

## Effects of environmental factors on phosphorus adsorption capacity and release risk in lake sediments

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**Abstract:** Sediment is an important part of the lake and reservoir ecosystem, and also an important "source" and "sink" of pollutants. In this paper, sediment A (Xinlicheng Reservoir Sediments), sediment B (eutrophic lake reservoir sediments) and soil C (topsoil at the inflow of Yitong River near Xinlicheng Reservoir) are used as research objects, and batch experiments are used to study the adsorption capacity and release risk of phosphorus (P). The results showed that the maximum adsorption capacity of the adsorbent for phosphorus accounted for 91.51–99.63% of the total adsorption capacity within 0–120 min; when the background liquid phosphorus concentration is lower, soil and sediment all have different degrees of phosphorus release. By this time soil and sediment is the "source" of pollutants; when the phosphorus concentration is 10 mg/L, the maximum adsorption capacity is 116.19–428.91 mg/kg, and the adsorption capacity of sediment A is 2.41 times and that of soil C and sediment B, respectively. 3.69 times, indicating that if phosphorus enters the water body from the soil due to surface runoff and other factors, the sediment has a strong adsorption capacity for phosphorus, that is, soil and sediment is an effective "sink" of phosphorus; the Henry equation is used to fit the P adsorption isotherm effect. Preferably, and  $r$  is greater than 0.968. The amount of phosphorus absorbed by sediment A and sediment B is affected by pH higher than that of soil C. When the value of pH is 7, the adsorption amount is the largest; the P induced lake eutrophication risk index (ERI) of sediment A, sediment B and soil C is sediment B > soil C > sediment A. As the temperature of sediment and soil rises, the ERI index of phosphorus gradually decreases.

**Keywords:** phosphorus sorption index; phosphorus form; pollution; adsorption characteristics of phosphorus; aquatic ecosystem

The eutrophication of rivers, lakes, reservoirs and bay water bodies have become one of the important ecological and environmental problems facing the world. Studies showed that phosphorus is the main limiting factor for water eutrophication (Tu et al. 2019). Nitrogen and phosphorus as one of the essential nutrients in plants, playing an important role in maintaining the sustainable development of agriculture and the balance of the ecosystem (Yang et al. 2019, Chen et al. 2003).

The environmental problems caused by non-point source pollution represented by nitrogen and phosphorus are becoming increasingly prominent and pose a great threat to the deterioration of water quality in today's world (Zhao et al. 2014). Nitrogen and phosphorus (P) in lakes mainly come from non-point source pollution sources such as agricultural soil, and non-point source pollution has become the primary pollution of aquatic ecosystems (Hahn et al. 2012).

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Sediment is an important part of the lake and reservoir ecosystem. Part of pollutants will enter lake and reservoir sediments through particle adsorption, sedimentation, etc., making the sediments becomes an important "source" and "sink" of pollutants, furthermore causing endogenous pollution. Phosphorus is mainly stored in sediments in the form of phosphate. The potential harm of phosphorus in sediments is not only related to the total phosphorus content but also affected by the occurrence of phosphorus in sediments. In 1982, Hedley et al. (1982) proposed a continuous extraction method of soil inorganic and organic phosphorus (Cross and Schlesinger 1995). Since then, domestic and foreign scholars have done a lot of related research on the continuous extraction of phosphorus and achieved varying degrees of progress, which were provided with a theoretical basis for future study of phosphorus form and content in sediments. Soil, as an adsorbent of available phosphorus, can maintain phosphorus nutrient levels in farmland for plant uptake and reduce pollution of groundwater and lakes by surface water loss (Zhao et al. 2022). According to Gérard (2016), clayey soil has a high P-adsorption potential due to its larger specific surface area compared to sandy soil. The latter may present P losses due to laminar erosion and leaching during periods of intense rains. Phosphorus exists in different forms in the entire lake and reservoir system. Phosphorus forms also have a certain impact on the variation of phosphorus in the aquatic environment and play a great role in the cause of eutrophication of water bodies (Wang et al. 2015).

Changes in phosphorus content in sediment and soil are mainly accomplished by adsorption and desorption. In order to evaluate the risk of phosphorus-induced lake eutrophication, Börling and Barberis pointed out that the phosphorus adsorption index was highly correlated with the maximum adsorption of phosphorus (Börling et al. 2001); the phosphorus adsorption saturation of sediment can be used as a reliable indicator to measure the phosphorus content level of sediment and evaluate the phosphorus adsorption capacity of sediment (Chen et al. 2003). Huang et al. (2004) proposed to use the phosphorus sorption index (PSI) and the degree of phosphorus saturation (DPS) to calculate the risk of phosphorus release (Huang et al. 2004). However, due to changes in external environmental factors, soil and sediment adsorption capacity and release risk of phosphorus in lake and reservoir water are also very different. Studies showed that temperature, pH, metal ions,

and biological activities all have a certain impact on soil and sediment adsorption phosphorus (Zhu et al. 2015). Therefore, studying the adsorption capacity and release risk of phosphorus on soil and sediment under different environmental factors can provide the scientific basis for phosphorus pollution control and lake eutrophication.

In this paper, the adsorption characteristics and release risks of phosphorus in lake sediment and riparian soil were analysed based on adsorption isotherms and adsorption kinetics tests of lake and reservoir sediment and relative riparian soil, as well as the effects of temperature and pH on phosphorus adsorption. Aimed at providing basic data for the prevention and control of phosphorus pollution.

## MATERIAL AND METHODS

### Sample collection and determination

**Sample collection.** The test soil and sediment were taken from Changchun Xinlicheng Reservoir, Jilin province, China (125°39'E, 43°05'N). The Xinlicheng Reservoir originates from the northwest of Daqingdingzi Mountain in the southeast of Yitong county of Hadaling Mountains, covering a watershed area of 1 970 km<sup>2</sup>, which is an important urban drinking water source in Changchun. The basin of Xinlicheng Reservoir is slightly rectangular with an average width of 20.7 km. Phosphorus pollution sources in the water of Xinlicheng Reservoir mainly come from sewage discharge from surrounding factories and phosphorus migration caused by rainfall. The soil type is chernozems, the land is agricultural cultivated land, the crop is maize, and NPK compound fertiliser was applied.

(1) Sediment sample collection: the columnar mud extractor ( $\phi = 6.5$  cm) was used to collect the sediment from Xinlicheng Reservoir (sediment A) and eutrophic lake (sediment B) at multiple points on the surface (0–20 cm), removed impurities in the sediment, mix evenly, dried naturally, ground through the 100-mesh sieve, and stored for reserve.

(2) Soil samples collection (soil C): collected the surface soil at the inflow of the Yitong River near Xinlicheng Reservoir by five-point sampling method, removed debris, dried it naturally, ground it through a 100-mesh sieve, and spare, and physical and chemical properties are shown in Table 1.

**Method for fractional determination of phosphorus.** The study used the Hedley classification

method (Hou et al. 2018) to classify the adsorbate for phosphorus, and determined Ca<sub>2</sub>-P, Al-P, Org-P, Fe-P, O-Al-P, O-Fe-P, Ca<sub>10</sub>-P.

(1) Ca<sub>2</sub>-P: put 0.5 g of the sample through a 100 mesh sieve into a 50 mL centrifuge tube, add 25 mL of 0.25 mol/L NaHCO<sub>3</sub> (pH 7.5), shake for 1 h, centrifuge, and wash the residue with 25 mL of ethanol;

(2) Al-P: add 25 mL of 0.5 mol/L NH<sub>4</sub>F (pH 8.5) to the residue in (1), shake for 1 h, centrifuge, and wash the residue with 25 mL of saturated NaCl;

(3) Org-P: (2) add 0.7 mol/L NaClO (pH 8.05) to the residue in a 25 mL boiling water bath for 30 min, cool and centrifuge, and wash the residue with 25 mL saturated NaCl;

(4) Fe-P: take residue from (3) and add 25 mL of 0.1 mol/L NaOH-0.1 mol/L Na<sub>2</sub>CO<sub>3</sub>, shake for 2 h, then let stand for 16 h, shake for 2 h, centrifuge, and use 25 mL of saturated NaCl for the residue wash 2 times;

(5) O-Al-P: take residue from (4) and add 25 mL of 1 mol/L NaOH to a water bath at 85 °C for 1 h. After cooling, centrifuge, and wash the residue twice with 25 mL of saturated NaCl;

(6) O-Fe-P: take residue from (5) and add 20 mL of 0.3 mol/L sodium citrate, stir evenly, add 0.5 g Na<sub>2</sub>S<sub>2</sub>O<sub>4</sub>, 80 °C water bath, add 1 mol/L NaOH 5 mL, centrifuge, then wash residue twice with 25 mL saturated NaCl and retained;

(7) Ca<sub>10</sub>-P: add 25 mL of 0.25 mol/L H<sub>2</sub>SO<sub>4</sub> to the residue in (6), shake for 1 h, and centrifuge.

## TEST DESIGN

### Adsorption characteristics of phosphorus

**Determination of equilibrium time of P adsorption.** Take 0.5000 ± 0.0005 g soil or sediment into a 50 mL polyethene centrifuge tube, and add 25 mL of a solution with a phosphorus concentration of 2 mg/L according to the water-soil ratio of 50:1. Add 2 drops of chloroform to inhibit the action of

microorganisms, shake at a constant temperature of 25 °C, and sample at 1, 3, 5, 10, 15, 20, 40, 60, 120, 240, 360, 480, 720 min, 4 000 r/after centrifugation for 10 min, the supernatant was passed through a 0.45 µm filter membrane to determine the content of phosphorus in the filtrate.

**P isothermal adsorption.** Refer to the OECD guideline106 equilibrium adsorption test. Take 0.5000 ± 0.0005 g adsorbent into a 50 mL polyethene centrifuge tube, add 25 mL of solution with a phosphorus concentration of 0, 0.01, 0.05, 0.1, 0.5, 1, 5, 10 mg/L according to a water-soil ratio of 50:1, and drop add 2 drops of chloroform to inhibit the action of microorganisms, shake at a constant temperature of 25 °C, sample 4 000 r/min and centrifuge for 10 min after adsorption equilibrium, take supernatant through 0.45 µm filter membrane, and determine the content of P in the filtrate.

**Influence of environmental factors on phosphorus adsorption.** (1) Control the reaction temperature of 15, 20, 25, 30 and 35 °C; (2) use 1 mol/L NaOH and HCl buffer solution to adjust the background solution pH to 4, 5, 6, 7, 8, 9 and 10.

### Analysis of adsorption data

Phosphorus adsorption amount expression.

$$C_g = (C_0 - C_e)V/m \quad (1)$$

Where:  $C_g$  – amount of phosphorus adsorbed (mg/kg);  $C_0$  and  $C_e$  – mass concentration of P in the initial solution and the mass concentration of P in the liquid phase at adsorption equilibrium (mg/L), respectively;  $V$  – volume in the solution (mL);  $m$  – mass of the soil sample (g).

### Kinetic equation of phosphorus adsorption.

Quasi-second-order kinetic equation: 
$$q_t = \frac{q_{e,2}^2 k_2 t}{1 + q_{e,2} k_2 t} \quad (2)$$

Elovich equation: 
$$q_t = a + b \ln t \quad (3)$$

Where:  $q_t$  – adsorption capacity at  $t$  (mg/kg);  $q_e$  – adsorption equilibrium capacity (mg/kg) and  $k_2$  adsorption rate

Table 1. Physicochemical properties of sediment and soil

	pH	Unit weight (g/cm <sup>3</sup> )	SOC (g/kg)	Available phosphorus (mg/kg)	Mechanical composition (%)			
					sand	coarse silt	fine silt	clay
Sediment A	6.47	1.79	23.92	70.10	9.80	39.40	23.90	26.90
Sediment B	6.32	1.65	27.06	82.40	9.26	38.45	22.96	22.93
Soil C	6.81	1.79	21.61	22.40	4.71	52.43	22.15	20.17

SOC – soil organic carbon

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constant [kg/(min/mg)];  $a$  and maximum adsorption capacity the relevant adsorption constant;  $b$  – adsorption rate, which is a measure of how fast the reaction rate drops over time.

#### Isothermal equation of phosphorus adsorption.

Langmuir equation:  
(non-linear form) 
$$q_e = \frac{K_L q_m C_t}{1 + K_L C_t} \quad (4)$$

Where:  $q_e$  – amount of P adsorbed (mg/kg);  $q_m$  – maximum amount of P adsorbed (mg/kg);  $K_L$  – parameter of the Langmuir model, representing the maximum adsorption energy of P (L/mg).

Henry linear equation: 
$$q_e = K_d \times C_e + m \quad (5)$$

Where:  $K_d$  – partition coefficient, which characterises the amount of phosphorus adsorption degree of solid particles (mg/kg);  $m$  – longitudinal intercept (mg/kg).

#### Thermodynamic equation of phosphorus adsorption.

$$\Delta G = -RT \ln KF \quad (6)$$

$$\Delta G = \Delta H - T \Delta S \quad (7)$$

Type:  $\Delta G$  for the change of Gibbs free energy (kJ/mol);  $\Delta G < 0$  indicates that reactions can occur spontaneously;  $\Delta G > 0$  reaction can not occur spontaneously;  $\Delta H$  – standard enthalpy change (kJ/mol);  $\Delta H < 0$  indicates the reaction is exothermic, while  $\Delta H > 0$  indicates the reaction is endothermic;  $T(K)$  – absolute temperature;  $R$  – ideal gas constant =  $8.314 \times 10^{-3}$  KJ/(mol/K);  $\Delta S$  – standard entropy change KJ/(mol/K);  $\Delta S < 0$  means chaotic degree is reduced;  $\Delta S > 0$  indicates confusion degree is increased;  $K_F$  stands for thermodynamic equilibrium constant. When the  $1/T$  and  $\ln K$  are used to draw horizontal and vertical curves,  $\Delta H$  and  $\Delta S$  can be obtained according to the slope and intercept, respectively.

#### Phosphorus release risk index

$$PSI = \frac{X}{lgC} \quad (8)$$

Where:  $X$  – amount of phosphorus absorbed (mg/100 g);  $C$  – concentration of dissolved phosphorus in the filtrate (umol/L);  $PSI$  – expressed as (mg P/100 g)/(umol/L) is the unit.

#### Phosphorus adsorption saturation (DPS):

According to the content of soil available phosphorus (Olsen – P) and the maximum adsorption amount of phosphorus in sediment, the phosphorus adsorption saturation can be obtained according to equation (1):

$$DPS = \frac{\text{Olsen} - P}{Q_{max} + \text{Olsen} - P} \times 100\% \quad (9)$$

#### Phosphorus release risk index (ERI):

According to the method proposed by Huang et al. (2004), phosphorus adsorption saturation and phosphorus adsorption index are used to calculate sediment phosphorus release risk index:

$$ERI = \frac{DPS}{PSI} \times 100\% \quad (10)$$

**The data processing.** All experiments were set to 3 repetitions. The data obtained were calculated and graphed using Excel 2010 (Microsoft Corporation, Redmond, USA) and Origin 8.5 (Origin Lab, Northampton, USA).

## RESULTS AND DISCUSSION

#### Phosphorus morphology analysis

The results of three kinds of adsorbate phosphorus classification are shown in Table 2. It showed that the total phosphorus contents of the three adsorbates were in the order of sediment A > sediment B

Table 2. Contents of different forms of phosphorus in the test samples

Phosphorus form	Sediment A	Sediment B (mg/kg)	Soil C
Ca <sub>2</sub> -P	38.04 ± 1.28	86.52 ± 3.45	24.13 ± 1.17
Al-P	1.01 ± 0.08	0.72 ± 0.02	18.69 ± 0.12
Org-P	74.63 ± 3.16	92.14 ± 4.25	39.18 ± 2.78
Fe-P	131.14 ± 5.20	159.44 ± 4.89	159.42 ± 4.64
O-Al-P	363.71 ± 7.88	74.55 ± 2.11	55.16 ± 1.96
O-Fe-P	2.59 ± 0.18	8.33 ± 0.56	0.02 ± 0.00
Ca <sub>10</sub> -P	1.19 ± 0.13	0.83 ± 0.09	0.14 ± 0.01
TP	612.31 ± 17.91	422.53 ± 15.37	296.74 ± 10.86



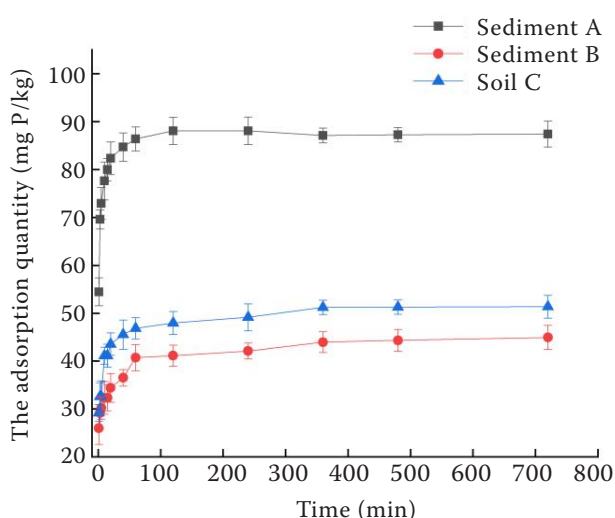


Figure 1. Phosphorus adsorption kinetics curve

> soil C. The highest content of aluminium and phosphorus in the closed storage state in sediment A is 363.71 mg/kg, accounting for 59.07% of TP. The available phosphorus content of the three adsorbates was sediment B > sediment A > soil C. The concentration of phosphorus in the reservoir water body was relatively low. The available phosphorus in sediment A exchanges with the phosphorus in the water body to reach the equilibrium of adsorption and desorption. Meanwhile, part of the available phosphorus was converted into closed storage state phosphorus, which did not participate in the adsorption and desorption reaction (Tang et al. 2014, Tian et al. 2020), sediment B was polluted by eutrophication in lake and reservoir sediments, and the invalid phosphorus content was far. It was lower than sediment A (Zhan et al. 2019), soil C had been affected by human activities for a long time, and the available phosphorus had been difficult for a long time. Cumulative transformation, so the content of invalid phosphorus in soil C was the lowest.

## Adsorption characteristics of phosphorus

### Determination of adsorption equilibrium time.

The changes amount of phosphorus adsorbed in soil and sediment over time is shown in Figure 1. As can be seen from Figure 1 the adsorption rate of soil and sediment is relatively fast within 0–120 min. Sediment A, sediment B, and soil C account for 99.63, 91.51 and 93.35% of the total adsorption, respectively. This is because phosphorus is mainly adsorbed on the outer surface of solid substance, when the outer surface reaches adsorption saturation, phosphorus enters the particles. At this time, it is mainly absorbed by the inner surface of the particles, and finally reaches the adsorption equilibrium (Jellali et al. 2011). When the time is 6 h, the adsorption capacity reached equilibrium, so it was determined that 6 h was taken as the adsorption equilibrium time in the subsequent experiments.

The adsorption kinetics of soil and sediment to phosphorus were fitted by the pseudo-second-order kinetic equation and the Elovich kinetic equation. As can be seen from Table 3, the fitting results of the two equations have reached a very significant level ( $P < 0.01$ ). The quasi-second-order kinetic equation has the best fitting effect on the phosphorus adsorption process of sediment A, and its  $r$  is 0.9961. The quasi-second-order kinetic equation may reflect all the kinetic mechanisms of the entire adsorption process. This equation covers surface adsorption, external liquid film diffusion, particle diffusion and other adsorption processes (Wang et al. 2016). The Elovich kinetic equation has the best fitting effect on the phosphorus adsorption process of sediment B and soil C. Wang found that in the adsorption process of porous media, the rate-limiting step can only be membrane diffusion or intra-particle diffusion, and the Elovich simulation of phosphorus in sediments and soil. The merging did not pass through

Table 3. Adsorption kinetic equation

Adsorbate	Quasi-second order kinetic parameters			Elovich kinetic parameters		
	$q_{e,2}$	$k_2$	$r$	$a$	$b$	$r$
Sediment A	86.20	0.02	0.9961**	64.60	4.45	0.9820**
Sediment B	39.82	0.03	0.9457**	25.56	3.08	0.9962**
Soil C	47.71	0.02	0.9671**	30.26	3.62	0.9894**

$n = 10$ ;  $r_{0.05} = 0.602$ ;  $R_{0.01} = 0.735$ ; \*\* $P < 0.01$ ;  $q_e$  – adsorption equilibrium capacity;  $k_2$  – adsorption rate constant;  $a$  – relevant adsorption constant;  $b$  – adsorption rate, which is a measure of how fast the reaction rate drops over time

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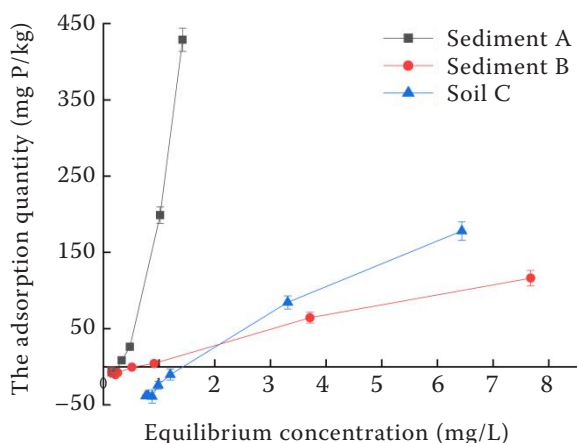


Figure 2. The equilibrium adsorption capacity of phosphorus

the zero point, so the adsorption process is very complicated, and intra-particle diffusion is not the only rate control step.

### Adsorption isotherm

The adsorption of phosphorus by soil and sediment is shown in Figure 2. As can be seen from Figure 2, when the background liquid phosphorus concentration is 0–0.1, 0–0.5, 0–1.0 mg/L, sediment A, sediment B and soil C all release phosphorus to varying degrees. At this time, the adsorbent is the "source" of pollutants. When the concentration of P is 10 mg/L, the adsorption capacity of sediment A (428.91 mg/kg) is 2.41 times and 3.69 times that of soil C (178.00 mg/kg) and sediment B (116.19 mg/kg), respectively, and the adsorbent is the "sink" of pollutants.

The adsorption of pollutants in sediments and soil can be fitted by the Langmuir equation and Henry equation.

As can be seen from Table 4, both the Langmuir equation and Henry equation can better fit the ad-

sorption of phosphorus by soil and sediment, and the fitting results have reached an extremely significant level ( $P < 0.01$ ). According to the fitting parameters of the Langmuir equation, it can be known that the adsorption of phosphorus by soil and sediment belongs to chemical adsorption, and chemical adsorption is dominant. The Henry linear equation has a better correlation to the fitting, and its  $r$  is greater than 0.968;  $K_d$  represents the adsorption degree of soil and sediment to phosphorus. It can be seen from Table 4 that the adsorption amount of sediment A is much larger than that of sediment B and soil C. This is due to the different content of powder, sand, and clay particles of soil and sediment, and different specific surface areas, there are differences in the effect of phosphorus exchange on the solid-liquid interface. Generally, the higher content of clay, the higher the specific surface area, and the stronger surface energy in adsorbed particles, the greater amount of phosphorus adsorbed (Zhao et al. 2014). On the other hand, the available phosphorus content of the three adsorbents is in the order of sediment B > soil C > sediment A. The lower the available phosphorus content, the stronger the phosphorus adsorption capacity, which also explained that the phosphorus adsorption capacity of the three adsorbents was in the order of sediment A > soil C > sediment B. The isotherms of sediment A, sediment B, and soil C are cross-type curves that cross the X coordinate axis instead of the origin, that is, the intercept of the adsorption isotherm equation  $m < 0$ , which is the reason that a certain amount of phosphorus is adsorbed in soil and sediment, and this part of the phosphorus that has been bound to the solid-phase medium is different from the adsorbed phosphorus in adsorption test in solid-liquid distribution properties and binding force, resulting in phosphorus release at low background concentration (Jin et al. 2013).

Table 4. Isothermal fitting parameters of phosphorus adsorption in soil and sediment

Adsorbate	Langmuir equation			Henry equation		
	$q_m$	$K_L$	$R$	$K_d$ (mg/kg)	$m$ (mg/kg)	$r$
Sediment A	416.277	2 976.292	0.8849**	323.72	–80.70	0.9689**
Sediment B	118.439	168.254	0.7364**	17.20	–10.67	0.9933**
Soil C	183.371	433.370	0.7383**	39.12	–64.71	0.9916**

$n = 10$ ;  $r_{0.05} = 0.602$ ;  $R_{0.01} = 0.735$ ; \*\* $P < 0.01$ ;  $q_m$  – maximum amount of P adsorbe;  $K_L$  – parameter of the Langmuir model, representing the maximum adsorption energy of P;  $K_d$  – partition coefficient, which characterises the amount of phosphorus adsorption degree of solid particles;  $m$  – longitudinal intercept

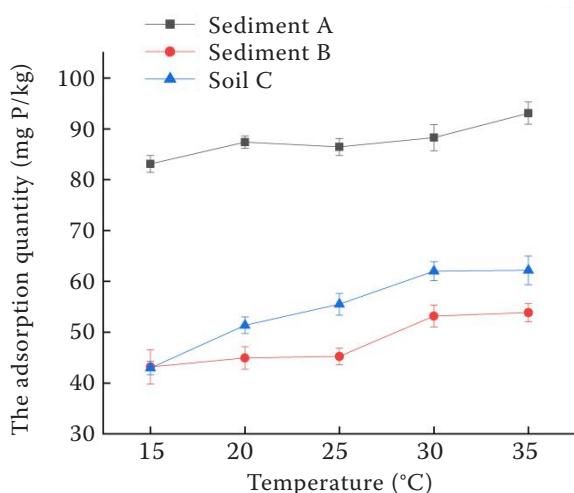


Figure 3. Influence of temperature on phosphorus adsorption

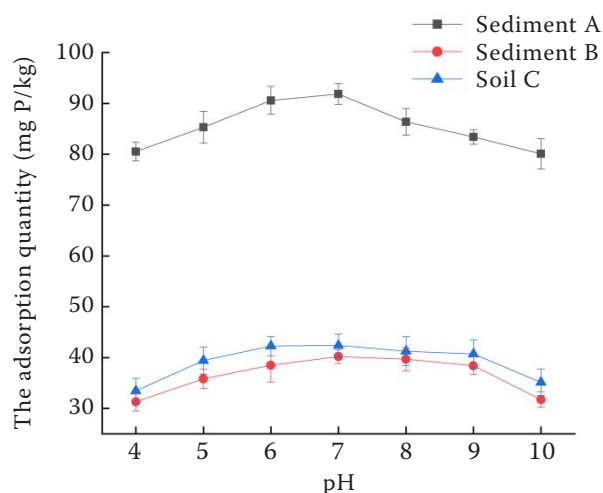


Figure 4. Influence of pH value of water on phosphorus adsorption amount phosphorus release risk assessment

### Influence of environmental factors on phosphorus adsorption

**Effect of temperature on adsorption.** The change in adsorption capacity of adsorbents at different temperatures was studied, as shown in Figure 3. As can be seen that the adsorption capacity increases with the increase in temperature. The equilibrium adsorption capacities of sediment A, sediment B and soil C at 15 °C were 96.14, 96.54 and 77.42%, respectively, at 25 °C, indicating that there is A chemical process of heat exchange at the same time as physical adsorption. The effect of temperature on soil equilibrium adsorption capacity is higher than that of sediment, which may be because the soil is greatly influenced by human factors, internal organic and inorganic composition is more complex, and temperature change has a great influence on internal biochemical reactions in soil (Yan et al. 2015, 2017, Yuan et al. 2019).

At different temperatures, the adsorption of phosphorus by adsorbed mass was fitted by the adsorption thermodynamic equation, as shown in Table 5.

As can be seen from Table 5,  $\Delta G < 0$  indicated that the adsorption reaction is spontaneous;  $\Delta H > 0$  indicated that the adsorption is an endothermic process;  $\Delta S > 0$  indicated that adsorption is disordered and random. With the increase in temperature,  $\Delta G$  decreases gradually, which further confirms that the increase in temperature is beneficial to the adsorption of phosphorus.

### Effect of different pH values of background liquid on phosphorus adsorption

As a basic physical and chemical index of soil and sediment, pH is the main factor affecting the adsorption of phosphorus. The amount of phosphorus adsorption under different pH conditions is shown in Figure 4. With the increase of pH, the adsorption capacity of soil and sediment on phosphorus first increases and then decreases, and the adsorption capacity reaches the maximum when pH = 7. When pH decreases, soil and sediment will be dissolved and released sequentially starting from aluminium oxides and phosphorus, and the equilibrium ad-

Table 5. Thermodynamic fitting parameters of phosphorus adsorption

Adsorbate	$\Delta G$					$\Delta H$	$\Delta S$
	15 °C	20 °C	25 °C	30 °C	35 °C		
Sediment A	-13.1816	-14.2455	-14.2821	-14.9401	-16.6828	3.7076	0.0184
Sediment B	-8.7088	-9.0357	-9.2199	-10.1748	-10.3093	1.9601	0.0104
Soil C	-8.6897	-9.6635	-10.2404	-11.0897	-11.2924	3.5580	0.0161

$\Delta G$  – change of Gibbs free energy;  $\Delta H$  – standard enthalpy change;  $\Delta S$  – standard entropy change

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Table 6. Phosphorus release risk index (%) of soil and sediment at different temperatures

	15 °C	20 °C	25 °C	30 °C	35 °C
Sediment A	2.34	1.73	1.64	1.24	0.97
Sediment B	14.92	14.04	13.20	11.93	10.09
Soil C	7.92	5.72	4.69	3.59	3.45

sorption capacity will decrease. When pH is greater than 7, the concentration of OH<sup>-</sup> in water gradually increases, thereby competing with phosphate anions for adsorption (Jin et al. 2005), and the equilibrium adsorption capacity decreases with an increase in pH. The influence of pH on the phosphorus adsorption capacity of sediment A and sediment B was higher than that of soil C, indicating that soil has a strong buffer capacity to pH.

The equilibrium adsorption concentration of phosphorus in sediment is an important indicator to determine the phosphorus adsorption or release of sediments. Analysing the eutrophication risk index characterised by phosphorus adsorption index and phosphorus adsorption saturation can predict freshwater lakes will face the risk of eutrophication. According to the phosphorus release risk index proposed by Huang et al. (2004) composed of PSI and DPS, ERI was divided into four grades. The highest (ERI > 25%), higher risk (20% < ERI < 25%), moderate risk (10% < ERI < 20%), and low risk (ERI < 10%). The range of PSI of soil and sediment is 4.995–47.593, the range of DPS is 28.9–69.9%, the range of ERI is 0.97–14.92%, the phosphorus release risk of sediment B was moderate since the eutrophic lake sediment B has the highest content of its available phosphorus, it has the smallest amount of adsorbed phosphorus and the highest release risk. Sediment A had the highest amount of phosphorus adsorption, and its release risk was less than that of sediment B and soil C. As can be seen from Table 6 with the increase in temperature, the maximum adsorption capacity of the adsorbent increases, and the phosphorus release risk index gradually decreases. The release risk of phosphorus is sediment B > soil C > sediment A.

By analysing the spatial distribution of phosphorus adsorption capacity parameters such as phosphorus adsorption index and phosphorus adsorption saturation of sediment, it was found that sediment B had the highest release risk index and faced the greatest eutrophication risk compared with sediment A and soil C, so it was necessary to pay attention to environmental migration risk.

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