Temporal-spatial distribution, environmental significance and release risks of phosphorus in the sediments of a tropical mountain’s deep drinking water reservoir in southeastern China

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ABSTRACT

In this study, the fractionation and distribution of phosphorus (P) in the core sediments of the Shanmei reservoir were investigated by using the chemical extraction method in directions for the first time in order to understand its bio-availability, adsorption characteristics, potential release and environmental significance. The results of the study showed that P in the sediments mainly consisted of inorganic phosphorus (IP) and that IP mainly consisted of non-apatite phosphorus (NAIP). The horizontal and temporal distributions of the P fractions were different from each other, but the vertical distribution was similar, which indicated a trend of stabilization after falling. The content of total phosphorus (TP), IP, organic phosphorus (OP), NAIP, apatite phosphorus (AP), and bio-available phosphorus (BAP) in the sediments during the three seasons ranged from 193.85 to 1664.05 mg·kg\textsuperscript{-1}, 126.90 to 1127.70 mg·kg\textsuperscript{-1}, 43.74 to 669.29 mg·kg\textsuperscript{-1}, 57.62 to 937.07 mg·kg\textsuperscript{-1}, 32.58 to 250.71 mg·kg\textsuperscript{-1}, and 41.06 to 871.82 mg·kg\textsuperscript{-1}, respectively. NAIP contents in the sediments accounted for more than 50% of TP. Using an analysis from three aspects, the eutrophication risk index (ERI) could be used to assess the potential release of P in the sediments, and there was a high release risk of P in the sediments in the Shanmei reservoir.

Abbreviations: phosphorus (P); inorganic phosphorus (IP); non-apatite phosphorus (NAIP); total phosphorus (TP); organic phosphorus (OP); apatite phosphorus (AP); bio-available phosphorus (BAP); global positioning system (GPS); SMT (Standard Measurements and Testing); soluble reactive phosphorus (SRP); phosphorus sorption index (PSI); equilibrium phosphate concentration (EPC\textsubscript{0}); eutrophication risk index (ERI)

1. Introduction

At present, due to increasingly serious water contamination, the safety of drinking water is becoming increasingly more important to the public. Therefore, the protection of drinking water sources is urgent, and we must pay close attention to internal pollution. Various pollutants may be absorbed into the sediments accumulated on the bottom of the rivers and lakes [1]. These sediments may accumulate over long periods of time and act as new pollutant sources to the overlying water [2–4]. The amount of P released from the sediments to the overlying water at various levels is comparable with that from external sources [5].

P has been recognized as the most important limiting nutrient for a lake’s primary productivity on a long-term scale [6–8]. P released from the sediments may induce the deterioration of water quality even while a lake (reservoir) is in a state of equilibrium. Accordingly, it is critically important to analyze P in the sediments of reservoirs that are sources of drinking water. The knowledge of P speciation involves the study of the environmental changes, the P cycle, the bioavailability and the N, S and O cycles [9]. Different forms of P with different release potentials have different availabilities. Therefore, it is necessary to carry out related studies to understand the distribution of different P fractions in the sediments and to clarify the release mechanism of P fractions from different polluted sediments [10]. The fraction of P in the sediments is complicated, and the release potential of P from the sediments into the overlying water is strongly related to the P fraction [11]. The sequential extraction of P is useful for the characterization of various P compounds [12–14]. It is therefore important to understand the different forms of P that exist in the sediments, the P adsorption characteristics, and the potential release of P.

The Shanmei reservoir, which is located in Fujian Province in southeastern China, covers a large area and is very deep (34.15 m). It is situated on a tributary...
of the Jinjiang River, one of the four largest rivers in Fujian Province. The reservoir covers a catchment area of 1023 km² and holds 6.55 × 10⁸ m³ of water. It provides drinking water for approximately 4 million people daily and agriculture water for 4.3 × 10⁴ hectares of farmland. The Shanmei reservoir is honored as ‘the life library of the Quanzhou people’ and ‘the ecological regulator of the Quanzhou area’. The Shanmei reservoir is a multi-functional body of water, used not only for drinking but also for hydropower, flood control, shipping, recreation and commercial aquaculture (fishing). In addition, the Shanmei reservoir was the only reservoir in Fujian Province that was listed positively in the National Good Lake Ecological Environment Protection planning report (2011–2020) by the Ministry of National Environmental Protection in October 2012. The Shanmei reservoir is listed as one of the priorities.

The current research on the sediment P fractions is more focused on shallow lakes [5, 7, 15]. There have been few studies of the spatial and temporal distribution of the sediment P fractions in a subtropical mountain deep-water lake (or reservoir). Chen et al. [16] found that the increase of sediment P release in the anoxic state associated with the density current initiated by the cold front in winter was the cause of the deterioration of the water quality of the Feitsui Reservoir, a subtropical deep reservoir. The main objectives of this study were (1) temporal-spatial distribution characteristics of the P fractions and their environment significance in the core sediments in the Shanmei reservoir, a subtropical mountain deep-water reservoir, and (2) discussing the P potential release in the sediments. The study is useful for the evaluation of the environmental effects of P. The results can be used to provide theories regarding the significance of the sediments as internal sources releasing P into the overlying water. This study will also be conducive to a better understanding of the evolution of the sediment environment of the subtropical mountain deep-water reservoir and to advance further studies of the mechanism and the restoration of the subtropical deep-water reservoir eutrophication.

2. Materials and methods

2.1. Sample collection

The core sediment samples were obtained from every site using a hand-driven stainless-steel corer, which is 60 cm long with an internal diameter of 59.5 mm. The water samples were taken from three layers by a water sampler during the months of July and November 2012 and March 2013, which respectively correspond to the wet season, dry season, and normal season. The nine locations were determined based on the hydrological conditions and the surroundings of the reservoir, as shown in Fig. 1. The reservoir was divided into four parts: the entrance region (S1, S2), the closed region (S3, S4), the middle region (S5, S6) and the dam region (S7, S8, S9). The closed region is next to the town of Jiudu. The precise collection sites were corrected in situ using a global positioning system (GPS). In addition, the Secchi transparency (20 cm) and the depth of the water were measured before sampling. The core sediment samples were sliced into sections at 5-cm intervals, except for the first interval (2 cm), in situ before being placed into polyethylene plastic bags. All of the samples were transported to the laboratory as soon as possible.

2.2. Core sediment P fractionation

The subsamples of the sediments were freeze-dried at −40 °C for 48 h and then ground into powders that were then screened through a stainless steel sieve. At this point, particles <150 μm were obtained. Studies were then performed on the phosphorus fractions and several parameters of the core sediments.

To determine the TP, an Standard Measurements and Testing (SMT) protocol developed by the SMT Program of the European Commission was applied in this study [17–19]. In brief, 0.2000 g of each freeze-dried sediment sample was weighted accurately into a crucible and calcined at 450 °C for 3 h. Then, each sample of the calcined sediment was transferred into a polyethylene centrifuge tube (50 mL), 20 mL of 3.5 mol·L⁻¹ HCl was added and then the sample was shaken on an oscillator at 200 r·min⁻¹ and 25 °C for 16 h. The extract was then separated by centrifugation at 4000 r·min⁻¹ for 15 min, after which the supernatant was analyzed by spectrophotometry.

The P fractions in the sediments were characterized by their differential solubilities in the various chemical extractants [20]. We can characterize the P fractions by their different solubility using different extraction methods. The phosphorus extraction method used in the present study was a SMT protocol, including non-apatite phosphorus (NAIP), AP, IP and OP.

Figure 1. Location of sampling sites in the Shanmei reservoir.
The availability of P in the core sediment determines the potential risk. This is why bio-available phosphorus (BAP) has long been a topic of interest in studies both in China and around the world. The BAP content can be measured generally by the cultivation of algal assays for approximately 7–100 days. In this study, a more rapid chemical extraction method was used to determine the bioavailability of P [14].

2.3. P sorption isotherm experiments

Sorption isotherm experiments were performed on all the core sediments. For each pretreated sediment sample, 0.2 g of freeze-dried sediment was weighted accurately into 20-mL polyethylene tubes, and 20 mL phosphate standard solutions (KH$_2$PO$_4$) of various concentrations from 0 to 1 mg·L$^{-1}$ ($C_0$) were added. A phosphate standard solution with 0 μg L$^{-1}$ was used as the control. The tubes were incubated in a shaker of 250 rpm at 25 ± 1°C for 24 h. The suspensions were then centrifuged at 4,000 rpm for 10 min and 10 mL of the supernatants were analyzed for soluble reactive phosphorus (SRP) by spectrophotometry. The amount of P sorbed by sediments was calculated as the difference between the mass of P initially added and that recovered in solution after 24 h adsorption, and the equilibrium phosphate concentrations were analyzed. The experiments were carried out in triplicate, and the data were expressed as averages.

2.4. P sorption index and degree of P saturation of core sediments

For each pretreated sediment sample, 1.0000 g of freeze-dried sediment was weighed accurately into 50-mL polyethylene tubes, and 20 mL 75 mg·L$^{-1}$ KH$_2$PO$_4$ (preparation in 0.01 mol·L$^{-1}$ CaCl$_2$) solution was added. The tubes were shaken at 250 rpm at 25 ± 1°C for 24 h. The suspensions were then centrifuged at 4,000 rpm for 10 min and 5 mL of the supernatants were analyzed for SRP by spectrophotometry. The amount of P sorbed by sediments was calculated as the difference between the mass of P initially added and that recovered in solution after 24 h adsorption. The amount of P adsorbed by 100 g of sediments was designated as X (mg P·100 g$^{-1}$) and the concentration of P in the filtrate as C (μmol·L$^{-1}$). The phosphorus sorption index (PSI) was

$$\text{PSI} = \frac{X}{\lg C}$$

Oxalate-extractable (ox) P, Fe, and Al were determined for all four cores using 0.1 mg·L$^{-1}$ oxalic acid plus 0.175 mol·L$^{-1}$ ammonium oxalate solution, equilibrated at pH = 3.0. P, Fe, and Al in the oxalate solution were determined using, and the degree of phosphorus saturation (DPS) was calculated as:

$$\text{DPS} = 2 \times \frac{\text{ox}(P)}{[\text{ox}(Fe) + \text{ox}(Al)]}$$

3. Results and discussion

3.1. P forms in sediment profiles of the Shanmei reservoir

The P contents of the sediments were determined by a number of factors, including the rate of sedimentation, the sediment type, the amount and type of organic matter, the intensity of mineralization of organic matter in the sediment and water column, the redox conditions in the sediment and near the bottom water, the Ca, Al and Fe contents in the sediment and near the bottom water, and the water depth [21]. A survey of approximately 180 samples showed that TP concentrations in the sediments ranged from 193.85 to 1664.05 mg·kg$^{-1}$, with a mean value of 803.81 mg·kg$^{-1}$. The highest value was observed at site 6 in the wet season. According to the Chinese environmental dredging common standards, when the TP concentrations in the lake sediments are over 500 mg·kg$^{-1}$, the lake sediments are considered to be polluted and should be dredged [20]. Hence, there may be a potential for the sediments to supply phosphorus to the overlying water. The vertical distribution of the TP content with depth in all three seasons tended toward stability after falling (Figure 2).

The concentrations of IP, OP, NAIP, and AP in the sediments ranged from 126.90 to 1127.70 mg·kg$^{-1}$, 43.74 to 669.29 mg·kg$^{-1}$, 57.62 to 937.07 mg·kg$^{-1}$, and 32.58 to 250.71 mg·kg$^{-1}$, respectively. As for TP, the highest value of IP was observed at site 6 in the wet season. The content of IP was higher than that of OP and the content of NAIP was higher than that of AP. IP is the major fraction of TP in the Shanmei reservoir, accounting for 63.80%, and OP, NAIP and AP accounted for 35.83, 50.82 and 12.76% of TP, respectively (Figure 3).

The vertical distributions of different P forms with depth in all three seasons are shown in Figure 4. Except for AP, the vertical distribution of different P forms with depth in all three seasons tended toward stability after falling, which indicated that the P concentration was related to human activity to a certain extent.
The average temporal distribution of the IP content was dry period (533.08 mg·kg\(^{-1}\)) > normal period (505.13 mg·kg\(^{-1}\)) > wet period (500.24 mg·kg\(^{-1}\)). The average temporal distribution of the OP content was wet period (363.44 mg·kg\(^{-1}\)) > dry period (263.20 mg·kg\(^{-1}\)) > normal period (237.47 mg·kg\(^{-1}\)).

The results showed that a mass of pollutant was transported into the reservoir in the wet season, and the majority of P transported into the reservoir was OP. From the wet season to the normal season, OP was decomposed and formed IP.

### 3.2. Distribution characteristics of P fractions

The origins of the sediments, biological activity, physical conditions, chemical conditions and hydrological conditions all determine the P fractions in the core sediments [22].

The lowest values of TP, IP, OP and NAIP in all three seasons were all in the closed region. This shows that the effect from the town was less than that from the flow. The flow in the closed region (which is off the main channel) was relatively slow, which may lead to vigorous biological activity, causing P to be released from the sediment into the water.

The average temporal distribution of the TP content was wet period (867.94 mg·kg\(^{-1}\)) > dry period (801.02 mg·kg\(^{-1}\)) > normal period (742.47 mg·kg\(^{-1}\)). The average temporal distribution of the OP content was wet period (363.44 mg·kg\(^{-1}\)) > dry period (263.20 mg·kg\(^{-1}\)) > normal period (237.47 mg·kg\(^{-1}\)). The results showed that a mass of pollutant was transported into the reservoir in the wet season, and the majority of P transported into the reservoir was OP. From the wet season to the normal season, OP was decomposed and formed IP.

### 3.3. BAP in the core sediments

The concentrations of BAP in the sediments ranged from 41.06 to 871.82 mg·kg\(^{-1}\), with an average of...
352.98 mg·kg⁻¹. The BAP content in the sediments accounted for 43.91%. In other words, nearly half of P in the sediments was bio-available or potentially bio-available in the Shanmei reservoir.

The question of BAP in the sediments is important to the assessment and control of eutrophication [23]. The tendency in the vertical distribution was to stabilize after falling (Figure 5). These results showed that the importation increased year by year, and the influence of the external environment on the sediments was confined to a specific depth. During the three seasons, the BAP content in the core sediments was thoroughly investigated. The results showed that the contents of BAP in the wet season and normal season were approximately equal, with only a 4% difference. However, the BAP content in the dry season was found to be at 30%, which was more than in the normal season. In the dry season, with a reduction of flow, the balance between the water and the sediment was destroyed. This led to the adsorption of BAP by the sediments. During the normal season, when the strong growth and reproduction of living beings occur, the consumption of BAP led to the reduction of BAP in the sediments. During the wet season, the BAP content decreased slightly. The results showed that although a large flow of agricultural runoff pollution entered the reservoir, the dilution and self-purification in the reservoir resulted in the BAP content of sediments remaining steady. This meant that although the variation of the flow and the season had an influence on the BAP content of the sediments, the BAP content was not epigenetically changed during the different seasons. During all three seasons, the lowest area of all was the closed region, and the BAP content in different seasons were approximately equal. The results indicated that although there was domestic pollution, the slow flow permitted vigorous metabolism, which led to a large consumption of BAP. However, the highest area was different in each season, and the BAP contents in different seasons were not similar. In the wet season, with the large flow of agricultural runoff pollution, the contaminant moved mainly horizontally and was gathered and retained in the dam region. In the dry season, as the flow was slower, the level of horizontal motion was minimal. Therefore, the retention was observed in the middle region. In the normal season, although the highest value was observed in the entrance region, it was approximately 22% lower than that in the wet and dry seasons. The results showed that the retention ability in the entrance region was weak. However, as for the quick flow, the biomass was small. The consumption of BAP was lower than that in other areas, which caused the highest value in the normal season to be found in the entrance region.

To test the distribution of BAP, the results showed approximately a normal distribution. Pearson Correlation analysis was used to research the relationship between BAP and the P fraction in the sediments.

The results of the study showed that NAIP and BAP were significantly correlated. Coincidently, NAIP was the main component of BAP in the sediment. NAIP might significantly contribute to BAP in the sediments by enhancing the cation-exchange capacity of the sediments and reducing the phosphorus fixation [20]. The correlation between OP and NAIP was relatively lower than that between NAIP and BAP. There was also a coincidental result that showed that part of OP was potentially available. The correlation between BAP and AP was very low, which showed that AP was almost unavailable.

3.4. EPC₀ of the sediments

The equilibrium phosphate concentration (EPC₀) in the sediments ranged from 0.0204 to 0.2240 mg·L⁻¹. The variation was very large. The vertical distribution of EPC₀ first fell from the surface sediment (2 cm) to the subsurface sediment, and then the EPC₀ fluctuated in a relatively small range with sediment depth (Figure 6).

The EPC₀ in the surface sediments ranged from 0.053 to 0.224 mg·L⁻¹, with an average of 0.131 mg·L⁻¹. The space variation was very large. The P content in the overlying water ranged from 0.051 to 0.105 mg·L⁻¹, with an average of 0.081 mg·L⁻¹.

3.5. PSI and DPS in the sediments

The PSI in the sediments ranged from 50.921 to 146.87 (mg-L)/(100 g·μmol), with an average of 72.849 (mg-L)/(100 g·μmol). The variation for the PSI in the core sediments was very large. The lowest value was observed at S9 in the wet season, for which the sediment at S9 in the wet season was sandy.

The ox (P), ox (Al), and ox (Fe) in the core sediments ranged from 5.797 to 95.006 mg·kg⁻¹, 72.097 to 231.050 mg·kg⁻¹, and 295.957 to 1859.345 mg·kg⁻¹, respectively. It was obvious that ox (Fe) > ox (Al) > ox (P) (Figure 7). The DPS in the core sediments ranged from 3.92 to 33.64%, with an average of 17.29%.

![Figure 5. Vertical profiles of the average content of BAP in different seasons.](image-url)
bio-available, being considered permanently buried [27]. AP in the sediments of the Shanmei Reservoir ranged from 32.58 to 250.71 mg·kg⁻¹, with a mean value of 102.56 mg·kg⁻¹, accounting for 12.76% of TP. In the Shanmei reservoir, AP is not the main portion of P in this fraction.

However, AP may temporarily control phosphorus release from sediments, since there may be a large number of phosphate-solubilizing bacteria that can transform insoluble phosphate into bio-available forms.

OP was considered to derive mainly from rural agricultural cultivation and fertilization and was a slow but continuous bio-available fraction of phosphorus. In the Shanmei reservoir, the highest area of OP was observed in the middle region. This may be due to the increasing water area in this region, with a relatively decreased flow rate, which may lead to the sedimentation of OP.

In the Shanmei reservoir, the OP concentration in the sediments was 288.04 mg·kg⁻¹, accounting for 35.83% of TP. Generally, OP has been considered a source of dissolved phosphate in interstitial water in sediments due to bacterial regeneration. In the former analysis, most of the P transported into the reservoir was in the form of OP, but the IP/OP ratio was approximately 1.8. Hence, in this reservoir, there was a higher depuration rate in OP than that in IP. Additionally, there may be a mass of conversion from OP to IP. This depuration effect of OP on the reservoir may produce a significant reduction of the release of phosphorus from the sediments [28].

3.7. Release potential of sediment P

We discussed the release potential of sediment P from three aspects: (1) P fractions in the sediments, (2) adsorption characteristics of sediment P, and (3) the PSI and DPS of the sediment.

Mobile P in sediments can be used to estimate the potential release of sediment P to the overlying water [29]. In this study, the vertical distribution of mobile P concentration (NAIP) tended to be stable after falling with depth in all the three seasons. In the former analysis, the result showed that NAIP was the major fraction of the sediments in the Shanmei reservoir. Hence, the

![Figure 6](image_url) Vertical profiles of EPC₀ (shown as averages).

![Figure 7](image_url) Concentration of P, Al, Fe extracted from sediment by ammonium oxalate.

### 3.6. Environment significance of P fractions

NAIP which is P bound to Fe, Al and Mn oxides and hydroxides, is extracted by 1 M NaOH solution. The main sources of NAIP are domestic water and industrial wastewater [18]. In addition, the degradation of OP can also form NAIP.

In the Shanmei reservoir, NAIP is the major fraction of IP and TP, accounting for 79.66 and 50.82%, respectively. Generally, NAIP has been shown to be used for estimation of short and long-term BAP in the sediment and is a measure of algal available phosphorus [14]. This fraction could be released for the growth of phytoplankton when anoxic conditions prevail at the sediment-water interface [24]. Because ligand competition between PO₄³⁻ and OH⁻ in the sediments would cause the availability of binding sites on ferric complexes to decrease with increased pH, NAIP in the sediments would also decrease [11]. From the high percentage of NAIP/TP, we know that, the Shanmei reservoir has a high potential availability of P for algae, which hinders eutrophication control. Previous research has suggested that P extraction with NaOH is time and concentration dependent and will also extract phytate P and OP [25]. Hence, an improved and more accurate extraction step is needed in future study.

AP (which is extracted by 1 M HCl solution) was assumed to be an inert fraction [26]. Thus, the P concentration in this extraction step will not be as readily
mobile P was the major fraction and increased rapidly toward the surface sediment, which showed that the pollution and potential release of sediment P was more serious in recent years. The oxidation-reduction potential was gradually reduced with increasing sediment depth. This leads to the reduction of ferric iron content as well as the content of NAIP. The average depth of the water in the Shanmei reservoir was approximately 30 m, and the oxidation-reduction potential was relatively low. The results showed that the retention ability of the sediments for NAIP was low, and the release potential of the mobile P was high. In the Shanmei reservoir, the study shows that more than 50% of TP was NAIP, which may be one of the reasons that the TP content was only 803.81 mg·kg⁻¹. The correlation between TP and NAIP is significant. Some researchers have evaluated the P release potential by the proportion of the P fraction [30], however, the risk assessment of eutrophication by the P release potential is only partial. Xie et al. [31] have proposed that the P release is more a result than a reason for the bloom outbreaks. However, the P release will contribute to extension of the duration of the blooms. The reasons for bloom outbreaks are very complex and depend not only on the release of sediment P.

The main objective of the P sorption isotherm experiment was to obtain the EPC₀ of the sediments. The EPC₀ in the surface sediments ranged from 0.053 to 0.224 mg·L⁻¹, with an average of 0.131 mg·L⁻¹. The space variation was very large, and showed that the P interaction on the water-sediment interface was different in different areas in the Shanmei reservoir. The phosphorus content in the overlying water ranged from 0.051 to 0.105 mg·L⁻¹, with an average of 0.081 mg·L⁻¹. The P content in the overlying water was lower than the EPC₀ in the surface sediment. Hence, the direction of P on the water-sediment interface came from the sediment to the overlying water. In the Shanmei reservoir, the sediments may be a P source for the overlying water.

The P sorption isotherm experiment was carried in a laboratory. The experimental conditions were constant temperature and constant speed, and there was a good contact between the sediment and the solution. Under field conditions, these factors do not exist. Hence, an improved method is needed that is closer to the natural field conditions in future study.

The PSI is an index that represents the fixation ability of soil particles on phosphate. The PSI of the surface sediment in the Shanmei reservoir was 74.81 (mg·L)/ (100 g·μmol) on average. Compared to some shallow lakes [32], the PSI of the surface sediment in the Shanmei reservoir was higher. However, compared to other shallow lakes [32,33], the PSI of the surface sediment in the Shanmei reservoir was lower. Hence, there was no direct relation between the fixation ability of the soil particles on phosphate and the depth of the lake. The size of the index is only relative, and there is not an absolute figure for PSI to assess the fixation ability of the soil particles on phosphate.

The DPS represents the degree of sorption on phosphate, and it is generally accepted as a good indicator for the risk of P loss from soils [34]. The DPS of the surface sediment in the Shanmei reservoir was 22.80% on average. Just as for the PSI, there was no general threshold value. Hence, the ERI (the P-induced lake eutrophication risk index (ERI)) was put forward [33]. We think that the eutrophication risk is a complex process and the induction is also complex. Hence, the assessment of eutrophication risk is partial if we only depend on P in the sediments. Therefore, we made a small modification to the ERI and changed it to ERI, which can be calculated as

\[
ERI = \frac{DPS}{PSI} \times 100
\]

The ERI of the surface sediment in the Shanmei reservoir was approximately 32 on average. According to the four risk levels put forward by Huang [32], i.e. high risk level (ERI > 25), less high risk level (25 > ERI > 20), middle risk level (20 > ERI > 10) and low risk level (ERI < 10), there was a high risk of P release in the Shanmei reservoir.

Combined with two former aspects of the discussion of the potential release in the Shanmei Reservoir, the ERI could be used to assess the release risks of the sediments in the Shanmei reservoir, at least in theory.

4. Conclusion

The results of the study revealed that different sediment areas in different seasons had various distributions of the P fractions due to their different hydrologic conditions and external environments. The TP content in the sediments ranged from 193.85 to 1664.05 mg·kg⁻¹, with an average of 803.81 mg·kg⁻¹. IP was the major phosphorus fraction in the sediments, and its content accounted for 63.8% of TP. NAIP was the dominant form of IP, with most values exceeding 50% of TP. The correlation analysis results showed that the TP content was significantly positive in correlation to IP, OP and NAIP and that the changes in the TP content could be dominantly controlled by NAIP and OP. The vertical distribution characteristics of TP and the P fractions were extraordinarily similar, and the vertical distribution of P showed a trend of tending toward stability after falling along with depth. For the sediment P, the effect from the anthropogenic sources was less than the one from the flow. The flow in the closed region (which is off the main channel) was relatively slow, which may lead to the vigorous biological activity causing P released from the sediment into the water. In the Shanmei reservoir, most of the P transported into the reservoir was in the form OP, but the IP/OP ratio was approximately 1.8. Hence, there was a higher depuration rate in OP than that in IP, and there may have been a mass of conversion from OP to IP.
The discussion of the potential release of P in the sediments from the three aspects resulted in the conclusion that there was a high release risk of P in the sediments in the Shanmei reservoir, and the use of ERI was considered correctly.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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