Oceanologia 64 (2022) 287—298

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.journals.elsevier.com/oceanologia

ORIGINAL RESEARCH ARTICLE

Distribution and ecological risk evaluation of bioavailable phosphorus in sediments of El Temsah Lake, Suez Canal

Alaa M. Younis[a], **Naglaa F. Soliman**[b,c,*], **Eman M. Elkady**[d], **Lamiaa I. Mohamedein**[d]

[a] *Department of Aquatic Environment, Faculty of Fish Resources, Suez University, Suez, Egypt*
[b] *Department of Environmental Studies, Institute of Graduate Studies & Research — Alexandria University, Egypt*
[c] *Basic and Applied Science Institute, Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt*
[d] *National Institute of Oceanography & Fisheries (NIOF), Suez, Egypt*

Received 23 March 2021; accepted 3 December 2021
Available online 17 December 2021

KEYWORDS
Sediments;
Bioavailable phosphorus;
Chemical extraction methods;
Phosphorus ecological risk;
El Temsah Lake;
Egypt

Abstract Phosphorus reactivity and bioavailability in lake sediments is determined by diverse fractions of phosphorus (P) and their distribution. To gain deeper insights into P dynamics in Lakes, sediments from El Temsah Lake were investigated for water soluble P (WSP), readily desorbable P (RDP), algal available P (AAP) and Olsen-P using different chemical extraction methods. Total P (TP), organic P (OP), inorganic P (IP) contents, were also investigated. The TP, OP and IP concentrations in the sediments were 598.39 μg/g, 199.76 μg/g and 398.63 μg/g, correspondingly. Concentrations of the bioavailable P in the sediments followed the order AAP (48.42 μg/g)>WSP (14.60 μg/g)>RDP (1.82 μg/g)>Olsen-P (1.50 μg/g). Pearson correlation analysis exposed that there were significant correlations among the bioavailable P fractions concentrations and the TP concentrations (r=0.83; $p>0.01$, r=0.94; $p>0.01$, r=0.62; $p>0.05$); for WSP, AAP, and Olsen-P respectively. Moreover, there were no obvious associations amongst total P and N, Al, Ca, Fe, Mg, Mn, and OM in the sediments. The outcomes of phosphorus ecological risk assessment in sediments by single pollution standard index method revealed that the standard index of TP varied from 0.19 to 1.85. It demonstrated that the ecological pollution risks of phosphorus in El Temsah Lake sediments was comparatively low.

* Corresponding author at: Basic and Applied Science Institute, Egypt-Japan University of Science and Technology (E-JUST) campus, P.O. Box 179, New Borg El-Arab City, Postal Code 21934, Alexandria, Egypt. Telephone: +201004830165; fax: +2034251038.
E-mail address: naglaa_farag2007@yahoo.com (N.F. Soliman).
Peer review under the responsibility of the Institute of Oceanology of the Polish Academy of Sciences.

Production and hosting by Elsevier

https://doi.org/10.1016/j.oceano.2021.12.001

1. Introduction

Phosphorus (P) has a crucial role in defining the function and productivity of the ecosystems. Sediments and soils embrace considerable amounts of inorganic, organic and microbial P. Therefore, phosphorus dynamics are managed by chemical and biological properties and processes (Reddy et al., 2005). Phosphorus is existing in the sediment matrix in the formulas of aluminum, calcium, iron complex salts and organic species, or adsorbed on the surface minerals (Pettersson et al., 1988). The quantity of mobile or bioavailable P in the sediments is a significant sign for supposing impending internal loading and the discharge to the water column (Rydin, 2000). In this context, it is requisite to identify not only the total P level in the sediments but also the levels of diverse P forms (Aydin et al., 2009).

A valuable way to appraise the stock of possibly available fractions is to fractionate P depending on the extractability by leaching chemicals of accumulative aggressiveness (Perkins and Underwood, 2001; Tiyapongpattana et al., 2004). Chemical sequential extractions have been projected to designate the several fractions in which phosphorus presents in the sediment (Psenner and Pucsko, 1988; Ruban et al., 1999; Ruttenberg, 1992). The chemical sequential extraction methods for P fractions in sediment are complicated and inefficient. The bioavailable P levels in lake sediments may be simply considered by quantifying the levels of readily desorbable P (RDP), water soluble P (WSP), algal available P (AAP), or $NaHCO_3$ extractable P (Olsen-P) (Zhou et al., 2001) than by P fractions as labile P, reductant P, metal bound P, occluded P and organic P (Soliman et al., 2017; Wang et al., 2010). These fractions of P in lake sediments were extensively considered by several investigators (Bo et al., 2014; Dapeng et al., 2011; Okbah, 2006; Soliman et al., 2017; Wang et al., 2010; Zhou et al., 2001; Zhu et al., 2013) and can be, easily analyzed by diverse chemical extraction methods (Zhou et al. 2001).

To the best of our knowledge, this corresponds to the first study to relate phosphorus fractionation to scrutinize its probable bioavailability in El Temsah Lake sediments. So, the leading objectives of the present study is to (1) appraise the spatial variability in total and bioavailable phosphorus levels in El Temsah Lake sediment, (2) evaluate the ecological risk of P, (3) recognize the relationship between P and various sedimentary parameters. Phosphorus fractions were also appraised in relative to the levels of the most important P binding elements Al, Ca, Fe, Mg, and Mn, along with other sediment physicochemical characteristics.

2. Material and methods

2.1. Sampling and study area

El Temsah Lake is the backbone of the tourism and fishing industries in the Suez Canal area (Kiser et al., 2009). However, the Lake suffers from accumulative pollution levels which are affected by untreated domestic and industrial wastewater (Donia, 2011) in addition to agricultural wastes consequences from land-based activities of Ismailia City, and fresh water from some drains: El-Mahsama, El-Bahtini and El-Forsan (Abdel Sabour et al., 1998) (Figure 1). The deterioration of the lake has prolonged to a severe level where urgent action is mandatory to restore the lake ecosystem (Donia, 2011).

Twelve surface sediment samples were collected in summer 2017 using Peterson grab sampler. Sampling sites were selected to cover different sorts of pollution to the Lake; domestic, agricultural, and industrial (Figure 1).

2.2. Geochemical characteristics of the sediments and elemental composition

Organic matter was assessed by the wet oxidation method following the method of (Loring and Rantala, 1992). Total carbonate was determined as designated by Black (1965). Grain size analysis was analyzed using the standard sieving technique (Folk, 1974). Total levels of Al, Ca, Fe, Mg and Mn in the sediment were measured after wet digestion (Oregioni and Aston, 1984) using an atomic absorption spectrometer (AAS, Model AA-6800 Shimadzu) operating in the flame mode. The total nitrogen (TN) was analyzed by Kjeldahl procedure (Bremner, 1960). Total phosphorus (TP) was analyzed by treating at 550°C (2.5 h), succeeded by 1 M HCl extraction for 16 h. Inorganic phosphorus (IP) was directly extracted with 1 M HCl for 16 h. Organic phosphorus (OP) was measured as the difference between TP and IP (Aspila et al., 1976).

2.3. Bioavailable phosphorus

Extractable P that is correlated to P bioavailability in the sediments incorporates algal available P (AAP), readily desorbable P (RDP), sodium bicarbonate ($NaHCO_3$) extractable P (Olsen-P), and water soluble P (WSP). These fractions of phosphorus were measured in line with Zhou et al. (2001) (Table 1).

2.4. Ecological risk assessment

The extensively used evaluation method for ecological risk of phosphorus is the single pollution index that was established based on the guidelines for environmental quality assessment expressed by the Department of Environment and Energy of Ontario, Canada (1992). This index was calculated using the subsequent formula:

$$S_{TP} = \frac{C_{TP}}{C_s}$$

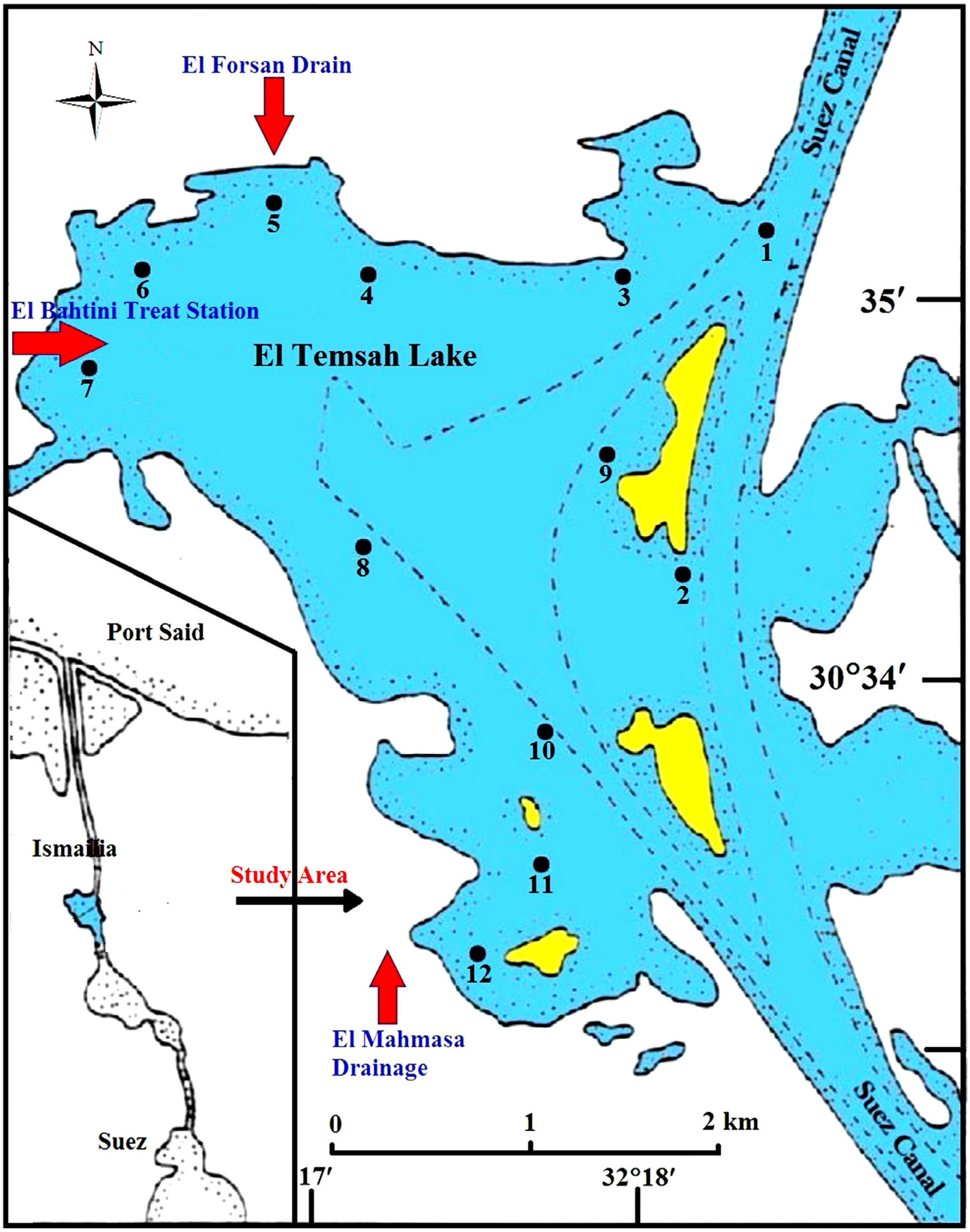

Figure 1 Study area of El Temsah Lake.

where S_{TP} is the single pollution index, C_{TP} is the determined concentration of *TP* and C_s is the standard concentration of *P*.

Relative to the regulations of the safe concentration limits for nutrients in the Sediment Quality Guidelines (SQGs) (Alvarez-Guerra et al., 2010), the standard concentrations of TP should be 600 µg/g. Consistent with the value of S_{TP} index, the risks are categorized into four grades, as indicated in Table 2.

2.5. Data analysis

Graphically depicting groups of numerical data through their quartiles were prepared using Minitab version 17. The correlation analyses and means appraisal analyses were accomplished by Pearson Correlation in SPSS 13.0 (Statistical Program for Social Sciences). Significance levels were labelled as non-significant (no signs, $p \geq 0.05$), significant (*, $0.05 > p \geq 0.01$) or highly significant (**, $p < 0.01$).

Table 1 Chemical extraction methods protocol (Zhou et al., 2001).

Bioavailable P form	Method
Algal available phosphorus (AAP)	0.2 g of sediment sample was shaken with 0.1 M NaOH (pH 13.1) for 4 h.
$NaHCO_3$ extractable phosphorus (Olsen-P)	2.5 g of sediment sample was shaken in 50 ml of 0.52 M $BaHCO_3$ (pH 8.5) for 0.5 h.
Readily desorbable phosphorus (RDP)	2 g of sediment sample was shaken in 50 ml of 0.01 M $CaCl_2$ for 1 h.
Water soluble phosphorus (WSP)	1 g of sediment sample was shaken with 100 ml of deionized water for 2 h at 25 °C.

Note: The P extracts in the four steps were filtered through0.45 mm pore size membrane filters.

Table 2 Evaluation criteria and values for ecological risk of phosphorus in sediments of El Temsah Lake.

Risk level	Value	Pollution assessment	Results for El Temsah Lake
Level I	$S_{TP} < 0.5$	Clean	Sites: 1, 2, 3, 9, 10
Level II	$0.5 \leq S_{TP} < 1$	Slightly polluted	Sites: 8, 11, 12
Level III	$1 \leq S_{TP} < 1.5$	Moderately polluted	Sites: 4, 5
Level IV	$1.5 \leq S_{TP}$	Seriously polluted	Sites: 6, 7

3. Results and discussion

3.1. Physicochemical characteristics of the sediments

Physical and chemical characters of sediments are essential for appraising the P exchange procedures between sediments and overlying waters (Gonsiorezyk et al., 1998). Outcomes of physicochemical characteristics of the sediments are demonstrated in Figure 2 in box and whisker plots.

Carbonate concentrations are considerably low, designating the influx of terrigenous materials (Soliman et al., 2018). Organic matter is needed in the fractionation of P under definite hydrolyzing circumstances. It may formulate complexes with elements, such as Al, Ca, Fe, Mg, and Mn, which possibly govern P fate in the aquatic ecosystems (Fu et al., 2000; Pardo et al., 2003). In this study, OM display concentrations ranging from 0.19 to 10.25%. The dispersal of grain size reveals the domination of the sand fraction (3.26—90.01%) followed by the clay fraction (3.03—89.88%).

Descriptive statistics of elemental composition in sediments of El Temsah Lake are presented in Table 3 and their distribution is illustrated in Figure 2. Calcium levels range from 5.62 to 22.63%, Mg from 1.9 to 10.85%, Al from 2280 to 3860 μg/g dw, while Fe from 4100 to 5778 μg/g dw, and Mn from 123.56 to 642.37 35 μg/g dw. The coefficients of variation (CV) for Mn in sediments are as high as 46.93%, followed by Mg (CV: 43.88%) and Ca (CV: 38.26%) (Table 3). This entitles the relatively great alterations in total Mn, Mg, and Ca levels in the sediments, which may be owing to manmade intrusions of metals (Huang et al., 2019), and the prevalent physicochemical conditions and complex reactions such as adsorption, flocculation and redox condition happening in the sediments (Sekhar et al., 2003). While the lowest metal

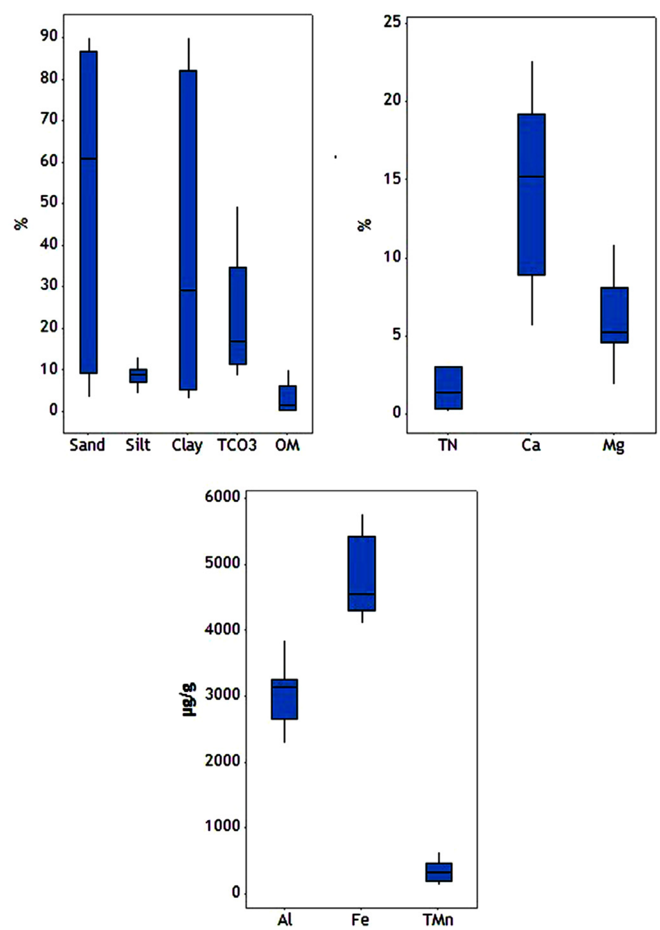

Figure 2 Box and whisker plots of $CaCO_3$, OM, Sand, Silt, Clay (%), and N, Ca, Mg (%), and Al, Fe, Mn (μg/g).

Table 3 Descriptive statistics of elemental composition in sediments of El Temsah Lake.

	Al (μg/g)	TP (μg/g)	Fe (μg/g)	Mn (μg/g)	Ca (%)	Mg (%)	IP (μg/g)	OP (μg/g)	TN (μg/g)	OC (%)
Min	2280	131.84	4100	123.56	5.64	1.9	73.44	32.91	1200	0.17
Max	3860	2028.76	5778	642.37	22.63	10.85	1365.74	663.02	31300	5.31
Average	3024	598.39	4783.7	335.43	14.52	5.98	398.63	199.76	15450	2.11
SD	462	563.78	588.6	157.41	5.55	2.625	384.5	183.04	12823	2.09
CV (%)	15.3	106.13	12.30	46.93	38.26	43.88	96.45	91.63	82.99	99.22

CV — coefficient of variance.
TP — total phosphorus.
IP — inorganic phosphorus.
OP — organic phosphorus.
TN — total nitrogen.
OC — organic carbon.

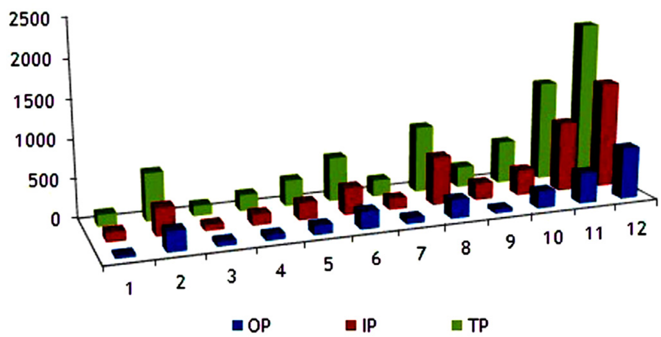

Figure 3 Distribution of organic, inorganic and total phosphorus (μg/g) in El Temsah Lake sediments.

deviations are perceived for Fe (CV: 12.30%) and Al (CV: 15.30%), proving an identical distribution of these elements in the considered sites (Bastami et al., 2016).

Total nitrogen (TN) fluctuates from 1200 to 31300 μg/g dw (CV: 82.99%). This proposes that the TN levels of the sediments varied significantly. Sites 4, 5, 6, 7, 11, and 12 display intensely greater levels than the other sites. All results exceed 1000 μg/g which is the Chinese environmental protection and EPA standard (US EPA, 2002; Wang et al., 2010). The standard is a level where the sediments must be dredged to protect the environment (US EPA, 2002; Wang et al., 2010).

The total phosphorus (TP) contents at different sites of the sediments are demonstrated in Figure 3. Total P contents are in general high, alternating from 131.84 to 2028.76 μg/g dw (CV: 106.13%), attaining the maximum concentrations in the sediments from sites (2, 6, 8, 10, 11, and 12). This entitles that the lake sediments may have a high prospective to provide P to the overlying water (Gao et al., 2005). There is no obvious homogeneousness recognized in the spatial distribution of TP levels in the sediments. The areas of the maximum TP accumulation in the sediments for the most part covered the areas of maximum TN levels in the sediments. This may be explained by the effluents of agriculture, domestic wastes, and shipping activities resulting from the governorate of Ismailia (Said and El Agroudy, 2006).

3.2. Phosphorus fractions and bioavailability

3.2.1. Inorganic, and organic fractions of phosphorus

Outcomes for the levels of inorganic phosphorus (IP) and organic phosphorus (OP) in El Temsah Lake sediments are depicted in Figure 3. It can be seen in Figure 3 that inorganic phosphorus is the most important form (around 66% of the TP). Inorganic phosphorus level range from 73.44 μg/g dw to 1365.74 μg/g dw. IP has been shown to be an essential source of bioavailable P in eutrophic sediments. NaOH-P, which mostly comprises P bound to Al and Fe oxides and hydroxides (Ruban et al., 2001), may be leached from sediment and bring about the growing of phytoplankton under the anoxic circumstances that succeed at the sediment—water interface (Bo et al., 2014). The level range of the organic phosphorus is 23.91—663.02 μg/g dw (about 33.56% of the TP). The concentrations of OP in sediments are in generally low. OP is leached only when organic matter in the lake is mineralized (Pedro et al., 2013). This is a significant character distinguishing sediments from soils, in which organic forms prevail (Gunduz et al., 2011). In general, OP may release bioavailable fractions of P which may possibly be utilized directly or indirectly by algae (Liu et al., 2012). The content of bioavailable P reveals the amount of contamination and the endogenous release capacity. Bioavailable P may be converted into active P by chemical and biological reactions and consecutively affect the water quality (Bridgeman et al., 2012). Numerous investigations have exposed that elevated quantities of bioavailable P in the sediments lead to superior release of P (Liu et al., 2012). According to Rydin (2000), around 50—60% of OP in sediments may be degraded or hydrolyzed to bioavailable P.

3.2.2. Bioavailable phosphorus

The levels of diverse bioavailable P fractions considered in this work are presented in Figure 4. The comparative involvement of each form to the TP is depicted in Figure 5. The rank order owing to the average levels of P fractions in El Temsah Lake is AAP>WSP>RDP>Olsen-P. A detached discussion of each bioavailable P form is given below.

3.2.2.1. Water soluble phosphorus (WSP). WSP is deliberated as the best evaluation of directly available P the sediments (Zhou et al., 2001). Levels of WSP are considerably

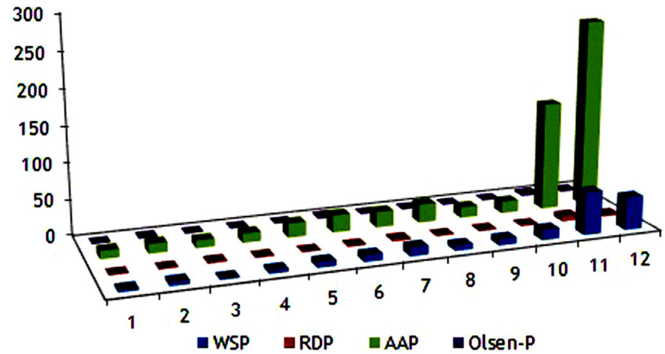

Figure 4 Distribution of bioavailable phosphorus fractions (μg/g) in El Temsah Lake sediments.

Table 4 Literature data concerning bioavailable phosphorus worldwide.

Location	Bioavailable Phosphorus fractions (μg/g)				Reference
	WSP	RDP	AAP	Olsen-P	
El Temsah Lake	14.60	1.84	48.42	1.50	This study
Lake Mariut, Egypt	40.81	9.08	107.12	89.27	Soliman et al. (2017)
Lake Edku, Egypt	9.77	1.70	59.70	42.40	Okbah (2006)
Taihu Lake, China	1.8	0.3	340	38.7	Bo et al. (2014)
West Lake, China	77.1	44.8	354.1	238.9	Zhou et al. (2001)
Lough Erne, Ireland	188.4	67.2	1293.9	512.2	Zhou et al. (2001)

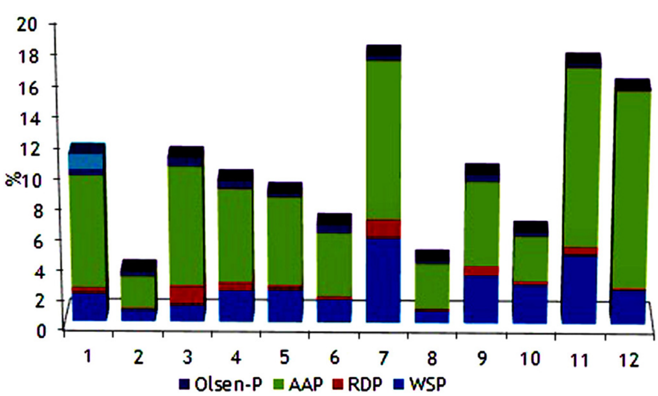

Figure 5 Percentage of bioavailable P fractions in El Temsah Lake sediments.

interrelated with P bound to clays (Hu et al., 2007). In El Temsah Lake the levels of WSP in the considered sediments range from 1.49 μg/g dw to 58.99 μg/g dw, and average 14.60 μg/g dw. The highest WSP concentration is demonstrated in sediment from site 11. This faction of phosphorus accounts for 2.39% of sedimentary TP in El Temsah Lake. These values are to some extent low in consideration to the values (40.81, 77.1 and 188.4 μg/g dw) described for Lake Mariut in Egypt, West Lake, China, and Lough Erne, Ireland, correspondingly, and higher than Lake Taihu, China (1.8 μg/g dw) and Lake Edku, Egypt (9.77 μg/g dw) (Table 4).

3.2.2.2. Readily desorbable phosphorus (RDP). Readily desorbable phosphorus signifies the simply desorbed and released P reflected as algal available P (Zhou et al., 2001). The RDP levels in El Temsah Lake display high variations ranging from 0.55 μg/g dw in site 1 to 6.85 μg/g dw in site 11 (Figure 4). The RDP concentration is nearly 12 times greater in sediment from site 11 than in sediment from site 1. By discharge of industrial wastes this site is contaminated with: 1) Liquid wastes such as oil and grease, paints, in addition to wastes from ships and discarding of domestic wastewater. 2) Solid wastes as metals, sand including metals debris and fouling (Abdel Sabour et al., 1998; Soliman et al., 2019). The proportional contribution of RDP to the available phosphorus ranges from 0.1% to 1.27%, and the average is lower than 1% (0.47%) (Figure 5). This designates that most of the phosphorus is bound in such a fraction that isn't exchangeable, and therefore, not available for direct uptake by plants (Branom and Sarkar, 2004). These levels are fairly small in accordance with the levels described for Mariut Lake, West Lake, China and Lough Erne, Ireland, and higher than Lake Taihu, China and Lake Edku, Egypt (Table 4).

3.2.2.3. Algal available phosphorus (AAP). This faction of sedimentary phosphorus denotes phosphorus combined with metal (hydr) oxides, mostly of Al, and Fe, which is exchangeable again with OH^-, anion of organic ligands and inorganic phosphorus complexes dissolved in alkali (Rydin, 2000). NaOH extractable P may be released for the growing of phytoplankton once anoxic circumstances dominate at the sediment-water interface (Ting, 1996). The AAP levels in the studied sediment samples range from 10.37 μg/g dw in sediment from site 3 to 262.47 μg/g dw in sediments from site 12 (Figure 4). The comparative contribution of AAP to the available phosphorus is between 2.13% (in site 2) to 12.94% (in site 12) (Figure 5). The outcomes acquired in this work were lesser than the outcomes described for other lakes (Table 4). This may be related to the sediment texture (high clay and silt amounts in the lake. Furthermore, these results were comparable to the outcomes in earlier researches that the comparative involvement of NaOH—P to TP ranged from 5 to 70% with elevated values in eutrophic lakes, and NaOH—P was an essential origin for bioavailable P in eutrophic sediments (Penn et al. 1995; Wang et al., 2010).

3.2.2.4. $NaHCO_3$ extractable phosphorus (Olsen-P). Olsen-P is an appropriate measure for demonstrating the situation of nutrients in soils. In agreement with Zhou et al. (2001), Olsen-P levels in soils that are >46 μg/g dw specify a high nutrient rank. Consequently, Olsen-P may be moreover deliberated as a measurable indicator of the availability of P for algae. Commonly, Olsen-P is represented as the active HCl—P since a possibly mobile percentage is shown to be involved in the HCl—P fraction (Kisand and Noges, 2003). The levels of this fraction of P in El Temsah Lake sediment range from 0.53 μg/g dw in site 1 to 3.3 μg/g dw in site 11, and accounts for from 0.1% in site 12 to 0.58% in site 3 of total phosphorus (Figures 4 and 5). The attained data reveals that agreeing to the standards of agricultural soils, all the locations of the study area have low Olsen-P.

Table 4 displays that the results attained in this work are lesser than the results of 89.72, 42.40, 238.9, 512.2, 38.7 μg/g dw designated for Lake Mariut, Lake Edku, West Lake, and Lough Erne, Lake Taihu, respectively.

3.2.2.5. Ecological risk of phosphorus in the sediments. The considered samples may be distributed into two categories based on the Chinese environmental dredging common standard (Liu et al. 1999). Samples that their TP levels were higher than 500 μg/g dw (sites 2, 6, 8, 10, 11, and 12) are deliberated as heavily polluted with certain ecological risk effects and would be dredged. The others (sites 1, 3, 4, 5, 7, and 9) are slightly polluted (mesotrophic or oligotrophic), in which TP levels were lesser than 500 μg/g dw.

Based on the Canadian Sediment Quality Guidelines (SQGs) (Mudroch and Azcue, 1995), the TP levels at 42% of the investigated sites surpassed the lower SQGs value (550 μg/g), and the TP concentrations at site 12 reached the upper SQGs value (2,000 μg/g) (Figure 4), demonstrating that there will be elevated levels of toxicity to sediment-dwelling organisms from phosphorus at site 12. Phosphorus gets into El Temsah Lake from greater amounts of wastes, comprising raw liquid and solid municipal wastewater, industrial wastewater and agricultural runoff that dumped into the lake (Abdel Sabour et al., 1998).

The single pollution index of phosphorus in El Temsah Lake sediment samples varies from 0.19 to 1.85, and the risk grade ranges from Grade I to III. Noticeably, 41% of the samples in El Temsah Lake are clean (grade I). On the other hand, other sites of the sediment samples are slightly (25%) or moderately (17%), or seriously (17%) polluted. Consequently, the average risk of total phosphorus contamination in El Temsah Lake is relatively low.

3.2.2.6. Relationships between bioavailable phosphorus fractions and geochemical components of the sediments. Phosphorus dynamics is associated with its collaboration with the diverse sediment matrix components, so the understanding of the diverse forms in which phosphorus exists in the sediments is required (Pardo et al., 2003). The correlation of Fe, Mn, and P in lake sediments is not obviously assumed, though there is an overall agreement from the deliberation of solubility product interactions that chemical interaction of phosphate would happen with Al, Ca, and Fe complexes. Phosphate anions may be taken up from the water by alumina, kaolinites, and montmorillonites (Chen et al., 1973) and similarly by precipitated ferric and aluminum hydroxides (Carritt and Goodall, 1954; Hsu, 1965).

Fe:P proportion is deliberated as a degree of available sorption places for phosphate ions on iron oxyhydroxide surfaces. The proportion of Fe:P beyond 15 is adequate for iron to adjust the benthic fluctuation of phosphorus from sediment to oxic water (Jensen et al., 1992). Rydin and Brunberg (1998) also designated the development of an active oxic barrier with the overhead Fe:P proportion. In El Temsah Lake sediments, the Fe:P proportion is lower than 15 excluding site 1 and, leading to lower levels of Fe:P. This can prove that the perceived phosphorus is associated with the geochemistry of the lake sediment. Consequently, there is no sufficient iron in the sediments to combine with phosphorus at the majority of the sampling locations, representing that iron can't manage the phosphorus release and the influence of NaOH-P on the water column phosphorus is great (Soliman et al., 2017). Additionally, a substantial negative relationship (−0.76; p>0.01) is established between the Fe:P atom proportion in surface sediments and mean values of TP in the lake sediments. These results propose, but do not ascertain, that the internal phosphorus loadings in this lake are not associated with the Fe:P atom proportion.

In this study, a high significant positive correlation coefficient (r= 0.79; p>0.01) between Fe-Mn is exhibited (Table 5). The close chemical resemblance between Fe and Mn is revealed geologically in their corporate association in rocks of all types. Hydrous oxides of iron and manganese are approximately plentiful in clays, soils, and sediments (Bortleson and Lee, 1974). However, there is no obvious relationship between TP-Fe and TP-Mn in El Temsah Lake. Agreeing with Mackereth (1966) P deposition is not affected by differences in the iron and manganese cycle, but the precipitation of P can be basically biological and constant. Fe is appearing to be associated with clay minerals (r= 0.94; p>0.01) which will afford slight prospects for P precipitation with Fe complexes (Bortleson, 1971). Additionally, there is no relationship between Ca and any of the bioavailable phosphorus fractions. This is similar with the results of others (Jensen et al., 1992) and confirms that the extent of calcium existing in the sediment has no effect on the dispersal of the different P pools (De Groot, 1991).

Results exhibit that, no association may be recognized between the IP/OP and the organic matter level in the sediment samples (Table 5). Consequently, the dispersal of phosphorus between the inorganic and organic fractions seemed not to be associated with the organic matter concentration in apparent way. This is possibly owing to the composite properties of organic matter and to the intricate relations amongst the diverse sediment characteristics (Pardo et al., 2003).

A significant relationship exists between organic matter (OM) and total nitrogen (TN) in the sediments of El Temsah Lake (r = 0.92, P < 0.01) which proposes that the content of TN can be regulated by organic source (Hakanson and Jansson, 1983) while total phosphorus associates nega-

Table 5 Correlation matrix for the different studied components in sediments of El Temsah Lake.

	Al	Ca	Fe	Mg	Mn	TN	TP	IP	OP	$CaCO_3$	OM	WSP	RDP	AAP	Olsen-P	Sand	Silt	Clay
Al	1																	
Ca	0.74**	1																
Fe	-0.76**	-0.95**	1															
Mg	-0.09	-0.51	0.59*	1														
Mn	-0.07**	-0.89**	0.79**	0.23	1													
TN	-0.73**	-0.83**	0.81**	0.53	0.59*	1												
TP	-0.48	-0.29	0.18	-0.59*	0.51	0.1	1											
IP	-0.47	-0.28	0.16	-0.61*	0.50	0.1	0.99**	1										
OP	-0.51	-0.31	0.21	-0.54	0.51	0.11	0.99**	0.97**	1									
$CaCO_3$	-0.54	-0.68**	0.62*	0.39	0.54	0.89**	0.14	0.14	0.152	1								
OM	-0.51	-0.61*	0.58*	0.51	0.35	0.92**	-0.11	-0.11	-0.09	0.94**	1							
WSP	-0.63*	-0.33	0.21	-0.61*	0.41	0.2	0.83**	0.84**	0.79**	0.11	-0.03	1						
RDP	-0.61*	-0.25	0.15	-0.49	0.24	0.18	0.50	0.53	0.44	0.002	0.001	0.87**	1					
AAP	-0.52	-0.38	0.25	-0.57*	0.59*	0.18	0.94**	0.94**	0.91**	0.27	0.003	0.88**	0.58*	1				
Olsen-P	-0.54	-0.26	0.17	0.34	0.16	0.20	0.62*	0.60*	0.64*	0.07	0.02	0.69**	0.63*	0.51	1			
Sand	0.73**	0.98**	-0.95**	-0.48	-0.88**	-0.82**	-0.33	-0.31	-0.35	-0.71**	-0.63*	-0.32	-0.19	-0.43	-0.24	1		
Silt	0.14	-0.21	0.13	0.34	-0.12	0.16	-0.43	-0.39	-0.49	0.09	0.2	-0.17	0.14	-0.28	-0.12	-0.12	1	
Clay	-0.75**	-0.98**	0.94**	0.46	0.89**	0.81**	0.36	0.34	0.38	0.71**	0.59*	0.33	0.19	0.46	0.25	-0.99**	0.06	1

Correlation is significant at * $P< 0.05$, ** $P < 0.01$; $n = 12$

Table 6 Total organic carbon/total nitrogen (TOC/TN), total organic carbon/total phosphorus (TOC/TP) and total nitrogen/total phosphorus (TN/TP) organic carbon/organic phosphorus (OC/OP), Iron/phosphorus, manganese/phosphorus ratios in El Temsah Lake sediments.

Station	TOC/TN	TOC/TP	TN/TP	OC/OP	Fe:P	Mn:P
1	1.50	14.75	9.84	54.70	15.20	0.72
2	1.00	15.32	15.32	6.60	4.09	0.16
3	1.46	17.65	12.11	87.33	19.31	1.74
4	1.74	74.37	42.86	774.57	12.12	0.59
5	1.47	53.09	36.12	377.74	9.67	0.79
6	1.30	36.60	28.15	182.90	5.40	0.43
7	1.63	49.56	30.34	715.30	14.82	1.33
8	0.68	14.32	20.99	24.20	2.82	0.22
9	0.78	10.14	13.04	39.47	8.82	0.26
10	0.33	10.67	32.02	8.64	4.35	0.22
11	0.99	50.68	51.22	47.39	2.08	0.15
12	1.36	47.28	34.69	41.93	1.42	0.18
Min	0.33	10.14	9.84	6.60	1.42	0.15
Max	1.74	74.37	51.22	774.57	19.31	1.74
Average	1.19	32.87	27.22	196.73	8.34	0.57
SD	0.43	21.68	13.15	276.37	5.92	0.51
CV	36.10	65.95	48.29	140.48	70.99	90.42

tively with OM (Table 5). This entails that sediment TP is influenced by parameters other than organic matter (Knosche, 2006). If N and P in the sediments are originated from the similar origin, they must have a good relationship. Though, it is designated that the relationship between TN and TP is insignificant in El Temsah Lake sediments, displaying dissimilar sources (Table 5).

Earlier investigations have revealed that the ratios of nutrient elements in sediments may reveal the geochemical reactions of elements, the environment and the origins of internal and external contaminations (Gu et al., 2017). Particularly, the TOC/TN ratio is extensively utilized to categorize the probable origins of organic matters and the differences among species. The TOC/TP ratio reveals the decomposition rate of OC and P fractions in sediments to a definite range (Peng, 2016). The TN/TP ratio reveals the dynamic progressions of the accumulation, deposition and release of N and P in water (Peng, 2016). If TOC/TN $>$ 10, the OM is principally from land sources; if TOC/TN $=$ 10, the internal and external OM is essentially in equilibrium; if TOC/TN $<$ 10, the OM is mostly from water bodies (Peng, 2016).

From Table 6, the TOC/TN in El Temsah Lake sediments differs from 0.3 to 1.7. Consequently, the TOC accumulation and TOC/TN in sediments in El Temsah Lake are positively interrelated to the organic components from the water body. The TOC/TP in sediments in El Temsah Lake alters from 10.1 to 74.4. The average value of the TOC/TP ratios is 32.9. Furthermore, the spatial dissimilarities of TOC/TP in the sediments have comparatively high coefficient of variance (CV) of 65.95% $>$ 50%. Great TOC contents in sites (4, 5, 6, 7, 11, and 12) have a substantial influence on the spatial differences of nutrient element ratios, compared with the other sites. These sites have greater amounts of TOC, which may be introduced into the sediments by untreated municipal and urban wastes (Abdel Sabour et al., 1998). Consequently, the accumulation of TOC dominates the TOC/TP ratio. Data of the ratio between OC and OP (OC/OP) may support the understanding of the provenance, decomposition and preservation of sedimentary organic matter (Sardans et al., 2012), in addition to the transformation of phosphorus in sediments. In general, approximately all of the sediment OM types in aquatic ecosystems are originated from biological photosynthetic activity in the aquatic and/or terrestrial environments. The OC/OP ratio of marine plankton is closer to the Redfield C/P ratio of 106:1 (Anderson and Sarmiento, 1994; Redfield et al., 1963), and differ from ~50:1 to 150:1 (Li and Peng, 2002), with an average of about 117:1 (Anderson and Sarmiento, 1994). In this work, the OC/OP ratios range from 6.6 to 774.6, with an average of 196.7± 276.37 (Table 6), which exceed the Redfield ratio, representing that El Temsah Lake sediments receive substantial quantity of OC from land-based origins.

Nitrogen and phosphorus are key parameters for the categorization of trophic status as they are nutrients most probable to limit aquatic primary producers in lakes and rivers. The total N to total P (TN:TP) ratio is usually utilized as a guide that signifies the nutrient limitation for algal growth. Elser et al. (2009) indicate that phosphorus is limiting when TN: TP by weight is $>$16, nitrogen is limiting when TN: TP is $<$14, and either nitrogen or phosphorus or both are limiting when TN:TP is between 14 and 16. Results display that the TN:TP in El Temsah Lake is fluctuated from 9.8 to 51.2 (average: 27.2), signifying that the limiting nutrient for the algal growth in El Temsah Lake is P.

The ratio of N: P in sediment is greater than the Redfield value, displaying that P in the considered lake sediment is primarily autogenic.

Table 5 exhibits that there is a significant relationship between WSP and TP in El Temsah Lake sediments ($r=0.83$; $p>0.01$). More or less P may be simply desorbed and released, predominantly when the level of P in the water column is decreased (Zhou et al., 2001). Additionally, outcomes of Pearson correlation analysis display a poor positive relationship concerning RDP and TP or IP (Table 5).

The Olsen-P fraction was the smallest of the extracted P fractions. In particular, RDP in sediments of El Temsah Lake only accounted for 0.34% of TP (Figure 5). The correlation between Olsen-P and TP was poorer than in any other analysis, but still highly significant ($P < 0.05$).

It is perceived that the AAP fraction displayed an enhanced sign of P bioavailability. The AAP fraction extracted greater quantities of P compared to WSP, RDP and Olsen-P, ranging between 2.13 and 12.94% (average: 6.67%) (Figure 5). The relationships between P extracted in the AAP fraction and TP or IP are somewhat much better than the other extracted fractions and are significant at a <0.01 level (Table 5), proposing that the elevation in TP and coinciding leaching of P from sediment improved the bioavailability and increase risk of P (Wang and Liang, 2015).

The comparatively larger quantity of extracted P and the significant relationship between extracted and sedimental TP designates that a substantial part of P in El Temsah Lake sediments is combined with Fe/Al oxides (Anjos et al., 2000), and a comparatively substantial fraction of Fe/Al-bound P is bioavailable. These fractions of P are easily dissolved under alkaline conditions and converted into dissolved P when the redox environment changes (Han et al., 2014). Dissolved P may then enter the overlying water, and finally deteriorates the water quality (Wang and Liang, 2015).

AAP discloses the impact of sediment texture, while a high clay percentage improves the level of AAP. This end result is sustained by Pearson correlation analysis where a positive correlation between AAP and clay ($r=0.46$) (Table 5) is designated.

4. Conclusion

This paper presents the results of P fractions (TP, OP, IP, and bioavailable P) in the surface sediment and from El Temsah Lake. Total phosphorus concentration is on average 598.39 μg/g. The IP level was higher than OP for the studied area and its average % contents were 66.50% of TP. Where the average level of the OP was 33.50% of TP. Relative abundances of the bioavailable P fractions in the sediment follow the rank: AAP>WSP>RDP>Olsen-P. The AAP method extracted the most P and the RDP and Olsen-P methods extracted the least P. Clearly, as the levels of WSP, RDP, and Olsen-P were low, accounting for lower than 4% of TP, these fractions were as insignificant as available P sources for algal growth. In contrast, AAP accounted for more than 7% of TP. WSP, AAP, and Olsen-P forms gave bioavailable P levels that were correlated to the IP, TP, and OP levels. Correlation coefficients showed that there were significant correlations among the bioavailable P fractions concentrations and the TP concentrations. Moreover, there were no apparent relationships between TP and N, Al, Ca, Fe, Mg, Mn, and OM in the sediments. This study exhibited that the TN:TP ratio in the water column fluctuated from 9.8 to 51.2, proposing that P was the limiting nutrient for the algal growth in El Temsah Lake. Moreover, Fe:P ratio was lower than 15 supposing that there wasn't adequate iron in the sediment to combine with phosphorus at most of the investigated samples. Consistent with the single pollution index method, the risk level of P contamination in the sediments was comparatively low. Results from this study establish a background of bioavailable phosphorus fractions in sediments from El Temsah Lake and can be utilized as a reference for forthcoming investigations on the fluctuations of phosphorus bioavailability over time.

Declaration of competing interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare that they have no conflict of interest.

Authors' contributions

Naglaa F. Soliman and Alaa M. Younis developed the concept and designed the experiments. Lamiaa I. Mohamedein carried out the sediments collection. Naglaa F. Soliman and Eman M. Elkady carried out sediment pollution analysis and risk assessment. Naglaa F. Soliman and Alaa M. Younis participated in the sequence alignment and drafted the manuscript. Alaa M. Younis, Eman M. Elkady and Lamiaa I. Mohamedein participated in the final version of manuscript and statistical analysis. All authors listed have made a significant, fundamental and direct contribution to the work, and approved it for publication.

Data availability

The dataset used and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Abdel Sabour, M.F., Ali, R.O., Khalil, M.T., Attwa, A.H.A., 1998. Indicators of Lake Temsah potential pollution by some heavy. Metals ii) heavy metals in sediment. International conference on hazardous waste sources, effects and management.

Alvarez-Guerra, M., Viguri, J.R., Casado-Martínez, M.C., DelValls, T.A., 2010. Sediment quality assessment and dredged material management in Spain: Part I, application of sediment quality guidelines in the Bay of Santande. Integr. Environ. Assess. Manag. 3, 529–538. https://doi.org/10.1897/IEAM_2006-055.1

Anderson, L.A., Sarmiento, J.L., 1994. Redfield ratios of remineralization determined by nutrient data analysis. Global Biogeochem. Cy. 8, 65–80. https://doi.org/10.1029/93GB03318

Anjos, S.M., De Ros, L.F., De Souza, R.S., De Assis Silva, C.M., Sombra, C.L., et al., 2000. Depositional and diagenetic controls on the reservoir quality of Lower Cretaceous Pendencia sandstones, Potiguar rift basin, Brazil. AAPG Bulletin 84 (11), 1719–1742. https://doi.org/10.1306/8626C375-173B-11D7-8645000102C1865D

Aspila, K.I., Agemian, H., Chau, A.S.Y., 1976. Semi-automated method for the determination of inorganic, organic and total phosphate in sediments. Analyst 101, 187–197. https://doi.org/10.1039/an9760100187

Aydina, I., Aydin, F., Saydut, A., Hamamci, C., 2009. A sequential extraction to determine the distribution of phosphorus in the

seawater and marine surface sediment. J. Hazard. Mater. 168, 664—669. https://doi.org/10.1016/j.jhazmat.2009.02.095
Bastami, K.D., Neyestani, M.R., Zadeh, M.E., Haghparast, S., Alavi, C., Fathi, S., Nourbakhsh, S., Shirzadi, E.A., Parhizgar, R., 2016. Geochemical speciation, bioavailability and source identification of selected metals in surface sediments of the Southern Caspian Sea. Marine Pollut. Bull. 114 (2), 1014—1023. https://doi.org/10.1016/j.marpolbul.2016.11.025
Black, C.A., 1965. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties. American Society of Agronomy, Inc., Madison, WI.
Bo, L., Wang, D., Zhang, G., Wang, C., 2014. Evaluating the relationship between phosphorus bioavailability and speciation in sediments from rural rivers in the Tahiu Lake area, China. Pol. J. Environ. Stud. 23, 1933—1940. https://doi.org/10.15244/pjoes/24924
Bortleson, 1971. The chemical investigation of recent lake sediments from Wisconsin lakc and their interpretation. U.S. Environ. Prot. Agency, 1601OEIIRO 3/71 Water Pollut. Contr. Res. Ser. Washington, D.C.
Bortleson, G.C., Lee, F., 1974. Phosphorus, iron, and manganese distribution in sediment cores of six Wisconsin lakes. Limnol. Oceanogr. 19 (5), 794—801. https://doi.org/10.4319/lo.1974.19.5.0794
Branom, J.R., Sarkar, D., 2004. Phosphorus bioavailability in sediments of a sludge disposal lake. Environ. Geosc. 11, 42—52. https://doi.org/10.1306/eg.08220303021
Bremner, J.M., 1960. Determination of nitrogen in soil by the Kjeldahl method. J. Agric. Sci. 55, 11—33. https://doi.org/10.1017/S0021859600021572
Bridgeman, T.B., Chaffin, J.D., Kane, D.D., Conroy, J.D., Panek, S.E., Armenio, P.M., 2012. From River to Lake: Phosphorus partitioning and algal community compositional changes in Western Lake Erie. J. Great Lakes Res. 38 (1), 90—97. https://doi.org/10.1016/j.jglr.2011.09.010
Carritt, D.E., Goodall, S., 1954. Sorption reactions and some ecological implications. Deep-Sea Res. 1, 224—243.
Chen, Y.S.R., Bulter, J.N., Stumm, W., 1973. Kinetic study of phosphate reaction with aluminum oxide and kaolinit. Environ. Sci. Technol. 7, 327—332. https://doi.org/10.1021/es60076a007
Dapeng, L., Yong, H., Chengxin, F., Yan, Y., 2011. Contributions of phosphorus on sedimentary phosphorus bioavailability under sediment resuspension conditions. Chem. Eng. J. 168, 1049—1054. https://doi.org/10.1016/j.cej.2011.01.082
De Groot, C., 1991. The influence of FeS on the inorganic phosphorus retention in lakes determined from ass balance and sediment core calculations. Wat. Res. 27, 659—668.
Donia, N., 2011. Water quality management of lake Temsah, Egypt using geographical information system (GIS). IJESE 2, 1—8. http://www.pvamu.edu/texged
Elser, J.J., Andersen, T., Baron, J.S., Bergström, A., Jansson, M., Kyle, M., Nydick, K.R., Steger, L., Hessene, D.O., 2009. Shifts in lake N: P stoichiometry and nutrient limitation driven by atmospheric nitrogen deposition. Science 326 (5954), 835—837. https://doi.org/10.1126/science.1176199
Folk, R.L., 1974. Petrology of sedimentary rocks. Austin: Hemphill Pub. Co.
Fu, Y., Zhoh, Y., Li, J., 2000. Sequential fractionation of reactive phosphorus in the sediment of a shallow eutrophic lake Donghu Lake. China, Int. J. Environ. Sci. 12, 57—62.
Gao, L., Zhou, J.M., Yang, H., Chen, J., 2005. Phosphorus fractions in sediment profiles and their potiential contributions to eutrophication in Dianchi Lake. Environ. Geol. 48, 835—844. https://doi.org/10.1007/s00254-005-0005-3
Gonsiorezyk, T., Casper, P., Koschel, R., 1998. Phosphorus binding forms in the sediment of an oligotrophic and an eutrophic hardwater lake of the Baltic Lake District (Germany). Water Sci. Technol. 37 (3), 51—58. https://doi.org/10.2166/wst.1998.0173
Gunduz, B., Aydın, F., Aydin, I., Hamamci, C., 2011. Study of phosphorus distribution in coastal surface sediment by sequential extraction procedure (NE Mediterranean Sea, Antalya-Turkey). Microchem. J. 98, 72—76. https://doi.org/10.1016/j.microc.2010.11.006
Gu, Y.G., Ouyang, J., Ning, J.J., Wang, Z.H., 2017. Distribution and sources of organic carbon, nitrogen and their isotopes in surface sediments from the largest mariculture zone of the eastern Guangdong coast, South China. Mar. Pollut. Bull. 120, 286—291. https://doi.org/10.1016/j.marpolbul.2017.05.013
Hakanson, L., Jansson, M., 1983. Principles of Lake Sedimentology. Springer-Verlag, Berlin.
Han, H., Lu, X., Burger, D.F., Joshi, U.M., Zhang, L., 2014. Nitrogen dynamics at the sediment-water interface in a tropical reservoir. Ecol. Eng. 73, 146—153. https://doi.org/10.1016/j.ecoleng.2014.09.016
Hu, J., Shen, Q., Liu, Y.D., 2007. Mobility of different phosphorus pools in the sediment of Lake Dianchi during cyanobacterial blooms. Environ. Monit. Assess. 132, 141—153. https://doi.org/10.1007/s10661-006-9509-x
Huang, B., Guo, Z., Xiao, X., Zeng, P., Peng, C., 2019. Changes in chemical fractions and ecological risk prediction of heavy metals in estuarine sediments of Chunfeng Lake estuary. China. Mar. Pollut. Bull. 138, 575—583. https://doi.org/10.1016/j.marpolbul.2018.12.015
Hsu, P.H., 1965. Fixation of phosphate by aluminum and iron in acidic soils. Soil Sci. 99, 398—402.
Jensen, H., Kristensen, P., Jeppesen, E., Skytthe, A., 1992. Iron: phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiologia 235/236, 731—743. https://doi.org/10.1007/BF00026261
Kaiser, M.F., Amin, A.S., Aboulela, H.A., 2009. Environmental Hazards in the El-Temsah Lake, Suez Canal District, Egypt. Adv. Geosci. Remote Sens. 57—70. https://doi.org/10.5772/8335
Knosche, R., 2006. Organic sediment nutrient concentrations and their relationship with the hydrological connectivity of floodplain waters (River Havel, NE Germany). Hydrobiologia 560, 63—76. https://doi.org/10.1007/s10750-005-0983-x
Kisand, A., Noges, P., 2003. Sediment phosphorus release in phytoplankton dominated versus macrophyte dominated shallow lakes: importance of oxygen conditions. Hydrobiologia 506—509, 129—133. https://doi.org/10.1023/B:HYDR.0000008620.87704.3b
Li, Y., Peng, T., 2002. Latitudinal change of remineralization ratios in the oceans and its implication for nutrient cycles. Global Biogeochem. Cy. 16 (4). https://doi.org/10.1029/2001GB001828Yuan-Hui
Liu, H.L., Jin, X.C., Jing, Y.F., 1999. Environmental dredging technology of lake sediment. Chinese Eng. Sci. 1, 81—84.
Liu, L., Zhang, Y., Efting, A., Barrow, T., Qian, B., Fang, Z., 2012. Modeling bioavailable phosphorus via other phosphorus fractions in sediment cores from Jiulongkou Lake, China. Environ. Earth Sci. 65 (3), 945—956. https://doi.org/10.1007/s12665-011-1295-2
Loring, D.H., Rantala, R.T.T., 1992. Manual for the geochemical analyses of marine sediments and suspended particulate matter. Earth Sci. Revi. 32, 235—283. https://doi.org/10.1016/0012-8252(92)90001-A
Mackereth, F.J.H., 1966. Some chemical observations on post-glacial lake sediments. Philos. T. Roy. Soc. B 250, 165—213
Mudroch, A., Azcue, O.M., 1995. Manual of Aquatic Sediment Sampling. Lewis Publisher, Ann. Arbor, Michigan, USA.
Okbah, M.A., 2006. Bioavailablility of phosphorus in Abu Qir and Lake Edku sediments, Mediterranean Sea. Egypt. Chem. Ecol. 6, 451—462. https://doi.org/10.1080/02757540601025006
Oregioni, B., Aston, S.R., 1984. The determination of selected trace metals in marine sediments by flame atomic absorption spec-

trophotometry. IAEA Monaco Laboratory Internal Report. UNEP, reference methods for marine pollution studies No 38.

Pardo, P., Lopez-Sanchez, J.F., Rauret, G., 2003. Relationships between phosphorus fractionation and major components in sediments using the SMT harmonized extraction procedure. Anal. Bioanal. Chem. 376, 248—254.

Pedro, T., Kimberley, S., Fernando, P., 2013. Dynamics of phosphorus in sediments of a naturally acidic lake. Int. J. Sediment Res. 28 (1), 90—102. https://doi.org/10.1007/s00216-003-1897-y

Peng, R., 2016. Spatiotemporal distribution and stoichiometry characteristics of carbon, nitrogen and phosphorus in surface soils of freshwater and brackish marshes in the Min River estuary. China Environ. Sci. 36, 917—926 (in Chinese).

Penn, M.R., Auer, M.T., Van Orman, E.L., Korienek, J.J., 1995. Phosphorus Diagenesis in Lake Sediments: Investigations using Fractionation Techniques. Mar. Freshwater Res. 46, 89—99. https://doi.org/10.1071/MF9950089

Perkins, R.G., Underwood, G.J.C., 2001. The potential for phosphorus release across the sediment—water interface in a eutrophic reservoir dosed with ferric sulphate. Water Res. 35, 1399—1406. https://doi.org/10.1016/S0043-1354(00)00413-9

Pettersson, K., Bostrom, B., Jacobsen, O.S., 1988. Phosphorus in sediments — speciation and analysis. Hydrobiologia 170, 91—101. https://doi.org/10.1007/BF00024900

Psenner, R., Pucsko, R., 1988. Phosphorus fractionation: advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Beih. 30, 43—59.

Reddy, K.R., Wetzel, R.G., Kadlec, R.H., 2005. Biogeochemistry of phosphorus in wetlands. In: Sims, J.T., Sharpley, A.N. (Eds.), Phosphorus: agriculture and the environment. Soil Science Society of America, Madison, 263—316.

Redfield, A.C., Ketchum, B.H., Richards, F.A., et al., 1963. The Influence of Organisms on the Composition of the Sea Water. In: In: Hill, M.N., Ed., The Sea, 2. Interscience Publishers, New York, 26—77.

Ruban, V., López-Sánchez, J.F., Pardo, P., Rauret, G., Muntau, H., Quevauviller, Ph., 1999. Selection and evaluation of sequential extraction procedures for the determination of phosphorus forms in lake sediment. J. Environ. Monitor. 1, 51—56. https://doi.org/10.1039/A807778I

Ruban, V., Lopez-Sanchez, J.F, Pardo, P., Rauret, G., Muntau, H., Quevauviller, P., 2001. Harmonized protocol and certified reference material for the determination of extractable contents of phosphorus in freshwater sediments — A synthesis of recent works. Fresenius. J. Anal. Chem. 370 (2—3), 224. https://doi.org/10.1007/s002160100753

Ruttenberg, K.C., 1992. Development of sequential extraction method for different forms of phosphorus in marine sediments. Limnol. Oceanogr. 37, 1460—1482. https://doi.org/10.4319/lo.1992.37.7.1460

Rydin, E., Brunberg, A.K., 1998. Seasonal dynamics of phosphorus in Lake Erken surface sediments. Archiv für Hydrobiologie 51, 157—167. https://doi.org/10.1023/A:1004050204587

Rydin, E., 2000. Potentially mobile phosphorus in Lake Erken sediment. Water Res. 34, 2037—2042. https://doi.org/10.1016/S0043-1354(99)00375-9

Said, T.O., El Agroudy, N.A., 2006. Assessment of PAHs in water and fish tissues from Great Bitter and El Temsah lakes, Suez Canal, as chemical markers of pollution sources. Chem. Ecol. 22, 159—173. https://doi.org/10.1080/02757540500526476

Sardans, J., Rivas-Ubach, A., Penuelas, J., et al., 2012. The elemental stoichiometry of aquatic and terrestrial ecosystems and its relationships with organismic lifestyle and ecosystem structure and function: A review and perspectives. Biogeochemistry 111 (1—3), 1—39. https://doi.org/10.1007/s10533-011-9640-9

Sekhara, K.C., Charya, N.S., Kamalaa, C.T., Suman, D.S., Rajb, A., Raoc, S., 2003. Fractionation studies and bioaccumulation of sediment-bound heavy metals in Kolleru lake by edible fish. Environ. Int. 29, 1001—1008. https://doi.org/10.1016/S0160-4120(03)00094-1

Soliman, N.F., El Zokm, G.M., Okbah, M.A., 2017. Evaluation of phosphorus bioavailability in El Mex Bay and Lake Mariut sediments. Int. J. Sediment Res. 32, 432—441. https://doi.org/10.1016/j.ijsrc.2017.05.006

Soliman, NF., Younis, A.M., Elkady, E.M., Mohamedein, L.I., 2018. Geochemical associations, risk assessment, and source identification of selected metals in sediments from the Suez Gulf, Egypt. Hum. Ecol. Risk Assess. 25 (3), 1—17. https://doi.org/10.1080/10807039.2018.1451301

Soliman, N.F., Younis, A.M., Elkady, E.M., 2019. An insight into fractionation, toxicity, mobility and source apportionment of metals in sediments from El Temsah Lake, Suez Canal. Chemosphere 222, 165—174. http://doi.org/10.1016/j.chemosphere.2019.01.009

Ting, D.S., Appan, A., 1996. General characteristics and fractions of phosphorus in aquatic sediments of two tropical reservoirs. Water Sci. Technol. 34, 53—59. https://doi.org/10.1016/S0273-1223(96)00724-X

Tiyapongpattana, W., Pongsakul, P., Shiowatana, J., Nacapricha, D., 2004. Sequential extraction of phosphorus in soil and sediment using a continuous-flow system. Talanta 62, 765—771. https://doi.org/10.1016/j.talanta.2003.09.018

US EPA (2002). National Recommended Water Quality Criteria: 2002. Office of Water, EPA-822-R-02047, U.S. Environmental Protection Agency, Washington DC. http://www.epa.gov/waterscience/standards/wqcriteria.html

Wang, S., Jin, X., Bu, Q., Liao, H., Wu, F., 2010. Evaluation of phosphorus bioavailability in sediments of the shallow lakes in the middle and lower reaches of the Yangtze River region, China. Environ. Earth Sci. 60, 1491—1498. https://doi.org/10.1007/S12665-009-0284-1

Wang, L., Liang, T., 2015. Distribution Characteristics of Phosphorus in the Sediments and Overlying Water of Poyang Lake. PLoS ONE 10 (5), e0125859. https://doi.org/10.1371/journal.pone.0125859

Zhou, Q., Gibson, C.E., Zhu, Y., 2001. Evaluation of phosphorus bioavailability in sediments of three contrasting lakes in China and the UK. Chemosphere 42, 221—225. https://doi.org/10.1016/s0045-6535(00)00129-6

Zhu, M., Zhu, G., Li, W., Zhang, Y., Zhao, L., Gu, Z., 2013. Estimation of the algal-available phosphorus pool in sediments of a large, shallow eutrophic lake (Taihu, China) using profiled SMT fractional analysis. Environ. Pollut. 173, 21. https://doi.org/10.1016/j.envpol.2012.10.016