Purification effect of aquatic plant communities in constructed wetland park: a comparative experiment of Tianhe wetland park in China

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Abstract
Constructed wetland parks in urban areas can offer the potential for integrating water conservation and purification. Compared with other treatments, filtering out pollutants by wetland plants is one of the methods used widely for its fast processing time and limited costs. And species allocation plays an important role in the purification process. However, some problems are still waiting for further discussions, such as the purification efficiency in winter due to plant growth rate, etc. Against this background, this paper introduced the Tianhe Wetland Park in China as the site for a comparative experiment, to propose a methodology for testing the purification effect under different plant communities. Through site investigation and lab experiments with water monitoring, the process of water purification by wetland was simulated in the park. After a period of observation and measurement, seven water indexes (pH value, dissolved oxygen, total phosphorus, total nitrogen, ammonia nitrogen, chemical oxygen demand, and turbidity) were selected for the evaluation of water quality to compare the different absorption efficiency by different communities. As a result, the research showed that a configuration of plant community using arboreal, emergent, and submerged plants can carry out a good purification effect during the winter, including Callistemon viminalis, Bischofia javanica, Canna indica, Juncus effusus, Vallisneria natans, and Hydrilla verticillata var. rosburghii. The removal rate of DO, TU, COD, TP, and TN by the designed community can reach 43%, 65%, 45%, 51%, and 62% in sampling sites. Finally, based on the research results, further suggestions for the development of wetlands were proposed to improve park management in the study area.

1. Introduction

Wetlands are significant and productive ecosystems on Earth, which bring various benefits to human beings. However, along with the process of industrialization, due to the desertification phenomenon and water crises, wetland systems have been gradually influenced and destroyed in recent years [1]. Especially in countries under a fast urbanization process, the status of wetlands is not promising [2]. Against this background, an increasing number of scholars are paying attention to the ecological values of wetland parks in urban areas [3–5]. As a constructed ecosystem with various facilities and services, wetland parks can be utilized to conserve valuable water resources and to provide green spaces for both urban and suburban residents [6]. They contain also other important functions, such as regulating microclimate, serving for environmental education [7], absorbing

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pollutants, including nitrogen, phosphorus, heavy metals, pathogenic bacteria, etc. [8]. Urban wetland parks can function as both entertaining facilities and environmental restoration tools, whose role in the treatment of contaminated water has been recognized increasingly in many cases [9–12], and constructing wetlands has been a hot issue discussed in more and more countries [13]. For example, the concept of ‘re-naturalization’ was proposed in Germany to emphasize the relationship between wetlands and urban constructions [14]. In the UK, the use of wetlands serving human societies was emphasized; while the scholars in the USA advocated that urban wetlands should focus more on ecological restoration as their primary functions [15]. In China, artificial wetlands were started to be constructed from the 1990s for dealing with industrial wastewater [16]. A large artificial wetland was successfully built in Yunnan province in 2015, named ‘Fuxianhu National Wetland Park’, which contains more than ten species of aquatic plants, such as Acorus calamus, Trapa natans, Sagittaria trifolia, and Phyllostachys heteroclada as the core of the aquatic system [17].

However, currently, eutrophication is still one of the biggest problems influencing water safety in urban areas [18]. The accumulation of nutrients in the water leads to the proliferation of algae and other organic matters, causing an imbalance of energy circulation and a series of environmental crises [19]. Reducing nitrogen and phosphorus in water is the primary task for controlling eutrophication. In previous projects, the methods using sewage and interception were widely applied. But these methods were difficult to reduce heavy pollution. Compared with chemical and physical treatments with the chances of secondary pollution and threats to ecological security, a comprehensive treatment by constructing wetlands is more friendly and effective to promote the internal cycle and restoration ability of an overall ecosystem [20, 21].

In academia, there has been a surge of interest in the relationship between aquatic plants and eutrophication, since aquatic plants are the crucial components in a wetland. They provide habitat for plankton and other animals and reduce the movement of sediments through a synergistic action between their roots and other microorganisms [22]. Current studies focus more on the removal efficiency of certain aquatic plants for different nutrients in water [23–25]. For example, for removing nitrogen in the water, wetland plants can directly absorb the inorganic nitrogen and transform it into organic nitrogen. Through a survey of submerged and floating-leaved plants, it is found that the nitrogen in the water is negatively correlated with plant diversity, especially for the nitrate nitrogen in water during winter [26]. Using floating beds can reduce the nitrogen in water by changing the number of bacteria and fungi at different levels to achieve an improvement in water quality [27]. Removing phosphorus by wetlands mainly involves three ways: adsorption, filtration, and precipitation [28]. The effective plants for dephosphorization include Hydrocharis dubia and Lemna minor in winter, Eichhornia crassipes in summer, etc. [29]. The removal rate of phosphorus by Ipomoea aquatica, Canna indica, and Chlorophytum comosum separately are relatively higher compared with other plants, with a value of 55.7%, 66.4%, and 30.6% respectively [30, 31].

Then, an allocation of different plants in constructed wetlands is an important factor that affects not only the treatment efficiency of eutrophic water but also the management and maintenance of urban parks [32]. The purification effects of several plant communities were tested in previous research, including Ceratophyllum Demersum, Zizania Caduciflora, Ceratophyllum Demersum, Trapa incisa, Potamogeton Pectinatus, etc [33]. In previous case studies, it was found that increasing the proportion of submerged plants can improve the removal rate of nitrogen in constructed wetlands; and developed roots in wetlands are also helpful for the purification effect of polluted water [34]. Among the current practices, new problems have arisen. For example, the death of aboveground plants in winter, like Phragmites australis, Pontederia cordata, Cyperus alternifolius, Typha angustifolia, may affect the decontamination process and their ornamental functions [35, 36]; The maintenance of herbaceous plants under a low temperature is also a hard task for many urban parks because the falling leaves of these herbaceous plants can also lead to a rising of maintenance costs. And if the stems and leaves become rotten in water, the absorbed substances will return to the ecosystem, aggravating secondary pollution in the water [37].

As is seen, a healthy aquatic community with species allocation is needed to guarantee the purification effect free from seasonal influences, at the same time limiting the secondary pollution in urban parks to achieve the goal of solving eutrophication and retaining biodiversity in urban areas. Choosing proper aquatic plants to form a community can improve the water purification effect of a constructed wetland and its functions in an ecosystem. After the literature review, it can be seen that previous studies are mainly focusing on single plants and their purification effects, and a few research studied the purification effects from the perspective of wetland communities. This paper focuses on a comparative experiment on the water purification effect using different groups of aquatic plants to form an effective aquatic community, especially for the regions in Guangzhou city, which can provide a reference for future construction and management in this area.
2. Materials and methods

2.1. Study area
This research chooses Tianhe wetland park as the study area, which is located in Guangzhou city in China. As an important economic center in the south of China, it is adjacent to Hongkong and Macau, known as the 'Guangdong-Hong Kong-Macao Greater Bay Area', containing many cultural and natural attractions, such as the Danxia landform recognized by UNESCO [38]. As the only wetland park in this area, Tianhe Wetland Park is the first ecological landscape in Guangzhou, constructed in accordance with the concept of ‘sponge city’ proposed by the scholar - Yu Kongjian [39]. Before its construction, this area was seriously contaminated. The wetland park improved the water quality by regulating and purifying rainwater to achieve the goal of self-purification. This park is currently surrounded by some densely populated areas, and it is now known as a ‘Green Necklace’ in Guangzhou, attracting nearby residents and white-collar workers to visit every day. Studying the water quality of this wetland park is meaningful to the ecological development of this whole area (figure 1). Also, the plants in Tianhe park are typical to represent the vegetation in the south of China [40]. Thus, the experiment results in this study can be learned by other urban parks in the south of China to provide a reference for protecting the ecological functions of wetlands in urban areas and avoiding further problems during park construction and maintenance [41, 42].

Based on this study area, a comparative experiment and simulation were designed and applied as the methodology to monitor and measure the wetland under different conditions. The experiment lasted for seven months for observing an overall and continuous purification effect of plant communities constructed by various aquatic plants to simulate the real environment in Guangzhou city. By measuring the changes in water under the influences of different communities, seven indexes for water quality and eutrophication were selected and calculated. And a statistical analysis of the monitoring results was made consequently. Specific research steps in this paper are as follows (figure 2):

(1) Analyze the current situation of the Wetland Park in Guangzhou and investigate the composition of vegetation communities.

(2) Establish sampling sites in the park and select environmental indicators to monitor the sites, including the contents of nitrogen, phosphorus, and ammonia nitrogen, as well as the comprehensive water quality index.

(3) Configure eutrophic water in the laboratory, then test the water purification effects under different combinations of plant communities; select the plant groups with better purification results.

(4) Plant the selected groups in the wetland park to monitor and compare the water quality between the configured communities and the original wetland plants in the park.

Finally, the authors put forward some suggestions for the improvement of plant allocation for other similar wetland parks in this region (Zhujiang delta in Guangdong province in South China).

Figure 1. Study area: (a). Location of Guangdong Province. (b). Tianhe district. (c). The location of Tianhe Wetland Park. (d) sampling site in the study area.
### 2.2. Site investigation

A site investigation was conducted at the beginning of this research, which aimed to figure out the current park conditions and plant configurations to lay a foundation for further experiments and plant selection. After ten times of fieldwork from April 2019 to January 2020, the authors figured out that there were mainly 68 species of plants distributed in Tianhe Wetland Park, of which the emergent plants account for 60%. The dominant species in the wetland park are Phragmites australis, Thalia dealbata, Syzygium jambos, and Taxodium distichum.

Then, 13 sample points were selected in the park as representative sites for further studies. The sampling sites were set based on the distribution of ponds in the park to make sure that every pond contains at least one sample site. During the fieldwork, the authors went to the sample sites to collect sampling water, which was obtained at a height of 5 cm from the surface of the water. With an interval of 30 days (the first data was 4th April 2019, the second date 4th May 2019, the third date 4th June 2019, and so forth), the samples were collected ten times from the same places. The software Statistical Product and Service Solutions (SPSS) was applied to analyze the measured values from the park. Inspired by previous studies [43–46], the authors chose seven indicators to test and evaluate the water quality, including pH value, dissolved oxygen (DO), total phosphorus (TP), total nitrogen (TN), ammonia nitrogen (NH3-N), chemical oxygen demand (COD), and turbidity (TU).

Especially, the Comprehensive Water Quality Identification Index (CWQII) as an important index was calculated according to the selected seven indicators [47–49]. Because CWQII is an objective and quantitative method for measuring water quality, widely used for a comparison of water quality in different sections of a river and the evaluation of water quality in several rivers [50]. The severity of polluted water can be reflected in this value. The two steps for calculating CWQII are as follows:

#### 2.2.1. Calculate the value of independent factors

Each index value is composed of two parts: \( X_1 \) means the integer part and \( X_2 \) means the decimal part, among which the \( X_1 \) is obtained according to the water quality standard issued by the Chinese Ministry of Environmental Protection (table 1) [51]. \( X_1 \) will have a value changing from 1-5 (five classes: I, II, III, IV, and V in the table). And \( X_2 \) is calculated as follows (using the DO as an example):

\[
p_m = \frac{p\ DO\ (high) - p\ DO}{p\ DO\ (high) - p\ DO\ (low)} \times 10
\]

In this equation, the \( p\ DO \) means the measured dissolved oxygen from the site. \( p\ DO\ (high) \) and \( p\ DO\ (low) \) mean the two values in the interval next to the real value. For example, if a measured value is 5.5, according to table 1, the \( p\ DO\ (high) \) and \( p\ DO\ (low) \) will be 6.0 and 5.0 separately.

#### 2.2.2. Calculate the CWQII value

CWQII is also composed of an integer part and four decimal places (\( X_1, X_2, X_3, \) and \( X_4 \)). \( X_1 \) means the integer part and \( X_2—X_4 \) means the decimal parts. The \( X_1 \) and \( X_2 \) places can be calculated according to the seven
independent factors. p1-p7 are the pm value obtained from step 1. The average value of the pm shows the $X_1$ and $X_2$ of the CWQII:

$$\frac{1}{7} \sum (p1 + p2 + p3 + \cdots + p7)$$  \hspace{1cm} (2)$$

Then, $X_3$ is the number of independent factors with the class lower than the IV class. $X_4$ is obtained according to $X_1$. If $X_1 \leq 4$, then $X_4 = 0$. If $X_1 > 4$, $X_4 = X_1 - 4$ [52].

After calculation, the water quality can be classified into five grades based on the CWQII value. A lower CWQII value means a better water quality and a higher value indicates a worse quality. Among these, grade I (1-2) mainly belongs to the water in national nature reserves with the highest standard; Grades II and III (2-4) refer to the surface water for domestic and drinking uses with an average quality; Grade IV (4-5) mainly includes industrial water and entertainment water; Grade V (5-7) has the worst quality and cannot be used as drinking water sources, mainly applicable to agricultural water or other requirements. After applying the seven indicators to the calculation, the CWQII in Tianhe Wetland Park was obtained for ten months as shown in Table 2.

### 2.3. Purification experiment in the lab

In this stage, single plants with good purification effects were selected for a vegetation configuration in the wetland. According to the previous literature review and site investigation results, the plants with better purification effects include Taxodium distichum, Syzygium jambos, Phragmites australis, Thalia dealbata, Myriophyllum verticillatum, Callistemon viminalis, Bischofia javanica, Triadica sebifera, Canna indica, Juncus effusus, Arundo donax, and Hydrilla verticillate, involving woody plants, emergent plants, and submerged plants.

The authors set up two blank groups and ten control groups for the experimentation. Based on the stimulated water conditions of Tianhe Wetland Park, this experiment took the plant communities selected from the park as the object to test their purification capacity. The two blank groups were T1 with only eutrophic water and T2 with eutrophic water and pond soil. Ten control groups were set by a combination of arboreal, emergent, and submerged plants as follows:

- **T3**: Taxodium distichum, Syzygium jambos, Phragmites australis, Thalia dealbata, Myriophyllum verticillatum.

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### Table 1. Water quality standard (GB3838-2002).

| Index | I   | II  | III | IV  | V   |
|-------|-----|-----|-----|-----|-----|
| TP    | 0.02| 0.1 | 0.2 | 0.3 | 0.4 |
| TN    | 0.2 | 0.5 | 1.0 | 1.5 | 2.0 |
| NH3-N | 0.15| 0.5 | 1.0 | 1.5 | 2.0 |
| DO    | 7.5 | 6.0 | 5.0 | 3.0 | 2.0 |
| COD   | 15  | 15  | 20  | 30  | 40  |
| TU    | 0.05| 0.5 | 1.0 | 2.0 | 3.0 |
| pH    | 6–9 |     |     |     |     |

### Table 2. The CWQII value.

| Site | Apr. 2019 | May 2019 | June 2019 | July 2019 | Aug. 2019 | Sept. 2019 | Oct. 2019 | Nov. 2019 | Dec. 2019 | Jan. 2020 |
|------|-----------|----------|-----------|-----------|-----------|------------|-----------|-----------|-----------|-----------|
| 0    | 5.831     | 4.51     | 4.71      | 4.41      | 5.431     | 4.63       | 6.142     | 6.542     | 6.033     | 6.13      |
| 1    | 5.631     | 3.81     | 4.11      | 4.01      | 5.021     | 5.031      | 5.231     | 4.21      | 4.42      | 5.441     |
| 2    | 5.331     | 3.91     | 3.31      | 4.01      | 5.131     | 4.21       | 4.41      | 4.22      | 4.11      | 4.43      |
| 3    | 5.121     | 4.31     | 4.12      | 4.21      | 5.321     | 4.82       | 4.11      | 4.02      | 4.21      | 3.71      |
| 4    | 5.131     | 4.42     | 3.81      | 3.81      | 5.331     | 4.42       | 4.21      | 4.12      | 3.5       | 3.61      |
| 5    | 6.352     | 3.71     | 3.71      | 3.41      | 5.221     | 4.21       | 4.31      | 3.82      | 3.3       | 3.61      |
| 6    | 5.231     | 5.32     | 4.21      | 3.91      | 4.82      | 4.21       | 4.71      | 4.11      | 3.7       | 4.22      |
| 7    | 4.62      | 4.01     | 4.21      | 4.51      | 5.431     | 5.331      | 5.531     | 5.431     | 4.93      | 4.31      |
| 8    | 4.41      | 4.51     | 5.931     | 4.72      | 5.531     | 5.631      | 5.721     | 4.62      | 5.021     | 4.01      |
| 9    | 4.44      | 4.93     | 5.831     | 3.91      | 5.121     | 5.331      | 5.641     | 5.231     | 3.91      | 3.91      |
| 10   | 4.01      | 4.71     | 6.242     | 4.02      | 5.331     | 4.42       | 5.131     | 4.51      | 4.11      | 4.22      |
| 11   | 4.52      | 3.91     | 5.031     | 4.01      | 5.641     | 4.52       | 4.52      | 4.21      | 4.62      | 4.72      |
| 12   | 4.81      | 4.72     | 5.131     | 4.41      | 5.231     | 4.42       | 5.341     | 5.131     | 5.741     | 4.93      |
The experiment was conducted from July 20, 2019, to January 25, 2020 (all seven months). The experiment device was a translucent plastic water tank with a size of 130 * 80 * 65 cm, containing a layer of soil (10 cm). The initial water depth for the test was 40 cm. The eutrophic water body was artificially configured in the laboratory with the following parameters: pH: 7.81 ± 0.13; DO: 7.52 ± 0.14 (mg/L); TU: 48.36 ± 0.12; NH3-N: 4.43 ± 0.14 (mg/L); TN: 7.85 ± 0.15 (mg/L); TP: 2.35 ± 0.13 (mg/L); COD 76.52 ± 0.15 (mg/L). After an observation and measurement (figure 3), the purification effect of eutrophic water by different communities was measured according to the changing rate of seven indicators in the experiment period.

2.4. Simulation in the park

After the experiment in the lab, in this step, the selected grouped plants were used as the experiment groups (same plant configuration as A groups: T1A, T2A, T3A, and T4A). And four new control groups (B groups: T1B, T2B, T3B, and T4B) followed the original vegetation from the sampling sites in Tianhe Wetland Park to compare with the experimental groups. All the groups were all put back to the sample sites 7-10, where there was with poorer water quality in the park during the investigation period. The plants in the experiment and control groups were as follows:

**T1A:** *Callistemon viminalis, Bischofia javanica, Canna indica, Juncus effusus, Vallisneria natans, Hydrilla verticillata var. rosburghii.*

**T1B:** *Taxodium distichum, Canna indica, Myriophyllum verticillatum.*
T2A: *Callistemon viminalis, Bischofia javanica, Canna indica, Juncus effusus, Vallisneria natans, Hydrilla verticillata var. rosburghii.*

T2B: *Taxodium distichum, Thalia dealbata, Colocasia tonoimo Nakai.*

T3A: *Callistemon viminalis, Bischofia javanica, Canna indica, Juncus effusus, Vallisneria natans, Hydrilla verticillata var. rosburghii.*

T3B: *Thalia dealbata, Pontederia cordata.*

T4A: *Callistemon viminalis, Bischofia javanica, Canna indica, Juncus effusus, Vallisneria natans, Hydrilla verticillata var. rosburghii.*

T4B: *Taxodium distichum, Scirpus validus Vahl.*

The experimental groups were planted in areas with a size of 2 m $\times$ 1 m in the park. The T1A and T1B groups were assigned to the No. 7 sampling site, T2A and T2B to the No. 8 site, T3A and T3B to the sampling point nine, and T4A and T4B to the sampling point ten. After planting, the water quality from sample points was monitored every 30 days from November 10, 2019, to January 10, 2020, mainly during the winter seasons in China (all three months). The simulation process was also aimed to test whether the designed plant community can functions well during the winter compared with the original plants in the park, especially facing the park management problems, such as the growth rate of plants, decay of tissues, and withered leaves. Then, each collected sample contained 100 ml for every measurement, and it was monitored and measured properly on the same day of the sample collection. A general look of the sampling site was attached in figure 4, which was recorded in October 2019.

3. Results

3.1. Investigation results

According to the records during the fieldwork, the pH value of the water in Tianhe Park began to rise in October, when the rainfall in Guangzhou began to decrease during the year, and the temperature gradually decreased. The level of COD started to deteriorate after September, which was caused by the decline of emergent plants after their growth in summer. November was the month when some deciduous plants started to defoliate in this area (subtropical area), including the *Taxodium distichum, Thalia dealbata,* and *Phragmites australis* in Tianhe Wetland Park. Falling leaves were the main reason that affected the COD value. As for the nutrients, the records showed that the phosphorus at sample zero exceeded the normal standard by 50%. But the phosphorus content in samples one to five was relatively low, mainly owing to the absorption by *Phragmites australis* and *Thalia*
After October, the phosphorus in the park increased in a larger area, which was due to the phenomenon of plants withering. In each sampling point of Tianhe Wetland Park, the content of total nitrogen was really high in November. As a result, the aquatic organisms and microorganisms multiplied and water eutrophication happened.

It was also found that samples No. 1–5 had a better capacity for absorbing phosphorus; samples five and six had a better capacity for the absorption of nitrogen. Due to a slow water flow, the purification effect of the park in the middle and posterior segments of the park deviated. The water quality began to deteriorate after the No. 7 sampling point. Especially at the sampling points eight and nine, the water quality deteriorated several times during the whole year. The unqualified water samples mainly belonged to the No. 12 site. According to the sampling results, the 7–10 sites were selected for the next simulation process.

### 3.2. Experiment results

For communities with arboreal plants, T4 was observed with seven indexes better than T3, T6 with 6 indexes better than T3, and T5 has four indexes better than T3; for communities composed of emergent plants, T7 owned six indexes better than T3, four indexes of T8 were better than T3, and three indexes of T9 were better than T3. For groups with submerged plants, T10 had seven indexes better than T3, T11 had 6 indexes better than T3, and T12 had five indexes better than T3.

Generally, a higher removal rate means a better capacity for absorbing pollutants (TU, COD, TP, TN, and NH3-N). For DO, a higher value means a better water quality and a lower value indicates a contaminated condition. For pH value, a lower changing rate means a more stable condition in the water. After a calculation of the seven indicators (table 3), it shows that the groups of T4, T7, and T10 are always with a good capacity for improving the water quality. They are: T4 (Callistemon viminalis, Bischofia javanica, Phragmites australis, Thalia dealbata, Myriophyllum verticillatum), T7 (Taxodium distichum, Syzygium jambos, Camna indica, Juncus effusus, Myriophyllum verticillatum), and T10 (Taxodium distichum, Syzygium jambos, Phragmites australis, Thalia dealbata, Vallisneria natans, Hydrilla verticillata var. rosburghii). Thus, the six plants: Callistemon viminalis, Bischofia javanica, Hydrilla verticillata var. rosburghii, Camna indica, Juncus effusus, and Vallisneria natans were regarded as the stimulated objects to put back to the Tianhe Wetland Park for observation under a natural condition of water flow.

### 3.3. Simulation results

After a three-month observation in the last step, as is seen in figure 5, the values of the seven indicators in the experiment groups were clear, and the changing rate of each indicator is also shown in the line charts associated. Specific changing rates are all included in the figure.

According to figure 5, it can be summarized that for pH value, the communities of T3A and T2A were most stable (with the lowest changing rate), and the pH values in these two sample areas were close to 7 during the three-month observation.

The result of TU showed that the T1A, T2A, and T3A had good turbidity removal rates. The structure of the plant community helped to form a stable living space among plants, and it was conducive to the growth of microorganisms and plankton in the water. The plant roots formed a multi-network underwater working cooperatively to reduce the turbidity.

The DO values show that both T1A and T3A were with a higher changing rate of dissolved oxygen, while T2A showed a weak increasing rate for dissolved oxygen, which was due to the influence of microorganisms in water and aquatic animals, such as fishes and shrimps.

For COD, the removal rates in T1A, T2A, and T3A were higher than those under the influence of the native plant communities. It was proved that the compound plant community had a consistent ability in COD reduction. Same as the indicators of TP, TN, and ammonia nitrogen, the removal rates in T1A, T2A, and T3A were higher than those from the original park communities.

| Indicators | Changing rate (from high to low values) |
|------------|----------------------------------------|
| TU         | T4 T7 T5 T6 T10 T8 T12 T11 T3 T9 T1 T2 |
| DO         | T7 T10 T8 T9 T11 T12 T4 T5 T6 T3 T1 T2 |
| COD        | T10 T4 T11 T12 T7 T6 T3 T9 T5 T8 T1 T2 |
| TN         | T7 T4 T10 T3 T12 T11 T9 T6 T5 T8 T1 T2 |
| NH3-N      | T7 T10 T12 T9 T4 T11 T8 T6 T5 T3 T2 T1 |
| TP         | T11 T10 T12 T4 T5 T7 T6 T8 T9 T3 T2 T1 |
| pH         | T9 T7 T8 T6 T5 T12 T3 T11 T2 T10 T4 T1 |
Finally, the overall CWQII for every group was calculated as shown in table 4. Both T1A and T1B showed an improvement in water quality from November to January. The CWQII value of T1A was lower than that of T1B during the three months (a lower value means better quality), with a difference of 0.3, 0.3, and 0.2 in three months. In the T2 experimental groups, both T2A and T2B showed a trend of quality improvement. The difference values between T2A and T2B are 0.09, 0.1, and 0.19. The same phenomenon was also observed in the T3 experimental groups, with a difference of 0.5, 0.4, and 0.4. It can be seen that the tested plant communities (A groups) in this area have a more positive effect on the overall water quality of Tianhe Wetland Park compared with the original conditions in the park.

Then, regression models were constructed to check the relationship among the indicators in the experiment. For example, DO and TP values had a significant correlation. The t-test result was 0.003 (less than 0.01), and the regression coefficient can be significant. DO and TP were significantly positively correlated (0.435). For the groups with missing values, the TP trend of group T4 can be inferred based on the DO value. DO and ammonia nitrogen also had a significant correlation. The t-test was 0.017 (less than 0.05), indicating that the regression coefficient was significant. Thus, DO and ammonia nitrogen were positively correlated with each other (0.315). And the ammonia nitrogen content of the experimental group T4 which was missed in the experiment can be inferred based on the dissolved oxygen value.

![Figure 5. Seven indicators for water quality.](image)

| Table 4. CWQII for experiment groups. |
|--------------------------------------|
| Sample | Nov. | Dec. | Jan. |
|--------|------|------|------|
| T1A    | 5.23 | 4.12 | 3.71 |
| T1B    | 5.53 | 4.42 | 3.91 |
| T2A    | 4.83 | 4.32 | 3.72 |
| T2B    | 4.92 | 4.42 | 3.91 |
| T3A    | 3.92 | 3.40 | 3.41 |
| T3B    | 4.42 | 3.80 | 3.61 |
4. Conclusion and discussions

In conclusion, as one of the important elements to improve the urban environment, wetland park is an ecological structure composed of urban water networks and plant communities. The services provided by wetland parks, such as ecological restoration, rainwater storage, and flood regulation are necessary for the normal function of human society. The wetland park not only optimizes landscape values in urban design but also provides abilities for the purification of polluted water in urban areas.

The site investigation process in the research found that the samples from Tianhe Wetland Park have different water qualities according to the CWQII value and seven water indexes. The 7-10 sites were selected for the simulation process because of their poor water quality. During the experiment, it showed that groups of T4, T7, and T10 were with a good capacity for improving the water quality reflected by the changing rate of water indexes. At last, in the simulation, it was found that the designed plant community showed a good capacity for improving the TU, DO, DOC, TP, TN, and ammonia nitrogen, at the same time keeping a stable pH value for the water compared with the original plants in the park.

Thus, this research showed that compared with the original vegetation communities, an allocation of Callistemon viminalis, Bischofia javanica, Canna indica, Juncus effusus, Vallisneria natans, and Hydrilla verticillata var. rosburghii as a community can function well in a constructed wetland park for better water purification. Focusing on the seven indicators, the designed community showed a good removal rate for the TU, COD, TP, TN, and ammonia nitrogen. The removal rate of DO, TU, COD, TP, and TN by the designed community can reach 43%, 65%, 45%, 51%, and 62% in sampling sites. And the CWQII value was decreased with the help of the designed community, with a changing value between 0.09 to 0.4. Also, because of a combination of the designed plants with arboreal, emergent, and submerged species, previous park problems were also relieved. Among the six selected plants, Callistemon viminalis and Bischofia javanica are arboreal; Hydrilla verticillata var. rosburghii and Vallisneria natans are submerged; Canna indica and Juncus effusus are emergent. These plants were with different growth periods, which made sure that the community can function well during the winter. At last, some suggestions are also made for the future park management in this area:

(1) The local urban parks in Guangzhou should strengthen the control of the pollution sources for water bodies. According to the fieldwork, the sampling points in the park with unqualified water indicated that the pollution source was not well controlled in Guangzhou. It is recommended to use a combination of aquatic plants for better water treatment. And a certain number of woody plants are needed in the wetland park. Emergent plants can grow fast and absorb nutrients during their growth period. However, some emergent plants have the problem of winter withering and deciduous leaves. When emergent plants reach the absorption saturation for absorbing pollutants, they are going to die. The substances absorbed by the emergent plants will re-enter the water cycle, causing the second pollution. Thus, woody plants are better choices for a wetland park because of their longer growth seasons [53, 54].

(2) Because of the large area and broad water body of the wetland park, it might be inconvenient for landscapers in the park to manage and monitor the whole park area. Drone and other advanced machines can be introduced to inspect the growth of plants and the water quality [55]. Introducing remote sensors to monitor water quality and establish an early warning system will facilitate water intervention and find the causes of pollution in time [56]. However, due to the limitation of time and research conditions, the methodology should still be improved. The following issues need to be further discussed:

A. In the water body of constructed wetland parks with dynamic water flow, suitable aquatic plant communities need to be selected according to some specific parameters, such as the water level, runoff, precipitation, and different pollution sources. In this paper, only one aquatic plant community was tested in the experiment for Tianhe Wetland Park. Thus, how to configure different plant communities for different wetlands should be an issue to be discussed in future research [57].

B. For the water purification effect in the constructed wetland park, more conditions during the process should be considered, such as a combination of different substrates to alleviate the unstable absorption of nitrogen and phosphorus during the initial plant growth stage. The saturation of absorption, especially the upper and lower limits of absorption for different plants should also be compared and discussed in the future [58].

Data availability statement

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

[1] Janssen R, Goosen H, Verhoeven M L, Verhoeven J T, Omtzigt A Q A and Mahly E 2005 Decision support for integrated wetland management Environ Model & Soft 20 215–229
[2] Niu Z, Zhang H, Wang X, Yao W, Zhou D, Zhao K and Gong P 2012 Mapping wetland changes in China between 1978 and 2008 Chin. Sci. Bullet. 57 2813–2823
[3] Quesnelle P E, Lindsay K E and Fahrig L 2015 Relative effects of landscape-scale wetland amount and landscape matrix quality on wetland vertebrates: a meta-analysis Eco Appl. 25 812–825
[4] Chen Y Y and Lu X G 2003 The wetland function and research tendency of wetland science Wet Sci. 17–11
[5] Nassauer J I 2004 Monitoring the success of metropolitan wetland restorations: cultural sustainability and ecological function Wetlands 24 756–765
[6] Li N, Wang Z and Zhang Z 2018 Influence of plant structure and flow path interactions on the plant purification system: dynamic evolution of the SO2 pollution Environ. Sci. & Pollut. Res. 25 35099–35108
[7] Jez J, Castilho A and Grass J 2013 Expression of functionally active sialylated human erythropoietin in plants Biotechnol. J. 8 371–382
[8] Yu Y 2012 The oxidation process of ammonia nitrogen in the water of the North Canal and the response of microorganisms features Doctoral thesis of Capital Normal University(Beijing, China)
[9] Conkle J L, White JR and Metcalfe C D 2008 Reduction of pharmaceutically active compounds by a lagoon wetland wastewater treatment system in Southeast Louisiana Chesmophere 73 1741–1748
[10] Kadlec R, Knight R, Vymazal J, Brix H, Cooper P and Haberl R 2000 Constructed Wetlands for Pollution Control: Processes, Performance, Design and Operation. (London, UK: IWA publishing)
[11] Brix H 1994 Use of constructed wetlands in water pollution control: historical development Present Status, and Future Per-Spectives. Water and Sci. And Techn. 30 209–223
[12] Zhang T, Xu D, He F, Zhang Y and Wu Z 2012 Application of constructed wetland for water pollution control in China during 1990–2010 Ecolog Enginee 47 189–197
[13] Todd M J, Muneepeerakul R, Pumo D, Azaele S, Miralles-Wilhelm F, Rinaldo A and Rodriguez-Iturbe I 2010 Hydrological drivers of wetland vegetation community distribution within everglades national park, Florida Adv. Water Res. 33 1279–1289
[14] Lidskog R 2021 The re-naturalization of society? Environmental challenges for sociology Current Sociology 49 113–136
[15] Wang Y 2011 Preliminary study on the design of urban wetland park Master thesis Beijing Forestry University( Beijing, China)
[16] Li J 2007 Practical research on combined constructed wetland sewage treatment system master thesis Central South University of Forestry and Technology(Changsha, China)
[17] Wu X, Deng K, Ge P, Wang Y and Xue Y 2019 Investigation on the ecological environment and resource protection management system of Fuxian lake Proc. of the 5th Int. Conf. on Mechatronics, Materials, Chemistry and Computer Engineering, Chongqing, China, 2017, pp.24-25
[18] Khan F A and Ansari A A 2003 Eutrophication: an ecological vision The Botan Review 71 449–482
[19] Li X, Jia J and Xiang L 2016 Correlation among soil enzyme activities, root enzyme activities, and contaminant removal in two-stage in S itu constructed wetlands purifying domestic wastewater Bull of Envi. Contam. and Toxic 97 1–12
[20] Zhao F 2012 Screening of energy plants for efficient purification of eutrophic water bodies and their physiological and ecological basis Master thesis Zhejiang University (Hangzhou, China)
[21] Schindler D W 2006 Recent advances in the understanding and management of eutrophication Limno and Oceano 51 356–363
[22] Kumbasar R A 2013 Selective extraction of cadmium from multi component acidic leach solutions by emulsion liquid membrane using amibeite LA-2 as extractant Sepa. Sci. and Tech. 48 1841–1850
[23] Chen X, Cheng X and Zhu H 2019 Influence of salt stress on propagation, growth, and nutrient uptake of typical aquatic plant species Nordic Journal of Botany 37 1–10
[24] Jodhi M L, Birnin-Yauri U A, Yahaya Y and Sokoto M A 2012 The use of some plants in water purification Glo Adv Res Jour of Chem and Mattr Sci. 17 71–75
[25] Issaveya A, Yeshibayev A, Tekueveya A and Issavey Y 2021 Use of phytomeliorant plants for wastewater purification Jour. of Ecolog Engin. 22 48–57
[26] Yang H 2008 Basic research on ecological restoration and reconstruction of Wuli Lake lakeside zone Master Thesis Shanghai Jiaotong University(Shanghai, China)
[27] Kuwabara T, Matsumura M and Hayashi N 2007 Effect of aquatic plants on float type hydroponic cultivation purification method Japa Jour of Wa Treat Bio 43 1–10
[28] Jeyalakshmi G, Saritha V and Dwarapureddi B K 2017 A review on native plant-based coagulants for water purification Inter Jour of Appl. Environ. Sci. 12 469–487
[29] Wang Z, Zhao Z, Cheng M, Zhang Y and Shi Z 2021 Influence of plant community on the purification of domestic sewage by constructed wetland Chin Jour of Environ Engin 15 1–10
[30] Li Y 2008 Research on the ecological types of shallow lakes and their ecological restoration Master Thesis China University of Mining and Technology( Beijing, China)
[31] Wu W, Qu J and Wang X 2011 Bio-purification of Macrobryachium nipponense by aquatic plant microbial enhancement system Eco. and Jour. of Rur. Enviir. 27 108–112
[32] Lv B 2012 New technology of sewage biological treatment Doctoral thesis Harbin Institute of Technology(Harbin, China)
[33] Shi Y, Wang X and Luan X 2009 Cold-resistant constructed wetland study on the combined use of plant shilongrui and rumex Jour. of Envir. Engin. 3 268–270
[34] Zhou Z, Chen C and Ye Q 2010 Purification effect of floating bed plant system on eutrophic water Jour of Hua Uni. (Natural Sci. -Ene Edition) 31 576–579
[35] Yang Y, Li Y and Wang Z 2010 Research on the removal of phosphorus in wastewater from rivers flowing into Yunnan by floating cultivated aquatic plants Agri Envir Acta Sci. 29 1763–1769
[36] O’Hare M T, Baattrup-Pedersen A, Baumgarte I, Freeman A, Gunn I D, Lázár A N and Bowes M J 2018 Responses of aquatic plants to eutrophication in rivers: a revised conceptual model Frontiers in plant science 9 451
[37] Qiao S 2019 Comparative analysis of purification effect of different wetland plant community allocation on high concentration wastewater Ekojlo 28 1709–1719
[38] Xu J and Yeh A G 2005 City repositioning and competitiveness building in regional development: new development strategies in Guangzhou China. Intern. Jour. of Urb. and Regi. Rese. 29 283–308
[39] Nguyen T T, Ngo H H, Guo W, Wang X C, Ren N, Li G and Liang H 2019 Implementation of a specific urban water management- Sponge city Sci. of the Tot. Envi. 652 147– 162
[40] Peng X F, Zhn X H, Wang F R, Tan W F and Cheng Z H 2006 A Primary study on the valuation of ecosystem services in Tianhe Park Ecozo Sci 25 176–179
[41] Kun LE I 2005 Some thoughts on wetland park construction and development in China Fore Reso Manag 2 1–15
[42] Zeng Y, Wang L and Li X 2019 A study on regional ecological design of overseas Chinese wetland-taking the design of Fenghewen wetland park-taking Kaiping city as an example Ekojlo 28 3177–3182
[43] Colford J M, Wade T J, Schiff K C, Wright C C, Griffith J F, Sandhu S K and Weisberg S B 2007 Water quality indicators and the risk of illness at beaches with nonpoint sources of fecal contamination Epidemi 18 27–35
[44] Mimikou M A, Balas E, Varanou E and Pantazis K 2000 Regional impacts of climate change on water resources quantity and quality water quality indicators Jour of Hydro 234 95– 109
[45] Teodosiu C, Robu B, Ciojocaru C, and Barjoveanu G 2015 Environmental impact and risk quantification based on selected water quality indicators Natur Haz 75 89–105
[46] Walsh P J and Milon J W 2016 Nutrient standards, water quality indicators, and economic benefits from water quality regulations Envir and Reso Econ 64 643–666
[47] Zhu Y H, Zeng T, Yang J and Tan Y 2010 Water quality assessment in Shashi of the Yangtze river by comprehensive water quality index Saw–to–Nor Wat Trans Wat Sci and Tech 8 122–124
[48] Qun M, Ying G, Zhi Q and Xiao H 2019 Application of comprehensive water quality identification index in water quality assessment of river WRI Global Congress on Intelligent Systems (May 19–21) (Xiamen, China) pp. 333–337
[49] Zhang Y, Hou K and Qian H 2020 Water quality assessment using comprehensive water quality index and modified nemorow index method: a case study of Jinghui Canal North China. In IOP Conf. Series: Earth and Environmental Science 21-23 (Changzhou, China)012125
[50] Yin H L and Xu Z X 2008 Comparative study on typical river comprehensive water quality assessment methods Reso and Enviro in Yang Bas 5 11
[51] Chinese Ministry of Environmental Protection 2022 Environmental quality standards for surface water https://mee.gov.cn/ywgz/fgbz/bz/bwsh/shj/hz/200206/W02006102750986672057.pdf
[52] Xu Z 2005 Comprehensive water quality identification index for environmental quality assessment of surface water Jour of Tongji Uni 33 44882–488
[53] Sim H, Oh Y, Park C and Kang W 2015 Natural purification treatment using soil brick with combined effective microor-ganisms and emergent plants Jour of Korean Soc of Wat and Wast 29 543–550
[54] Xu J, Liu J, Hu J, Wang H, Sheng L, Dong X and Jiang X 2021 Nitrogen and phosphorus removal in simulated wastewater by two aquatic plants Envir Sci and Pollu Re 28 65327
[55] Del Castillo E M, Garcia-Martín A, Aladrén L A L and De Luis M 2015 Evaluation of forest cover change using remote sensing techniques and landscape metrics in Moncayo natural park (Spain) Appl Geog 62 247–255
[56] Alabassi S A and Al-Jameel H A 2018 Design and study of a smart park system: university of kufa as a case study Kufa Jour of Engin 91–10
[57] Liu Y, Lei S, Chen X, Chen M, Zhang X and Long L 2021 Study of plant allocation pattern in guided vegetation restoration: a case study of semiarid underground mining areas in Western China Ecol Engin 170 106334
[58] Cao B, Wang L and Yin F 2019 Measurement of saturated water absorption of the contamination layer deposited on insulator surface IEEE Sens Jour. 19 10804–10811