

Phytoplankton community structure and its driving factors in autumn in Jinan, China

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ABSTRACT

Human activities often cause multiple impacts on aquatic ecosystems, including changes in water quality, biodiversity, community composition, etc. However, the effects of human activities on phytoplankton in highly urbanized aquatic ecosystems are poorly understood. In this study, we conducted an in-depth analysis of phytoplankton communities and water environment factors in the Jinan City watershed in September 2020, focusing on 18 water environment factors. We found that nitrate nitrogen, total nitrogen, total phosphorus, and phosphate were the key drivers affecting the quality of the water environment in the area through principal component analysis (PCA). The results of the phytoplankton investigation showed that 143 species of phytoplankton from 8 phyla were found in the Jinan watershed, dominated by Chlorophyta, Bacillariophyta, and Cyanobacteria, of which cyanobacteria were dominant in density, while cryptophytes were the first in biomass. The assessment of phytoplankton diversity showed that the Jinan City watershed had high biodiversity, with an average Shannon Wiener Diversity Index of 3.12. RDA analysis revealed that permanganate index, total phosphorus, bathymetry, chlorophyll a, pH, and phosphate were significantly correlated with the structure of the phytoplankton community. Comprehensive trophic index (TLI) analysis showed that most of the watersheds in Jinan were moderately eutrophic. These results provide essential information for understanding the water quality status and aquatic biodiversity in Jinan City watersheds and provide a scientific basis for water environment management and protection.

KEYWORDS

Phytoplankton; Community structure; Jinan City; Water environment

1. INTRODUCTION

Aquatic ecosystems, as an essential natural component of the planet, harbor high biodiversity and provide many ecological services (Arthington et al., 2010; Vaughn, 2010). Phytoplankton plays a vital role in aquatic ecosystems by contributing to the maintenance of the primary productivity of rivers, as well as being a source of food for aquatic animals, including some phytophagous fish, mollusks, and rotifers (Borowitzka, 1997). It has been recognized as an ecological indicator of ecological health and the effects of chemical pollutant stress in aquatic ecosystems due to its wide distribution, high variability, and ability to integrate water quality changes, and is now widely used in river bioassessment (Lepistö et al., 2004; Xu et al., 2001). Therefore, we can understand the dynamic characteristics of the phytoplankton community in Jinan by studying its distributional characteristics to provide a reference basis for aquatic ecological health management and biodiversity conservation.

The community structure of phytoplankton is governed by various environmental factors, including the chemical composition of the water body, flow rate, substrate type, and light conditions (Cao et al., 2018; Jiang et al., 2014). Changes in these environmental factors, to a certain extent, threaten the services and stability of river ecosystem functions by influencing changes in phytoplankton

community structure. In recent years, aquatic ecosystems have faced unprecedented pressures with increased human activities and global climate change, making scientific and practical monitoring and management of aquatic ecosystems vital (Yang et al., 2017). Therefore, we can comprehensively describe water quality by combining phytoplankton with physical and chemical indicators.

In recent years, there has been a gradual increase in the application of environmental factors in water quality monitoring. However, we still know little about what are the key ecological factors driving changes in phytoplankton communities and how phytoplankton respond to environmental changes in highly urbanized river ecosystems (Yi et al., 2014). Therefore, an in-depth study of the dynamics of phytoplankton community structure and its response relationship with environmental factors in Jinan City can provide an essential scientific basis for the development of scientific water ecological protection strategies, the promotion of sustainable utilization of water resources, the monitoring and assessment of watershed ecosystem health, and the protection of biodiversity.

2. MATERIAL AND METHODS

2.1. Study Area

Jinan City (latitude 36°00'-37°40', longitude 116°20'-118°00') is located in the west-central part of Shandong Province, with an altitude of 5 to 1108.4 m, and a watershed area of 8,177 km. The city relies on the Taishan Mountains in the south and straddles the Yellow River in the north, which is backed by the water and the mountains. It forms a terrain of high in the south and low in the north. Topographically, it is divided into the northern yellow belt, the central mountainous plain belt, and the southern hilly and mountainous belt. The three regions have dense water networks and complex water ecosystem types, represented by springs, rivers, reservoirs, lakes, wetlands, and urban water control gates and dams, according to the Jinan watershed's natural and geographic environmental characteristics. Twenty-eight survey stations were set in September 2020 (Fig. 1), and the latitude, longitude, and elevation of the 28 survey stations were selected from the MAGELLAN global positioning system (eXplorist-200) for positioning.

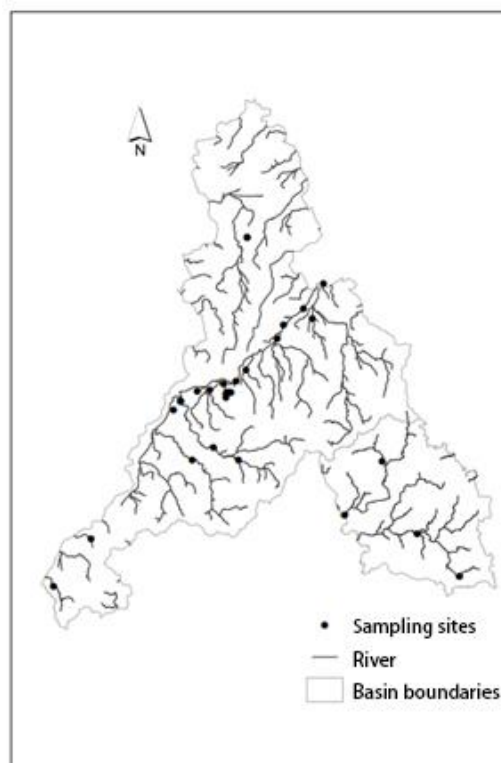


Figure 1. Distribution of sampling points in Jinan City

2.2. Phytoplankton Sample Collection And Processing

Phytoplankton quantitative and qualitative samples were collected at 0.5 m from the surface of the water body, and the water samples were collected with a plexiglass water collector, put into 1000 ml plastic bottles, labeled, and added with Lugol's reagent at 1~1.5% by volume for field fixation. The quantitative phytoplankton algae samples were precipitated in the usual way for 48h, and then the supernatant was carefully aspirated with a siphon tube and concentrated to 50 mL. The phytoplankton needed to be shaken in the sample bottle before counting to mix the samples thoroughly, aspirated, and dropped 0.1 mL in the counting frame, and then counted with the phytoplankton counting frame under the light microscope at a magnification of 40×10 times for observation and counting. Count two slices of each bottle of sample and take the average value.

2.3. Measurement Of Samples From The Aquatic Environment

The physicochemical indexes of the water body in this study were measured by combining field measurement and laboratory testing. A total of 15 indexes were measured, among which, the water depth (Dept) and flow velocity (Velo) were measured in the field using a flow meter (FP111), the river width (Width) data were realized with a distance meter, and a portable water analyzer (AZ86031) was used to determine the water temperature (WT), electrical conductivity (EC), dissolved oxygen (DO), total suspended solids (TSS), and pH; meanwhile, two 1L water samples were collected at each sampling location, placed in an insulated box for low-temperature storage, and transported to the laboratory for determination on the same day. Indicators were determined according to the national environmental protection standards issued by the Ministry of Environmental Protection: UV spectrophotometry was used to determine ammonia nitrogen (NH₃--N), nitrate nitrogen (NO₃--N) and phosphate (PO₄--P), permanganate index (CODMn) was determined using the permanganate method (GB11892-89), total nitrogen (TN) was determined using the alkaline potassium persulfate digestion UV spectrophotometry, ammonium molybdate spectrophotometry was used to determine total nitrogen (TSS) and pH; at the same time, two L samples were collected from each sampling point and stored in a holding tank at low temperature.), and total phosphorus (TP) was determined using ammonium molybdate spectrophotometry.

2.4. Data Analysis And Processing

Firstly, a principal component analysis (PCA) was conducted to determine the water environmental factors at each site in Jinan City to screen the environmental drivers that mainly affected the community. Partial Correlation Test (PCT) was used to identify the correlation between the environmental factors, and one of the environmental factors was retained if it was significantly correlated ($P < 0.05$). Then, the Partial Correlation Test (PCT) was used to identify the correlation between environmental factors, and if there was a significant correlation ($P < 0.05$), one of the environmental factors was retained. Next, the phytoplankton community data were subjected to Detrended Correspondence Analysis (DCA) [135]. If the maximum gradient of the output results was < 3 , Redundancy Correspondence Analysis (RDA) was used to discriminate the correlation between the phytoplankton community and the filtered water environmental factors. If the maximum gradient value of the output result was < 3 , then Redundancy Correspondence Analysis (RDA) was used to discriminate the correlation between the phytoplankton community and the screened water environment factors; if the output result was > 4 , Canonical Correspondence Analysis (CCA) was chosen, and if the result was between 3 and 4, either CCA or RDA analysis could be used. In this study, the maximum gradient value of DCA was 3.92, so we performed RDA analysis. In addition, when performing DCA and RDA analysis, the bioindicators must use the relative abundance data of benthic algal communities, $\log_{10}(x+1)$ conversion of water environment factors (except pH), and relative abundance data of benthic algae.

The distribution map of sampling sites in Jinan City was realized using ArcGIS version 10.8, PCA and CCA analyses were carried out using Canoco 5.0, and phytoplankton diversity was calculated using Biodiversity software.

3. RESULTS

3.1. Quality of the Water Environment

Jinan City Water Ecology Survey water environment factors are mainly tested for water temperature, water depth, transparency, turbidity, PH, conductivity, dissolved oxygen, salinity, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, total nitrogen, total phosphorus, phosphate, permanganate index, biochemical oxygen demand, suspended solids, and chlorophyll a, a total of 18 water environment factors, which were screened out through the PCA analysis of the water environment in Jinan City. The top four driving factors with higher correlation were nitrate nitrogen, total nitrogen, phosphorus, and phosphate (Fig. 2). Among them, the total nitrogen content of Jinan water environmental factors was 0.84-24.00 mg/L, with an average value of 7.70 mg/L; the total phosphorus content was 0.04-0.21 mg/L, with an average value of 0.10 mg/L; the phosphate content was 0.04-0.46 mg/L, with an average value of 0.19 mg/L; the nitrate nitrogen content was 0.40-19.00 mg/L, with an average value of 4.71 mg/L—mean value of 4.71 mg/L (Fig. 3).

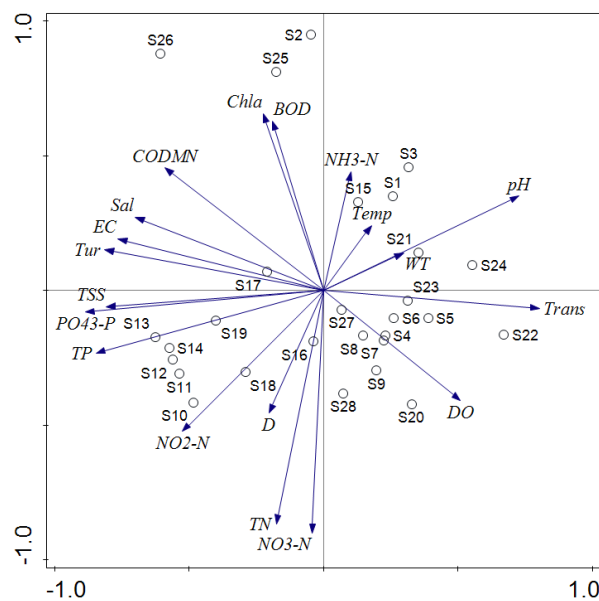


Figure 2. Principal component analysis of water environmental factors at various points in Jinan City

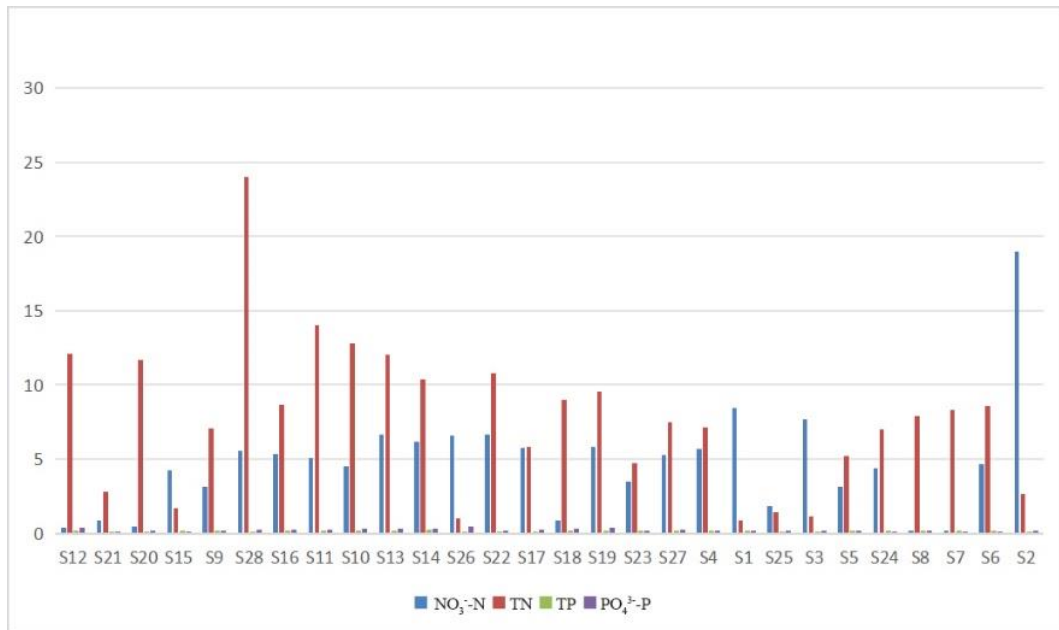


Figure 3. Distribution of major environmental drivers at various points in Jinan City

3.2. Characterization Of Phytoplankton Diversity And Community Structure

The 2020 Jinan Basin Water Ecology Survey identified eight phytoplankton phyla with 143 species. Among the identified species, the green algae phylum has the most significant number of species, with 53 species of green algae identified, accounting for 37% of the total phytoplankton species, followed by the diatom phylum, with 45 species identified, accounting for 32% of the total phytoplankton species; the cyanobacteria phylum is located in the third place, with 26 species identified, accounting for 18% of the total phytoplankton species; the remaining six phylums accounted for a relatively small proportion of the total phytoplankton species. From the identification results of phytoplankton density in the Jinan watershed, the phytoplankton density of Cyanobacteria was the highest, accounting for 62% of the total phytoplankton density; the phytoplankton density of Green Algae was in the second place, accounting for 22% of the total phytoplankton density; and the phytoplankton density of Diatoms was in the third place, accounting for 11% of the total phytoplankton density. From the results of phytoplankton biomass identification in Jinan watershed, the phytoplankton biomass of Cryptophyta was the largest, accounting for 44% of the total phytoplankton biomass investigated; the phytoplankton biomass of Diatom was located in the second, accounting for 30% of the total phytoplankton biomass investigated; the phytoplankton biomass of Cyanobacteria was located in the third, accounting for 17% of the total phytoplankton biomass investigated (Fig. 4).

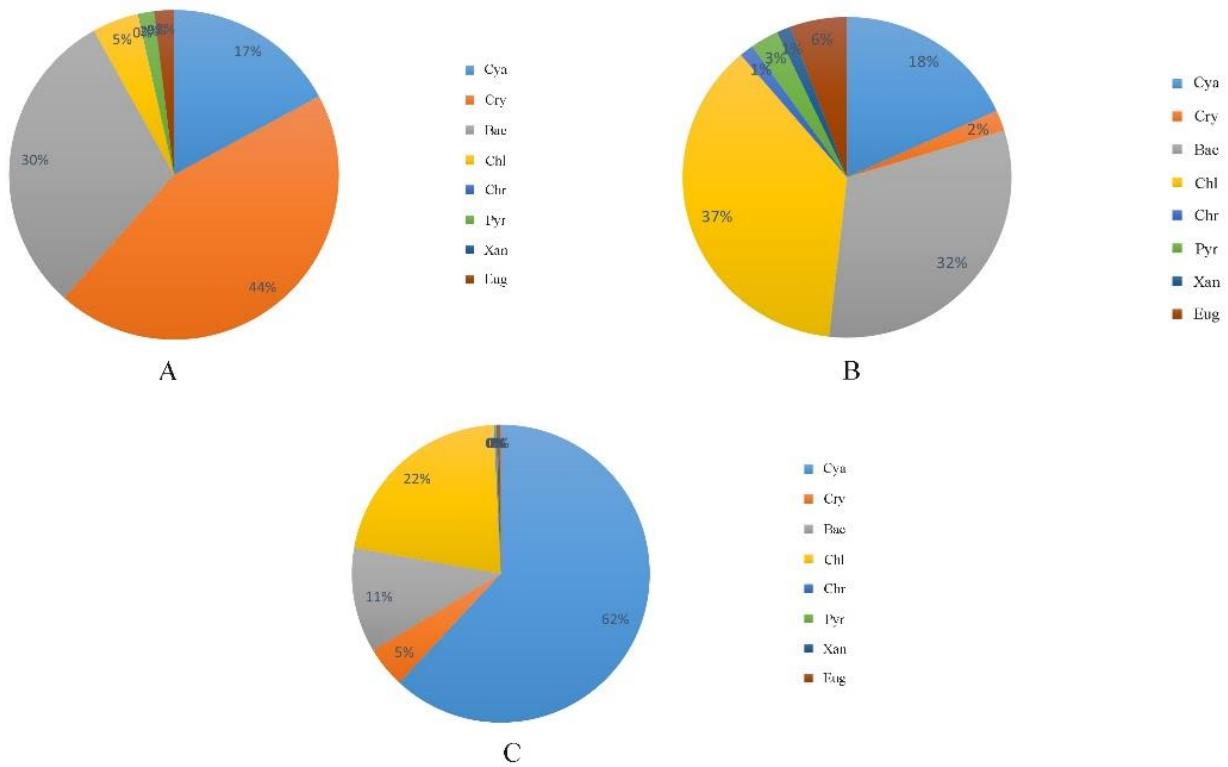


Figure 4. Distribution of phytoplankton in the Jinan watershed (where A represents biomass; B represents number of species; and C represents density. Cya represents Cyanobacteria, Cry represents Cryptophyta, Bac represents Bacillariophyta, Chl represents Chlorophyta, Chr represents Chrysophyta, Pyr represents Pyrropha, Xan represents Xanthophyta, and Eug represents Euglenophyta)

The distribution of phytoplankton species at each station of the Jinan River Basin Water Ecology Survey ranged from 11 to 40 species. The average number of phytoplankton species at each station was 24, with 40 species at Xiaodong Lake (S9), 39 species at Daming Lake (S7), 38 species at Wangjiawa (S28), and 14 species at Ximenqiao (S20). From the distribution of phytoplankton density in each station in the Jinan watershed, the density of phytoplankton in each station in the Jinan wetland ranged from 241.63 to 9844.90 million species/L, with an average density of 22,181,300 species/L. The highest phytoplankton density was found in Xiaodong Lake (S9) in the Jinan watershed, followed by Baiyun Lake Wetland (S2), with a 76,974,100 species/L density. The highest density in Ximenqiao (S20) was in Wangjiawa (S28), with 38 species, and the lowest was in Ximenqiao (S20), with 14 species. The lowest phytoplankton density was found in Ximenqiao (S20). From the distribution of phytoplankton biomass at each station in Jinan watershed, the phytoplankton biomass at each station in Jinan watershed ranged from 3.16 to 91.75 mg/L, with an average biomass of 28.72 mg/L. The highest phytoplankton biomass was found at the monitoring station of Baiyun Lake in the Jinan watershed (S2), followed by the station of Huangtai Hydrographic Station (S19) and the lowest one at the station of Fujiaqiao (S11). The lowest phytoplankton biomass was found at Fujiaqiao (S11). Through the survey of the Jinan watershed, the average Shannon Wiener diversity index of phytoplankton was 3.12, which indicated that the diversity of phytoplankton in the Jinan watershed was high. The distribution of diversity in the Jinan watershed ranged from 2.20 to 3.86, and the highest phytoplankton diversity was observed at the monitoring stations of Yawangkou (S13) and Zhaike (S21) (Fig. 5).

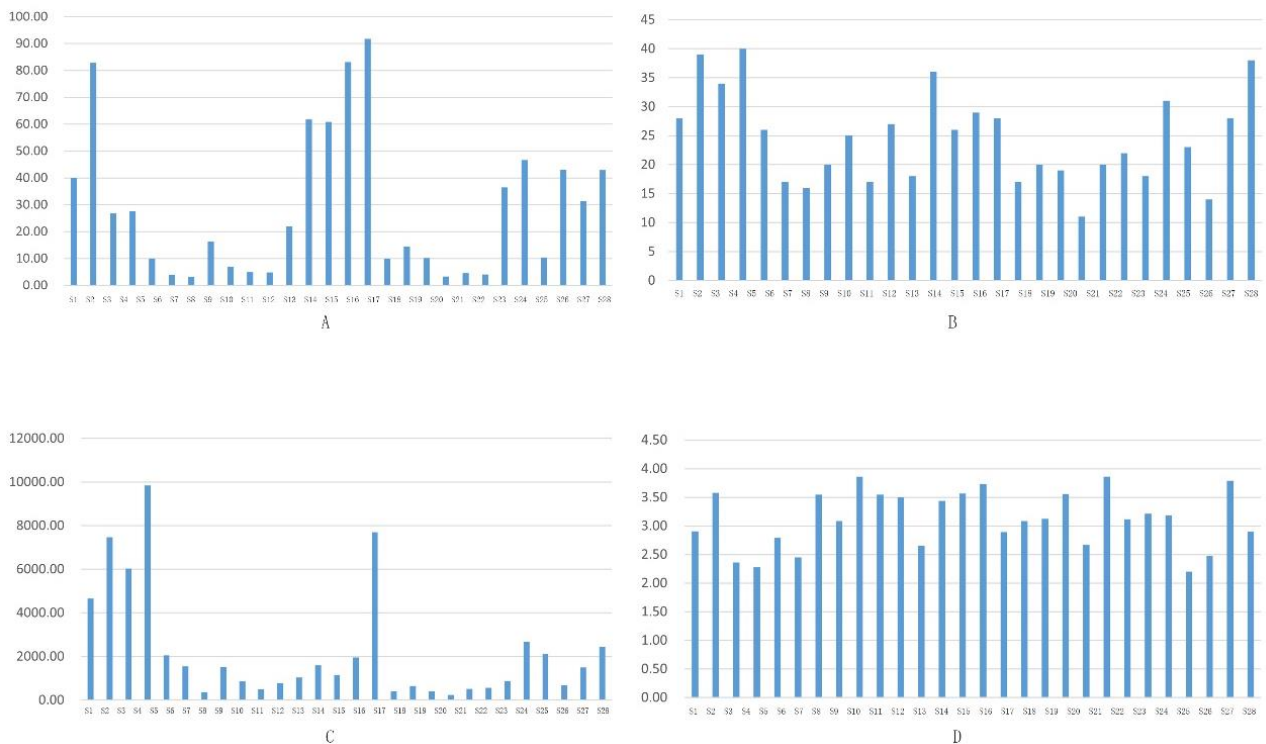


Figure 5. Distribution of phytoplankton algae at various sites in Jinan (where A represents biomass; B represents number of species; C represents density; and D represents diversity)

Through the analysis of phytoplankton representative species, the common phytoplankton species in the Jinan City watershed were ovate cryptophytes, with a frequency of 6 occurrences, and sickle-shaped fibrous algae, tiny matting algae, proximal bridging curved algae, constricted isopods, and chlorella, with a frequency of 5 occurrences. The dominant species of phytoplankton density in the Jinan watershed were the fine flatworms and the small seaweeds.

3.3. Analysis Of Environmental Drivers Of Phytoplankton

Through the RDA analysis of phytoplankton environmental drivers in September in the Jinan watershed (Fig. 6), Monte-Carlo screening was performed with the criterion of significant difference of $p < 0.05$. The screening results showed that the environmental factors corresponding to the phytoplankton in Jinan watershed with significant difference were permanganate index ($p=0.014$), total phosphorus ($p=0.034$), water depth ($p=0.012$), chlorophyll a ($p=0.016$), pH (0.044), and phosphate ($p=0.048$), where permanganate index was negatively correlated with the first axis, and representative phytoplankton species that responded to each other with the environmental driver, permanganate index, were *Bentella parviflora*, *Tetragona multilinear*, *Thin Arachidium*, and *Rhombomorpha linear*.

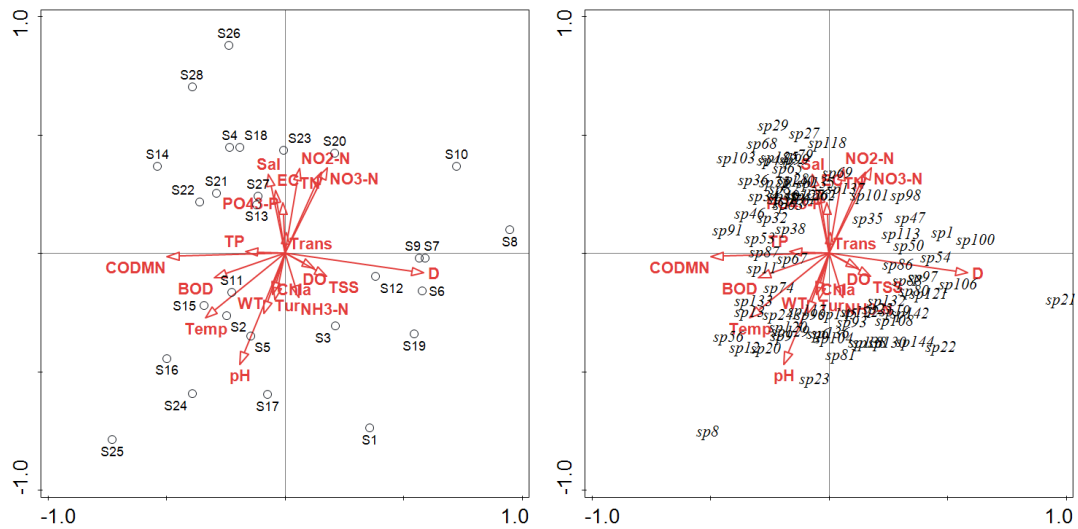


Figure 6. Redundancy analysis of water environmental factors at points in Jinan (left panel shows environmental factors and points, right panel shows ecological factors and species)

3.4. Analysis Of Environmental Drivers Of Phytoplankton

The results of the identification of the comprehensive nutrient index TLI of the Jinan watershed show (Fig. 7) that the range of the TLI index of the Jinan watershed in 2020 is 26.05-67.43, and the average comprehensive nutrient index TLI of the Jinan watershed is 54.03, which indicates that the Jinan watershed as a whole is at a certain eutrophic level, among which Baiyun Lake wetland, the downstream of Xiaoqing River (Wulongtang-Yunxie North Road), the upstream of Xiaoqing River (Huanggang-Huangtai Hydrological Station) and Yingzi lock belong to moderate eutrophic level; Ximenqiao belongs to poor nutrient level.

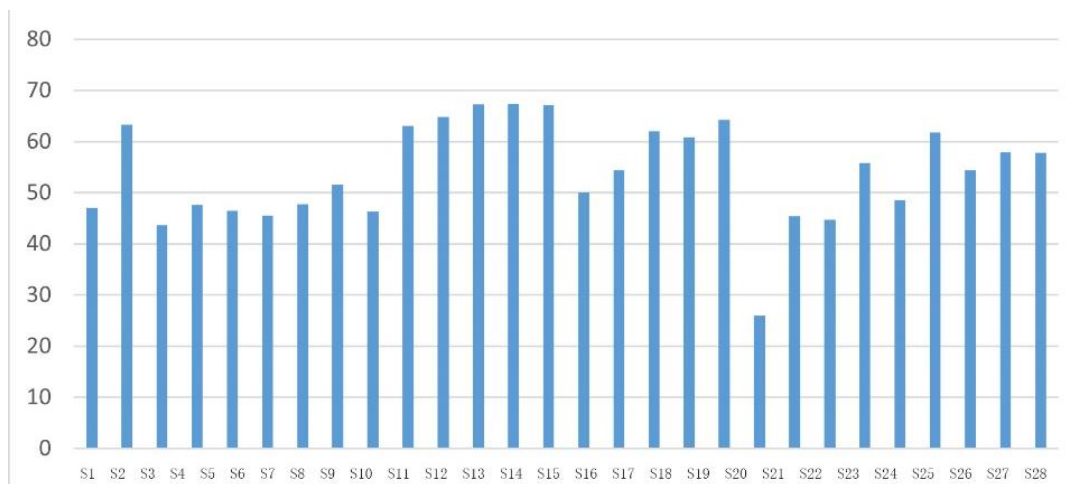


Figure 7. Distribution of TLI of Comprehensive Nutritional Index by Points in Jinan City

4. DISCUSSION

The results of the fall Jinan City Water Ecology Survey conducted this time revealed the complexity and diversity of the region's water environment, in which 18 water environmental factors such as water temperature, water depth, transparency, turbidity, pH, conductivity, dissolved oxygen, salinity, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, total nitrogen, total phosphorus, phosphate, permanganate index, biochemical oxygen demand, suspended solids, and chlorophyll a were tested to provide a comprehensive perspective for understanding the regional water quality conditions

offered a comprehensive perspective. Through principal component analysis (PCA), nitrate nitrogen, total nitrogen, total phosphorus, and phosphate were identified as the main drivers affecting the water environmental quality in Jinan, reflecting the essential roles of these factors in water eutrophication and ecological balance. Nitrate nitrogen and total nitrogen are mainly derived from agricultural fertilizers, industrial discharges, and domestic wastewater, and their excesses can lead to the eutrophication of water bodies, increase the growth of algae and aquatic plants, and thus disrupt the balance of the marine ecosystem (Bužančić et al., 2016). High levels of total nitrogen are usually closely associated with agricultural surface pollution and urban runoff, indicating that Jinan may be under pressure from these sources. Total phosphorus and phosphate are essential nutrients in water bodies, and the primary sources include agricultural runoff, domestic sewage discharge, and industrial wastewater. Their excessive accumulation can stimulate algal blooms, leading to blooms and affecting water clarity and ecological health (Zhang et al., 2019). As a directly available form for plant and algal uptake and utilization, an increase in phosphate concentration directly affects the growth rate of aquatic plants and the degree of eutrophication of water bodies.

The phytoplankton survey in the Jinan City watershed showed that the phylum Chlorophyta, Diatoms, and Cyanobacteria were the main phytoplankton species in the region, with Chlorophyta having the highest number of species, and Diatoms and Cyanobacteria in the second and third places, respectively. The distribution of phytoplankton species and density reflected the biodiversity and ecological status of the water body. The high density of the cyanobacteria species may be related to the eutrophication state, which leads to the explosive growth of algae, thus affecting the water quality and ecological balance. The RDA analysis further identified the environmental factors affecting the distribution of phytoplankton in the Ji'nan watershed, including the permanganate index, total phosphorus, bathymetry, chlorophyll pH, etc. The results of the RDA analysis indicated that the distribution of phytoplankton in the Jinan watershed was insignificant. The significance of the permanganate index noted that organic matter pollution and redox status significantly affected the phytoplankton community structure. These results emphasize the importance of understanding the interactions between environmental factors and biological communities and provide a scientific basis for developing effective water quality management and ecological protection strategies (Dunck et al., 2019). The comprehensive Trophic Level Index (TLI) analysis shows that most areas of the Jinan watershed are at moderate eutrophic levels, pointing out the prevalence and severity of the eutrophication problem in water bodies. Eutrophication not only leads to overgrowth of phytoplankton but also may trigger the phenomenon of water bloom, which reduces water quality and poses a threat to ecosystem health (Wang et al., 2022).

Overall, this study provides insights into the aquatic environment and phytoplankton diversity in Jinan City, highlighting the urgent need to manage and improve the ecological health of the region's water. Future research should further explore the specific impacts of different water environmental factors on ecosystem functioning and develop targeted conservation measures to maintain biodiversity and ensure the sustainable use of water resources.

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