Spatio-temporal variations in water quality of urban landscape waters in the plain city

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ABSTRACT
Urban landscape waters (ULWs) are important components of ecological city; however, eutrophication has become increasingly serious. In Yancheng city, an eco-civilized city, the spatio-temporal characteristics of water quality indexes and the eutrophication degree were evaluated in Julong lake (ULW) artificial ecological restoration and campus natural landscape (YCIT) waters. Since ecological restoration in 2016, the seasonal average concentrations of N, P in JL waters have been significantly decreased by more than 70%, satisfying the standards for water quality with light eutrophication. Conversely, the European Flower Street (EFS) and YCIT waters were hyper eutrophic, severely exceeding the Grade V water quality standard. The spatial distribution of ULWs quality deterioration in the plain area indicated that the human activities and endogenous pollutions contributed to ULWs eutrophication because of sluices controlling and low flow rate. This study provided a scientific basis for controlling the ULWs eutrophication via integrated eco-remediation technology in plain cities.

1. Introduction
Urban landscape waters (ULWs) include natural lakes, river courses and artificial lakes contained within public places in urban areas, such as parks, living quarters and entertainment places, which not only have recreational value, but also regulate the climate and improve the ecological diversity, as well as discharging flood and controlling soil erosion under special circumstances [1]. With urban expansion and growth of the human population, ULWs are vulnerable to the exogenous pollution, leading to eutrophication due to the small surface area, shallow depth and low flow rate [2,3]. Coordinating the conflict between ULWs conservation and the rapid urbanization remains a significant task for urban sustainability development [4]. Moreover, seeking suitable (green, economical and efficient) approaches is necessary to control eutrophication and satisfy the preferences of the public.

Eutrophication is a major problem in the many lakes due to anthropogenic activities worldwide [5,6], and degradation of urban landscape waters has rapidly emerged with increased discharge both of phosphorus (P) and nitrogen (N) [7,8]. Chang et al. [9] studied the water environment of the 189 urban landscape lakes widely distributed in 26 provinces of China, of which 60% could not meet the lowest requirement and total nitrogen (TN) concentration was the most limiting factor. To solve the eutrophication problems and protect water quality of ULWs, researchers have conducted several control methods on the eutrophic waters. Bormans et al. [10] summarized the efficiency of major physical methods to control and reduce nutrients, such as hypolimnetic withdrawal, artificial aeration, and the sediment dredging. Furthermore, the chemical methods have been adopted to improve the water quality of severely eutrophic waters, including chemical alga-killing, calcium peroxide and flocculation precipitation [11,12]. Nevertheless, nitrogen and phosphorus are essential to plants and animals for maintaining their growth and metabolism [13]. Waajen et al. [14] used the biomanipulation (involving fish biomass control and the introduction of macrophytes) with and without the addition of the flocculant polyaluminium chloride to control eutrophication in two urban ponds. The bio-eco remediation methods has become the preferred technology, including ecological floating bed and constructed wetlands [15]. Therefore, the ecological restorations may be indispensable in reversing eutrophication [16], and combined with physical and chemical methods could be more successful in reversing eutrophication.

The ecological civilization was proposed during the Third Plenary Session of the 18th Central Committee of China in 2013 [17], and written into the country’s Constitution in 2018. Since the goal of ecological civilization development was put forward, all the provinces and cities of China have actively responded to the call and vigorously implemented changes to promote a more ecological civilization [18]. Yancheng city is an eastern coastal...
plain city in China. The migratory bird sanctuaries along the coast of Yellow Sea-Bohai gulf in Yancheng of China (Phase I) was listed on the World Heritage List by the World Heritage Committee in 2019, and Yancheng city was approved as a national ecological civilization construction demonstration city in 2021. Currently, plain rivers form a complex hybrid human-natural system due to their geomorphic features, and changes in river network structures affect circulation and self-purification of water bodies and alter the biodiversity, productivity, and the function of aquatic ecosystems [19]. Based on the aim of ecological civilization, Yancheng has set a goal of creating an international wetland city, so that numerous wetland parks will be built over a period of five years. To reveal the nutrient removal efficiency of ecological remediation on landscape water quality, the paper selected two types of landscape water (artificial and natural landscape waters), analyzed the spatiotemporal characteristics and evaluated the eutrophication degree using the comprehensive trophic level index (TLI) method. The research could provide a scientific basis for policy making in the sustainable development between the water environment and urban development under the ecological civilization system.

2. Materials and methods

2.1 Study areas and data

Yancheng city is one of 27 cities in the central area of the Yangtze River Delta and is located in the mid-eastern Jiangsu Province, China. The urban area of Yancheng belongs to the abdomen of the Lixia River watershed and is a typical plain river network area. This region is part of the Jianghuai Plain formed by long-term accumulation of sediment from the Old Yellow, Yangtze, and Huai rivers [20], and the ground elevation is less than 5 m. The main types of soils are loamy soil and clayey soil. The area is characterized by a typical monsoon climate, with an annual average temperature of 14.7°C, and a mean annual precipitation of more than 1000 mm. There are two distinct seasons: the dry season ranging from December to February of the following year and the wet season from July to September, in which more than two-thirds of rainfall is concentrated.

Yancheng city is famous for hundred rivers with a drainage density of 3.1 km/km² [1], of which the park green areas comprised 13.85 km² in 2021 (sourced from http://tj.jiangsu.gov.cn/2021/nj18/nj1805.htm). Julong lake (JL) is located in the center of the southern new district and the landmark eco-park in Yancheng city. Since 2016, an aquatic ecosystem consisting of submerged plants and animals has been rebuilt using artificial measures, including the formation of a pore aeration system in JL. Moreover, any dead submerged plants are typically removed to maintain proper water quality and clean. The Europic Flower Street (EFS) waters, an urban canal surrounded by a Europe architectural street encompassing catering service that lacks integrated eco-remediation, connects with eastern part of JL, while the eastern portion connects with Chuanchang River. Compared with those in the urban parks, the campus waters of Yancheng Institute of Technology (YCIT) are almost natural waters that are divided into three parts: the west ditch, east canal and south pond, of which the west inlet end connects to the Xifeng and Tongyu Rivers by the sluice.

Generalization and sampling sites of the urban landscape water bodies are presented in Figure 1. There are 14 monitoring points recorded in the JL waters (Samples 1–12 for the main water of JL, and samples 13 and 14 for EFS waters connected with JL), and 11 points in campus landscapes waters of YCIT recorded using handheld GPS navigator. The water samples were collected at 0.3 m under the water surface with 500 ml polythene and organic glass bottles from February to July 2019. The water quality parameters, total nitrogen (TN), ammonium (NH₄⁺-N), nitrate (NO₃⁻), total phosphorus (TP), phosphate (PO₄³⁻), dissolved oxygen (DO), chlorophyll a (Chl-a) and the permanganate index (CODₘₚₐₚ), were analysed and tested in the laboratory according to the national standard methods [21].

2.2 Methods

The spatiotemporal variations in water quality and nutrient concentrations at different sampling sites were analyzed using ArcGIS and Origin software. The water quality was determined via the single-factor evaluation according to the National Quality Guidelines for Surface Water [22].

The comprehensive trophic level index (TLI) has been confirmed as the appropriate eutrophication assessment method for Chinese lakes [23,24], and used in the present study to evaluate the eutrophic state of ULW via the evaluation indicators, such as CODₘₚₐₚ, TP, Chl-a, Secchi Depth (SD) and TN. In the study area, the JL is a shallow artificial lake, and water ecological managements are conducted by the professionals to ensure that the waters are clear to satisfy the function of an ecopark. Conversely, the EFS and YCIT waters are natural landscape. Therefore, the SD could influence the evaluation results, leading to either an underestimation or overestimation of the eutrophication status. Based on these factors, CODₘₚₐₚ, TP, Chl-a and TN were selected to analyze the eutrophic state of ULWs using the TLI.

The general form of TLI is shown as follows:
Where, \( TLI(\Sigma) \) is the comprehensive trophic level index; \( W_j \) denotes the weight of different \( TLI \) (\( \sum W_j \) and \( W_j>0 \)); and \( TLI(j) \) is the \( TLI \) of the evaluation factors \( j \).

Chl-\( \alpha \), TP, TN and COD\(_{\text{Mn}}\) were selected as evaluation indicators, which are all related with the Chl-\( \alpha \). The weights have been obtained from the correlation between Chl-\( \alpha \) with other indicators of lake (reservoirs) in China [25], as shown in model 2 and Table 1.

\[
TLI(\Sigma) = \sum_{j=1}^{m} W_j \times TLI(j) \tag{1-1}
\]

Finally, the trophic degrees of the ULWs are evaluated via the comprehensive scores (0–100), and divided into five grades, as shown in Table 2.

3. Results and discussion

3.1 Variations of water quality

The water quality parameters of the sampling sites were evaluated in the laboratory. The average concentrations of N, P, DO and COD\(_{\text{Mn}}\) were shown in the boxplots (Figure 2), which included the concentrations of TN, \( \text{NH}_4^+\)-N, \( \text{NO}_3^- \), TP, \( \text{PO}_4^{3-} \) and Chl-\( \alpha \) in the JL waters (Samples 1–12) and YCIT waters.

From February to July 2019, the average concentrations of \( \text{NH}_4^+\)-N, \( \text{NO}_3^- \) and TN (ranges of 0.023–0.813, 0.01–0.736 and 0.342–1.603 mg/L, respectively) in the JL waters were far lower than those in the YCIT waters (ranges of 0.589–3.43, 0.111–4.11 and 1.64–5.36 mg/L, respectively). The
average concentrations of TP and PO$_4^{3-}$ (ranges of 0.023–0.813 and 0.342–1.603 mg/L, respectively) in the JL waters were slight lower than those in the YCIT waters (ranges of 0.589–3.43, 0.111–4.11 and 1.64–5.36, respectively). Furthermore, there were high dispersion degrees of the N and P concentrations in the YCIT waters. As shown in Figure 2c, the average concentrations of COD$_{Mn}$, DO and Chl-α in the JL waters were 11.8, 11.91 and 0.0264 mg/L, respectively, while those were 12.1 mg/L, 10.49 mg/L and 0.0505 mg/L in the YCIT waters, respectively. The average concentrations of TN, NH$_4^+$-N, NO$_3^-$, TP, PO$_4^{3-}$ and Chl-α in JL waters were substantial lower than those in YCIT waters, whereas the average DO concentration in the JL waters was slight higher. Overall, the water quality of YCIT waters was greatly inferior to that of JL waters, especially for N and P nutrients.

### 3.2 Seasonal variation of nutrient salt

The seasonal concentrations of TN, NH$_4^+$-N, TP and COD$_{Mn}$ were monitored and calculated to assess the temporal differences in water variables between the ULWs and among the different sampling sites (Table 3). According to National Quality Standards for Surface Waters in China [22], surface water can be categorized into five grade (I, II, III, IV and V), among which the concentrations of TP, TN, NH$_4^+$-N and COD$_{Mn}$ were 0.2, 2, 2 and 15 mg/L in a Grade V waterbody, respectively; 0.1, 1.5, 1.5 and 10 mg/L in Grade IV waterbody, respectively; and 0.05, 1, 1 and 6 mg/L in Grade III waterbody, respectively, as shown in Table 4.

In the JL artificial waters, the average TP, TN, NH$_4^+$-N and COD$_{Mn}$ concentrations were classified as the standard of Grade IV during the wet season. The average TN and NH$_4^+$-N concentrations of

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**Table 2. Evaluation standard of eutrophication degree.**

| Trophic grades | I (OL) | II (M) | III (LE) | IV (ME) | V (HE) |
|----------------|--------|--------|----------|---------|--------|
| Trophic state  | Oligotrophic | Mesotrophic | Light eutrophic | Middle eutrophic | Hypereutrophic |
| Grade scores  | TLI<30 | 30<TLI<50 | 50<TLI<60 | 60<TLI<70 | TLI>70 |

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**Figure 2.** Water quality parameters values of ULWs (JL- Julong lake, YCIT- campus landscape water).
Table 3. Season variations of nutrients concentrations of ULWs.

| Parameters | Wet season (Jul. 2019) | Dry season (Feb. 2019) |
|------------|------------------------|------------------------|
| TN (mg/L)  | Min–Max                | Min–Max                |
|            | 0.81–1.6               | 1.64–5.36              |
|            | 6.2–6.49               | 0.34–1.35              |
|            | (S.D.)                 | (S.D.)                 |
|            | 1.34 (0.2)             | 3.86 (1.19)            |
|            | 6.3 (0.2)              | 0.67 (0.316)           |
|            | (S.D.)                 | 7.09 (0.11)            |
|            | 4.08 (0.79)            |
| NH₃-N (mg/L)| Min–Max                | Min–Max                |
|            | 0.18–0.81              | 1.29–1.63              |
|            | 1.29–3.43              | 0.023–0.099            |
|            | (S.D.)                 | (S.D.)                 |
|            | 0.36 (0.17)            | 2.45 (0.66)            |
|            | 1.46 (0.24)            | 0.056 (0.025)          |
|            | (S.D.)                 | 0.86 (0.32)            |
|            | 1.63 (0.57)            |
| NO₃-N (mg/L)| Min–Max                | Min–Max                |
|            | 0.15–0.44              | 1.63–3.13              |
|            | 0.035–0.48             | 0.007–0.43             |
|            | (S.D.)                 | (S.D.)                 |
|            | 0.21 (0.077)           | 2.34 (0.45)            |
|            | 0.29 (0.13)            | 0.14 (0.127)           |
|            | (S.D.)                 | (S.D.)                 |
|            | 0.09 (0.08)            | 1.63 (0.57)            |
|            | 1.1 (0.36)             | 0.78 (0.1)             |
|            | (S.D.)                 | 0.296 (0.062)          |
| TP (mg/L)  | Min–Max                | Min–Max                |
|            | 0.006–0.28             | 0.85–1.36              |
|            | 0.23–1.23              | 0.09–0.47              |
|            | (S.D.)                 | (S.D.)                 |
|            | 0.09 (0.08)            | 0.57 (0.28)            |
|            | 1.1 (0.36)             | 0.3 (0.16)             |
|            | (S.D.)                 | (S.D.)                 |
|            | 2.0 (0.15)             | 0.78 (0.1)             |
|            | 1.0 (0.05)             | 0.296 (0.062)          |
| CODd₄₅ (mg/L)| Min–Max                | Min–Max                |
|            | 8.58–10.44             | 7.11–10.54             |
|            | 7.71–10.54             | 13.44–15.47            |
|            | (S.D.)                 | (S.D.)                 |
|            | 9.27 (0.55)            | 9.16 (0.921)           |
|            | 10 (1.02)              | 14.43 (0.55)           |
|            | (S.D.)                 | (S.D.)                 |
|            | 5.14 (1.48)            | 15.7 (1.13)            |
| TN/TP      | Min–Max                | Min–Max                |
|            | 5.68–23.6              | 4.76–7.25              |
|            | 3.21–13.88             | 0.74–6.58              |
|            | (S.D.)                 | (S.D.)                 |
|            | 4.35 (1.48)            | 7.67 (0.39)            |
|            | 6.0 (1.76)             | 3.01 (1.93)            |
|            | (S.D.)                 | (S.D.)                 |
|            | 9.23 (1.06)            | 13.9 (2.82)            |

Note: S.D addresses standard deviation.

Table 4. National quality standard for surface waters in China.

| Parameters | I   | II  | III | IV  | V   |
|------------|-----|-----|-----|-----|-----|
| TN(mg/L)   | ≤ 0.2 | 0.3 | 1.0 | 1.5 | 2.0 |
| NH₃-N(mg/L) | ≤ 0.15 | 0.5 | 1.0 | 1.5 | 2.0 |
| TP(mg/L)   | ≤ 0.01 | 0.025 | 0.05 | 0.1 | 0.2 |
| CODd₄₅(mg/L)| ≤ 2 | 4 | 6 | 10 | 15 |

The JL waters were superior to the standard of Grade III, whereas the average TP concentration exceeded Grade V during the dry season. Therefore, the water quality of the JL waters was inferior in the dry season compared to that in the wet season. In the wet season and dry season, the EFS waters connected with JL were inferior with to the Grade V standard. Compared with those in the EFS waters, the average TN, NH₃-N, TP and CODd₄₅ concentrations of JL waters decreased by 90.55%, 93.5%, 61.5% and 8.9%, respectively, during the dry season, and 78.7%, 75.3%, 91.8% and 8.2%, respectively, during the wet season. The removal rates of N and P nutrients in the JL waters exhibited great seasonal variability.

In the natural waters of YCIT, the average concentrations of TP, TN and NH₃-N were above the standard of Grade V during the wet season. During the dry season, the average TN, TP, CODd₄₅ concentrations of the YCIT waters were above the standard for Grade V. Numerous studies have indicated that the concentrations of TP, TN and NH₃-N were higher in the wet season than those in the dry season in natural basins [26,27]. Similar to the previous research, the NH₃-N, TP concentrations of YCIT waters were higher in the wet season than those in the dry season.

Figure 3. TLI results of urban landscape waters (a- Julong lake (1–12); a- EFS (13–14); b- YCIT).
3.3 Eutrophication characteristics

Basing on the TLI values of ULWs, the eutrophic situation of the JL waters was nearly middle eutrophication and below; conversely, the EFS waters exhibited hyper eutrophication (Figure 3a). Moreover, the campus landscape waters of the YCIT were beyond the middle eutrophic condition (Figure 3b). There were season variations of eutrophication between different ULWs. The TLI values in winter were higher than those in summer for the YCIT waters, although, although the JL and EFS waters exhibited a converse pattern.

The N: P ratio is widely useful as a measure of which nutrient may limit phytoplankton growth in freshwater ecosystems [28]. When TN: TP < 22 by weight in freshwater environments, P may be present in excess and N often limits algal growth; otherwise, P is often the limiting factor [29]. As shown in Table 3, the TN: TP ratio varied from 5.68 to

![Figure 4](image-url)  
Figure 4. Spatial distribution in TN, TP, COD₃₅₀ concentrations of YCIT waters.
to 232.6 with an average of 43.35 in the JL waters in July 2019, of which P was the limiting factor. Conversely, N limited phytoplankton growth in EFS and YCIT waters in July 2019, and in JL, EFS and YCIT waters in February 2019.

3.4 Human influences on nutrient loads

3.4.1 Effect of artificial sluices

The campus landscape waters of YCIT represent a natural landscape, which is connected with Xinfeng and Tongyu Rivers, as shown in Figure 1. Due to the flat area, the sluice gate was built to regulate the flow of water in different seasons. During the wet season, the waters can flow in from the upper end of the west (point 1) and flow out from the upper end of the east (point 7), while the waters could remain at a steady level during the dry season.

The spatial distribution of water quality of the YCIT waters were displayed by using the inverse distance weighted interpolation (Figure 4). In the eastern area, the living area and campus dining hall are distributed along the river (point 7–9). The concentrations of TN, TP
and COD$_{mn}$ were higher in the south open waters of the YCIT in February, while those were lower in July. During the dry season, the quality of the landscape water were poor due to the domestic contaminant inputs (such as N and P), slow-moving waters and lower temperatures, as demonstrated by the previous research [30]. During the wet season, the spatial distribution of TN and COD$_{mn}$ from the entrance zone in the west to the exit zone in the east showed a downward gradient, although the influent water quality of the Tongyu River satisfied Grade III of the surface water in July 2019 (sourced from http://www.yancheng.gov.cn/col/col826/index.html?number=A00038A00005A00003), which was a larger river and the principal surface water source in Yancheng city. It is possible that the waters at the entrance area were stirred and further influenced by the inner pollution of sediment via N and P releasing. Overall, the eutrophication of ULWs are vulnerable to human activities and endogenous pollution.

3.4.2 Effect of ecological restoration

Due to the public requirements and aesthetic values, maintaining suitable water quality is essential for ULWs [31]. According to the previous research [32], the average NH$_4^+$-N, TP and COD$_{mn}$ concentrations of the JL waters were 1.15, 0.143 and 7.68 mg/L in November of 2015. The average concentrations of NH$_4^+$-N and TP decreased by 95% and 33% between November 2015 and February 2019, while the COD$_{mn}$ increased. Located on the eastern side of Renmin Road and connected with JL, the EFS waters have not undergone water restoration and sampling points were selected here to determine the water quality in contrast to those of the JL waters.

Using the inverse distance weighted interpolation, the spatial analyses were conducted to determine the spatial distribution of water quality between the JL and EFS waters (Figure 5). The spatial patterns of TN, TP from JL to EFS showed a significant upward gradient during the wet and dry seasons, whereas the average COD$_{mn}$ values exhibited a less pronounced spatial variability. Without the aquatic ecological rehabilitation, the N, P concentrations of the EFS waters around with the catering service were higher than those in the JL waters due to the human activities. According to other research about the long term effects of aquatic vegetation rehabilitation on the eutrophicated urban waters in Shanghai City [33], the average TN, NH$_4^+$-N, TP and COD$_{mn}$ contents were 1.71, 0.72, 0.16 and 21.5 mg/L, respectively, during the wet and dry seasons from 2008–2010. Similar aquatic vegetation rehabilitation has been applied to the JL waters, with lower average concentrations of N and P following the aquatic ecological rehabilitation, as shown in the Table 1. The stability of aquatic ecosystems could improve eutrophication problems, affecting water transparency directly [34] and supporting the survival of benthic animals and plants [35]. Overall, the removal of N, P nutrient were obviously between the sampling times, providing proof of the effect of ecological restoration on water quality improvement of JL waters. Moreover, the urban ecological landscape would promote sustainable construction for supporting ecology to a certain extent, which could guarantee the sustainable development of human society and nature.

4. Conclusion

In the present research, the two type of ULWs in Yancheng city exhibited different extents of eutrophication states and a large diversity in the spatiotemporal variations of the N, P concentrations during wet and dry seasons. Since the aquatic ecosystem was rebuilt in 2016, the water quality of the JL artificial landscape waters have improved significantly and met the scenic water requirements. The EFS and YCIT waters severely exceed the Grade V level of water quality during different seasons, showing inferior water quality to that of the JL waters. According to the results of TLI method, the eutrophication ranking of the JL waters was light or middle eutrophic, while that of the EFS and YCIT waters were middle and high eutrophic, indicating the initial serious ecological state, in which the N limited phytoplankton growth.

In the plain area, the high N, P concentrations and eutrophication problem of the natural landscape waters were vulnerable to the human activities and endogenous pollution, because of the lower flows and influences of the sluice gates. Based on the spatiotemporal nutrients and eutrophication analyses of the artificial landscape waters, the concentrations of N and P in the JL waters have decreased by 70%-90%, indicated the ecological restoration technology improved the eutrophication problem to a certain extent. Landscape waters become important components of ecological cities, and ecological restoration technology could be an effective measure for controlling the nutrients to promote management and refinement of ULWs.

Disclosure statement

The authors declare that they have no conflicts of interest.

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