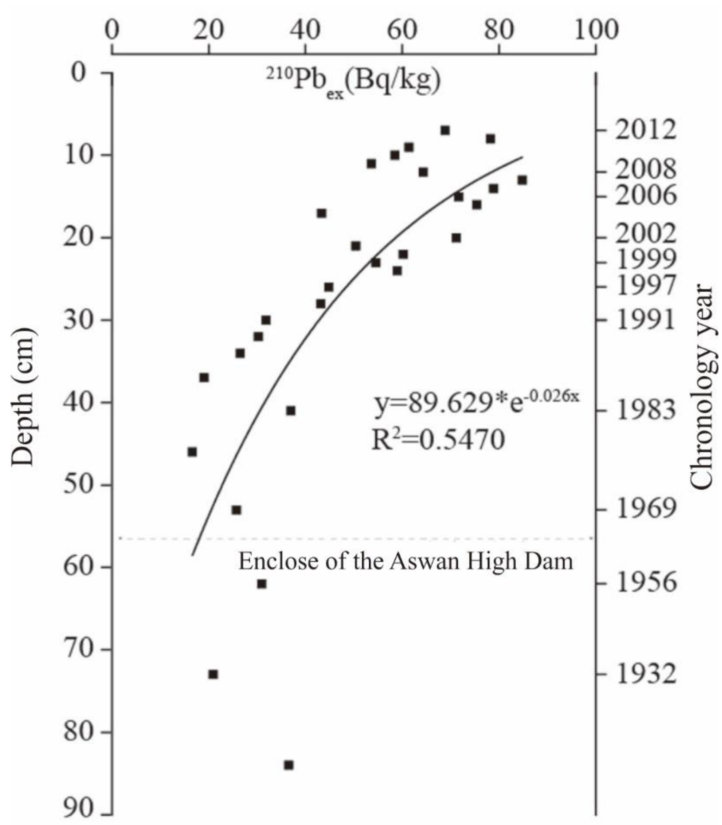

Fig. 2. B1 core $^{210}Pb_{ex}$ - depth and chronological framework map

2. Changes in biogenic elements

From bottom to top, the contents of carbon (C), nitrogen (N), and phosphorus (P) increased, while silica (Si) content decreased. Specifically, total organic carbon (TOC), total nitrogen (TN), and total phosphorus (TP) showed a significant upward trend around the 60cm mark. Below 60cm, the average TOC, TN, and TP contents were 3.18, 0.21, and 0.049%, respectively. Above 60cm, these values increased to 4.46, 0.29, and 0.068%, representing increases of 40, 38, and 39%, respectively (Fig. 3).

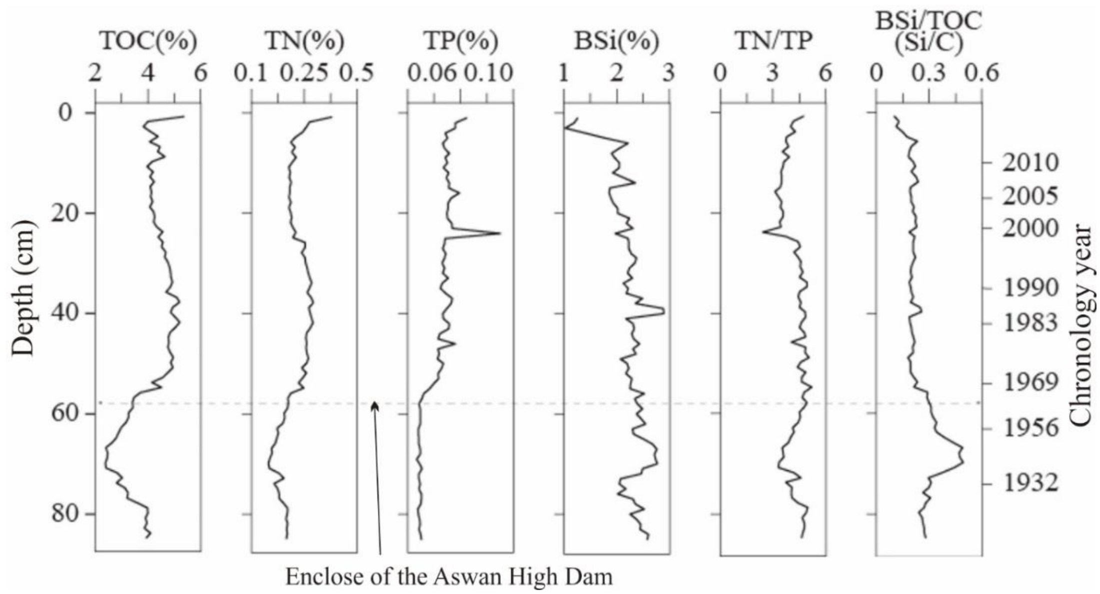

Fig. 3. Plot of vertical variation of raw elements and inter-element ratios in core B1 (dashed line indicates Aswan High Dam closure). Vertical variation of nutrients and their ratios in B1 core. (The dotted line indicates the closing time of Aswan High Dam).

The BSi content showed a clear trend of decrease from the bottom to the top. It gradually decreased from 2.60% below 1.26% in the surface layer, and from a mean value of 2.44% below 60cm to a mean value of 2.16% above 60cm, a decrease of nearly 12% (Fig. 3).

The TN/TP ratio showed a stable trend from the bottom to the top in general, and the ratios were all less than 6. The BSi/TOC ratio showed a significant decreasing trend from the bottom to the top, decreasing from 0.66 in the lower part to 0.24 in the surface layer (Fig. 3).

DISCUSSION

1. Effects of dams and human discharges on lagoon's TOC, TN and TP

The result that sedimentary TOC, TN, and TP in Burullus Lagoon all increased after the construction of Aswan Dam (Fig. 3) indicates that the concentrations of TOC, TN, and TP in Burullus Lagoon waters have been generally increasing for nearly 100 years. This increasing trend is clearly opposite to the trend of nutrient retention and flux reduction due to the basin reservoirs. For example, after the construction of Aswan Dam, N and P in downstream runoff decreased from 6700t and 3200t per year to 200t and 30t per year, and more than 98% of sediment was trapped in front of the dam **(Ye *et al.*, 2003)**, and sediment adsorbed P also decreased from 4000t~8000t per year to nearly 0t per year **(Marin *et al.*, 2007)**. The Nile estuary and offshore N and P contents also showed a precipitous decrease after the construction of the dam **(Ludwing *et al.*, 2009)** (Fig. 4-A). Therefore, the primary source of the increased TOC, TN, and TP concentrations in the waters of Burullus Lagoon is likely the growing nutrient influx from human discharges.

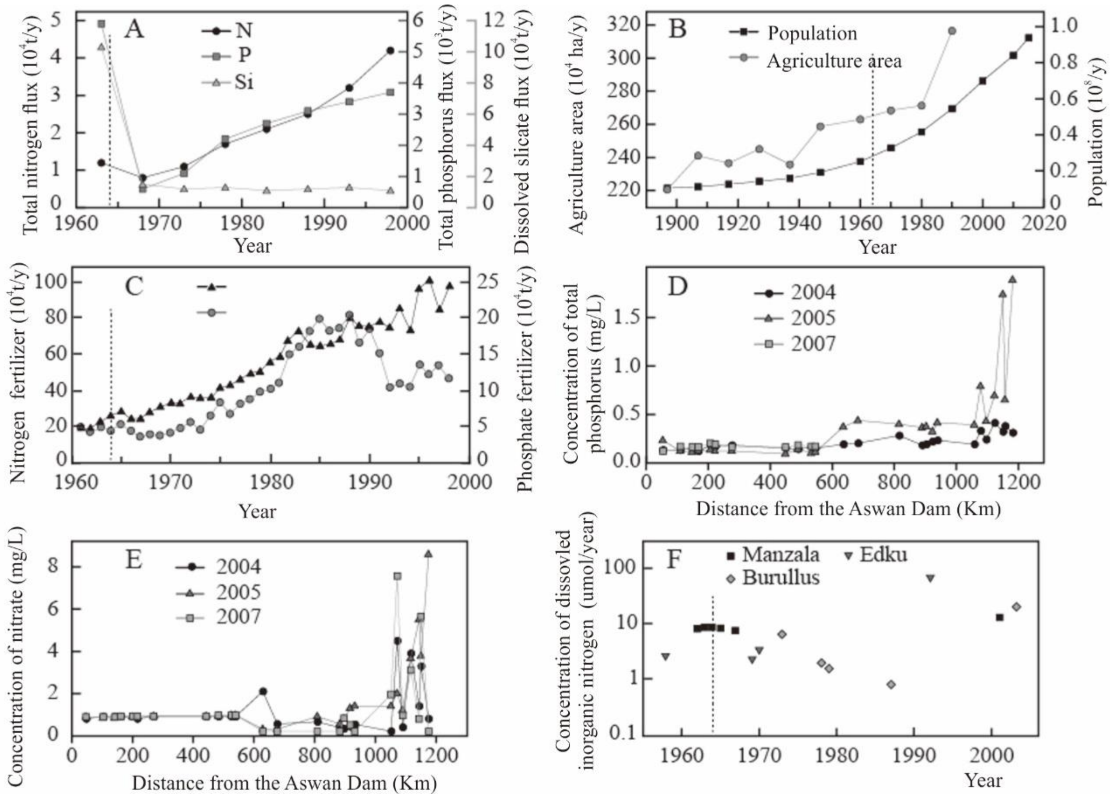

Fig. 4. Map of changes in nutrient levels in the Nile and offshore waters and changes in population and arable land in Egypt (dashed line represents Aswan Dam closure) **A.** Changes in N, P, and Si levels in the eastern Mediterranean Sea, each data point representing a 5-year average **(Ludwing *et al*., 2009)**. **B.** Changes in population and arable land area in Egypt **(Dumont & El-shabrawy, 2007)**. **C.** Changes in nitrogen and phosphorus fertilizer application in Egypt in tons of P O_{25} for phosphorus and tons of nitrogen **(Nixon 2003)**. **D.** Changes in TP concentrations in runoff below Aswan Dam for different years versus distance from Aswan Dam. **E.** Changes in nitrate concentrations in runoff below Aswan Dam for different years versus distance from Aswan Dam. Variation in nitrate concentration in runoff below Aswan Dam for different years versus distance from Aswan Dam. **F.** Variation in DIN levels in Manzala, Burullus, Edku lagoons, Egypt **(Oczkowski & Nixon, 2008)**.

Since the construction of the Aswan Dam, due to the rapid increase in both population and arable land area in Egypt **(Dumont & El-shabrawy, 2007)** (Fig. 4-B), the fertilizer application and domestic sewage discharge also increased rapidly **(Marin *et al*., 2007**) (Fig. 4-C), resulting in a dramatic increase in human discharges of nutrient fluxes, especially in the delta region, which accounts for nearly half of the country's population, where human discharges of nutrient concentrations are nearly four times higher than those in the upstream region (Fig. 4-D, E). In particular, the potential N and P content of domestic sewage discharges in the Greater Cairo and Alexandria areas increased from 5,000t and 1,100t in 1965 to 65,000t and 9,500t in 1995, respectively **(Marin *et al*., 2007)**, and this part of domestic sewage alone has approached the total amount of N and P brought by the Nile runoff each year before the dam was built. It is the continuous increase of human discharges of N and P in the basin, especially in the Nile Delta region in the last hundred years; this has led to the overall increasing concentrations of TOC, TN and TP in the water bodies of Burullus Lagoon. This is also the reason why the inorganic nitrogen (DIN) levels in the two neighboring lagoons (Manzala and Edku) are higher than the pre-dam levels **(Nixon 2003)** (Fig. 4-F), and the continued increase in N and P has contributed to the continued increase in algal productivity (TOC) (Fig. 3).

The TN/TP ratio can determine whether the sediment is N-limited or P-limited, and if the ratio is less than 16, it is P-limited **(Oczkowski & Nixon, 2008)**. The result that the TN/TP ratio is stable from bottom to top and the ratios are all less than 16 (Fig. 3) indicates a clear P-limitation in Burullus Lagoon.

2. Effect of dams on lagoon's BSi

The result of a continuous decreasing trend of sedimentary BSi in Burullus Lagoon after the construction of Aswan Dam (Fig. 3) indicates that DSi concentrations in Burullus Lagoon waters have been decreasing for nearly 100 years. This decreasing trend is consistent with the trend of DSi retention and flux reduction due to Naser reservoir after the construction of the dam. For example, before the construction of Aswan Dam, the Nile River used to deliver about 110,000*t* of Si per year to the Egyptian Mediterranean Sea and coastal lagoons, etc., promoting diatom blooms in the aforementioned waters **(Marin *et al*., 2007)**, resulting in high sedimentary BSi levels in the lagoon (Fig. 3). However, after the construction of the Aswan Dam, the DSi concentration in the Nile estuary decreased by 200μmol/ L, a reduction of about 95% **(Li *et al*., 2016)**. The Si content in the Nile estuary and offshore decreased from more than 100,000*t* to less than 10,000*t* before and after the construction of the dam **(Ludwing *et al*., 2009)** (Fig. 4-A), resulting in a significant Si-limited state in the estuary and offshore **(Ludwing *et al*., 2009)**. Since DSi is mainly derived from natural weathering input from the watershed, unlike the large anthropogenic input of N and P, the decrease of BSi in Burullus Lagoon is mainly caused by water and sand retention by the upstream dams and the retention of DSi by the reservoir.

The BSi/TOC ratio can better reflect the contribution of diatoms to total primary productivity, the higher the ratio, the greater the contribution of diatoms. The bottom-up BSi/TOC ratio showed a clear decreasing trend (Fig. 3), indicating that the reduction of sediment caused by the construction of Aswan Dam and the retention of DSi in the reservoir did cause a gradual decrease of diatom biomass and its ratio to total primary productivity in Burullus Lagoon. The absence of DSi will cause changes in the structure and ratio of nutrients in the water column, which will lead to phytoplankton shift from diatom to non-diatom primary productivity in the long run, and this is detrimental to the healthy development of the whole water body ecosystem.

CONCLUSION

The construction of the Aswan Dam and human discharges in the lower basin have significantly different effects on controlling the evolution of different nutrients in the Nile Delta lagoons.

Although Aswan Dam retains large amounts of N and P, the surge in downstream human discharge of N and P fluxes has led to an overall increase in sedimentary TOC, TN and TP in Burullus Lagoon over the last 100 years. However, since DSi is mainly a natural weathering input from the watershed, the retention of DSi by Aswan Dam has led to a continuous decrease in sedimentary BSi and BSi/ TOC in Burullus Lagoon, i.e., it has resulted in a decrease in the biomass of diatoms and their share of total primary productivity in the lagoon and a shift from diatom to non-diatom communities, causing a deterioration of the water column ecology.

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REFERENCES

Chen, S. L. and Chen, J. Y. (2002). Estuarine and coastal challenges in China. Chinese Journal of Oceanology and Limnology, 20: 174-181.

Coutellier, V. and Stanley, D. J. (1987). Late Quaternary stratigraphy and paleogeography of the eastern Nile Delta, Egypt. Marine geology, 77(3-4): 257-275.

Dumont, H. J. and El-Shabrawy, G. M. (2007). Lake Borullus of the Nile Delta: a short history and an uncertain future. Journal of the Human Environment, 36(8): 677-682.

El-Shinnawy, I. A. (2003). Reservoir hydrologic routing for water balance of Al-Burullus wetland, Egypt. Proceedings of the Seventh International Water Technology Conference IWTC7: 867-877.

Humborg, C.; Conley, D. J.; Rahm, L.; Wulff, F.; Cociasu, A. and Ittekkot, V. (2000). Silicon retention in river basins: far-reaching effects on biogeochemistry and aquatic food webs in coastal marine environments. Journal of the Human Environment, 29(1): 45-50.

Ji, J.; Zeng, L.; Bian, H. and Chen, X. (2018). Variations in sedimentary nitrogen, phosphorus and silicon and regional environmental changes in East Dongting Lake in recent 50 years. Quaternary Sciences, 38(4): 1017-1023.

Jossette, G.; Leporcq, B.; Sanchez, N. and Philippon. (1999). Biogeochemical mass-balances (C, N, P, Si) in three large reservoirs of the Seine Basin, France. Biogeochemistry, 47: 119-146.

Li, L.; Wang Y. L. and Jiang, M. E. (2014). Characteristics of changes in dissolved silicate (DSi) and nutrient structure in the Yangtze River estuary after water storage of the Three Gorges Project and analysis of their ecological impacts. J. Environmental Chemistry, 33(1): 135-141.

Li, M. T.; Sun, Q. L. and Wang, H. (2014). The filter effect of big reservoirs on dissolved silicate flux decrease in the Yangtze River drainage basin. Journal of Lake Sciences, 26(4): 505-514.

Li, M. T.; Chen, Z.; Finlayson, B.; Yuan, W. T.; Chen, J.; C. J.; Dan, W. X. and Wang, M. (2015). Water diversion and sea-level rise: potential threats to freshwater supplies in the Changjiang River estuary. Estuarine, Coastal and Shelf Science, 156: 52-60.

Li, M.; Wang, H.; Li, Y.; Ai, W.; Hou, L. and Chen, Z. (2016). Sedimentary BSi and TOC quantifies the degradation of the Changjiang Estuary, China, from river basin alteration and warming SST. Estuarine, Coastal and Shelf Science, 183: 392-401.

Liu, N. N. (2017). Progress of research on dam construction and nutrient transport in the Yangtze River basin in the last 50 years. J. Environmental Chemistry, 36(7): 1579-1587.

Marin, A.; Montoya, S.; Vita, R.; Marín-Guirao, L.; Lloret, J. and Aguado, F. (2007). Utility of sea urchin embryo–larval bioassays for assessing the environmental impact of marine fishcage farming. Aquaculture, 271(1-4): 286-297.

Meng, X.; Liu, Y. and Wang, X. (2005). Response of river fluxes to sea and land environmental changes. Advances in Marine Science, 23(4): 391-397.

Oczkowski, A. and Nixon, S. (2008). Increasing nutrient concentrations and the rise and fall of a coastal fishery, a review of data from the Nile Delta, Egypt. Estuarine, Coastal and Shelf Science, 77(3): 309-319.

Ran, X.; Yu, Z. and Yao, Q. (2009). Research progress on reservoir effects on nutrient retention in rivers. Journal of Lake Sciences, 21(5): 614-622.

Shaltout, K. H.; Khalil, M. T. and Al-Sodany, Y. M. (2005). Lake Burullus: Burullus protected area. Publication of National Biodiversity Unit, (13): Egyptian Environmental Affairs Agency, Egypt, 578 pp.

Ye, X.; Liu, S. and Zhang, J. (2003). The determination of biogenic silica and its biogeochemistry significance. Advances in Earth Science, 18(3): 420-426.

Zalat, A. and Vildary, S. S. (2005). Distribution of diatom assemblages and their relationship to environmental variables in the surface sediments of three northern Egyptian lakes. Journal of Paleolimnology, 34: 159-174.

Zhou, J. J.; Zhang, M. and Li, Z. (2018). Altered phosphorus fluxes, effects and remediation measures in the upper Yangtze River reservoirs in the mainstem. Journal of Lake Sciences, 30(4): 865-880.