Sediment phosphate release flux under hydraulic disturbances in the shallow lake of Chaohu, China

Wenguang Luo1,2 · Yao Yue1 · Jing Lu1 · Lina Pang3 · Senlin Zhu4

Received: 11 November 2021 / Accepted: 1 April 2022 / Published online: 18 April 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
Quantifying the effect of hydraulic disturbances on sediment phosphate release is a key issue in the water quality assessment of lakes, especially for the shallow lakes which are susceptible to winds and waves. Here, we sampled the original sediment columns from 12 positions in the eastern, central, and western areas of the Chaohu Lake, a representative shallow lake in China, and observed phosphate release under three levels of hydraulic disturbances in the laboratory. When the disturbance was weak and sediment on the surface of bottom mud moved individually (the Individual Motion Mode), sediment phosphate release rate was insignificant (0.24 mg/m²/day). When the disturbance was medium and only a small percentage (<16%) of surface sediment started to move (the Small Motion Mode), the phosphate release rate sharply increased to 4.81 mg/m²/day. When the disturbance was further strengthened and most (≥16%) of the surface sediment moved (the General Motion Mode), the phosphate release rate was more than doubled (10.23 mg/m²/day). With the increase in hydraulic disturbance intensity, the variation range of phosphate release also became wider. Spatial distribution showed that the release rate varies the most in the western area, followed by the eastern and the central areas. By extrapolating the experimental results to the real scale, it was found that the phosphate release fluxes would probably fall within a wide range between 203.43 to 7311.01 kg/day under different levels of hydrodynamic disturbances which considerably affects phosphate release from shallow lakes. This study also has implications for the pollutant management in other shallow lakes.

Keywords Sediment resuspension · Phosphate release · Hydraulic disturbance · Shallow lakes

Introduction
As the main destination of lake nutrients, sediment exchanges phosphorus with the upper water constantly, inducing larger risks to the environment (Carpenter 2008; Norton et al. 2008; Qin et al. 2019). Previous research revealed that phosphorus release due to sediment resuspension could solely account for 23.7–39.4% to the total phosphorus load, leading to eutrophication of lakes (Deng et al. 2020). Since the dissolved form of phosphorus is more likely to be emitted into water than the granular form, more attention should be paid to phosphate release. The environmental risk is even larger in shallow lakes, because sediment is more frequently resuspended under hydraulic interference due to poor circulation (Hu et al. 2021), altering the sediment–water interface. However, quantitative assessments of phosphate flux from sediment in response to hydraulic disturbance in shallow lakes are very scarce (Jin et al. 2020), due to poor understanding of the sedimentation and resuspension processes (Reed et al. 2011). In addition, high-frequency sampling required for quantification is difficult to achieve in practice (Yuan et al. 2020). Thus, experiments are necessary to capture the characteristics of phosphate release under different intensities of sediment resuspension stirred by hydraulic disturbance. Although

Wenguang Luo
wgluo@whu.edu.cn

1 State Key Laboratory of Water Resources and Hydropower Engineering Science, Wuhan University, Wuhan 430072, China
2 State Key Laboratory of Eco-Hydraulics in Northwest Arid Region of China, Xi’an University of Technology, Xi’an 710048, China
3 College of Architecture and Environment, Sichuan University, Chengdu 610065, China
4 College of Hydraulic Science and Engineering, Yangzhou University, Yangzhou, China
the in-place culture experiment provides an actual situation, it is rarely used due to the high cost and technical restrictions (Wu et al. 2020b). By culturing column cores, rather than the surface sediment, laboratory experiment can reproduce the phosphate release process under conditions that are very close to the real environment (Teal et al. 2008; Gu et al. 2017). Therefore, the phosphate release process can be observed by the properly designed in-door experiments.

Chaohu Lake is a representative shallow lake subject to serious phosphorus pollution (Chen and Liu 2015). Under various degrees of hydraulic disturbance, sediment movement in the Chaohu Lake can be very complicated, leading to different situations of phosphate release to the overlying water. According to Chen et al. (2018a, b), sediment initiation is classified into the Individual Motion Mode, the Small Motion Mode, and the General Motion Mode. The characteristics of phosphate release from sediments in different modes should be studied based on laboratory experiments. This paper collected undisturbed sediment column cores from the eastern, western, and central areas of the Chaohu Lake and simulated phosphate release under the three sediment motion modes initiated by different levels of hydraulic disturbances in the laboratory. Thus, the spatial and temporal characteristics of the release fluxes could be analyzed and estimated, providing a reference to the management of phosphorus pollution in other shallow lakes.

Methods and material

**Study area**

Chaohu Lake is one of the most famous freshwater lakes located in Hefei City (31.60° N, 117.87° E), Anhui Province, China, which has typical characteristics of large shallow lakes. According to statistics, it has an average water level of 8.37 m, a lake basin length of 61.7 km, a width of 12.47 km, a water area of 769.55 km², and an average depth of 2.89 m. The lake basin also consists an important water system in the middle and lower regions of the Yangtze River Basin (Wu et al. 2020a, b).

In order to estimate phosphate release from the sediments of Chaohu Lake, 12 sediment core sampling sites are selected according to the water’s distribution feature of the lake area, which are evenly distributed in the Western, Central and Eastern lake regions (Table 1 and Fig. 1). Therefore, the experimental results of phosphorus release could represent the situation of the region.

| Serial number | Area  | Sample number | Latitude (°N) | Longitude (°E) |
|---------------|-------|---------------|---------------|---------------|
| 1             | Western | W1            | 31.7292       | 117.4065     |
| 2             |        | W2            | 31.7289       | 117.3795     |
| 3             |        | W3            | 31.7083       | 117.3868     |
| 4             |        | W4            | 31.6729       | 117.3700     |
| 5             | Central | C1            | 31.6548       | 117.3955     |
| 6             |        | C2            | 31.6473       | 117.4524     |
| 7             |        | C3            | 31.6078       | 117.5196     |
| 8             |        | C4            | 31.5842       | 117.5466     |
| 9             | Eastern | E1            | 31.6188       | 117.6038     |
| 10            |        | E2            | 31.6644       | 117.6615     |
| 11            |        | E3            | 31.6798       | 117.7191     |
| 12            |        | E4            | 31.6661       | 117.7881     |

**Design of experiment device**

In this study, a sediment column core from 12 sites of the Chaohu Lake in a large-scale column-shaped cylinder was prepared (Fig. 2). In the light of three starting modes, the sediment moves in the Individual Motion Mode when the hydrodynamic force of the overlying water is close to zero; the sediment is in the Small Motion Mode when the hydrodynamic disturbance is weak, and the sediment suspends in the General Motion Mode when the hydrodynamic force is strong (Guo et al. 2014). Therefore, the phosphate release process is simulated in the three sediment starting modes by controlling hydrodynamic disturbance in experiments using a rotary slurry. According to Alonso (1981) and Chun et al. (2010), each motion mode has a corresponding occurrence probability. For instance, the moving percentage of the Individual Motion Mode does not exceed 2%, while that of the Small Motion Mode is less than 16%. When the General Motion Mode occurs, the moving percentage of sediment exceeds 16%. Thus, the motion modes can be recognized by observing the occurrence probability of sediment movement. The three motion modes were labeled as “Experiment A,” “Experiment B” and “Experiment C,” respectively. The speed range of the rotary slurry corresponds to each experiment is listed in Table 2. In addition, the indoor water temperature should be kept consistent with that of the outdoor water.

The experimental container is a bottom-closed cylinder with a height of 1.2 m and an inner diameter of 70 mm. The internal diameter is similar to the diameter of the sediment column sample which is 68 mm, and the wall thickness of
Fig. 1 Sampling locations of the original sediment column cores of the Chaohu Lake

Fig. 2 Device for simulating measuring sediment phosphate release

Table 2 Controlling conditions for the sediment phosphate release

| Indicators                              | Experiment A          | Experiment B          | Experiment C          |
|-----------------------------------------|-----------------------|-----------------------|-----------------------|
| Start mode                              | Individual movement   | Small movement        | General movement      |
| Speed range of the cyclone (r/min)      | 0                     | 200–500               | 500–1200              |
| Probability of movement occurrence (%)  | ≤ 2                   | 2–16                  | ≥ 16                  |
the sampling tube is 2.5 mm. The sample is a 20-cm-high cylinder with a diameter of 63 mm, which fits rightly into the experimental container. The hydrodynamic control system consists of a speed controller, a perturbation propeller, and a 3D positioning system. The perturbation propeller was linked to a 3D positioning system, which controls the propeller position on the original bottom mud test container. The perturbation propeller was connected to the speed controller, which controls the propeller speed (0–3000 ± 5 r/min). The overlying water was artificially configured according to the water quality index of each sampling site. Different levels of resuspended sediment concentration are represented by different water colors: the blue column indicates a very small concentration, the light column indicates a small concentration, and the gray column indicates a high concentration. The water and sediment samples in experiment A were collected at three heights (i.e., 20 cm, 60 cm, and 80 cm) to calculate the average value due to the unevenly distributed sediment concentration, while those in experiments A and C were taken only under 30 cm of the water surface.

**Measurement of phosphate release**

The phosphate concentration changes of the overlying water as an index of phosphate release were measured. Since the phosphate exchanging rate was low in experiment A, the experimental period was set longer (6–7 days, or 144–168 h). During the early stage of the experiment, the substance concentration differed largely, leading to faster molecular diffusion speed. Then, the diffusion rate of the substance gradually decreased over time. Therefore, sampling intervals were lengthened gradually, i.e., 0, 2, 4, 8, 12, 24, 48, 72, 96, 120, and 144 h after the experiment was completed. In experiments B and C, the exchanging rate of phosphate was elevated under stronger hydrostatic disturbance. Therefore, the experimental period was set shorter (3–4 days or 72–96 h). Due to similar reasons, the sampling intervals were set unevenly as 0, 0.5, 1, 2, 4, 8, 12, 24, 48, and 72 h after the experiments were completed.

Based on the phosphate concentration monitoring, the cumulative phosphate release rate is calculated using Eq. 1 (Luo and Lu 2020):

$$ R(\text{mg} \cdot \text{m}^{-2} \cdot \text{day}^{-1}) = \frac{\sum (C_{i+1} \cdot V - C_i \cdot V + C_{i+1} \cdot V_s)}{S \cdot T} $$  \hspace{1cm} (1)

where $C_i$ and $C_{i+1}$ (mg/L) are the phosphate concentration at the $i$th and $(i+1)$th moments, respectively; $V$ is the water volume (4.34 L in this study); $V_s$ is the monitoring sample volume (0.3 L in this study); $S$ (0.00312 m$^2$ in this study) is the contacting area of the bottom mud sample and water body in the experiments; and $T$ is the time of the experiment.

**Results**

**Changes of phosphate concentration in the overlying water**

Hydraulic disturbances caused significant changes in phosphate concentrations released in water bodies in three experimental groups; however, the effects of disturbances were greater at the western area than at the eastern and central areas in each group (Fig. 3). In the view of disturbance intensity, the highest phosphate concentration (0.539 mg/L) was released in experiment C with the strongest hydraulic disturbance (500–1200 r/min), followed by those in experiment B (0.526 mg/L, 200–500 r/min) and experiment A (0.502 mg/L, 0 r/min). Regarding monitoring points, the average variation value of phosphate concentration was always largest at the western area (W2), eastern area (E4), and central area (C1) (Fig. 3).

**Changes of the accumulative sediment release rates and the effective rates**

According to Eq. 1, the release rate of phosphate in the three series of experiments is obtained, and the concrete results are as shown in Fig. 4.

All cumulative release rates of phosphate went stable no matter which area the sediment was collected from (Fig. 4), which is consistent with the release law of sediment phosphate in many other lakes (Precht and Huettel 2004; You et al. 2007; Chen et al. 2018a, b). The cumulative phosphate release rate fluctuated greatly in the initial stages in three experiments, due to sediment collision and the unsaturated phosphate concentration in the overlying water. As the test proceeded, the phosphate release rate became dynamically stable since the external environment did not change significantly. Meanwhile, the time required to reach the stable cumulative release rate varied, and the stronger the hydraulic disturbance, the longer the stabilization time. In this study, the time to stabilization were 24, 32, and 40 h in experiments A, B, and C, respectively. The stabilized cumulative release rates illustrated in Fig. 5 could present the final and effective release rates of phosphate from sediment. In the view of disturbance intensity, the highest phosphate release rate (25.06 mg/m$^2$/day) was in experiment C with the strongest hydraulic disturbance (500–1200 r/min), followed by those in experiment B (14.83 mg/m$^2$/day, 200–500 r/min) and experiment A (1.65 mg/m$^2$/day, 0 r/min). Regarding monitoring points, the average variation value of the
Fig. 3  Phosphate concentration in the overlying water during the monitoring period

Fig. 4  Cumulative release rates of phosphates during the monitoring period
phosphate concentration was always largest at the western area (W4), eastern area (E3), and central area (C3). The effects of disturbances were greater at the western area than at the eastern and central areas in each group (Fig. 5). Thus, the average phosphate release rate in the sediments of the three lake regions shows a law that the values of experiment A < B < C, and the fluctuation of phosphate release rate is also A < B < C. It can be seen that the release of phosphate in the sediments of the whole Chaohu Lake is mainly affected by the hydrodynamics of the overlying water.

Besides, the five negative effective release rates appeared when the overlying water is stationary, resulting from the relative relationship between phosphate content in sediments and phosphate concentration in water. As the hydrodynamic force increases, the effective release rate increased while the number of negative rates declined. Moreover, the profiles of the effective release rate of phosphate at all sampling sites in this study conformed to results in a previous study involving hydraulic disturbance (Zhu et al. 2005).

### The total phosphate release flux of the Chaohu Lake

The contribution of released phosphate from sediment to water quality has also been assessed by exploring the phosphate release flux throughout the whole lake region. According to the integral of the cumulative phosphate release rate and lake area (Table 3), it shows that the maximum phosphate release flux from sediments in the Individual Motion Mode (or the lake water is almost stationary) approximately reached 203.43 kg/day; the maximum flux is about 3642.68 kg/day under the sediments’ Small Motion Mode (or the overlying water is weakly disturbed); and the maximum flux from sediments in the General Motion Mode (or the overlying water is strongly stirred) could probably reach 7311.01 kg/day. Considering that the three modes would appear alternately in the Chaohu Lake during a period, the total sediment release flux of phosphates may vary between 203.43 and 7311.01 kg/day. The interpolated values of precise cumulative phosphate release rates in the lake area were calculated and shown in an equipotential diagram (Fig. 6). It is interesting to find emission centers at two western sites.

### Table 3 Phosphate release flux from the Chaohu Lake sediment

| Serial number | Area  | Coverage (km²) | Experiment A (kg/day) | Experiment B (kg/day) | Experiment C (kg/day) |
|---------------|-------|----------------|-----------------------|-----------------------|-----------------------|
| 1             | Western | 190.79         | 13.36                 | 1014.05               | 3015.44               |
| 2             | Central | 293.80         | 90.34                 | 1179.61               | 1816.42               |
| 3             | Eastern | 284.96         | 99.74                 | 1449.02               | 2479.15               |
| 4             | All     | 769.55         | 203.43                | 3642.68               | 7311.01               |
(W2 and W4) and two eastern sites (E3 and E4) in all the three modes, while in the central area, the phosphate releasing center shifted from C2 in the Individual Motion Mode, to C3 in the Small Motion Mode, and to C3 in the General Motion Mode. It may be influenced by the rivers that enter the lake. Survey data show that there are several tributaries in both the west and east areas of Chaohu Lake (Zhang et al. 2020), among which are in the western area of the surrounding Shiwuli River, Tangxi River, and Pai river; the water discharged into the lake by Gaozhe River and Shuangqiao River in the eastern area. The pollutants they carry flow into the lakes and accumulate in the sediments, which contain excessive levels of pollutants. This would result in concentrated emission in both regions. In addition, studies have shown that the water moves back and forth in the central area under the influence of the monsoon (Teng et al. 2021). As a result, the discharge of pollutants in the sediments in the central area is closely related to the hydraulic conditions. This explains the variation of the strongest emission with the increase in hydraulic disturbance (Bryan et al. 2008).

Discussion

Reliability of the laboratory simulations and extrapolation

In simulating the physical process of pollutant release from sediments in shallow lakes, a hypothetical porous structure of the top layer sediments is usually assumed. Thus, the simulation results generally reflect the release rate in ideal conditions, which also provide a reference to solving the real-world problem. The second controversial problem is determining the thickness of the sampling layer (Corcoran et al. 2015). From the perspective of the influence depth of environmental factors, the thickness should be within 10 cm of the top silt (Liu et al. 2017). In addition, the sediment core within 10 cm in shallow lakes is easily re-suspended by waves into the water (Qin et al. 2020). Furthermore, the species and biomass of microorganisms and benthic animals are abundant in the top 10-cm-layer sediments, resulting in significant benthic disturbances, especially around the depth of 5.75 ± 5.67 cm in global waters (Lgab and Bcgg 2015). In this study, undisturbed sediment columns of 20 cm from the top sediment were sampled, which should be deep enough to simulate the external interference.

In simulating the phosphate release rate under different levels of disturbance, the process by which phosphate emission increases with water disturbance and sediment resuspension has been successfully reproduced. This is consistent with the sediment kinematics law that the increase in water disturbance intensity leads to the shifting of the sediment threshold mode. The great variation of the release rate also confirmed the fact that shallow lakes are susceptible to flows of tributary bays and to human activities. On this basis, by comparing other research results on phosphate release in the Chaohu Lake, it was found that the maximum phosphate release was 9.91 mg/m²/day (Peng, et al. 2019). Then the total release flux can be estimated to be 7626.24 kg/day,
which is very close to the total maximum release flux estimated in this study (7311.01 kg/day). Therefore, the laboratory simulations of this study are generally reliable.

However, in extrapolating the simulation results to the real-world scale, limitations exist in this study. For one thing, the randomness of wind force of the Chaohu Lake area, which makes the phosphate release process more complex and highly variable, should be further taken into account (Yuan et al. 2020; Yu et al. 2016). In particular, the shift between different motion modes of sediments under the effect of winds generally corresponds with great changes in the phosphate release rate, leading to large uncertainty in the extrapolation. For the other, the effect of temperature should also be studied due to its great impact (Wu et al. 2020a; Yu et al. 2020).

**Implication to the pollutant management in other shallow lakes**

Sediment resuspension has been demonstrated as the key factor affecting the water quality of shallow lakes (LikaiNiE 2020). However, sediment resuspension is a complicated and random process in real lakes, which cannot be easily observed. Meanwhile, studies on sediment threshold under different levels of disturbances have also been widely carried out by employing empirical and/or theoretical derivation formulas, yet now the evidence obtained from observation and experiment used to confirm and verify the scientific theories are limited (Tang et al. 2020). Thus, correlating sediment movement and endogenous pollutants release appears meaningful, since the sediment environment monitoring guideline for release flux has not been established in China yet, which will result in a poor management of shallow water lakes and further a high ecological risk induced by endogenous released pollutants. In this study, established motion models of phosphate release from sediment with different sediment thresholds can standardize the phosphate release process from random sediment resuspension into three standard intensities, and it provides a feasible method of quantifying sediment release and facilitates assessment on endogenous phosphate release in all shallow lakes under uniform standards.

In addition, three sediment starting modes, induced by sediment resuspension, are applicable in most shallow lake sediments. That is to say, the phosphate release model in this study is highly universal without being affected by the natural boundary conditions of shallow lakes.

**Conclusion**

In a typical shallow lake of Chaohu, the phosphate release fluxes from sediment under different hydrodynamic disturbances driven by wind were studied by setting up a simulation system in the laboratory. Sediment column cores were collected from 12 sites and placed in a properly designed device which integrated a hydraulic control system to simulate different levels of disturbance. The experiment results demonstrate a significant difference in the release rates among the three sediment threshold modes, i.e., varying from 0.24 mg/m²/day in the Individual Motion Mode, to 4.81 mg/m²/day in the Small Motion Mode, and finally reaching 10.23 mg/m²/day in the General Motion Mode. Correspondingly, the total phosphate release fluxes changes from 203.43 to 7311.01 kg/day after a simple extrapolation. For a more accurate estimation of the release flux of the lake, the randomness of wind force and the effect of temperature should be taken into account. The method proposed by this study is also applicable to other shallow lakes where sediment resuspension commonly occurs under wind and wave forces.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s11356-022-20102-7.

**Author contribution** This research was done at Wuhan University with strong support from the Chaohu Lake administration in Hefei. We have given guidance and help to the collection of sediments in our experiment. W Luo was responsible for the whole research work, including the experimental work and the analysis of the results. Y Yue designed the main content framework of the manuscript and assisted in the analysis of the experimental results. J Lu assisted in the preparation and operation of the experiment. L Pang mainly assisted in the in-depth analysis of experimental data and the collation of results. S Zhu assisted in some data analysis and the writing of this manuscript.

**Funding** This study is supported by the National Natural Science Foundation of China (Grant No. 52109099), the Fundamental Research Funds for the Central Universities (Grant No. 2042020kf0004), and the National Natural Science Foundation of China (Grant No. 52079094).

**Data Availability** All data generated or analyzed during this study are included in this manuscript. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

**Declarations**

**Ethics approval** The experimental protocol was established according to the ethical guidelines of the Helsinki Declaration and was approved by the Human Ethics Committee of Wuhan University. Written informed consent was obtained from individual or guardian participants.

**Consent to participate** Not applicable.

**Consent for publication** The author confirms that the work described has not been published before; that it is not under consideration for publication elsewhere; that its publication has been approved by all co-authors, if any; and that its publication has been approved by the responsible authorities at the institution where the work is carried out. The author agrees to publication in the Journal indicated below and also to publication of the article in English by Springer in Springer’s corresponding English-language journal. The copyright to the English-
language article is transferred to Springer effective if and when the article is accepted for publication. The author warrants that his/her contribution is original and that he/she has full power to make this grant. The author signs for and accepts responsibility for releasing this material on behalf of any and all co-authors. The copyright transfer covers the exclusive right to reproduce and distribute the article, including reprints, translations, photographic reproductions, microform, electronic form (offline, online), or any other reproductions of similar nature. After submission of the agreement signed by the corresponding author, changes of authorship or in the order of the authors listed will not be accepted by Springer.

Competing interests The authors declare no competing interests.

References

Alonso CV (1981) Stochastic models of suspended-sediment dispersion. Am Soc Civil Eng 107(6):733–757
Bryan MS, Carvalho L, Perkins R, et al (2008) Effects of light on sediment nutrient flux and water column nutrient stoichiometry in a shallow lake. Water Res 42(4)/5:977–986
Chun RL, Li YD, Aode H (2010) Probability of sediment incipient motion under complex flows. China Ocean Engineering 24(001):93–104
Chen M, Ding S, Chen X et al (2018a) Mechanisms driving phosphorus release during algal blooms based on hourly changes in iron and phosphorus concentrations in sediments. Water Res 133:153–164
Chen S, Yang G, Lu J et al (2018b) Water quality in simulated eutrophic shallow lakes in the presence of periphyton under different flow conditions. Environ Sci Pollut Res 25(5):4584–4595
Chen Y, Liu Q (2015) Numerical study of hydrodynamic process in Chaohu Lake. J Hydrodyn 27(5):720–729
Corcoran P L, Norris T, Ccecanese T et al (2015) Hidden plastics of Lake Ontario, Canada and their potential preservation in the sediment record. Environ Pollut 204(SEP.):17–25
Carpenter SR (2008) Phosphorus control is critical to mitigating eutrophication. Proc Natl Acad Sci USA 105(32):11039–11040
Deng J, Zhang Y, Yin H et al (2020) Ecological risk assessment and source apportionment of metals in the surface sediments of river systems in Lake Taihu basin, china. Environ Sci Pollut Res 27(21):25943–25955
Gu BW, Lee CG, Lee TG et al (2017) Evaluation of sediment capping with activated carbon and nonwoven fabric mat to interrupt nutrient release from lake sediments. Sci Total Environ 599:413–421
Guo J, Cao Y, Zheng S (2014) Numerical research on the mechanism of contaminant release through the porous sediment-overlying water interface. J Hydrodyn 26(6):971–979
Hu B, Wang P, Bao T et al (2021) Mechanisms of photochemical release of dissolved organic matter and iron from resuspended sediments. J Environ Sci 104:288–295
Jin G, Onodera SI, Saito M et al (2020) Sediment phosphorus cycling in a nutrient-rich embayment in relation to sediment phosphorus pool and release. Limnology 21:415–425
Luo W, Lu J (2020) Inhibition of in situ coating of sediment ceramics on sediment nutrient release of eutrophic lakes. Environ Geochem Health 4:13–27
Liu Y, Li C, Anderson B et al (2017) A modified QWASI model for fate and transport modeling of mercury between the water–ice–sediment in Lake Ulansuahi. Chemosphere, 176(JUN.):117–124
Lgab A, Bcgg B (2015) Microplastics in the marine environment: current trends and future perspectives - science direct. Mar Pollut Bull 97(1–2):5–12

LikaiNiE. (2020) Review of effects of macrobenthos bioturbation on sediment biogeochemical cycle. Agric Biotechnol 9(02):90–92
Norton SA, Coolidge K, Amirbahman A et al (2008) Speciation of AL, FE, and Pb in recent sediment from three lakes in Maine, USA. Sci Total Environ 404(2–3):276–283
Precht E, Huettel M (2004) Rapid wave-driven advective pore water exchange in a permeable coastal sediment. J Sea Res 51(2):93–107
Peng C, Zhang Y, Huang S et al (2019) Sediment phosphorus release in response to flood event across different land covers in a restored wetland. Environ Sci Pollut Res 26:9113–9122
Qin B, Paerl H et al (2019) Why Lake Taihu continues to be plagued with cyanobacterial blooms through 10 years (2007–2017) efforts. Sci Bulletin 64(06):7–9
Qin Y, Wang Z, Li W et al (2020) Microplastics in the sediment of Lake Ulansuahi of Yellow River Basin, China. Water Environ Res 92:829–839
Reed DC, Slomp CP, Gustafsson BG (2011) Sedimentary phosphorus dynamics and the evolution of bottom-water hypoxia: a coupled benthic–pelagic model of a coastal system. Limnol Oceanogr 56(3):1075–1092
Teal LR, Bulling MT, Parker ER et al (2008) Global patterns of bioturbation intensity and mixed depth of marine soft sediments. Aquat Biol 2:207–218
Teng Z, Fan W, Wang HL et al (2021) Structural and functional alterations in soil bacterial community compositions after fifteen-years restoration of Chaohu Lakeside Wetland, East China. Eurasian Soil Sci 54(1):98–107
Tang C, Li Y, He C et al (2020) Dynamic behavior of sediment resuspension and nutrients release in the shallow and wind-exposed Meiliang Bay of Lake Taihu. Sci Total Environ 708(3):135131.1–135131.10
Wu H, Yang T, Liu X et al (2020a) Towards an integrated nutrient management in crop species to improve nitrogen and phosphorus use efficiencies of Chaohu Watershed. J Cleaner Prod 272:122765
Wu T, Zhu G, Chen J et al (2020b) In-situ observations of internal dissolved heavy metal release in relation to sediment suspension in lake Taihu, China. J Environ Sci 97:120–131
Yu J, Chen J, Zeng Y et al (2020) Carbon and phosphorus transformation during the deposition of particulate matter in the large deep reservoir. J Environ Manag 265:110514
Yu J, Fan C, Zhong J et al (2016) Effects of sediment dredging on nitrogen cycling in Lake Taihu, China: insight from mass balance based on a 2-year field study. Environ Sci Pollut Res 23(4):3871–3883
Yuan H, Yin H, Yang Z et al (2020) Diffusion kinetic process of heavy metals in lacustrine sediment assessed under different redox conditions by DGT and DIFS model. Sci Total Environ 741(1):401–418
You B, Zhong J, Fan C et al (2007) Effects of hydrodynamics processes on phosphorus fluxes from sediment in large, shallow Taihu Lake. J Environ Sci 19(9):1055–1060
Zhu G, Qin B, Gao G (2005) Direct evidence of phosphorus out-break release from sediment to overlying water in a large shallow lake caused by strong wind wave disturbance. Chin Sci Bull 50(6):577–582
Zhang W, Li H, Xiao Q et al (2020) Urban rivers are hotspots of riverine greenhouse gas (N2O, CH4, CO2) emissions in the mixed-landscape Chaohu Lake Basin. Water Res

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.