

Environmental dynamics of nitrogen and phosphorus release from river sediments of arid areas

Postprint

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Abstract

Human activities lead to the accumulation of a large amount of nitrogen and phosphorus in sediments in rivers. Simultaneously, nitrogen and phosphorus can be affected by environment and re-enter the upper water body, causing secondary pollution of the river water. In this study, laboratory simulation experiments were conducted initially to investigate the release of nitrogen and phosphorus from river sediments in Urumqi City and the surrounding areas in Xinjiang Uygur Autonomous Region of China and determine the factors that influence their release. The results of this study showed significant short-term differences in nitrogen and phosphorus release characteristics from sediments at different sampling points. The proposed secondary kinetics model (i.e., pseudo-second-order kinetics model) better fitted the release process of sediment nitrogen and phosphorus. The release of nitrogen and phosphorus from sediments is a complex process driven by multiple factors, therefore, we tested the influence of three factors (pH, temperature, and disturbance intensity) on the release of nitrogen and phosphorus from sediments in this study. The most amount of nitrate nitrogen ($\text{NO}_3\text{-N}$) was released under neutral conditions, while the most significant release of ammonia nitrogen ($\text{NH}_4\text{-N}$) occurred under acidic and alkaline conditions. The release of nitrite nitrogen ($\text{NO}_2\text{-N}$) was less affected by pH. The dissolved total phosphorus (DTP) released significantly in the alkaline water environment, while the release of dissolved organic phosphorus (DOP) was more significant in acidic water. The release amount of soluble reactive phosphorus (SRP) increased with an increase in pH. The sediments released nitrogen and phosphorus at higher temperatures, particularly $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, and SRP. The highest amount of DOP was released at 15.0°C . An increase in disturbance intensity exacerbated the release of nitrogen and phosphorus from sediments. $\text{NH}_4\text{-N}$, DTP, and SRP levels increased linearly with the intensity of disturbance, while $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$ were more stable. This study provides valuable information for protecting and restoring the water environment

in arid areas and has significant practical reference value.

Full Text

Preamble

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Environmental Dynamics of Nitrogen and Phosphorus Release from River Sediments in Arid Areas

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Abstract: Human activities have led to substantial accumulation of nitrogen and phosphorus in river sediments. These nutrients can be remobilized by environmental factors and re-enter the overlying water column, causing secondary pollution. This study investigated the release characteristics of nitrogen and phosphorus from river sediments in Urumqi City, Xinjiang Uygur Autonomous Region, China, and identified key influencing factors through laboratory simulation experiments. The results revealed significant short-term variations in nitrogen and phosphorus release among different sampling sites. A pseudo-second-order kinetics model provided the best fit for the release process. The release of nitrogen and phosphorus from sediments is a complex process driven by multiple factors; therefore, we examined the effects of pH, temperature, and disturbance intensity. Maximum nitrate nitrogen (NO_3^- -N) release occurred under neutral conditions, whereas ammonia nitrogen (NH_4^+ -N) release was most pronounced under acidic and alkaline conditions. Nitrite nitrogen (NO_2^- -N) was less affected by pH. Dissolved total phosphorus (DTP) released significantly in alkaline environments, while dissolved organic phosphorus (DOP) release was more substantial under acidic conditions. Soluble reactive phosphorus (SRP) release increased with pH. Higher temperatures enhanced nitrogen and phosphorus release, particularly NO_3^- -N and SRP. The highest DOP release occurred at 15.0°C. Increased disturbance intensity exacerbated nitrogen and phosphorus release, with NH_4^+ -N, DTP, and SRP increasing linearly with disturbance intensity, while NO_3^- -N remained more stable. These findings provide valuable information for water environment protection and restoration in arid regions.

Keywords: sediment; nitrogen and phosphorus; environmental dynamics;

pseudo-second-order kinetics model; dissolved organic phosphorus (DOP); Urumqi City

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1 Introduction

The release of nitrogen and phosphorus from sediments is a critical ecological process at the sediment-water interface that maintains the balance and functionality of aquatic ecosystems. However, anthropogenic inputs of nitrogen and phosphorus into the biosphere have increased globally since the late 1980s (Wu et al., 2022). Excessive nutrients accumulate in river and lake sediments and can become secondary pollution sources for overlying water bodies due to external disturbances, adversely affecting water quality, biodiversity, and human health (Peñuelas and Sardans, 2022). This issue is particularly concerning in water-scarce arid regions and has attracted attention from environmental management authorities.

Sediment nitrogen and phosphorus primarily exist as organic nitrogen and inorganic phosphorus, released into overlying water through diffusion (Cheng et al., 2019) and resuspension (Liu et al., 2020). Previous research has identified numerous factors influencing nutrient release from lake sediments, including sediment characteristics, overlying water physicochemical properties, biological activities, water level fluctuations, and physical disturbances. Sediment properties such as chemical composition and grain size affect nitrogen and phosphorus speciation and mobility (Li et al., 2022). Overlying water properties, including nutrient concentrations and organic matter content, influence chemical equilibria. Biological processes, particularly microbial and plant activities, strongly affect nutrient cycling and release. Water level fluctuations and physical disturbances, such as flow velocity changes and mechanical mixing, alter sediment structure and affect nutrient release (House and Denison, 2000; Jiang et al., 2008; Rippey et al., 2021; Zhao et al., 2021; Li et al., 2022). Dissolved oxygen content, pH, and temperature are key factors controlling nutrient release, with low oxygen, non-neutral pH, and elevated temperatures increasing release rates and exacerbating eutrophication.

The unique geographical and climatic characteristics of arid regions must be considered when assessing river sediment nutrient dynamics. Urumqi City in Xinjiang Uygur Autonomous Region, Northwest China, experiences an arid to semi-arid climate with large diurnal temperature variations that strongly influence nutrient release from river sediments. James and Barko (2004) and Jiang et al. (2008) demonstrated that the temperature-phosphorus release relationship is non-linear due to biological activity and diffusion rates. Temperature effects

vary between lakes and rivers due to differences in sediment characteristics (Lovley and Phillips, 1986; Jensen and Andersen, 1992; Jiang et al., 2008; Anthony and Lewis Jr., 2012; Hunting and Kampfraath, 2013; Small et al., 2014; Wu et al., 2014), necessitating site-specific investigations.

Furthermore, water bodies in Xinjiang frequently exhibit non-neutral pH, likely related to the region's unique geological background and soil types. Water scarcity in arid regions means that water bodies are primarily replenished by mountain glacier melt, causing significant seasonal variations. Arid region water bodies also experience more frequent anthropogenic disturbances than humid areas, including water level regulation, water resource management, and agricultural activities. These disturbances cause surface sediment particle resuspension, promoting phosphorus release (He et al., 2022). The combined effects of these factors may produce unique nitrogen and phosphorus release characteristics in Xinjiang's arid regions compared to other areas. Investigating these processes will help understand local eutrophication extent and provide insights for water environment management in arid regions.

This study examined the kinetic characteristics and environmental factor effects on short-term nitrogen and phosphorus release from sediments in arid areas. Laboratory simulation experiments were conducted to investigate primary release characteristics and construct kinetic models. The effects of pH, temperature, and disturbance intensity on nutrient release were examined to deepen understanding of sediment nutrient speciation and release patterns, providing theoretical and technical support for water body protection and restoration in arid regions.

2.1 Study Area

Urumqi City, Xinjiang Uygur Autonomous Region, China, is located in the arid northwestern Eurasian continent, on the northern slope of the Tianshan Mountains and the southern margin of the Junggar Basin. The city experiences large diurnal temperature differences, with maximum daily variations reaching 20.0°C. In 2020, the annual average temperature was 8.7°C and annual precipitation was only 199.6 mm. Rivers flowing through the city are primarily fed by Tianshan Mountain snowmelt and surrounding discharge, making sediment nutrient migration highly sensitive to local climate and human activities.

The Shuimogou and Toutunhe rivers are the main waterways flowing through Urumqi City, maintaining consistent year-round flow. The Shuimogou River, located in the eastern suburbs, flows through Shuimogou District, Midong District, and Wujiaqu City before discharging into Dongdao Haizi after merging with Bayi Reservoir. The river is 27.2 km long and serves as the primary water source for agricultural irrigation, with portions used for drinking water and landscape greening. The Toutunhe River originates on the northern slopes of the Haga Mountains in the central Tianshan range, is a mountain stream river

with a total length of 190.0 km. Its upper reaches are closed for ecological landscaping in the Changji Tingzhou Ecological Green Valley, while downstream flow is supplemented by reclaimed water from the Changji No. 2 Wastewater Treatment Plant.

Fifteen pre-sampling sites were established along both rivers. Following field surveys, three sites with the slowest flow and lowest external influence were selected for this study [Figure 1: see original paper]. River flow direction was from S1 to S3, with physicochemical properties presented in Table 1. Pre-study analysis demonstrated the most pronounced spatial variations in nitrogen and phosphorus concentrations among these three sites, with S2 and S3 showing the highest concentrations among all 15 pre-sampling sites, likely due to surrounding residential discharges (Su et al., 2023).

Sediment samples were collected in May 2022 using a Petersen grab sampler. Three samples were collected at each site and combined into one representative sample. After removing rocks, plant roots, and debris, samples were transported to the laboratory in clean polyethylene bags and stored at 4.0°C. Fresh sediment portions were analyzed for physicochemical properties (Table 1). pH was measured using a YSI ProPlus (Xylem Inc., Yellow Springs, Ohio, USA). Water content was determined by weight loss after drying at 105.0°C for 24 h, and organic matter by heating dried sediment at 550.0°C for 4 h (Yin et al., 2017). Metal oxides (Fe_2O_3 , Al_2O_3 , CaO) were determined by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) after HNO_3 - HClO_4 -HF digestion. Additional samples were air-dried, ground, and sieved through 0.15 mm mesh for simulation experiments.

2.2.1 Release Dynamics of Nitrogen and Phosphorus from Sediments

Sediment nitrogen exists in inorganic and organic forms. Organic nitrogen must be converted to inorganic nitrogen by microorganisms before utilization by aquatic organisms. Inorganic nitrogen primarily includes ammonium nitrogen (NH_4^+ -N), nitrate nitrogen (NO_3^- -N), and nitrite nitrogen (NO_2^- -N). Most phosphorus release studies have focused on soluble reactive phosphorus (SRP) (James and Barko, 2004; Jin et al., 2006; Zhang et al., 2014; Yin et al., 2017), while DOP release remains understudied. DOP is an important phosphorus source for aquatic organisms and is calculated as the difference between dissolved total phosphorus (DTP) and SRP.

Each sediment sample was thoroughly blended and divided into eight equal 0.50 g portions, each corresponding to a specific time point. Portions were placed in 50 mL centrifuge tubes with 30 mL of 0.02 mol/L KCl solution, then shaken at 25.0°C and 150 r/min in a constant temperature shaker. Samples were collected at 5, 15, 30, 60, 90, 120, 180, and 300 min, yielding eight samples per site. Samples were centrifuged (5000 r/min, 15 min) and filtered through 0.45 μm membranes. Concentrations of NH_4^+ -N, NO_3^- -N, NO_2^- -N, DTP, SRP,

and DOP in supernatants were measured. $\text{NH}_4^+\text{-N}$ was detected by Nessler's reagent spectrophotometry (UV8000, Shanghai Metash Instruments Co. Ltd., Shanghai, China), $\text{NO}_3^-\text{-N}$ by ultraviolet spectrophotometry, and $\text{NO}_2^-\text{-N}$ by N-(1-naphthyl)ethylenediamine spectrophotometry (Han et al., 2022). DTP concentration was determined by potassium persulfate digestion-molybdenum antimony spectrophotometry, while SRP was evaluated by molybdenum blue colorimetry (Kong et al., 2020; Liu et al., 2022). Release time and corresponding quantities were substituted into kinetic equations to calculate parameters and plot curves. All samples were analyzed in triplicate, with data presented as mean values.

Pseudo-first-order kinetic equation:

$$Q_t = Q_e(1 - e^{-k_1t})$$

Pseudo-second-order kinetic equation:

$$\frac{t}{Q_t} = \frac{1}{k_2Q_e^2} + \frac{t}{Q_e}$$

where Q is the amount of phosphorus released or adsorbed at equilibrium (mg/kg); Q_t is the amount released or adsorbed at time t (mg/kg); and k_1 and k_2 are rate constants for pseudo-first-order and pseudo-second-order adsorption, respectively.

2.2.2 Effects of pH on Nitrogen and Phosphorus Release

The average pH of Dongdao Haizi sediments (tailwater channel of Toutunhe and Shuimogou rivers) was 9.60, 7.30, and 9.50 during dry, normal, and wet seasons, respectively (Song, 2017). Another survey reported sediment pH ranging from 6.83 to 8.16 (Su et al., 2023). Therefore, this study examined three pH levels (5.00, 7.00, and 9.00) to determine pH effects on nutrient release.

Dried sediment samples (0.50 g) were placed in centrifuge tubes with 30 mL of 0.02 mol/L KCl solution (pH adjusted to 5.00, 7.00, or 9.00 using 0.10 mol/L HCl and NaOH). Tubes were shaken at 25.0°C and 150 r/min. Samples were collected at 5, 15, 30, 60, 90, 120, 180, and 300 min, centrifuged (5000 r/min, 15 min), filtered through 0.45 μm membranes, and analyzed for $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, $\text{NO}_2^-\text{-N}$, DTP, SRP, and DOP concentrations.

2.2.3 Effects of Temperature on Nitrogen and Phosphorus Release

Average water temperatures in Dongdao Haizi were 4.1°C, 14.5°C, and 32.4°C during dry, normal, and wet seasons, respectively (Song, 2017). During the

wet season, desert river temperatures reached 45.0°C, indicating extremely high water temperatures. Upstream river temperatures during the wet season were estimated at approximately 25.0°C. Therefore, three temperature treatments (5.0°C, 15.0°C, and 25.0°C) were designed to investigate temperature effects.

Dried sediment samples (0.50 g) were placed in centrifuge tubes with 30 mL of 0.02 mol/L KCl solution (pH adjusted to 7.00). Tubes were shaken at 150 r/min at 5.0°C, 15.0°C, or 25.0°C. Samples were collected at 5, 15, 30, 60, 90, 120, 180, and 300 min, centrifuged (5000 r/min, 15 min), filtered through 0.45 µm membranes, and analyzed for nutrient concentrations.

2.2.4 Effects of Disturbance Intensity on Nitrogen and Phosphorus Release

Dried sediment samples (0.50 g) were placed in centrifuge tubes with 30 mL of 0.02 mol/L KCl solution (pH adjusted to 7.00). Tubes were shaken at 25.0°C with different shaking speeds (50, 150, and 250 r/min). Samples were collected at 5, 15, 30, 60, 90, 120, 180, and 300 min, centrifuged (5000 r/min, 15 min), and filtered through 0.45 µm membranes for nutrient concentration analysis.

2.3 Data Analysis

All treatments were independently repeated three times, with average values used for analysis. Data were processed using Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) to obtain means and standard deviations. Origin 2021 software (OriginLab, Northampton, Massachusetts, USA) was used to fit release data to pseudo-first-order and pseudo-second-order kinetic models and generate plots. The most appropriate model was selected by comparing R² values (Liu et al., 2022). Bar plots were constructed using GraphPad Prism 10 (GraphPad Software, Boston, Massachusetts, USA), with multiple comparisons performed using Bonferroni correction to determine significant differences within groups.

3.1 Characterization of Nitrogen and Phosphorus Release from Sediments

Short-term release characteristics over 300 min are shown in Figure 2 [Figure 2: see original paper]. The release process exhibited three stages: rapid release, slow release, and equilibrium. For NH₄⁺-N and NO₃⁻-N, rapid release occurred primarily within the first 15 min, ranging from 47.74-72.75 mg/kg and 13.72-36.18 mg/kg, respectively (Figures 2a and 2b). The lowest NH₄⁺-N and NO₃⁻-

N releases occurred at S2, while the highest occurred at S1 and S3. NH_4^+ -N release was similar at S1 and S3, but NO_3^- -N release was higher at S1 than S3.

NO_2^- -N release characteristics differed significantly among sampling sites (Figure 2c). S2 showed continuous NO_2^- -N release, while S1 exhibited a fast-to-slow trend. S3 released more NO_2^- -N than S2 before 60 min, after which it reached equilibrium. NO_2^- -N release from S1 sediment increased throughout the 300 min period and could not be fitted with kinetic equations. The rapid NH_4^+ -N and NO_2^- -N release indicated active nitrogen biogeochemical cycling in sediments, likely due to strong organic matter mineralization combined with nitrification and denitrification processes (Liu et al., 2020). Differences in nitrogen release may relate to sediment organic matter content, microbial activity, and environmental conditions (Li et al., 2022).

DTP and SRP release amounts increased with contact time (Figures 2d and 2e). Release increased rapidly within 15 min, reaching 9.39–17.85 mg/kg and 7.62–14.36 mg/kg, respectively, then slowed and approached equilibrium after 180 min. DTP and SRP release trends were consistent across sites, following the order $\text{S2} > \text{S3} > \text{S1}$.

DOP release trends resembled DTP and SRP, but characteristics differed among sites (Figure 2f). Kinetic curves showed rapid DOP release in S1 (within 30 min) and S2 (within 15 min), slowing and approaching equilibrium after 30 min. Differences in phosphorus release trends among sites were mainly due to DOP variations. Previous research indicated sediment organic phosphorus content followed $\text{S2} > \text{S3} > \text{S1}$, with HCl-OP as the main form in S2 and S3 (Su et al., 2023). Organic phosphorus release is influenced by organophosphorus morphology and mineralization (Lü et al., 2016). Morphological effects involve DOP conversion to reactive organophosphorus in water (Kong et al., 2020), while mineralization converts organophosphorus to inorganic phosphorus through microbial activity (Joshi et al., 2015). Liu et al. (2022) also showed that changes in dissolved organic matter humification and aromaticity may affect DOP release rates and patterns. Functional group variations (hydroxyl, carboxyl, carbonyl) on hydrophobic DOM phenyl rings can influence phosphorus release (Liu et al., 2022).

Kinetic model fitting parameters are presented in Table 2. The coefficient of determination (R^2) evaluated model fit (Liu et al., 2022). Except for NO_2^- -N release at S1, which did not follow kinetic characteristics and could not be fitted, the lowest R^2 was 0.63 for pseudo-first-order and 0.59 for pseudo-second-order models. However, pseudo-second-order models generally showed higher R^2 values, indicating better fit to actual data.

3.2 Release of Nitrogen and Phosphorus from Sediments under Different pH Conditions

NH_4^+ -N release varied significantly with pH (Figure 3a [Figure 3: see original paper]). Release was highest at pH 5.00, followed by pH 9.00 and 7.00, indicating that acidic conditions promoted NH_4^+ -N release. This likely occurred because H^+ inhibits nitrifying bacteria activity in surface sediments, suppressing ammonium conversion to nitrate and promoting ammonium release (Zhang et al., 2014). Ammonium ions in sediment colloids exchanged with high-concentration hydrogen ions in water, facilitating release (Liang et al., 2010). In alkaline environments, excess OH^- converts NH_4^+ to NH_3 , which easily escapes from water, reducing NH_4^+ concentration. However, this creates a greater concentration gradient between sediment and water than in neutral conditions, facilitating NH_4^+ -N release.

Phosphorus release under different pH conditions is shown in Figure 3b. DTP release did not differ significantly between pH 5.00 and 7.00 but increased substantially at pH 9.00. SRP release increased with pH and differed significantly among all three conditions. Conversely, DOP release decreased with increasing pH, with no significant difference between pH 7.00 and 9.00. pH effects on phosphorus release primarily involve phosphorus binding with metals (iron, aluminum, calcium) (Kim et al., 2003). In acidic environments, metal ions dissolve and adsorb phosphates, promoting release (Temporetti et al., 2019). However, excessive H^+ can protonate sediment surface functional groups, enhancing electrostatic phosphate adsorption (Gong et al., 2020), partially counteracting release. Under alkaline conditions, HPO_4^{2-} is the dominant phosphorus form, and release occurs through OH^- -phosphate anion exchange, enhancing dissolution. High pH favors NaOH-P release, while low pH favors HCl-P release (Jin et al., 2004). As pH increases, iron and aluminum compounds' phosphorus binding capacity decreases because OH^- replaces orthophosphate in coordination exchange reactions (Jin et al., 2006).

3.3 Release of Nitrogen and Phosphorus from Sediments at Different Temperatures

NO_3^- -N and NO_2^- -N release exceeded NH_4^+ -N release at all temperatures (Figure 4a [Figure 4: see original paper]). As temperature increased, NO_3^- -N and NH_4^+ -N release increased. NO_3^- -N release at 25.0°C was higher than at 5.0°C and 15.0°C, but NH_4^+ -N release at 15.0°C was only half that at 5.0°C. Typically, high temperatures promote NH_4^+ -N release, while low temperatures inhibit it (Jäntti and Hietanen, 2012). However, this study showed different patterns. Temperature increases enhance biological activity, accelerating organic nitrogen mineralization to soluble inorganic nitrogen at the sediment-water interface. Under aerobic conditions, ammonium converts to nitrate through nitrification (Zhang et al., 2014), while under low-temperature, low-oxygen conditions, ni-

trate can be reduced to ammonium through microbial heterotrophic denitrification (Søndergaard et al., 1999). NO_3^- -N and NH_4^+ -N release increased with temperature, showing significant differences among treatments, while NO_2^- -N release showed no temperature effect. These results indicate that in Xinjiang's arid regions, higher daytime temperatures may increase NO_3^- -N and NH_4^+ -N release compared to lower nighttime temperatures.

DTP release exceeded SRP release at all temperatures, with DOP release being lowest (Figure 4b). DTP and SRP release increased with temperature, with SRP showing significant differences among all three temperatures. DTP release did not differ significantly between 15.0°C and 25.0°C. DOP release at 15.0°C was significantly higher than at 25.0°C. Temperature increases likely enhanced solubility of insoluble compounds (Coffman and Kildsig, 1996), decreased sediment phosphorus adsorption capacity, increased microbial activity, and promoted biological disturbance and mineralization of organically bound phosphorus (Lovley and Phillips, 1986; Jensen and Andersen, 1992; Cornelissen et al., 1997; Katsev et al., 2006; Wu et al., 2008; Hunting and Kampfraath, 2013; Small et al., 2014). Microbial consumption reduced dissolved oxygen concentration and redox potential, enhancing Fe^{3+} to Fe^{2+} transition and releasing Fe-P from sediments (Holdren and Armstrong, 1980; Jensen and Andersen, 1992; Kosten et al., 2012). From a diffusion perspective, temperature increases enhanced ion activity, increasing diffusion rates and phosphorus flux from sediments to water (Jiang et al., 2008; Anthony and Lewis Jr., 2012).

3.4 Release of Nitrogen and Phosphorus from Sediments under Different Disturbance Intensities

Disturbance intensity significantly affected NH_4^+ -N release (Figure 5a [Figure 5: see original paper]). As disturbance intensity increased, NH_4^+ -N release increased accordingly, consistent with Wang et al. (2008). Controlled experiments showed that non-disturbed treatments with lower dissolved oxygen had reduced NH_4^+ -N release. Continuous disturbance increased dissolved oxygen, enhancing nitrifying bacteria proliferation and activity (Pauer and Auer, 2000), thus promoting NH_4^+ -N nitrification (Jäntti and Hietanen, 2012; Zhang et al., 2014). However, high-speed disturbance may lead to dissolved oxygen saturation (Peng et al., 2021). NO_3^- -N release did not change significantly across disturbance intensities, except for a significant difference between 50 and 150 r/min. NO_3^- -N release at 150 r/min was slightly higher than at 250 r/min. NO_2^- -N release was relatively small and showed no significant differences across disturbance intensities. Hydrodynamic disturbance can promote short-term NO_2^- -N release because high-speed disturbance (200 r/min) creates high dissolved oxygen conditions favorable for nitrifying bacteria to convert NO_2^- -N to NO_3^- -N (Peng et al., 2021). The low NO_2^- -N content in sediments likely resulted in non-significant release amounts. Additionally, the long-term aerobic environment under hydrodynamic disturbance is unsuitable for denitrification (Reddy et al.,

1984), potentially depleting NO_2^- -N at the sediment-water interface (Peng et al., 2021).

DTP, SRP, and DOP release increased with disturbance intensity, particularly at 250 r/min, which was significantly higher than at 150 and 50 r/min, indicating that disturbance significantly affected nutrient release. Phosphate release is generally positively correlated with disturbance rate (Holdren and Armstrong, 1980). Water disturbance causes surficial sediment resuspension, increases particle-water contact area, and accelerates phosphorus diffusion from sediment interstitial water, promoting rapid release to the overlying water column (Holdren and Armstrong, 1980; Li and Huang, 2010; Xu et al., 2018). Moderate hydrodynamic disturbance promoted nitrogen and phosphorus release from Taihu Lake sediments, worsening eutrophication (Huang et al., 2016). At disturbance intensities of 25, 50, and 100 r/min, total phosphorus and nitrogen release rates increased by 36.2%, 41.7%, and 127.6%, respectively, compared to static conditions, confirming disturbance effects on nutrient release (Jiang et al., 2010).

4 Conclusions

This study investigated nitrogen and phosphorus release processes from river sediments in Urumqi City and surrounding arid areas of Northwest China, and identified influencing factors through laboratory simulation experiments. Sediment nutrient release is a complex, multifactorial process.

Release characteristics differed significantly among sampling sites, with pseudo-second-order kinetics models providing better fit than pseudo-first-order models. Ambient pH significantly affected nitrogen release, with greater NH_4^+ -N release under acidic and alkaline versus neutral conditions. NO_3^- -N release was highest at pH 7.00, while NO_2^- -N release was unaffected by pH. Increased temperature and disturbance intensity significantly promoted nitrogen and phosphorus release, particularly NH_4^+ -N, NO_3^- -N, DTP, and SRP. In summary, pH, temperature, and disturbance intensity strongly influence sediment nutrient release in arid regions.

A comprehensive understanding of sediment nutrient release requires consideration of additional environmental factors and long-term monitoring and modeling. These measures have important theoretical and practical implications for water resource conservation and restoration in arid areas.

Conflict of Interest: The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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References

- Anthony J L, Lewis Jr. W M. 2012. Low boundary layer response and temperature dependence of nitrogen and phosphorus releases from oxic sediments of an oligotrophic lake. *Aquatic Sciences*, 74(3): 611-617.
- Cheng D D, Song J, Zhao X T, et al. 2019. Effects of chironomid larvae and *Limnodrilus hoffmeisteri* bioturbation on the distribution and flux of chromium at the sediment-water interface. *Journal of Environmental Management*, 245: 151-159.
- Coffman R E, Kildsig D O. 1996. Hydrotropic solubilization-mechanistic studies. *Pharmaceutical Research*, 13(10): 1460-1463.
- Cornelissen G, Noort P C M V, Parsons J R, et al. 1997. Temperature dependence of slow adsorption and desorption kinetics of organic compounds in sediments. *Environmental Science & Technology*, 31(2): 454-460.
- Gong Y H, Liu Y G, Yang S L, et al. 2020. Effects of pH value on the release of phosphorus from the sediment in scattered farming rural ditch in plateau region. *Jiangsu Journal of Agricultural Sciences*, 36(4): 955-964. (in Chinese)
- Han T L, Zhou K, Li J L, et al. 2022. The spatial distribution and characterization of phosphorus and nitrogen in a water-carrying lake: a case study of Lake Jiaogang, China. *Environmental Science and Pollution Research*, 30(7): 18674-18684.
- He J, Feng H Y, Diao Z Y, et al. 2022. Effect of temperature variation on phosphorus flux at the sediment-water interface of the steppe wetlands. *Environmental Science and Pollution Research*, 30(5): 12441-12452.
- Holdren G C, Armstrong D E. 1980. Factors affecting phosphorus release from intact lake sediment cores. *Environmental Science & Technology*, 14(1): 79-87.
- House W, Denison F. 2000. Factors influencing the measurement of equilibrium phosphate concentrations in river sediments. *Water Research*, 34(4): 1187-1200.
- Huang J, Xi B D, Xu Q J, et al. 2016. Experiment study of the effects of hydrodynamic disturbance on the interaction between the cyanobacterial growth and the nutrients. *Journal of Hydrodynamics*, 28(3): 411-422.

- Hunting E R, Kampfraath A A. 2013. Contribution of bacteria to redox potential (Eh) measurements in sediments. *International Journal of Environmental Science and Technology*, 10(1): 55-62.
- James W F, Barko J W. 2004. Diffusive fluxes and equilibrium processes in relation to phosphorus dynamics in the upper Mississippi River. *River Research and Applications*, 20(4): 473-484.
- Jäntti H, Hietanen S. 2012. The effects of hypoxia on sediment nitrogen cycling in the Baltic Sea. *Ambio*, 41(2): 161-169.
- Jensen H S, Andersen F O. 1992. Importance of temperature, nitrate, and pH for phosphate release from aerobic sediments of four shallow, eutrophic lakes. *Limnology and Oceanography*, 37(3): 577-589.
- Jiang X, Jin X C, Yao Y, et al. 2008. Effects of biological activity, light, temperature and oxygen on phosphorus release processes at the sediment and water interface of Taihu Lake, China. *Water Research*, 42(8-9): 2251-2259.
- Jiang Y S, Li X C, Xing Y H, et al. 2010. Impacts of disturbance on release of total nitrogen and total phosphorus from surficial sediments of Dongping Lake. *Environmental Science & Technology*, 33(8): 41-44.
- Jin X C, Wang S R, Pang Y. 2004. The influence of phosphorus forms and pH on the phosphorus release of the sediments in Taihu Lake. *China Environmental Science*, 6: 68-72. (in Chinese)
- Jin X C, Wang S R, Pang Y, et al. 2006. Phosphorus fractions and the effect of pH on the phosphorus release of the sediments from different trophic areas in Taihu Lake, China. *Environmental Pollution*, 139(2): 288-295.
- Joshi S R, Kukkadapu R K, Burdige D J, et al. 2015. Organic matter remineralization predominates phosphorus cycling in the mid-bay sediments in the Chesapeake Bay. *Environmental Science & Technology*, 49(10): 5887-5896.
- Katsev S, Tsandev I, L'Heureux I, et al. 2006. Factors controlling long-term phosphorus efflux from lake sediments: exploratory reactive-transport modeling. *Chemical Geology*, 234(1-2): 127-147.
- Kim L H, Choi E, Stenstrom M K. 2003. Sediment characteristics, phosphorus types and phosphorus release rates between river and lake sediments. *Chemosphere*, 50(1): 53-61.
- Kong M, Liu F F, Tao Y, et al. 2020. First attempt for in situ capping with lanthanum modified bentonite (LMB) on the immobilization and transformation of organic phosphorus at the sediment-water interface. *Science of the Total Environment*, 741: 140342, doi: 10.1016/j.scitotenv.2020.140342.
- Kosten S, Huszar V L M, Bécares E, et al. 2012. Warmer climates boost cyanobacterial dominance in shallow lakes. *Global Change Biology*, 18(1): 118-126.

- Li D P, Huang Y. 2010. Sedimentary phosphorus fractions and bioavailability as influenced by repeated sediment resuspension. *Ecological Engineering*, 36(7): 958-962.
- Li Q G, Tian Y, Liu L, et al. 2022. Research progress on release mechanisms of nitrogen and phosphorus of sediments in water bodies and their influencing factors. *Wetland Science*, 20(1): 94-103. (in Chinese)
- Liang S X, Jia Y L, Yan X, et al. 2010. Effect of the pH value on the nitrogen and phosphorus release from the sediment Baiyangdian. *Journal of Anhui Agricultural Sciences*, 38(36): 20859-20862. (in Chinese)
- Liu W, Zhou B, Wang P, et al. 2020. Mechanism and influencing factors of nitrogen and phosphorus release via sediment resuspension. *Science Technology and Engineering*, 20(4): 1311-1318.
- Liu Z Z, Ni Z K, Liu S R, et al. 2022. Kinetic release characteristics of organic phosphorus of sediment-water and water quality risks. *Environmental Science*, 43(6): 3058-3065.
- Lovley D R, Phillips E J P. 1986. Organic matter mineralization with reduction of ferric iron in anaerobic sediments. *Applied and Environmental Microbiology*, 51(4): 683-689.
- Lü C W, He J, Zuo L, et al. 2016. Processes and their explanatory factors governing distribution of organic phosphorous pools in lake sediments. *Chemosphere*, 145: 125-134.
- Pauer J, Auer M. 2000. Nitrification in the water column and sediment of a hypereutrophic lake and adjoining river system. *Water Research*, 34(4): 1247-1254.
- Peng C, Huang Y Y, Yan X C, et al. 2021. Effect of overlying water pH, temperature, and hydraulic disturbance on heavy metal and nutrient release from drinking water reservoir sediments. *Water Environment Research*, 93(10): 2135-2148.
- Peñuelas J, Sardans J. 2022. The global nitrogen-phosphorus imbalance. *Science*, 375(6578): 266-267.
- Reddy K R, Patrick W H, Broadbent F E. 1984. Nitrogen transformations and loss in flooded soils and sediments. *C R C Critical Reviews in Environmental Control*, 13(4): 273-309.
- Rippey B, Campbell J, McElarney Y, et al. 2021. Timescale of reduction of long-term phosphorus release from sediment in lakes. *Water Research*, 200: 117283, doi: 10.1016/j.watres.2021.117283.
- Small G E, Cotner J B, Finlay J C, et al. 2014. Nitrogen transformations at the sediment-water interface across redox gradients in the Laurentian Great Lakes. *Hydrobiologia*, 731(1): 95-108.

- Søndergaard M, Jensen J P, Jeppesen E. 1999. Internal phosphorus loading in shallow Danish lakes. *Hydrobiologia*, 408-409: 145-152.
- Song Y J. 2017. Study on the migrating characteristics of nitrogen at sediment-water interface in Xinjiang Dongdaohaizi. MSc Thesis. Urumqi: Xinjiang Agricultural University. (in Chinese)
- Su W H, Zhu X P, Wang L, et al. 2023. Characteristics and pollution assessment of nitrogen and phosphorus fractions in river sediments in Urumqi and surrounding areas. *Journal of Ecology and Rural Environment*, 39(12): 1547-1558. (in Chinese)
- Temporetti P, Beamud G, Nichela D, et al. 2019. The effect of pH on phosphorus sorbed from sediments in a river with a natural pH gradient. *Chemosphere*, 228: 287-299.
- Wang P B, Song J M, Guo Z Y, et al. 2008. The release behavior of inorganic nitrogen and phosphorus in sediment during disturbance. *Journal of Oceanology and Limnology*, 26(2): 197-202.
- Wu Q H, Zhang R D, Huang S, et al. 2008. Effects of bacteria on nitrogen and phosphorus release from river sediment. *Journal of Environmental Sciences*, 20(4): 404-412.
- Wu Y H, Wen Y J, Zhou J X, et al. 2014. Phosphorus release from lake sediments: effects of pH, temperature and dissolved oxygen. *KSCE Journal of Civil Engineering*, 18(1): 323-329.
- Wu Z, Li J C, Sun Y X, et al. 2022. Imbalance of global nutrient cycles exacerbated by the greater retention of phosphorus over nitrogen in lakes. *Nature Geoscience*, 15(6): 464-468.
- Xu S Y, Lu J, Chen L C, et al. 2023. Experiment on sediment ammonia nitrogen release of Chaohu Lake in varying hydrodynamic disturbance. *Sustainability*, 15(2): 1581, doi: 10.3390/su15021581.
- Xu Z, Woodhouse J N, Te S H, et al. 2018. Seasonal variation in the bacterial community composition of a large estuarine reservoir and response to cyanobacterial proliferation. *Chemosphere*, 202: 576-585.
- Yin H B, Du Y X, Kong M, et al. 2017. Interactions of riverine suspended particulate matter with phosphorus inactivation agents across sediment-water interface and the implications for eutrophic lake restoration. *Chemical Engineering Journal*, 327: 150-162.
- Zhang L, Wang S R, Wu Z. 2014. Coupling effect of pH and dissolved oxygen in water column on nitrogen release at water-sediment interface of Erhai Lake, China. *Estuarine, Coastal and Shelf Science*, 149: 178-186.
- Zhao Y P, Wu S J, Yu M T, et al. 2021. Seasonal iron-sulfur interactions and the stimulated phosphorus mobilization in freshwater lake sediments. *Science of the Total Environment*, 768: 144336, doi: 10.1016/j.scitotenv.2020.144336.

Note: Figure translations are in progress. See original paper for figures.

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