Aquaculture 612 (2026) 743089

Contents lists available at ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aquaculture

Effects of KMPS on eutrophic sediment-water interface in pond aquaculture: Based on physicochemical properties, DOM characteristics and microbial community structure

Peng Yin [a], Dugeng Wang [a], Xiaoyu Zhang [a], Gaofeng Zhang [b], Haiyong Zhao [b], Yingying Zhang [a], Hui Yang [a,*]

[a] College of Animal Science and Technology, Yangzhou University, Yangzhou 225009, Jiangsu, China
[b] Jiangsu Yongrong Biotechnology Co., Ltd., Huai'an 223001, Jiangsu, China

ARTICLE INFO

Keywords:
DOM
Enzyme activity
KMPS
Microbial diversity
Pond sediment

ABSTRACT

Eutrophic sediments represent a major threat to the health of aquatic ecosystems, and their restoration is critical for aquaculture and inland water management. Potassium persulfate composite salt ($K_2SO_4 \cdot KHSO_4 \cdot 2KHSO_5$, KMPS) is a strong oxidant with high efficiency, safety, and environmental friendliness. However, its application and mechanism of action in eutrophic sediment remediation have not been systematically studied. This study utilizes an acrylic column simulation system to explore the effects of different KMPS dosages on the physicochemical properties of sediment-water interfaces (SWI), dissolved organic matter (DOM) characteristics, enzyme activity, and microbial community structure, aiming to reveal the mechanism of KMPS in eutrophic sediment remediation and provide scientific evidence for its practical application. The study indicates that KMPS significantly reduces sediment particle size, increasing the proportion of clay and silt particles, thereby optimizing the material exchange capacity of sediments. Nitrogen form analysis revealed that KMPS significantly reduced IEF-N, particularly the IEF-NH_4^+ content, decreasing the storage of bioavailable nitrogen and promoting nitrogen transformation between sediments and the water column. KMPS also significantly increased the dissolved organic carbon (DOC) content in both sediments and water, and by degrading complex organic matter, it promoted the generation of low molecular weight hydrophilic dissolved organic matter (DOM), thereby improving its bioavailability. Enzyme activity tests showed that KMPS enhanced the activities of cellulase and peroxidase, promoting organic matter decomposition, while microbial community analysis indicated that KMPS optimized the functional microbial community structure, enhancing sediment pollution degradation potential and promoting material cycling. KMPS significantly improved the material cycling and ecological function of the SWI system by optimizing sediment particle size distribution, regulating nitrogen forms, degrading DOM, and reorganizing microbial communities. The results reveal the high efficiency and application potential of KMPS in eutrophic sediment remediation.

1. Introduction

The application of strong oxidizers in pollutant treatment and bacterial disinfection is widespread, primarily due to their powerful oxidative ability, which can decompose pollutants or eliminate microorganisms (Kim et al., 2002; Zhou et al., 2019). Traditional strong oxidizers include chlorine, ozone, hydrogen peroxide, hypochlorite, and potassium permanganate (Luan et al., 2024). Potassium persulfate composite salt ($K_2SO_4 \cdot KHSO_4 \cdot 2KHSO_5$, abbreviated as KMPS) is also a commonly used strong oxidizer. $KHSO_5$ (PMS) is the main active component of KMPS (Fernandez et al., 2004), which can destroy the chemical structure of pollutants through its strong oxidizing properties, and it can break down bacterial cell walls, inhibit bacterial metabolic processes, and cause oxidative damage to cells (Lee et al., 2020). This gives KMPS significant effectiveness in pollutant degradation and microbial disinfection (Totaro et al., 2023; Wu et al., 2024). Compared to traditional strong oxidizers, KMPS has a shorter application history, but its efficiency, safety, stability, and environmental friendliness have

* Corresponding author at: College of Animal Science and Technology, Yangzhou University, 48 Wenhui Road, Yangzhou, Jiangsu 225009, China.
E-mail address: huiyang@yzu.edu.cn (H. Yang).

https://doi.org/10.1016/j.aquaculture.2025.743089
Received 19 February 2025; Received in revised form 20 July 2025; Accepted 20 August 2025
Available online 21 August 2025

made it increasingly popular in various fields (Feng et al., 2023). KMPS has shown good results in industrial wastewater treatment and aquaculture water quality regulation (Wang et al., 2023; Wang and Zhang, 2023), and it has also been effective in degrading organic pollutants in sediments, such as pyrene and polycyclic aromatic hydrocarbons (Hung et al., 2021; Shi et al., 2022).

To date, there have been few reports on the application and mechanisms of strong oxidizers, including KMPS, in the remediation of eutrophic sediments. Taking aquaculture pond sediments as an example, KMPS has been widely employed in the routine management of aquaculture systems, particularly in shrimp farming across numerous Asian countries, where it plays a dual role in enhancing water quality and mitigating disease outbreaks (Rico et al., 2013). For example, KMPS is commonly applied at concentrations ranging from 1 to 15 g/m^3 to suppress pathogenic bacteria and degrade organic pollutants within the water column (Zhao et al., 2022). Despite its widespread use, the specific applications and remediation efficacy of KMPS in aquaculture pond sediments remain poorly understood. In intensive aquaculture systems, uneaten feed and excreta from farmed organisms accumulate continuously, resulting in the formation of organic-rich sediments and promoting the development of anaerobic processes at the sediment–water interface (SWI). These processes generate harmful substances such as ammonia nitrogen, hydrogen sulfide, and methane, and lead to the proliferation of pathogenic microorganisms, posing a serious threat to the survival and health of the cultured animals (Boyd and Queiroz, 2014; Boyd, 1995). Therefore, the remediation of eutrophic sediments is crucial. Given the successful application of strong oxidizers in other areas, investigating the role and mechanisms of strong oxidizers in the remediation of eutrophic sediments is essential.

Representative indicators of the SWI system include the particle size distribution of sediments, nitrogen forms, dissolved organic matter (DOM), enzyme activity, and microbial communities. Particle size distribution influences the distribution of pollutants in sediments as well as the content of total nitrogen (TN), total phosphorus (TP), and soluble organic carbon (Chen et al., 2022). Nitrogen forms, including ion-exchangeable nitrogen (IEF-N), weak acid-extractable nitrogen (WAEF-N), strong base-extractable nitrogen (SAEF-N), and strong oxidant-extractable nitrogen (SOEF-N) (Zheng et al., 2008), play a central role in water eutrophication, nitrogen cycling, and microbial metabolism (Hargreaves, 1998; Ye et al., 2021). Studying nitrogen forms in the SWI system helps to understand the nitrogen release mechanisms, the nitrogen cycling between sediments and water, and the biogeochemical processes of nitrogen (Gardner et al., 2001; Jinming et al., 2002). DOM is an active component in aquatic ecosystems, directly involved in the nutrient cycling of water bodies and influencing microbial metabolic activities (Polubesova and Chefetz, 2014). Changes in DOM can serve as an indicator of the transformation of substances and pollutant degradation between water and sediments under the action of oxidizers (Romera-Castillo and Jaffé, 2015; Zhang et al., 2021). Enzyme activity in sediments primarily originates from microorganisms, which are directly involved in the decomposition of organic matter, nitrogen transformation, and nutrient cycling, making them key to the ecological functions of sediments (Bai et al., 2018; Zhao et al., 2018). In addition to participating in the metabolism of various nutrients, microorganisms also play an important role as indicators of environmental changes, ecological health, pollution status, and ecological restoration (Hu et al., 2011).

This study utilizes an acrylic column-based simulated pond SWI system (including sediment and overlying water) to systematically investigate the effects of applying different doses of KMPS to the sediment. The study examines changes in sediment particle size distribution, nitrogen forms, DOM composition and characteristics, enzyme activity, and microbial community structure within the SWI system. The objective is to reveal the impact of KMPS treatment on the biogeochemical cycles in the SWI system and to elucidate the mechanisms of KMPS in the remediation of aquaculture pond sediments. This research will provide scientific evidence for the use of strong oxidizers, such as KMPS, in the remediation of eutrophic sediments.

2. Materials and methods

2.1. Experimental materials

The sediment used in this study was collected from a prawn farming pond at the Yangtze River System Fish Breeding Base in Guangling, Jiangsu Province (119°29′0.204″E, 32°17′51.140″N) in June 2024, using a core sampler. The biogeochemical processes in the SWI typically occur within a depth range of 0–10 cm, which is characterized by significant material exchange and a rich microbial community (Liao et al., 2021). Therefore, the sampling depth was set at 10 cm from the sediment-water interface (SWI). After being collected, the samples were passed through a 2 mm aperture 10-mesh stainless steel sieve to remove large particulate impurities. The samples were then stored in a 30 L open polyethylene barrel, sealed with black polyethylene plastic film to prevent light exposure, and transported back to the laboratory within 30 min of sampling for subsequent analysis and ecosystem setup. The KMPS powder used in this study was provided by Jiangsu Yongrong (Huai'an, China). To minimize the loss of KMPS in the water during application, we pressed the KMPS powder into tablets using a tablet press. The experimental containers were made of polymethyl methacrylate (PMMA) acrylic columns, purchased from Shengyuanda Plastic Products Co., Ltd. (Huizhou, China), with a diameter of 15 cm and a height of 10 cm.

2.2. Experimental design

In the simulated aquaculture pond SWI system, based on the sediment-to-overlying water ratio typical of conventional aquaculture ponds, the sediment depth in the experimental columns was set to 4 cm, and the overlying water depth was set to 6 cm (sediment wet weight of 500 g with a moisture content of 85 %) (Tang et al., 2024). The experiment included four treatment groups and one blank control group (Con, with no treatment applied), with three replicates per group. Based on recommended dosages used in aquaculture practice, published literature (e.g., Zhao et al., 2022), and results from preliminary pre-experiments, the KMPS dosages were determined through comprehensive consideration. The treatment groups were dosed with 0.2 g, 0.4 g, 0.6 g, and 0.8 g of KMPS (designated as KP0.2, KP0.4, KP0.6, and KP0.8), with one application administered every three days, respectively. The total experimental duration was 15 days, with five dosing events in total. Throughout the experiment, the experimental columns were covered with black polyethylene plastic film to simulate the pond bottom environment, ensuring that the experiment was conducted under low-light conditions.

2.3. Physicochemical index measurement

On the day following each KMPS application, the pH, temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP) of the overlying water and sediment in each experimental column were measured. At the end of the experiment, samples of the overlying water and sediment were collected for storage and analysis. At the end of the experiment, samples of the overlying water and sediment were collected for storage and analysis. Specifically, for sediment sampling, the remaining overlying water in the experimental columns was first pumped out, and then the surface sediment was excavated and collected using a stainless steel weighing spoon. The overlying water was collected in opaque white polyethylene bottles for subsequent analysis. The sediment was divided into two portions: one portion was used for microbial community structure analysis and enzyme activity measurements, while the other portion was air-dried, ground, and sieved through a 100-mesh stainless steel sieve for subsequent measurements.

The sediment particle size distribution was measured using a particle size analyzer (Mastersizer 2000, Malvern Instruments, UK). Total Nitrogen (TN) in the overlying water was measured using the alkaline persulfate digestion ultraviolet spectrophotometric method; ammonia nitrogen (NH_4^+-N) and nitrite nitrogen (NO_2^--N) were measured using the NESSLER's reagent ultraviolet spectrophotometric method (Wang et al., 1998; Wu and Cao, 2013); nitrate nitrogen (NO_3^--N) was measured using the spectrophotometric metho (Wang et al., 2017). The forms of potentially exchangeable nitrogen (TTN) in the sediment were measured using a sequential extraction method, determining the contents of ion exchangeable nitrogen (IEF-N), weak acid extractable nitrogen (WAEF-N), strong base extractable nitrogen (SAEF-N), and strong oxidant extractable nitrogen (SOEF-N) (Lü et al., 2005). Total nitrogen content in the sediment was measured using an elemental analyzer (Vario EL cube Elementar, Germany). Total organic carbon (TOC) in the sediment was measured using the potassium dichromate dilution-heat method (Nelson and Sommers, 1996). The pH, temperature, and ORP of the overlying water were measured using a portable water quality tester (PCT-407, portable multiparameter water quality tester, LOOBO, China), while dissolved oxygen (DO) in the overlying water was measured using a portable dissolved oxygen meter (PDO 508, Beijing Huamei Water Analytical Instruments, China). Sediment pH, temperature, and ORP were measured using a soil redox potential meter (LT-OPW Soil Oxidation-Reduction Potential Meter, LVBO, China).

2.4. Extraction and analysis of dissolved organic matter (DOM)

The extraction steps for DOM in the overlying water are as follows: samples were centrifuged at 8000 rpm for 10 min, and the supernatant was filtered through a 0.45 μm glass fiber filter. The filtrate was then collected and stored at 4 °C. For sediment DOM extraction, sieved sediment samples were extracted with Milli-Q ultrapure water (v/w = 10: 1) and shaken in a constant temperature shaker (ZQPL-200, Labotery, China) at 220 rpm for 24 h. DOM concentration was expressed as dissolved organic carbon (DOC) and measured using a total organic carbon analyzer (TOC-LCPN, Shimadzu, Japan). The three-dimensional fluorescence spectra (EEM) and UV–visible spectra (UV–vis) of all samples were measured using a fluorescence spectrophotometer (F-7000, Hitachi, Japan) and a UV–visible-NIR spectrometer (Cary 5000, Varian, USA), respectively. EEM measurements used a 150 W xenon lamp as the excitation light source, with a PMT voltage set to 700 V and a signal-to-noise ratio > 110. A 1 cm quartz cuvette was used, with the excitation wavelength range from 200 to 500 nm and the emission wavelength range from 250 to 600 nm. The instrument was automatically calibrated. Milli-Q ultrapure water was used as a blank, and the parallel factor (PARAFAC) model was used for analysis. Rayleigh scattering was manually removed, and the background of Milli-Q water was subtracted from the fluorescence spectra to eliminate Raman scattering. The PARAFAC model and humification parameters of DOM were analyzed using Matlab 2021a. UV–visible spectroscopy measured the range from 200 to 800 nm with a scanning interval of 2 nm. The humification parameters include the fluorescence index (FI), humification index (HIX), and biogenic index (BIX), while the UV–visible spectral parameters include a(355), $SUVA_{254}$, $SUVA_{280}$, E_2/E_3, E_4/E_6, and $S_{275–295}$, as detailed in Table S1.

2.5. Enzyme activity measurement

Enzymes are an important component of sediment, and their activity directly influences the release of endogenous substances. In this study, the activities of six enzymes, including protease, peroxidase, urease, cellulase, dehydrogenase, and invertase, were measured for different treatment groups. Protease activity was determined using the method of Huang et al. (Huang et al., 2015), where the amino acids produced by protease hydrolysis form a blue complex with ninhydrin, which is measured spectrophotometrically at 560 nm. Dehydrogenase activity was measured by the reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to 2,3,5-triphenylformazan (TPF) (Polyak et al., 2017). The activities of catalase, urease, transglutaminase, and cellulase were determined using the purple gallic acid colorimetric method, Nessler's reagent method, and 3,5-dinitrosalicylic acid spectrophotometric method, respectively (Teixeira et al., 2012; Zhao et al., 2018; Zusfahair et al., 2022).

2.6. Microbial community 16S rRNA gene analysis

To assess the effects of different doses of KMPS on the microbial community in the WSI interface system, we conducted microbial detection and analysis of the sediment. At the conclusion of the experiment, sediment samples were immediately submerged in liquid nitrogen for flash-freezing and subsequently stored at −80 °C to preserve microbial integrity prior to analysis. The sequencing and subsequent analysis were carried out by BaiMaiKe Biotechnology Co., Ltd. (Beijing, China). First, genomic DNA was extracted from the sediment samples. The V3-V4 region of the 16S rRNA gene was utilized to characterize the bacterial communities. The amplification was carried out using the primer pair 338F/806R. Subsequently, the PCR products were purified, quantified, pooled, and sequenced on Illumina NovaSeq 6000 platform.

2.7. Statistical analysis

Data were analyzed using SPSS 18 and presented as Mean ± standard deviation (SD). Parametric data were assessed by one-way ANOVA followed by Tukey's post-hoc test. For non-normal or heteroscedastic data, logarithmic transformation was applied before ANOVA, and the significance level was set at $P < 0.05$. Figures were generated with OriginPro 2021. High-throughput sequencing data were analyzed on the BMKcloud platform (https://international.biocloud.net/zh/dashboard), and correlation analysis of environmental factors and significant changes in microbial communities was conducted using Cloudtutu (http://cloudtutu.com.cn/), with significant positive correlations defined as $P \leq 0.01$ and $r \geq 0.4$.

3. Results

3.1. Sediment particle size analysis

After treatment with different doses of KMPS, the overall particle size of the sediment decreased, and the trend became more pronounced with increasing dose ($p < 0.05$) (Fig. 1A). D10, D50, and D90 represent the particle sizes corresponding to cumulative particle size distribution values of 10 %, 50 %, and 90 %, respectively (te Slaa, 2020). These results also show that under KMPS treatment, the sediment particle size decreased in a dose-dependent manner, with significant differences observed at the KP0.8 level ($p < 0.05$) (Fig. 1B). The sediment particles were primarily classified into three types based on particle size: clay (< 2 μm), silt (2–50 μm), and sand (50–2000 μm) (Turlan et al., 2007). Compared to the control group (Con), the proportion of sand in all treatment groups decreased in a dose-dependent manner, from 18.58 % in the Con group to 10.10 %–0.83 %. In contrast, the proportions of silt and clay increased in a dose-dependent manner, with the silt proportion rising from 75.63 % in the Con group to 83.03 %–88.03 %, and the clay proportion increasing from 5.74 % in the Con group to 7.56 %–11.14 % (Fig. 1C).

3.2. Changes in the physicochemical parameters of sediment and overlying water

Under the KP0.2 to KP0.8 treatments, the pH of the sediment significantly decreased in a dose-dependent manner, whereas the ORP significantly decreased only in the KP0.4 treatment group. The TN content decreased in a dose-dependent manner but did not reach a

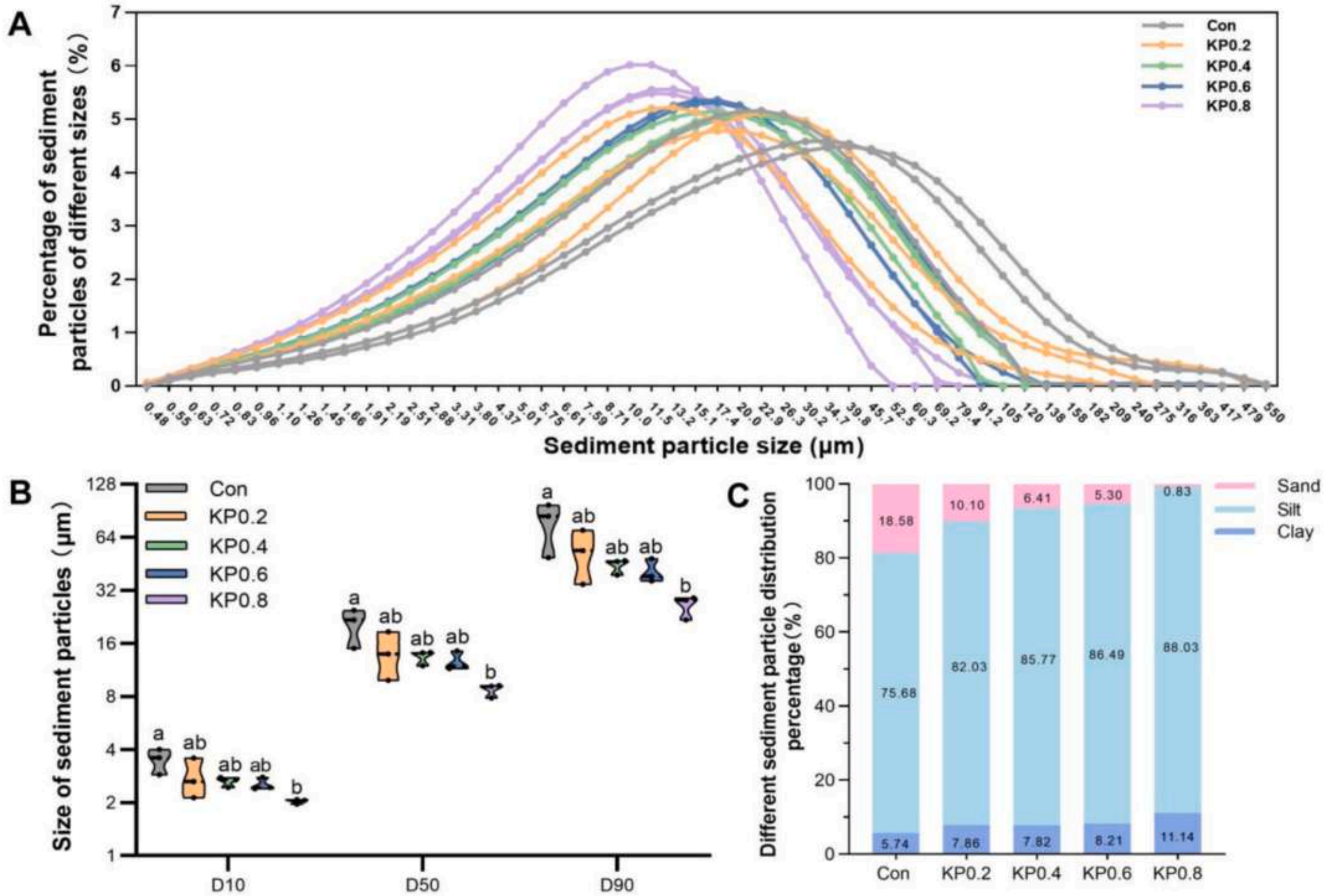

Fig. 1. Effect of KMPS on sediment particle size; (A) Sediment particle size distribution; (B) D10, D50, and D90 of sediment particle size; (C) Composition percentage of sediment particle content. Sediment particles are mainly divided into three classified: clay (< 2 μm), silt (2–50 μm), and sand (50–2000 μm); D10, D50, and D90 represent the particle sizes corresponding to cumulative particle size distribution values of 10 %, 50 %, and 90 %, respectively; Significant differences between treatments without the same letter are indicated ($p < 0.05$).

significant level ($p < 0.05$). In the water body, pH and ORP significantly decreased in a dose-dependent manner, while DO significantly decreased across the KP0.2 to KP0.8 treatment groups ($p < 0.05$). TN and NH_4^+-N significantly increased in all treatment groups, with TN following a dose-dependent trend. The NO_3^--N level significantly increased in the KP0.8 group, while NO_2^--N significantly decreased in the KP0.2 to KP0.6 groups, with a greater decrease observed in the lower concentration treatment groups ($p < 0.05$) (Fig. 2).

3.3. Changes in nitrogen forms in sediment

The IEF-N content in the sediment of the Con group was 158.59 mg/kg. The IEF-N content in all KMPS treatment groups significantly decreased, ranging from 30.49 to 45.21 mg/kg ($p < 0.05$). However, the contents of WAEF-N, SAEF-N, and SOEF-N in the treatment groups showed no significant changes compared to the Con group (Fig. 3A). Further analysis of the NH_4^+-N and NO_3^--N forms in IEF-N revealed that the IEF-NH_4^+ content in the Con group was 127.30 mg/kg, which significantly decreased after KMPS treatment ($p < 0.05$), ranging from 24.36 to 33.67 mg/kg. However, the IEF-NO_3^- content showed no significant changes ($p < 0.05$) (Fig. 3B).

3.4. Changes in TOC and DOC in sediment

Under KMPS treatment, the total organic carbon (TOC) content in the sediment showed a downward trend compared to the Con group, but the difference was not significant. The dissolved organic carbon (DOC) content in both sediment and water exhibited a dose-dependent increase under all KMPS treatment concentrations. The DOC in the sediment was significantly higher in the KP0.8 group compared to the control group, and the DOC in the water was significantly higher in the KP0.4 to KP0.8 groups compared to the control group ($p < 0.05$) (Fig. 4).

3.5. Composition and spectral parameters of DOM

3.5.1. Identification and changes in the composition of DOM

In this study, five fluorescent components were identified in the dissolved organic matter (DOM) samples, including three protein-like components (C1, C2, and C4) and two humic-like components (C3 and C5) (Fig. 5A). These components exhibited high matching with the Open Fluor database, with similarity scores greater than 0.95. C1 showed a maximum at 275/320 nm (Ex/Em), representing a protein-like component (Dainard et al., 2015); C2, at 220/301 nm, is a protein-like or tyrosine-like component (Derrien et al., 2020); C3, at 240, 305/396 nm, represents a combination of the A + M peaks, indicative of humic substances derived from biological/microbial activity (Cárdenas et al., 2017; Garcia et al., 2018); C4, at 290/352 nm, is a protein-like or tryptophan-like component (Murphy et al., 2011); C5, at <260, 365/475 nm, represents terrestrial humic substances (DeFrancesco and Guéguen, 2021). Fig. 5B shows the percentage composition of each DOM fluorescent component. The results indicated that C1 and C2 are the major components of DOM, with C1 and C2 accounting for 30.67 % and

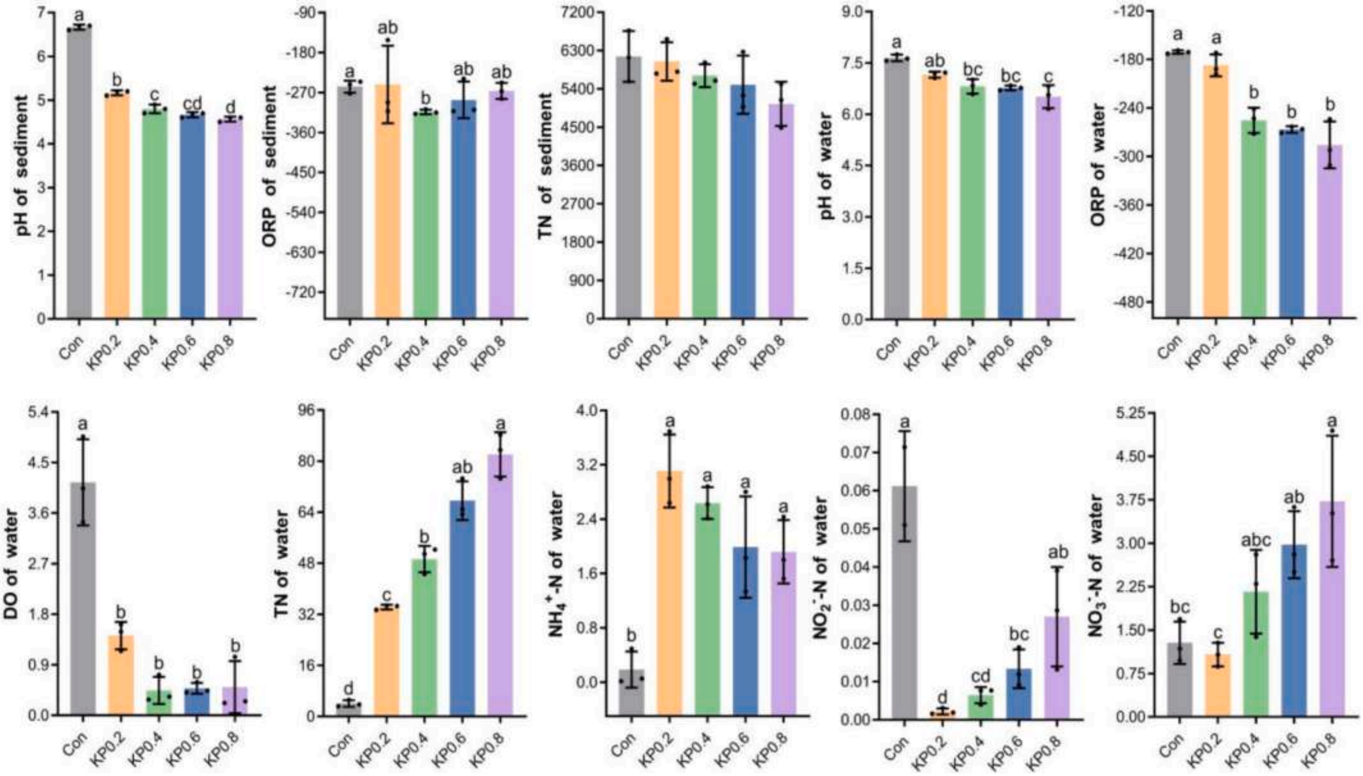

Fig. 2. Effects of KMPS on the physicochemical parameters of sediment and water.

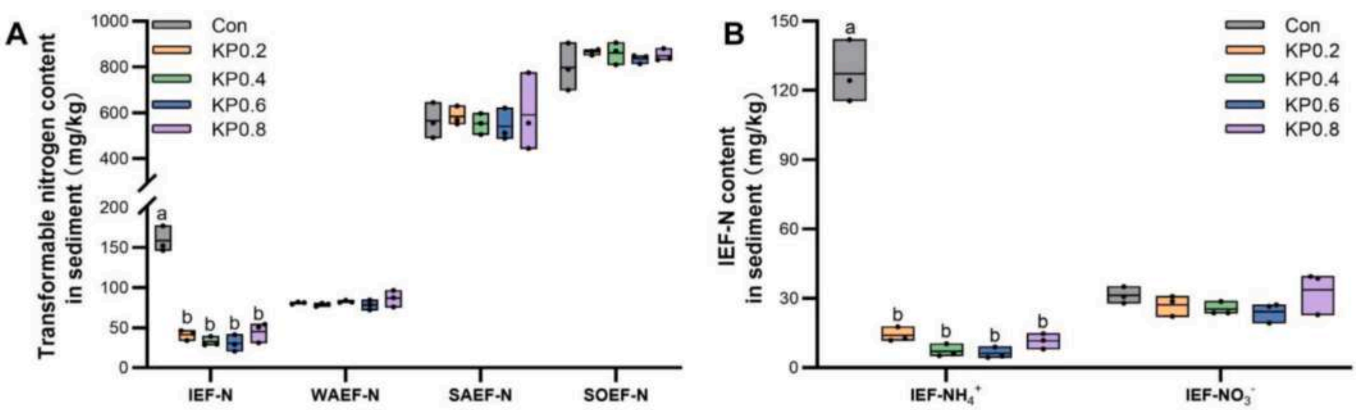

Fig. 3. Changes in Nitrogen Forms in Sediment; (A) Changes in the content of different forms of potentially available nitrogen in sediment; (B) Changes in the content of IEF-NH_4^+ and IEF-NO_3^- nitrogen forms; Differences between treatments without the same letter are significant ($p < 0.05$).

54.44 %, respectively, in sediment, and 38.44 % and 41.90 %, respectively, in water. C3, C4, and C5 in sediment accounted for 6.82 %, 3.30 %, and 4.78 %, respectively, while in water, they accounted for 11.55 %, 1.73 %, and 6.38 %, respectively. The sum of the protein-like components C1, C2, and C4 in sediment and water were 88.37 % and 82.07 %, respectively, while the sum of the humic-like components C3 and C5 were 11.6 % and 17.93 %, respectively. This indicates that the protein-like components are the predominant components in both sediment and water of the pond. Under KMPS treatment, except for C5 in sediment, which significantly increased in the KP0.4 group, the other components in both sediment and water showed some fluctuations but did not exhibit significant changes.

3.5.2. UV–visible absorption spectral parameters and humification parameters of DOM

Under the influence of KMPS, the changes in the UV–visible absorption spectral parameters and humification parameters of the sediment and water we detected were mostly consistent. Among them, the parameters a(355), E_2/E_3, and $S_{275–295}$ showed an increase under KMPS treatment, mostly exhibiting dose-dependent characteristics. The E_4/E_6 value did not show significant changes in sediment, but in water, it significantly increased in a dose-dependent manner. $SUVA_{254}$ significantly decreased in both sediment and water, $SUVA_{280}$ significantly decreased in water but showed no significant change in sediment. The fluorescence index (FI) showed no significant change in either sediment or water, while the humification index (HIX) generally showed a significant dose-dependent decrease. The BIX index in water showed no significant change compared to the Con group, while in sediment, the BIX value significantly increased at the KP0.6 level, with no significant changes in the other groups ($p < 0.05$) (Fig. 6).

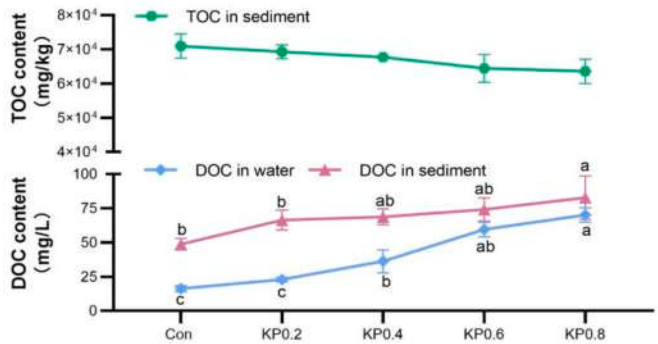

Fig. 4. Effect of KMPS on TOC in sediment and DOC content in sediment and water; Differences between treatments without the same letter are significant ($p < 0.05$).

3.6. Changes in enzyme activity in sediment

Under KMPS treatment, urease activity was significantly lower than the control group (Con), and no significant differences were observed between different KMPS concentrations ($p < 0.05$). Cellulase activity significantly increased in all treatment groups, with the increase in KP0.2 and KP0.4 groups being much higher than in the KP0.6 and KP0.8 groups ($p < 0.05$). Peroxidase activity significantly increased in the KP0.2, KP0.4, and KP0.6 groups, with the increase in KP0.2 and KP0.4 being much greater than in the KP0.6 group. No significant difference was observed between the KP0.8 group and the control group ($p < 0.05$). No significant changes were observed in the activity of protease, dehydrogenase, or invertase in all KMPS treatment groups (Fig. 7).

3.7. Effect of KMPS on sediment microbial community structure

A total of 50 microbial taxa were detected at the phylum level, with Proteobacteria being the predominant dominant group. After KMPS treatment, the relative abundance of Proteobacteria increased from 26.37 % in the control group (Con) to 30.52–35.02 %. Among other dominant groups, the relative abundance of *Desulfobacterota*,

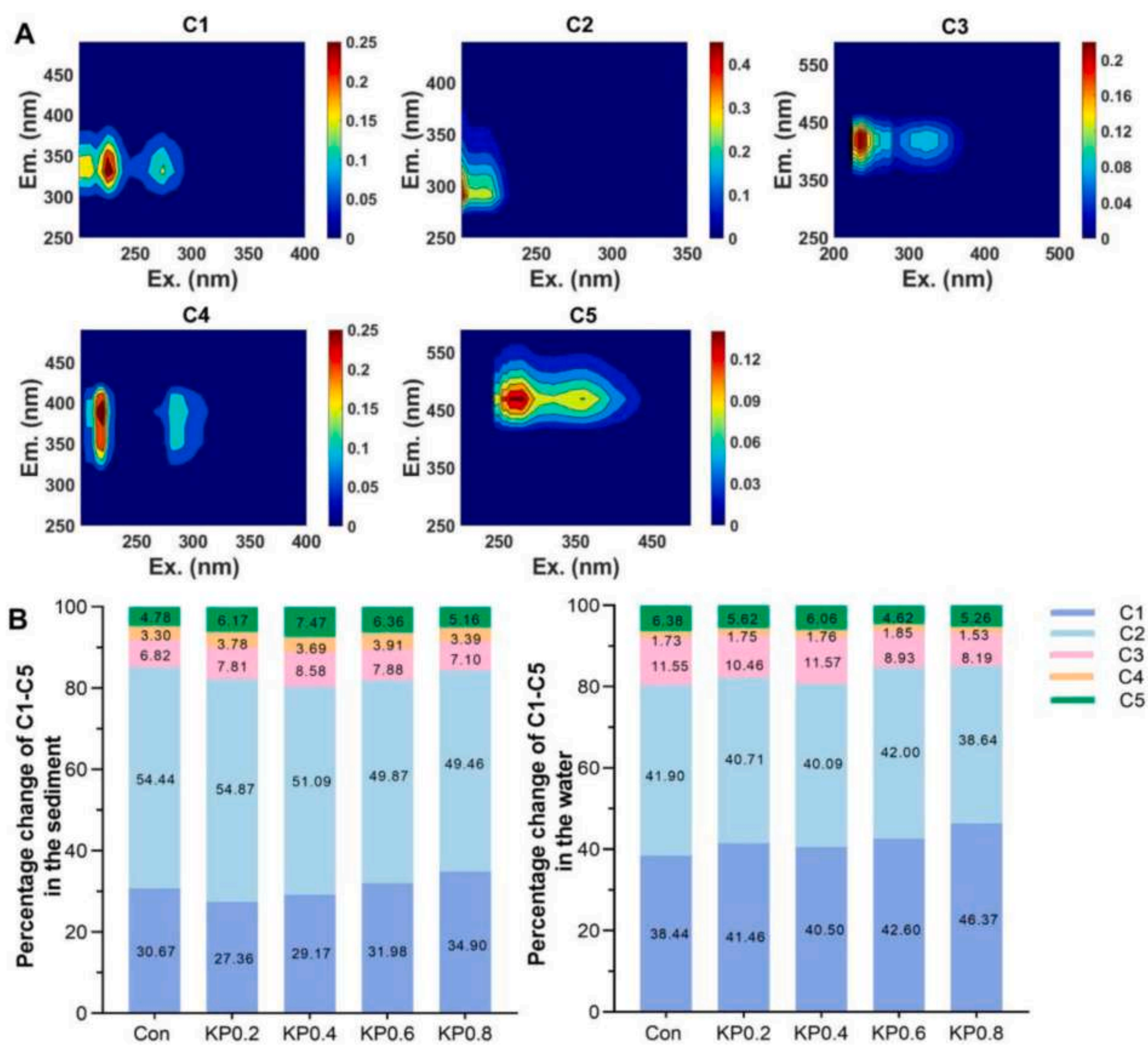

Fig. 5. Composition of DOM and the effect of KMPS on its composition; (A) Five different DOM fluorescent components; (B) Percentage and variation of each component in sediment and water; C1 is a protein-like component; C2 is a protein-like or tyrosine-like component; C3 is humic substances derived from biological/microbial activity; C4 is a protein-like or tryptophan-like component; C5 represents terrestrial humic substances; differences between treatments without the same letter are significant ($p < 0.05$).

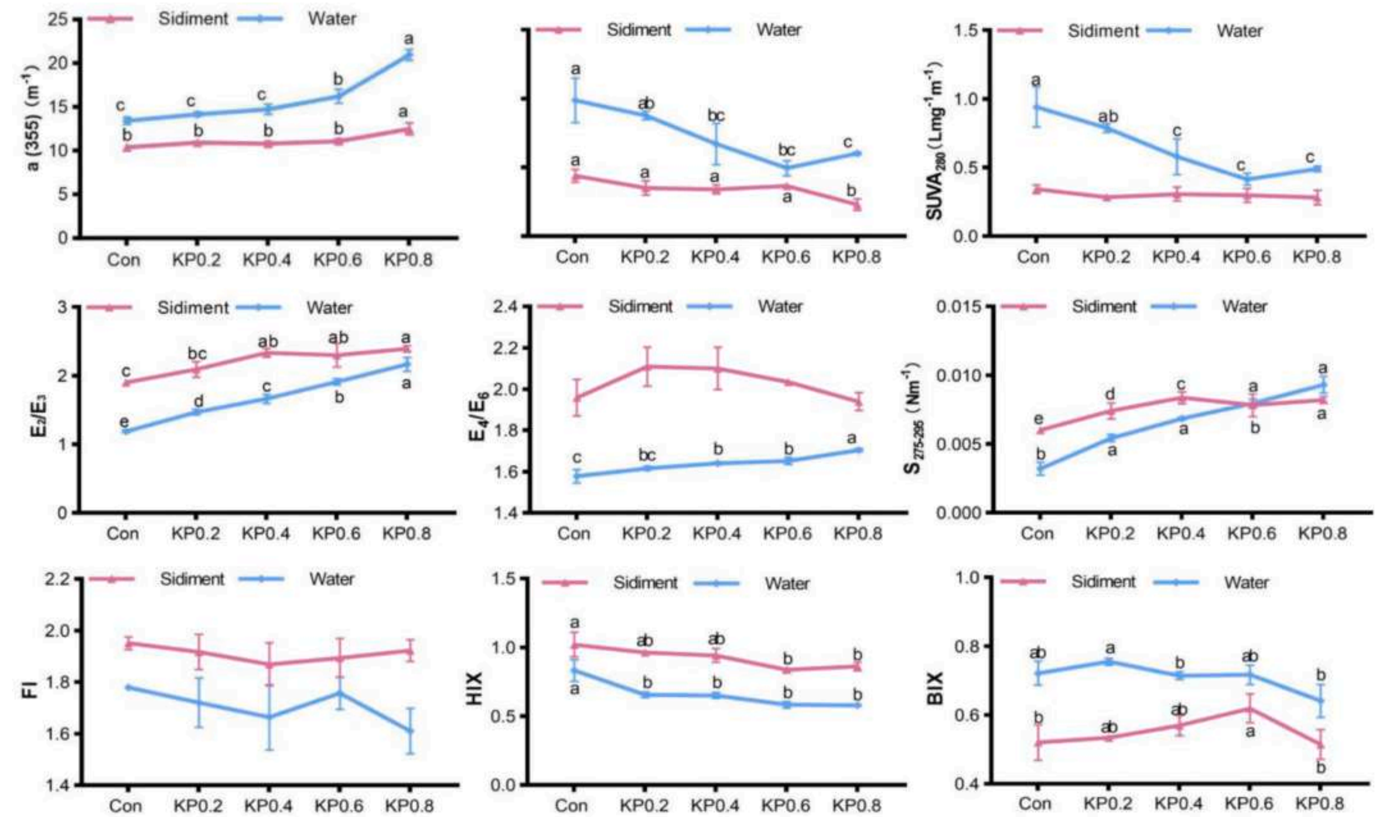

Fig. 6. Effect of KMPS on UV–Visible absorption spectral parameters and humification parameters of DOM; a(355) represents the abundance of CDOM; $SUVA_{254}$ represents the aromaticity and humification degree of DOM; $SUVA_{280}$ represents the content of hydrophobic organic components in DOM; E_2/E_3 represents the relative molecular mass of DOM; E_4/E_6 represents the humification degree and source of DOM; $S_{275-295}$ represents the molecular weight and photochemical reactivity of DOM; HIX reflects the humification degree of DOM; FI reflects the source and degradation degree of DOM; BIX reflects the relative contribution of endogenous substances to DOM; All data are presented as Mean ± SD; Differences between treatments that do not share the same letter are significant ($p < 0.05$).

Acidobacteriota, and *Bacteroidota* showed no significant trends, maintaining relative abundances around 11.41 %, 9.29 %, and 7.05 %, respectively. However, the relative abundance of *unclassified_Bacteria*, *Chloroflexi*, *Nitrospirota*, *Spirochaetota*, and *Verrucomicrobiota* showed a decreasing trend. Specifically, the relative abundances of *unclassified_Bacteria*, *Spirochaetota*, and *Verrucomicrobiota* in the experimental groups decreased by 25.27 %, 29.83 %, and 26.58 %, respectively, compared to the Con group. Furthermore, Firmicutes was the only dominant phylum, other than Proteobacteria, whose relative abundance increased significantly, rising from 0.8 % in the Con group to 2.46–8.56 % in the KMPS treatment groups (Fig. 8A). At the genus level, a total of 1361 microbial taxa were detected, with dominant genera shown in Fig. 8B, including *unclassified_Bacteria*, *uncultured_prokaryote*, *Pseudomonas*, *unclassified_Thermodesulfovibrionia*, *Candidatus_Competibacter*, *unclassified_Gammaproteobacteria*, *Thiobacillus*, *Desulfatiglans*, *Trichococcus unclassified_Anaerolineae*. After KMPS treatment, the abundance of *Pseudomonas* and *Trichococcus* increased. The α-diversity indices revealed a downward trend in microbial diversity following KMPS treatment, although most of the changes were not statistically significant, except for the Shannon index in the KP0.6 group, which was significantly lower than the Con group (Fig. 8C). Among the top 50 genera by abundance, the relative abundance of *Pseudomonas*, *Formivibrio*, *Shewanella*, *Desulfomicrobium*, and *unclassified_Hydrogenophila* increased under KMPS treatment, while *Thiobacillus*, *Spirochaeta*, *unclassified_Latescibacteraceae*, *uncultured_Chloroflexi_bacterium*, *Clostridium_sensu_stricto*, and *soil_bacterium* showed decreased abundance (Fig. 8D).

3.8. Correlation between microbial communities and environmental factors

The results of the Mantel Test showed that under KMPS treatment, the changes in sediment microbial communities were highly significantly correlated with pH, IEF-NH_4^+, DOC, E_2/E_3, $S_{275-295}$, and HIX, as well as significantly correlated with sediment particle size (D50) and TOC. Enzymatic activities were significantly correlated with the E_4/E_6 ratio. Significant correlations also existed among various environmental factors: pH was positively correlated with D50, IEF-NH_4^+, $SUVA_{254}$, and HIX, and negatively correlated with DOC, E_2/E_3, and $S_{275-295}$; TN was positively correlated with TOC and HIX; D50 was positively correlated with IEF-NH_4^+ and $SUVA_{254}$, and negatively correlated with DOC, a (355), E_2/E_3, and $S_{275-295}$; IEF-NH_4^+ was positively correlated with HIX, and negatively correlated with DOC, E_2/E_3, and $S_{275-295}$; DOC was positively correlated with a(355), E_2/E_3, and $S_{275-295}$, and negatively correlated with $SUVA_{254}$, $SUVA_{280}$, and HIX. TOC was positively correlated with HIX. a(355) was positively correlated with E_2/E_3, and negatively correlated with $SUVA_{254}$ and HIX. $SUVA_{254}$ was negatively correlated with $SUVA_{280}$, and negatively correlated with E_2/E_3 and $S_{275-295}$. E_2/E_3 was positively correlated with $S_{275-295}$, and negatively correlated with HIX (Fig. 9).

4. Discussion

4.1. Positive regulation of sediment physicochemical properties by KMPS

KMPS significantly reduced the sediment particle size, optimizing the particle size distribution by increasing the proportion of clay and silt particles while reducing the proportion of sand particles. The sediment

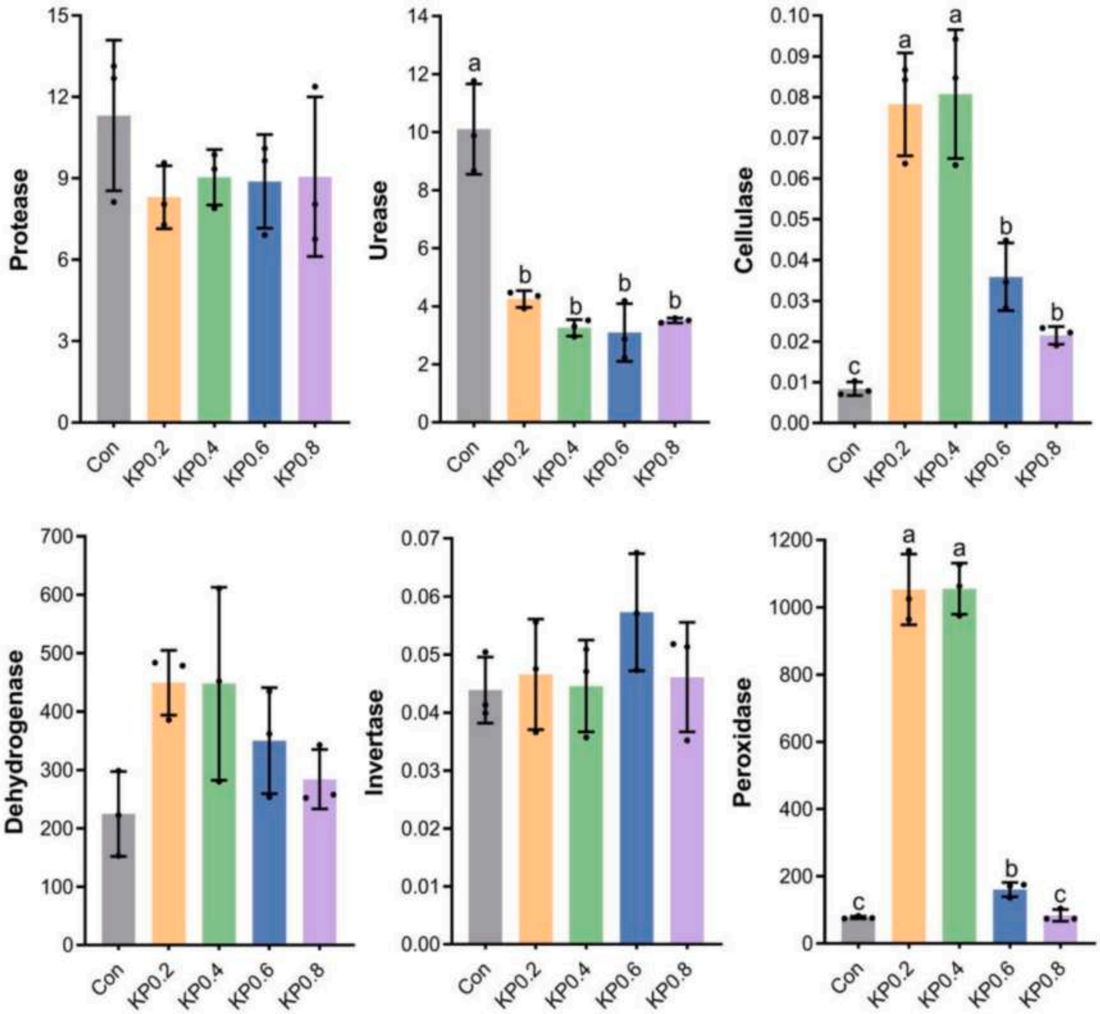

Fig. 7. Effect of KMPS on Enzyme Activity Levels in Sediment; All data are presented as Mean ± SD. Significant differences were observed between treatments without the same letter ($p < 0.05$).

particles are rich in mineral components, including iron-manganese minerals, which are susceptible to oxidation, and carbonate and aluminosilicate minerals, which are prone to acidification (Aplin, 2000). After KMPS treatment, the sediment remained under acidic conditions (pH 4.57 to 5.17), combined with the strong oxidizing nature of KMPS itself (Qi et al., 2016; Wang and Wang, 2018). This likely contributed to changes in the sediment's mineral composition, ultimately leading to changes in the particle size distribution. The optimization of particle size increased the sediment's specific surface area and adsorption capacity, thereby improving the material exchange conditions between the sediment and the overlying water. Mantel testing indicated significant correlations between D50 and multiple environmental factors, such as pH, IEF-NH_4^+, and DOC, suggesting that KMPS's regulation of the sediment's physical properties further impacted nitrogen cycling and material transformation in the sediment. Previous studies have also shown that microbial biomass increases as sediment particle size decreases (Hemkemeyer et al., 2015), and the capacity to carry nutrients also improves (Liu et al., 2015). This also means that KMPS's impact on the sediment particle size distribution is beneficial to the SWI system.

Nitrogen species analysis indicated that KMPS effectively reduced the IEF-N content in sediments, especially IEF-NH_4^+, suggesting that its strong oxidative action significantly decreased the availability of easily released nitrogen and mitigated the risk of endogenous nitrogen pollution. IEF-N is the most active and readily involved nitrogen form in the nitrogen cycle within sediments (Wang et al., 2008), with NH_4^+-N being the primary component of IEF-N, mainly derived from the decomposition of organic nitrogen in sediments, and stable only in reducing environments (Ma et al., 2003). When KMPS enters the SWI system, highly oxidative free radicals such as ·OH and SO_4^-· are generated and react with the organic matter in the sediments (Long et al., 2014; Wacławek et al., 2017; Wang and Wang, 2018), which alters the physicochemical properties of the sediment and causes the nitrogen balance in the SWI system to be disrupted. Consequently, the IEF-N in the surface sediments is first released through nitrogen exchange between the SWI systems (Wang et al., 2009), leading to a moderate increase of NH_4^+-N and NO_3^--N in the overlying water. Therefore, KMPS in this study facilitated the nitrogen transformation process between sediment and water, accelerating the release of TTN to the overlying water, thus providing a key pathway for the restoration of eutrophic sediments.

4.2. DOM characteristic changes and their ecological values

The results of this study indicate that increasing KMPS treatment led to a decreasing trend in HIX, with lower HIX typically indicating a lower degree of humification, accompanied by lower aromaticity and molecular weight. This is similar to the DOM characteristics observed in high-salinity lakes (Zhang et al., 2024). This phenomenon may be attributed to KMPS reducing microbial diversity, as microorganisms typically prioritize the degradation of structurally unstable proteinaceous substances, thus promoting the formation of relatively stable humic

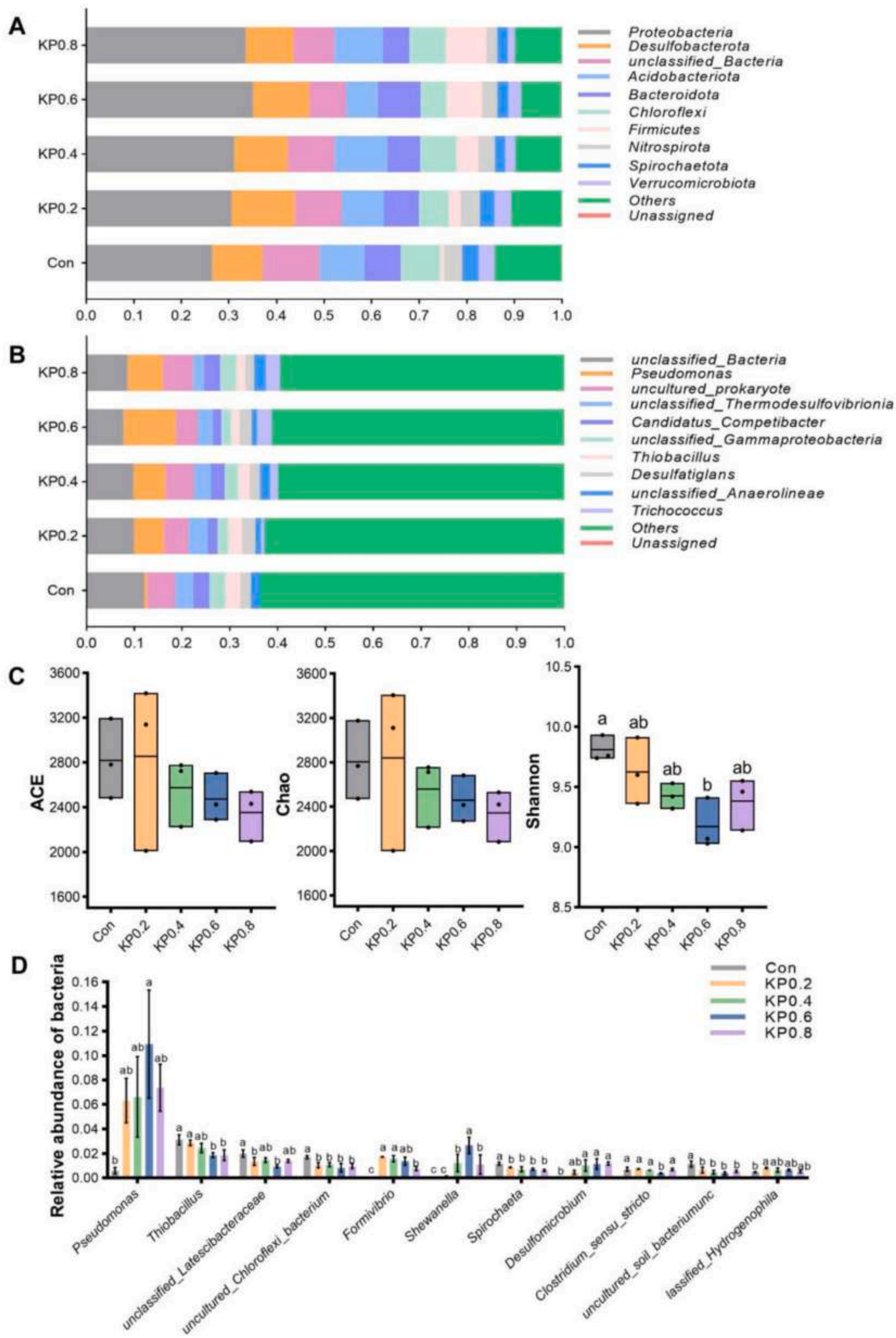

Fig. 8. Relative Abundance of Bacterial Communities in Sediment after Different Doses of KMPS Treatment; (A) Changes at the microbial phylum level; (B) Changes at the microbial genus level. (C) Significant changes in the top 50 abundant genera; (D) Diversity analysis.

substances and leading to an increase in soil humification (Song et al., 2022). This aligns with the results of the α-diversity index, which showed a downward trend in microbial diversity in sediment after KMPS treatment. Furthermore, Mantel test results revealed a significant correlation between sediment HIX and the microbial community. $SUVA_{254}$ is widely used to estimate the aromatic content of DOM, with higher $SUVA_{254}$ values indicating higher aromaticity (Zhang et al., 2022). Previous studies have shown that the consumption of chemical oxidants by DOM and the production of certain disinfection/oxidation by-products are positively correlated with $SUVA_{254}$ (Wenk et al., 2013),

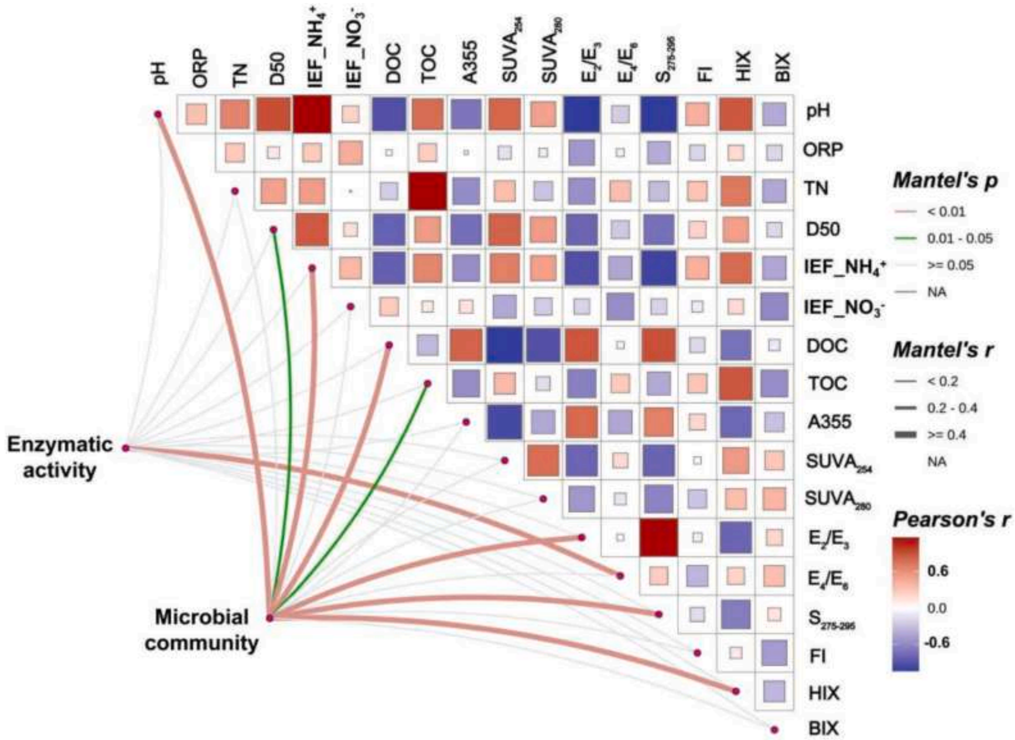

Fig. 9. Mantel test of microbial community and function correlation with environmental factors; The microbial community selected for analysis comprised the top 50 genera that exhibited significant changes in abundance under KMPS treatment; Enzymatic activities assessed included those of proteases, ureases, cellulases, transglutaminases, dehydrogenases, and peroxidases.

with more hydrophobic and aromatic-rich DOM molecules (Yang et al., 2022). However, as an oxidant and disinfectant, KMPS yielded contrasting results, with $SUVA_{254}$ and $SUVA_{280}$ negatively correlated with its dosage. This indicates that the aromaticity of DOM decreased under KMPS treatment, along with a reduction in hydrophobic organic components. The study also showed that the DOM after KMPS treatment primarily consisted of low molecular weight compounds with a higher degree of decomposition. Lower molecular weight DOM generally indicates that the DOM is newly produced (Fichot and Benner, 2012). Numerous studies have indicated that the aromaticity and molecular weight of natural DOM typically decrease under photochemical oxidation (Maizel and Remucal, 2017; Lv et al., 2017; Milstead et al., 2023). In this study, KMPS may have acted as a substitute for photochemical oxidation. The hydroxyl radicals generated by KMPS can react with DOM and alter its composition (Remucal et al., 2020), promoting the production of more unstable, low molecular weight DOM, while also increasing the bioavailability of DOM (Pullin et al., 2004). The release of low molecular weight DOM, which is more bioavailable, not only stimulates the activity of planktonic bacteria but also enhances the turnover rate of DOM (Kaiser and Sulzberger, 2004). Studies on soil DOM have also shown that low molecular weight DOM exhibits lower biological stability and higher transformation potential, interacting more closely with various microorganisms, while high molecular weight DOM interacts with only a few microorganisms (Li et al., 2023a). Additionally, high molecular weight DOM molecules are typically more resistant to degradation, whereas most low molecular weight DOM molecules are rapidly mineralized (Docherty et al., 2006). In conclusion, under the influence of KMPS, the turnover rate of DOM, both in sediments and water, was enhanced. This not only helps reduce the accumulation of organic pollutants in sediments but also improves the physicochemical properties of sediments, accelerates the carbon cycling rate, and enhances the stability of aquatic ecosystems.

4.3. *Positive response of enzyme activity to microbial communities*

KMPS significantly enhanced the activity of cellulase and peroxidase, indicating that it markedly improved the degradation capacity of organic matter by modulating the oxidizing environment of the sediment. The increase in enzyme activities not only accelerated the breakdown of complex organic matter in the sediments but also provided a driving force for the cycling of nutrients such as nitrogen and carbon. Enzyme activity is influenced by various abiotic factors, including temperature, pH, moisture content, and oxygen levels (Pavel et al., 2004). Under KMPS treatment, the sediment pH decreased to 4.57–5.17, making pH the main factor affecting enzyme activity. The optimal pH for cellulase activity is 5.5, and cellulolytic fungi exhibit the highest cellulase production at a pH of 5.0; excessively high or low pH can inhibit enzyme activity (Bakhiet, 2018; Deng and Tabatabai, 1994). In the experimental results, the sediments from the KP0.2 and KP0.4 groups had pH values of 5.17 and 4.80, respectively, both within the optimal range for cellulase activity, resulting in significantly higher enzyme activity compared to the other groups. Among the peroxidases, manganese peroxidase and lignin peroxidase are redox enzymes with high oxidative potential in the soil. Their activity typically increases with the rise in soil pH (Hofrichter et al., 2010; Sinsabaugh, 2010). MnP, in particular, is more common in moderately acidic environments (pH > 5.0), where it exhibits high activity (Fujii et al., 2013). Similar to cellulase, the KP0.2 and KP0.4 groups also showed the highest peroxidase activity. However, excessively low pH can suppress the activity of some enzymes. For instance, protease activity in sediment microbial communities is highest under neutral to slightly alkaline conditions (Abrar, 2017), and urease activity peaks at a pH of 6.5–7.0 (Dharmakeerthi and Thenabadu, 1996). The reduced pH in the experimental groups likely explains why the protease and urease activities were lower than those of the control group. Additionally, overly low pH may inhibit dehydrogenase activity (Wolińska and Stępniewska, 2012). However, we hypothesize that dehydrogenase activity is primarily influenced by the ORP, which plays a decisive role in soil dehydrogenase levels. Previous studies have suggested a significant negative correlation between dehydrogenase activity and ORP (Wolińska, 2010), a finding also verified in this study, as the ORP of the experimental group sediments was lower than that of the control group, while dehydrogenase activity was relatively higher.

In terms of microbial communities, KMPS significantly increased the abundance of dominant bacteria such as *Proteobacteria* and *Firmicutes*, which promote material cycling, while also optimizing the metabolic activity of functional bacteria like *Pseudomonas*. Previous studies have reported that the major phyla in diazotrophic microorganisms are *Proteobacteria* and *Firmicutes*, and their metabolic activity drives the biogeochemical cycling of nitrogen in aquatic ecosystems (Jabir et al., 2018; Lu et al., 2024). In this study, similar to the results from using CaO_2 for the restoration of polluted sediments (Shao et al., 2022), the relative abundance of *Proteobacteria* and *Firmicutes* increased in the microbial communities of sediment treated with KMPS, especially *Firmicutes*, whose relative abundance significantly increased and showed a strong correlation with KMPS dosage. This increase may be related to sulfur metabolism carried out by *Firmicutes* (Torres-Beltrán et al., 2021), with the large amount of SO_4^{2-} from KMPS in the sediment facilitating the growth of *Firmicutes*. At the genus level, larger changes were observed. The relative abundance of various functional genera, including *Pseudomonas*, *Desulfomicrobium*, and *Trichococcus*, was elevated. Pseudomonas is commonly used in bioremediation of environmental organic pollutants and is a beneficial genus frequently utilized in biological control in soils. It can specifically promote sediment functionality (Hu et al., 2023; Tao et al., 2020). Furthermore, *Pseudomonas* can secrete various enzymes, including cellulase, peroxidase, and dehydrogenase (Fong and Tan, 1999; Twala et al., 2020; Zhang et al., 2016a). The enhanced enzyme activities imply that the metabolic activity of *Pseudomonas* was improved. *Desulfomicrobium* plays an important role in the biogeochemical cycles of sulfur and carbon, and it also plays a critical role in anaerobic bioremediation in polluted water and sediment environments (Franzmann et al., 2002; Zhang et al., 2012). *Trichococcus*, a fermentative bacterium, collaborates with other microorganisms to promote organic matter degradation and methane production, driving the transformation of organic carbon and energy release in sediments (Doloman et al., 2022; Schwan et al., 2020). The significant increase in the relative abundance of these functional genera indicates that KMPS plays a positive role in the bioremediation of organic matter in sediments. Additionally, it is worth noting that the α-diversity measurements indicated that KMPS addition did not significantly affect the microbial community's α-diversity in the sediments. This is consistent with the findings of Hung et al. (Hung et al., 2022), when using PMS to restore marine sediments, suggesting that, on a macroscopic level, KMPS did not cause significant changes in the species richness and evenness of the sediment microbial community. Previous studies have shown that shifts in sediment microbial communities are typically linked to abiotic factors such as temperature, pH, TOC, and SO_4^{2-} (Badhai et al., 2015; Huang et al., 2017; Konduri et al., 2024). In this study, we believe that KMPS dominated these changes, as its addition greatly altered the physical and chemical properties of the sediment, potentially introducing more SO_4^{2-}. The reshuffling of the microbial community highlights KMPS's significant role in promoting material cycling in sediments and enhancing the degradation potential of organic pollutants.

The Mantel test revealed that changes in the microbial community were significantly correlated not only with environmental factors such as pH, D50, and IEF-NH_4^+, but also with DOM, including four key parameters that characterize DOM properties: DOC, E_2/E_3, $S_{275\text{-}295}$, and HIX. This result is consistent with the findings of Li et al. (Li et al., 2022), further confirming the close relationship between DOM and microbial communities (Muscarella et al., 2019). DOM is the most active organic matter component in sediments and serves as a carbon source influencing microbial activity, directly or indirectly affecting the composition and development of microbial communities (Li et al., 2020; Zhang et al., 2016b). Additionally, the composition and functional groups of DOM can influence microbial community diversity (Yu et al., 2020). Photochemical processes can promote the abundance and instability of DOM, as well as enhance the microbial community's ability to metabolize DOM through light-induced alterations (Ward et al., 2017). Unstable DOM can serve as both a material and energy source for various microorganisms, with some functional microbes potentially preferring certain DOM components. Thus, changes in DOM chemical composition are considered an important factor affecting the abundance of microbial communities (Li et al., 2023b). In this study, we hypothesize that KMPS substitutes for similar photochemical processes, promoting changes in DOM abundance and structure, which in turn led to different responses within the sediment microbial community. Overall, this suggests that KMPS can indirectly optimize microbial ecological functions by regulating sediment environmental conditions. However, the mechanisms underlying the formation of DOM chemical diversity under the influence of KMPS, and the role of microbes in driving the biogeochemical cycling of DOM in aquatic ecosystems, require further in-depth investigation.

5. Conclusion

This study highlights the significant role of KMPS in sediment remediation, demonstrating its great potential in environmental restoration by optimizing the physicochemical properties of sediments, regulating the structure of DOM, enhancing enzyme activity, and optimizing microbial communities. However, its application must be carefully optimized to balance its high remediation efficiency with potential environmental risks.

CRediT authorship contribution statement

Peng Yin: Writing – review & editing, Writing – original draft, Visualization, Investigation, Data curation, Conceptualization. **Dugeng Wang:** Visualization, Investigation, Data curation. **Xiaoyu Zhang:** Validation, Investigation, Formal analysis. **Gaofeng Zhang:** Methodology, Conceptualization. **Haiyong Zhao:** Methodology, Conceptualization. **Yingying Zhang:** Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Data curation. **Hui Yang:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This research was conducted with support from High-level Talent Program of Yangzhou University of Hui Yang and Yingying Zhang, Undergraduate Science and Innovation Fund Program of Yangzhou University (XCX20250748).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aquaculture.2025.743089.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Abrar, T., 2017. Optimization of culture growth parameters for production of protease from Bacteria, isolated from soil. J. Biosci. Bioeng. 03, 1–10.

Aplin, A.C., 2000. Mineralogy of modern marine sediments: a geochemical framework. EMU Notes Mineral. 2, 125–172. https://doi.org/10.1180/EMU-NOTES.2.4.

Badhai, J., Ghosh, T.S., Das, S.K., 2015. Taxonomic and functional characteristics of microbial communities and their correlation with physicochemical properties of four geothermal springs in Odisha, India. Front. Microbiol. 6, 1166. https://doi.org/10.3389/fmicb.2015.01166.

Bai, Y.P., Li, F., Yang, G., Shi, S.W., Dong, F.Q., Liu, M.X., Nie, X.Q., Hai, J.B., 2018. Meta-analysis of experimental warming on soil invertase and urease activities. Acta Agric. Scand. Sect. B 68 (2), 104–109. https://doi.org/10.1080/09064710.2017.1375140.

Bakhiet, S., 2018. Optimization of factors influencing Cellulase production by some indigenous isolated fungal species. Jordan J. Biol. Sci. 11 (1), 31–36.

Boyd, C.E., 1995. Bottom Soils, Sediment, and Pond Aquaculture. Springer, US. https://doi.org/10.1007/978-1-4615-1785-6.

Boyd, C.E., Queiroz, J.F., 2014. The role and management of bottom soils in aquaculture ponds. Info Fish Int. 2014 (2), 22–28.

Cárdenas, C.S., Gerea, M., Garcia, P.E., Pérez, G.L., Diéguez, M.C., Rapacioli, R., Reissig, M., Queimaliños, C., 2017. Interplay between climate and hydrogeomorphic features and their effect on the seasonal variation of dissolved organic matter in shallow temperate lakes of the southern Andes (Patagonia, Argentina): a field study based on optical properties. Ecohydrology 10 (7), e1872. https://doi.org/10.1002/eco.1872.

Chen, W., Wang, Y., Wang, L., Ji, Y., Wang, Q., Li, M., Gao, L., 2022. Emerging investigator series: effects of sediment particle size on the spatial distributions of contaminants and bacterial communities in the reservoir sediments. Environ. Sci.: Water Res. Technol. 8 (5), 957–967. https://doi.org/10.1039/D1EW00877C.

Dainard, P.G., Guéguen, C., McDonald, N., Williams, W.J., 2015. Photobleaching of fluorescent dissolved organic matter in Beaufort Sea and North Atlantic subtropical gyre. Mar. Chem. 177, 630–637. https://doi.org/10.1016/j.marchem.2015.10.004.

DeFrancesco, C., Guéguen, C., 2021. Long-term trends in dissolved organic matter composition and its relation to sea ice in the Canada Basin, Arctic Ocean (2007-2017). J. Geophys. Res.: Oceans. 126 (2). https://doi.org/10.1029/2020JC016578.

Deng, S.P., Tabatabai, M.A., 1994. Cellulase activity of soils. Soil Biol. Biochem. 26 (10), 1347–1354. https://doi.org/10.1016/0038-0717(94)90216-X.

Derrien, M., Lee, M.H., Choi, K., Lee, K.S., Hur, J., 2020. Tracking the evolution of particulate organic matter sources during summer storm events via end-member mixing analysis based on spectroscopic proxies. Chemosphere 252, 126445. https://doi.org/10.1016/j.chemosphere.2020.126445.

Dharmakeerthi, R.S., Thenabadu, M.W., 1996. Urease activity in soils: a review. J. Natl. Sci. Found. 24, 159. https://doi.org/10.4038/jnsfsr.v24i3.5548.

Docherty, K.M., Young, K.C., Maurice, P.A., Bridgham, S.D., 2006. Dissolved organic matter concentration and quality influences upon structure and function of freshwater microbial communities. Microb. Ecol. 52 (3), 378–388. https://doi.org/10.1007/s00248-006-9089-x.

Doloman, A., Boeren, S., Miller, C.D., Sousa, D.Z., 2022. Stimulating effect of *Trichococcus flocculiformis* on a Coculture of *Syntrophomonas wolfei* and *Methanospirillum hungatei*. Appl. Environ. Microbiol. 88 (13), e0039122. https://doi.org/10.1128/aem.00391-22.

Feng, S., Yu, C., Guo, S., Ouyang, J., Yin, F., Zhang, X., Zhang, Y., Chen, M., Han, D., Gong, J., Wang, J., 2023. Design spherical particles of potassium peroxymonosulfate compound salt with high stability and good powder properties via an agglomeration-dissolution mechanism. Particuol 80, 157–169. https://doi.org/10.1016/j.partic.2022.11.020.

Fernandez, J., Maruthamuthu, P., Kiwi, J., 2004. Photobleaching and mineralization of Orange II by oxone and metal-ions involving Fenton-like chemistry under visible light. J. Photochem. Photobiol. A. 161 (2), 185–192. https://doi.org/10.1016/S1010-6030(03)00293-4.

Fichot, C.G., Benner, R., 2012. The spectral slope coefficient of chromophoric dissolved organic matter as a tracer of terrigenous dissolved organic carbon in river-influenced ocean margins. Limnol. Oceanogr. 57 (5), 1453–1466. https://doi.org/10.4319/lo.2012.57.5.1453.

Fong, K.P.Y., Tan, H.M., 1999. Characterization of a novel cis-benzene dihydrodiol dehydrogenase from *Pseudomonas putida* ML2. FEBS Lett. 451 (1), 5–9. https://doi.org/10.1016/S0014-5793(99)00520-7.

Franzmann, P.D., Robertson, W.J., Zappia, L.R., Davis, G.B., 2002. The role of microbial populations in the containment of aromatic hydrocarbons in the subsurface. Biodegradation 13 (1), 65–78. https://doi.org/10.1023/a:1016318706753.

Fujii, K., Uemura, M., Hayakawa, C., Funakawa, S., Kosaki, T., 2013. Environmental control of lignin peroxidase, manganese peroxidase, and laccase activities in forest floor layers in humid Asia. Soil Biol. Biochem. 57, 109–115. https://doi.org/10.1016/j.soilbio.2012.07.007.

Garcia, R.D., Diéguez, M.D., Gerea, M., Garcia, P.E., Reissig, M., 2018. Characterisation and reactivity continuum of dissolved organic matter in forested headwater catchments of Andean Patagonia. Freshw. Biol. 63 (9), 1049–1062. https://doi.org/10.1111/fwb.13114.

Gardner, W.S., Yang, L., Cotner, J.B., Johengen, T.H., Lavrentyev, P.J., 2001. Nitrogen dynamics in Sandy freshwater sediments (Saginaw Bay, Lake Huron). J. Great Lakes Res. 27 (1), 84–97. https://doi.org/10.1016/S0380-1330(01)70624-7.

Hargreaves, J.A., 1998. Nitrogen biogeochemistry of aquaculture. Ponds Aquac. 166 (3), 181–212. https://doi.org/10.1016/S0044-8486(98)00298-1.

Hemkemeyer, M., Christensen, B.T., Martens, R., Tebbe, C.C., 2015. Soil particle size fractions harbour distinct microbial communities and differ in potential for microbial mineralisation of organic pollutants. Soil Biol. Biochem. 90, 255–265. https://doi.org/10.1016/j.soilbio.2015.08.018.

Hofrichter, M., Ullrich, R., Pecyna, M.J., Liers, C., Lundell, T., 2010. New and classic families of secreted fungal heme peroxidases. Appl. Microbiol. Biotechnol. 87 (3), 871–897. https://doi.org/10.1007/s00253-010-2633-0.

Hu, J., Lin, X., Wang, J., Dai, J., Chen, R., Zhang, J., Wong, M.H., 2011. Microbial functional diversity, metabolic quotient, and invertase activity of a sandy loam soil as affected by long-term application of organic amendment and mineral fertilizer. J. Soils Sediments 11 (2), 271–280. https://doi.org/10.1007/s11368-010-0308-1.

Hu, F., Wang, P., Li, Y., Ling, J., Ruan, Y., Yu, J., Zhang, L., 2023. Bioremediation of environmental organic pollutants by *Pseudomonas aeruginosa*: mechanisms, methods and challenges. Environ. Res. 239, 117211. https://doi.org/10.1016/j.envres.2023.117211.

Huang, D., Xu, J., Zeng, G., Lai, C., Yuan, X., Luo, X., Wang, C., Xu, P., Huang, C., 2015. Influence of exogenous lead pollution on enzyme activities and organic matter degradation in the surface of river sediment. Environ. Sci. Pollut. Res. 22 (15), 11422–11435. https://doi.org/10.1007/s11356-015-4375-0.

Huang, W., Chen, X., Jiang, X., Zheng, B.H., 2017. Characterization of sediment bacterial communities in plain lakes with different trophic statuses. Microbiol. Open. 6 (5). https://doi.org/10.1002/mbo3.503.

Hung, C.M., Huang, C.P., Chen, C.W., Dong, C.D., 2021. Degradation of organic contaminants in marine sediments by peroxymonosulfate over LaFeO3 nanoparticles supported on water caltrop shell-derived biochar and the associated microbial community responses. J. Hazard. Mater. 420, 126553. https://doi.org/10.1016/j.jhazmat.2021.126553.

Hung, C.M., Chen, C.W., Huang, C.P., Cheng, J.W., Dong, C.D., 2022. Algae-derived metal-free boron-doped biochar as an efficient bioremediation pretreatment for persistent organic pollutants in marine sediments. J. Clean. Prod. 336, 130448. https://doi.org/10.1016/j.jclepro.2022.130448.

Jabir, T., Jesmi, Y., Vipindas, P.V., Mohamed Hatha, A., 2018. Diversity of nitrogen fixing bacterial communities in the coastal sediments of southeastern Arabian Sea (SEAS). Deep - Sea Res. Part II. 156, 51–59. https://doi.org/10.1016/j.dsr2.2018.09.010.

Jinming, S., Hongbo, M., Xiaoxia, L., 2002. Nitrogen forms and decomposition of organic carbon in the southern Bohai Sea core sediments. Acta Oceanol. Sin. 21, 125–133.

Kaiser, E., Sulzberger, B., 2004. Phototransformation of riverine dissolved organic matter (DOM) in the presence of abundant iron: effect on DOM bioavailability. Limnol. Oceanogr. 49 (2), 540–554. https://doi.org/10.4319/lo.2004.49.2.0540.

Kim, B.R., Anderson, J.E., Mueller, S.A., Gaines, W.A., Kendall, A.M., 2002. Literature review–efficacy of various disinfectants against *Legionella* in water systems. Water Res. 36 (18), 4433–4444. https://doi.org/10.1016/s0043-1354(02)00188-4.

Konduri, A., Bharti, V.S., Kumar, S., Krishnan, S., Sahu, N.P., Bhardwaj, A.K., Rani, A.M. B., Shukla, S.P., Verma, A.K., Adakney, S., 2024. Paddy straw biochar amended sediment enhances pond productivity, growth and physiological profile of *Penaeus vannamei* cultured in inland saline nursery ponds. Environ. Sci. Pollut. Res. 31 (52), 61711–61729. https://doi.org/10.1007/s11356-024-35342-y.

Lee, J., von Gunten, U., Kim, J.H., 2020. Persulfate-based advanced oxidation: critical assessment of opportunities and roadblocks. Environ. Sci. Technol. 54 (6), 3064–3081. https://doi.org/10.1021/acs.est.9b07082.

Li, Y., Xu, C., Zhang, W., Lin, L., Wang, L., Niu, L., Zhang, H., Wang, P., Wang, C., 2020. Response of bacterial community in composition and function to the various DOM at river confluences in the urban area. Water Res. 169, 115293. https://doi.org/10.1016/j.watres.2019.115293.

Li, S., Fang, J., Zhu, X., Spencer, R.G.M., Álvarez-Salgado, X.A., Deng, Y., Huang, T., Yang, H., Huang, C., 2022. Properties of sediment dissolved organic matter respond to eutrophication and interact with bacterial communities in a plateau lake. Environ. Pollut. 301, 118996. https://doi.org/10.1016/j.envpol.2022.118996.

Li, W., Liu, N., Li, J., Wang, B., Shi, X., Liang, X., Yang, M., Xu, S., Liu, C.Q., 2023a. Chemodiversity of dissolved organic matter is governed by microbial biogeography in inland waters. Environ. Sci. Technol. 57 (20), 7753–7763. https://doi.org/10.1021/acs.est.3c00896.

Li, P., Wu, M., Li, T., Dumbrell, A.J., Saleem, M., Kuang, L., Luan, L., Wang, S., Li, Z., Jiang, J., 2023b. Molecular weight of dissolved organic matter determines its interactions with microbes and its assembly processes in soils. Soil Biol. Biochem. 184, 109117. https://doi.org/10.1016/j.soilbio.2023.109117.

Liao, W., Tong, D., Li, Z., Nie, X., Liu, Y., Ran, F., Liao, S., 2021. Characteristics of microbial community composition and its relationship with carbon, nitrogen and sulfur in sediments. Sci. Total Environ. 795, 148848. https://doi.org/10.1016/j.scitotenv.2021.148848.

Liu, X., Li, Z., Li, P., Zhu, B., Long, F., Cheng, Y., Wang, T., Lu, K., 2015. Changes in carbon and nitrogen with particle size in bottom sediments in the Dan River, China. Quat. Int. 380-381, 305–313. https://doi.org/10.1016/j.quaint.2015.02.024.

Long, A.H., Lei, Y., Zhang, H., 2014. In situ chemical oxidation of organic contaminated soil and groundwater using activated persulfate process. Prog. Chem. 26 (5), 898–908. https://doi.org/10.7536/PC130952.

Lü, X., Song, J., Li, X., Yuan, H., Zhan, T., Li, N., Gao, X., 2005. Geochemical characteristics of nitrogen in the southern Yellow Sea surface sediments. J. Mar. Syst. 56 (1–2), 17–27. https://doi.org/10.1016/J.JMARSYS.2004.06.009.

Lu, J., Qing, C., Huang, X., Zeng, J., Zheng, Y., Xia, P., 2024. Seasonal dynamics and driving mechanisms of microbial biogenic elements cycling function, assembly process, and co-occurrence network in plateau lake sediments. Sci. Total Environ. 951, 175510. https://doi.org/10.1016/j.scitotenv.2024.175510.

Luan, Y., Wang, Y., Liu, C., Lv, L., Xu, A., Song, Z., 2024. Effects of potassium monopersulfate on nitrification activity and bacterial community structure of sponge biocarrier biofilm in *Litopenaeus vannamei* aquaculture system. Environ. Technol. 45 (17), 3354–3366. https://doi.org/10.1080/09593330.2023.2215455.

Lv, J.T., Li, D., Luo, L., Wu, T., Zhang, S.Z., 2017. Molecular transformation of natural and anthropogenic dissolved organic matter under photo-irradiation in the presence of nano TiO2. Water Res. 125, 201–208. https://doi.org/10.1016/j.watres.2017.08.051.

Ma, H.B., Song, J.M., Lv, X.X., Yuan, H.M., 2003. Nitrogen forms and their functions in recycling of the Bohai Sea sediments. Geochimica. https://doi.org/10.1007/s11769-003-0089-1.

Maizel, A.C., Remucal, C.K., 2017. Molecular composition and photochemical reactivity of size-fractionated dissolved organic matter. Environ. Sci. Technol. 51 (4), 11876–11885. https://doi.org/10.1021/acs.est.6b05140.

Milstead, R.P., Horvath, E.R., Remucal, C.K., 2023. Dissolved organic matter composition determines its susceptibility to complete and partial Photooxidation within lakes. Environ. Sci. Technol. 57 (32), 11876–11885. https://doi.org/10.1021/acs.est.3c01500.

Murphy, K.R., Hambly, A., Singh, S., Henderson, R.K., Baker, A., Stuetz, R., Khan, S.J., 2011. Organic matter fluorescence in municipal water recycling schemes: toward a unified PARAFAC model. Environ. Sci. Technol. 45 (7), 2909–2916. https://doi.org/10.1021/es103015e.

Muscarella, M.E., Boot, C.M., Broeckling, C.D., Lennon, J.T., 2019. Resource heterogeneity structures aquatic bacterial communities. ISME J. 13 (9), 2183–2195. https://doi.org/10.1038/s41396-019-0427-7.

Nelson, D.W., Sommers, L.E., 1996. Total carbon, organic carbon, and organic matter. Meth. Soil Anal. Part 3 Chem. Meth. 5, 961–1010. https://doi.org/10.2136/sssabookser5.3.c34.

Pavel, R., Doyle, J., Steinberger, Y., 2004. Seasonal patterns of cellulase concentration in desert soil. Soil Biol. Biochem. 36 (3), 549–554. https://doi.org/10.1016/j.soilbio.2003.10.024.

Polubesova, T., Chefetz, B., 2014. DOM-affected transformation of contaminants on mineral surfaces: a review. Crit. Rev. Environ. Sci. Technol. 44, 223–254. https://doi.org/10.1080/10643389.2012.710455.

Polyak, Y., Shigaeva, T., Gubelit, Y., Bakina, L., Kudryavtseva, V., Polyak, M., 2017. Sediment microbial activity and its relation to environmental variables along the eastern gulf of Finland coastline. J. Mar. Syst. 171, 101–110. https://doi.org/10.1016/j.jmarsys.2016.11.017.

Pullin, M.J., Bertilsson, S., Goldstone, J.V., Voelker, B.M., 2004. Effects of sunlight and hydroxyl radical on dissolved organic matter: bacterial growth efficiency and production of carboxylic acids and other substrates. Limnol. Oceanogr. 49 (6), 2011–2022. https://doi.org/10.4319/lo.2004.49.6.2011.

Qi, C., Liu, X., Ma, J., Lin, C., Li, X., Zhang, H., 2016. Activation of peroxymonosulfate by base: implications for the degradation of organic pollutants. Chemosphere 151, 280–288. https://doi.org/10.1016/j.chemosphere.2016.02.089.

Remucal, C.K., Salhi, E., Walpen, N., von Gunten, U., 2020. Molecular-level transformation of dissolved organic matter during oxidation by ozone and hydroxyl radical. Environ. Sci. Technol. 54 (16), 10351–10360. https://doi.org/10.1021/acs.est.0c03052.

Rico, A., Phu, T.M., Satapornvanit, K., Min, J., Shahabuddin, A.M., Henriksson, P.J.G., Murray, F.J., Little, D.C., Dalsgaard, A., Van den Brink, P.J., 2013. Use of veterinary medicines, feed additives and probiotics in four major internationally traded aquaculture species farmed in Asia. Aquaculture 412-413, 231–243. https://doi.org/10.1016/j.aquaculture.2013.07.028.

Romera-Castillo, C., Jaffé, R., 2015. Free radical scavenging (antioxidant activity) of natural dissolved organic matter. Mar. Chem. 177, 668–676. https://doi.org/10.1016/j.marchem.2015.10.008.

Schwan, B., Abendroth, C., Latorre-Pérez, A., Porcar, M., Vilanova, C., Dornack, C., 2020. Chemically stressed bacterial communities in anaerobic digesters exhibit resilience and ecological flexibility. Front. Microbiol. 11, 867. https://doi.org/10.3389/fmicb.2020.00867.

Shao, Y., He, Q., Fu, Y., Zhang, G., Liu, Y., 2022. Environmental impact and variation analysis of different CaO2 and ca(NO3)2 dosing modes on microbial community in black-odorous sediment. Process. Saf. Environ. Prot. 167, 641–650. https://doi.org/10.1016/j.psep.2022.09.058.

Shi, M., Song, L., Wu, Y., Gu, C., Zhang, J., Lv, J., 2022. Degradation of pyrene in sediments based on the activation of peroxymonosulfate with nitrogen-doped magnetic biochar: synergistic effect and mechanism. J. Environ. Chem. Eng. 10 (6), 108910. https://doi.org/10.1016/j.jece.2022.108910.

Sinsabaugh, R.L., 2010. Phenol oxidase, peroxidase and organic matter dynamics of soil. Soil Biol. Biochem. 42 (3), 391–404. https://doi.org/10.1016/j.soilbio.2009.10.014.

Song, P., Li, J., Liang, Y., Jiao, L., Li, H., Zhang, Q., 2022. Research of the influences of utilization of sediment and exogenous materials on the changes of SDOM and WSOC of soil. Ecol. Indic. 136, 108689. https://doi.org/10.1016/j.ecolind.2022.108689.

Tang, S.Q., Gong, J.L., Song, B., Li, J., Cao, W.C., Zhao, J., 2024. Co-influence of biochar-supported effective microorganisms and seasonal changes on dissolved organic matter and microbial activity in eutrophic lake. Sci. Total Environ. 923, 171476. https://doi.org/10.1016/j.scitotenv.2024.171476.

Tao, C., Li, R., Xiong, W., Shen, Z., Liu, S., Wang, B., Ruan, Y., Geisen, S., Shen, Q., Kowalchuk, G.A., 2020. Bio-organic fertilizers stimulate indigenous soil *Pseudomonas* populations to enhance plant disease suppression. Microbiome 8 (1), 137. https://doi.org/10.1186/s40168-020-00892-z.

te Slaa, S., 2020. Deposition and Erosion of Silt-rich Sediment-water Mixtures. https://doi.org/10.4233/uuid:c50eb76c-b2ea-49cf-9873-5c929ff496dc.

Teixeira, R.S.S., da Silva, A.S.A., Ferreira-Leitão, V.S., Bon, E.P.D.S., 2012. Amino acids interference on the quantification of reducing sugars by the 3,5-dinitrosalicylic acid assay mislead carbohydrase activity measurements. Carbohydr. Res. 363, 33–37. https://doi.org/10.1016/j.carres.2012.09.024.

Torres-Beltrán, M., Vargas-Gastélum, L., Magdaleno-Moncayo, D., Riquelme, M., Herguera-García, J.C., Prieto-Davó, A., Lago-Lestón, A., 2021. The metabolic core of the prokaryotic community from deep-sea sediments of the southern Gulf of Mexico shows different functional signatures between the continental slope and abyssal plain. Peerj 9, e12474. https://doi.org/10.7717/peerj.12474.

Totaro, M., Castellani, F., Di Serafino, F., Zotti, N., Badalucco, F., Rocchi, D., Civitelli, S., Geminale, G., Masetti, D., Baggiani, A., 2023. Role of Environmental Sanitization in Health Clinics: Evaluation of Potassium Peroxymonosulfate (KMPS) Efficacy.

Turlan, T., Birgand, F., Marmonier, P., 2007. Comparative use of field and laboratory mesocosms for in-stream nitrate uptake measurement. Ann. Limnol. Int. J. Limnol. 43 (1), 41–51. https://doi.org/10.1051/limn/2007026.

Twala, P.P., Mitema, A., Baburam, C., Feto, N.A., 2020. Breakthroughs in the discovery and use of different peroxidase isoforms of microbial origin. AIMS Microbiol. 6 (3), 330–349. https://doi.org/10.3934/microbiol.2020020.

Wacławek, S., Lutze, H.V., Grübel, K., Padil, V.V.T., Černík, M., Dionysiou, D.D., 2017. Chemistry of persulfates in water and wastewater treatment: a review. Chem. Eng. J. 330, 44–62. https://doi.org/10.1016/j.cej.2017.07.132.

Wang, J., Wang, S., 2018. Activation of persulfate (PS) and peroxymonosulfate (PMS) and application for the degradation of emerging contaminants. Chem. Eng. J. 334, 1502–1517. https://doi.org/10.1016/j.cej.2017.11.059.

Wang, S., Zhang, Y.G., 2023. Zero valent iron-electro-Fenton-peroxymonosulfate (ZVI-E-Fenton-PMS) process for industrial wastewater treatment. RSC Adv. 13 (22), 15063–15076. https://doi.org/10.1039/D2RA06653J.

Wang, G., Satake, M., Horita, K., 1998. Spectrophotometric determination of nitrate and nitrite in water and some fruit samples using column preconcentration. Talanta 46 (4), 671–678. https://doi.org/10.1016/s0039-9140(97)00325-1.

Wang, S., Jin, X., Jiao, L., Wu, F., 2008. Nitrogen fractions and release in the sediments from the Shallow Lakes in the middle and lower reaches of the Yangtze River area, China. Water Air Soil Pollut. 187 (1), 5–14. https://doi.org/10.1007/s11270-007-9453-6.

Wang, P.F., Zhao, L., Wang, C., Hou, J., Schnoebelen, D.J., 2009. Nitrogen distribution and potential mobility in sediments of three typical shallow Urban Lakes in China. Environ. Eng. Sci. 26 (10), 1511–1521. https://doi.org/10.1089/EES.2008.0367.

Wang, Q.H., Yu, L.J., Liu, Y., Lin, L., Lu, R.G., Zhu, J.P., He, L., Lu, Z.L., 2017. Methods for the detection and determination of nitrite and nitrate: a review. Talanta 165, 709–720. https://doi.org/10.1016/j.talanta.2016.12.044.

Wang, L.G., Liu, M.Q., Xie, X.D., Sun, Y.B., Zhang, M.L., Zhao, Y., Chen, Q., Ding, Y.Q., Yu, M.L., Liang, Z.M., 2023. Effects of different water quality regulators on growth performance, immunologic function, and domestic water quality of GIFT tilapia. PLoS One 18 (8), e0290854. https://doi.org/10.1371/journal.pone.0290854.

Ward, C.P., Nalven, S.G., Crump, B.C., Kling, G.W., Cory, R.M., 2017. Photochemical alteration of organic carbon draining permafrost soils shifts microbial metabolic pathways and stimulates respiration. Nat. Commun. 8 (1), 772. https://doi.org/10.1038/s41467-017-00759-2.

Wenk, J., Aeschbacher, M., Salhi, E., Canonica, S., von Gunten, U., Sander, M., 2013. Chemical oxidation of dissolved organic matter by chlorine dioxide, chlorine, and ozone: effects on its optical and antioxidant properties. Environ. Sci. Technol. 47 (19), 11147–11156. https://doi.org/10.1021/es402516b.

Wolińska, A., 2010. Dehydrogenase Activity of Soil Microorganism and Oxygen Availability during Reoxidation Process of Selected Mineral Soils from Poland.

Wolińska, A., Stępniewska, Z., 2012. Dehydrogenase Activity in the Soil Environment. InTech, Croatia.

Wu, H.Z., Cao, A., 2013. Preparation and adding methods of Nessler's reagent having effects on determination of water quality ammonia nitrogen. Adv. Mater. Res. 726, 1362–1366. https://doi.org/10.4028/www.scientific.net%2FAMR.726-731.1362.

Wu, G., Wan, Q., Lu, J., Wen, G., 2024. Impact of metal ions on PMS/cl− disinfection efficacy: enhancing or impeding microbial inactivation? Sci. Total Environ. 953, 176087. https://doi.org/10.1016/j.scitotenv.2024.176087.

Yang, X., Rosario-Ortiz, F.L., Lei, Y., Pan, Y., Lei, X., Westerhoff, P., 2022. Multiple roles of dissolved organic matter in advanced oxidation processes. Environ. Sci. Technol. 56 (16), 11111–11131. https://doi.org/10.1021/acs.est.2c01017.

Ye, H., Huang, C., Yuan, X., Wang, H., Huang, T., Yang, H., 2021. Morphological characteristics and ecological risk assessment of nitrogen and phosphorus in the sediments of Futunxi watershed in Fujian province. Environ. Monit. Assess. 193 (6), 335. https://doi.org/10.1007/s10661-021-09106-x.

Yu, M., Liu, S., Li, G., Zhang, H., Xi, B., Tian, Z., Zhang, Y., He, X., 2020. Municipal wastewater effluent influences dissolved organic matter quality and microbial community composition in an urbanized stream. Sci. Total Environ. 705, 135952. https://doi.org/10.1016/j.scitotenv.2019.135952.

Zhang, W., Wang, Z.L., Wang, M.Y., 2012. Analyses of the vertical and temporal distributions of sulfate-reducing bacteria in sediments of Lake Erhai, Southwest China. Res. J. Chem. Environ. 16, 44–51. https://doi.org/10.1007/s00254-007-0787-6.

Zhang, J., Hou, H., Chen, G., Wang, S., Zhang, J., 2016a. The isolation and functional identification on producing cellulase of *Pseudomonas mendocina*. Bioengineered 7 (5), 382–391. https://doi.org/10.1080/21655979.2016.1227143.

Zhang, C., Nie, S., Liang, J., Zeng, G., Wu, H., Hua, S., Liu, J., Yuan, Y., Xiao, H., Deng, L., Xiang, H., 2016b. Effects of heavy metals and soil physicochemical properties on wetland soil microbial biomass and bacterial community structure. Sci. Total Environ. 557-558, 785–790. https://doi.org/10.1016/j.scitotenv.2016.01.170.

Zhang, J., McKenna, A.M., Zhu, M., 2021. Macromolecular characterization of compound selectivity for oxidation and oxidative alterations of dissolved organic matter by manganese oxide. Environ. Sci. Technol. 55 (11), 7741–7751. https://doi.org/10.1021/acs.est.1c01283.

Zhang, L., Sun, Q., Zhang, K., Cao, Z., Zhao, H., Zhao, H., Wang, J., Li, P., 2022. Composition characteristics of dissolved organic matter at the vegetation-soil Interface under the influence of mining disturbances. Pol. J. Environ. Stud. 31 (1), 439–449. https://doi.org/10.15244/pjoes%2F137658.

Zhang, P., Zhang, H., Li, Y., Zhang, J., Ma, C., Weng, N., Gao, X., Wu, F., Huo, S., 2024. Strong associations between dissolved organic matter and microbial communities in the sediments of Qinghai-Tibetan plateau lakes depend on salinity. Sci. Total Environ. 926, 171857. https://doi.org/10.1016/j.scitotenv.2024.171857.

Zhao, Q., Tang, J., Li, Z.Y., Yang, W., Duan, Y.C., 2018. The influence of soil Physico-chemical properties and enzyme activities on soil quality of saline-alkali agroecosystems in Western Jilin Province, China. Sustainability 10 (5). https://doi.org/10.3390/su10051529.

Zhao, Z., Wang, B.J., Liu, M., Jiang, K.Y., Wang, L., 2022. Effects of the non-chlorine oxidizer potassium monopersulfate on the water quality, growth performance and microbial community of Pacific white shrimp (*Penaeus vannamei*) culture systems with limited water exchange. Aquac. Res. 53 (10), 3555–3567. https://doi.org/10.1111/are.15881.

Zheng, G., Song, J., Sun, Y., Dai, J., Zhang, P., 2008. Characteristics of nitrogen forms in the surface sediments of southwestern Nansha trough, South China Sea. Chin. J. Oceanol. Limnol. 26 (3), 280–288. https://doi.org/10.1007/s00343-008-0280-4.

Zhou, Z., Liu, X., Sun, K., Lin, C., Ma, J., He, M., Ouyang, W., 2019. Persulfate-based advanced oxidation processes (AOPs) for organic-contaminated soil remediation: a review. Chem. Eng. J. 372, 836–851. https://doi.org/10.1016/j.cej.2019.04.213.

Zusfahair, Z., Ningsih, D.R., Fatoni, A., Age, D.I.L., Kurniasih, M., 2022. Immobilization and characterization of urease from *Phaseolus vulgaris* L using bentonite chitosan matrix. AIP Conf. Proc. 2553 (1), 020044. https://doi.org/10.1063/5.0103676.