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Wetland water quality assessment of eco-engineered landscaping practices: a case study of constructed wetland parks in Hangzhou

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ABSTRACT

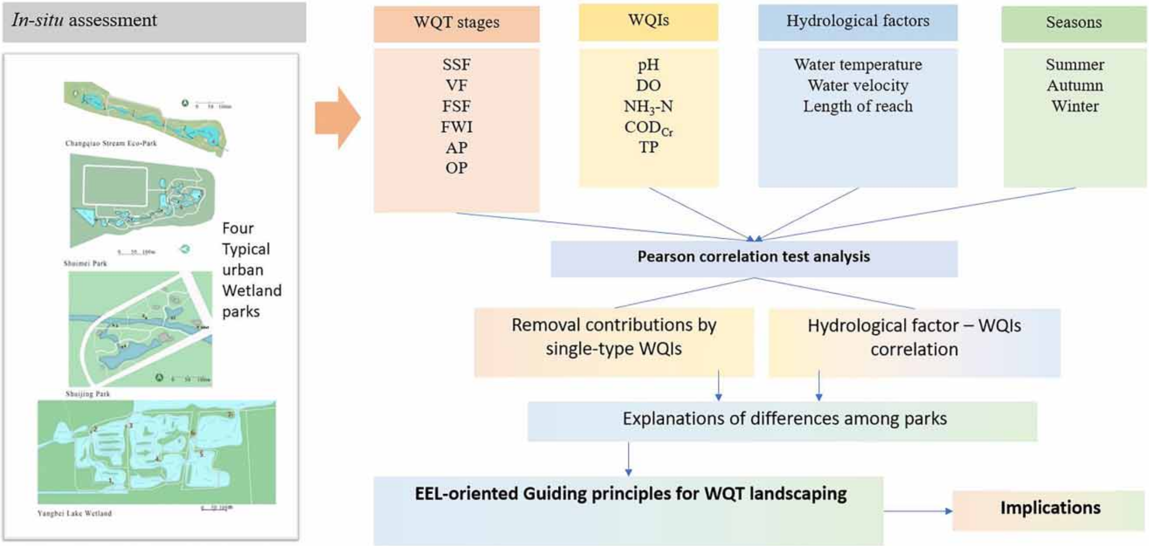
Urban constructed water quality treatment (WQT) wetlands are often applied to be integrated with ecological engineered landscaping (EEL) measures for wastewater treatments. This study aims to identify the interrelationships between the hydrological factors and pollutant removal contributions of typical WQT wetlands at each WQT stage, i.e., subsurface flow wetlands (SSF), vertical flow wetlands (VF), free surface flow wetland (FSF), floating wetland island (FWI), aeration ponds (APs), and ornamental ponds (OPs) in four typical wetland parks in Hangzhou, China. Water quality indices (WQIs) of wetland parks have been monitored. Interactive comparisons and correlations between hydrological indicators and WQIs (i.e., pH, DO, NH_3-N, COD_{Cr}, and TP) are developed, while the removal contribution of each WQI was explained. It is found that each stage had heterogeneous effects on wastewater treatment due to various geo-ecological factors, including hydraulic conditions, plant type, and microbial microenvironment, whereas the temperature of waterbodies affected WQT performances at full sites in all seasons. Three corresponding EEL guiding principles were derived, i.e., optimising the EEL measures, adapting planting methods, and incorporating multifunctional design and adaptive management. The findings will be helpful for improving the efficacy of WQT stages as one of the potential ecosystem services provided by wetland parks.

Key words: ecological engineered landscaping (EEL), wastewater, water quality indicator (WQI), WQT wetlands

HIGHLIGHTS

- In the *in-situ* survey, hydrological factors and water quality indices at each treatment stage in wetland parks are assessed.
- The DO, COD_{Cr}, NH_3-N, TP, and pH levels at most stages are explicitly related to seasons.
- Hydraulic factors are closely related to reducing pollutants.
- Guidance for urban constructed wetland EEL projects should be further optimised to provide better ecosystem services.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Over the past decade, urban water systems have been affected by a range of detrimental impacts, including water quality and aquatic habitat degradation. Constructed wetlands (CWs) have proven to be effective in treating both domestic and industrial wastewater (Stefanakis 2019). Due to their impressive geo-ecological and landscape characteristics, constructed water quality treatment (WQT) wetlands have been extensively used worldwide for the treatment of wastewater. It has been observed that the pollutant removal rates of CWs are generally higher than other treatment measures when treating wastewater with high pollutant concentrations (80–99%) (Girts *et al.* 2012).

Constructed WQT wetlands are fundamentally different from artificial water features for they can function as a 'filter' and a 'barrier' (Knight & Kadlec 2000). The 'water-soil-bacteria-plant' system in WQT wetlands plays a complex role in diverse treatment processes, i.e., physical sedimentation, chemisorption, ion exchange, and biological uptake (Kurzbaum *et al.* 2012), whereas microorganisms, soils, substrates, and vegetation can interact synergistically with CW ecosystems to remove a broad range of pollutants (Greenway 2010). In addition to the characteristics of pollutants themselves, other local physical geographical factors can also affect WQT effectiveness, especially active storage retention time, wastewater treatment stages, size, layout, type, and density of aquatic vegetation (Acharya & Adak 2009). For practical ecological engineered landscaping (EEL) projects of constructed WQT wetland parks, several types of treatment stages have been typically applied, i.e., subsurface flow wetlands (SSF), vertical flow wetlands (VF), free surface flow wetlands (FSF), and floating wetland island (FWI). Primary treatment ponds (PTPs), aeration ponds (APs), and ornamental ponds (OPs) are also utilised in WQT wetland systems.

Researchers have also summarised different WQI evaluation criteria. Ammonia nitrogen, TP, TDS, and metals are the most common pollutants in domestic wastewater and industrial tailwater (Akcer & Dzemydiene 2020). It is believed that FWIs often perform TP and DO removal, while TN, TP, and TSS removal effects are also found (Oddsson *et al.* 2021). FWIs are also capable of removing targeted pollutants from stormwater. Seasonal WQIs, such as pH, salinity, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), and temperature, have been investigated for adaptive EEL projects. *In-situ* WQI monitoring of urban river wetlands in the cold regions of northern China with their complete purification stages, i.e., horizontal subsurface flow wetland (HF), FSF, and FWI, while their effects on NH_3-N, TN, and TP removal have been indicated. Depth profiles of DO are found to be associated with several physical geographical factors, especially hydrological factors (Haddout *et al.* 2022). Effects of WQTs on plant-associated microbial communities are also primarily monitored on a laboratory scale (Clairmont & Slawson 2020). WQIs are also proven to be strongly related to habitat qualities and biodiversity conditions. The abundance of freshwater fish is often positively correlated with specific WQIs, i.e., TSS, water temperature, NH_3-N, DO, and TP (Koushlesh *et al.* 2022).

In recent decades, not enough attention has been paid to WQT-oriented EEL in high-modified urban CWs, and increasing anthropogenic stress has brought high negative impacts, i.e., water quality, biodiversity, and multi-functionalities. Though a few small-scale projects integrated with potential landscaping frameworks and measures with certain characteristics of EEL planning strategies have been proven to be highly sustainable (Olsson *et al.* 2004; Haron & Feisal 2020), most studies have omitted comparative analysis among constructed WQT wetland parks with EEL characteristics. Some geographical studies suggested that lakes ecological restoration projects may potentially be conducted by constructed integrated CWs to face severe environmental challenges, while extensive management and monitoring programmes are also necessary (Mostafa *et al.* 2022). Sustainable EEL designs with aesthetic characteristics have been implemented with proper development of nature-based solutions (NBS) and proven WQT technologies in some applicable geodesign-based EEL practices, especially ones being applied for river wetlands (Li *et al.* 2022), while typical WQT-oriented EEL in eco-parks design have seldom been studied by civil engineers, environmental geographers, and landscape architects (Zhao *et al.* 2015).

Hybrid wetlands comprising multiple WQT stages have seldom been applied in wetland EEL projects, despite their being economical and cost-effective (Deswal *et al.* 2023). Generally, there is an urgent need for assessments of EEL-oriented techniques for integrated WQT management in urban CWs. Correlation analysis among hydrological factors (e.g., temperature, water flow velocity, length of reach) and pollutant removal contributions of different WQT stages of hybrid WQT wetlands have rarely been conducted by researchers, which is significant for promoting practical design for WQT wetlands. Therefore, the research objective of this research is further *in-situ* research to identify the interrelationships between the hydrological factors and pollutant removal contributions of typical urban wetland parks at each WQT stage during different seasons, in order to reveal the WQT effectiveness of typical urban wetland parks with EEL measures in multiple stage WQT engineering projects.

2. METHODS

2.1. Research process

The experiment was designed to identify the interrelationships among the WQT stages, WQIs (i.e., pH, DO, NH_3-N, COD_{Cr}, and TP), and the hydrological factors (i.e., temperature, velocity, and length of waterbodies) of four typical WQT wetland parks in Hangzhou City, P.R. China in three seasons (summer, autumn, and winter) at their WQT stages (SSF, VF, FSF, FWI, APs, and OPs). WQIs and hydraulic factors were monitored at each sample sites *in-situ*, respectively.

Water sampling was conducted on clear days during three seasons in 2021. Samples were taken under approximately 15 cm of water. Hydrologic indicators, i.e., pH, DO, and temperature, were measured *in situ* via the electrochemical probe by 86031 AZ IP67 instrument (manufactured by AZ Instrument Corp.) during the monitoring. Simultaneously, COD_{Cr}, NH_3-N, and TP levels were measured *in situ* by the LOHAND water testing field kit. These WQIs have been proven to be representative indices for WQT assessments and aquatic ecosystems in urban for human consumption. All the measurement procedures were performed in triplicate with mean ± standard deviation. Moreover, the water velocity was assessed by the time taken for each buoy to pass a fixed distance between each pair of adjacent points above the waterbodies.

Furthermore, several circumstantial factors were identified and recorded for additional WQT-oriented evaluations for sites, i.e., type of vegetation, geomorphology of the waterbody, length of reach, and landscape feature elements. These indicators show the correlation between each factor, i.e., temperature, water velocity, and length of reach.

The Pearson correlation test analysis was then processed through a Python statistical programme to quantitatively reveal the linear correlations between hydrological factors and pollutant removal contributions in different WQT stages, while the removal contribution of each WQI was quantitatively performed and explained.

2.2. Site characterisation

Four constructed WQT wetland parks with EEL measures are selected in Hangzhou City (Table 1) for *in-situ* assessments. In accordance with the *in-situ* survey, the detailed 2D map of four wetland parks is presented in Figure 1.

2.2.1. Changqiao Stream Eco-Park

At outlets of each treatment stage in Changqiao Creek Eco-Park, four sampling sites were selected. Descriptions of the per site are given in Table 2. Firstly, treated effluents from a buried treatment station were released into a

Table 1 | Brief introductions of four study areas

Areas	Source of the inlet	Type	EEL character
Changqiao Stream Eco-Park	Sewages collected from the surrounding communities and rainwater	Eco-park constructed with WQT wetlands	Integrations of ecological engineering methodologies and ecological landscape simultaneously
Shuimei Park	Tailwaters primarily treated by Linping Sewage Plant	WQT wetland systems attached to a sewage plant	Designed with native landscape characteristics of the basin of Qiantang River
Shuijing Park	Waters from a highly modified urban river	Riparian WQT wetland based on linear river	Well-known for its waterscape along the river reach in summer seasons
Yangbei Lake Wetland	Waters from upstream waterways	WQT wetland system constructed on the site of an existing lake	The Fishing Garden attached to the project own unique local cultural characteristics

PTP (site 1) and aerated via several influent cascades by an AP (site 2). An FSF wetland was then abundantly vegetated with aquatic, submerged, and floating plants (site 3). Finally, effluent flowed into integrated FSF + FWI wetlands (site 4).

2.2.2. Shuimei Park

At outlets of different water treatment stages in Shuimei Park, five sampling sites were selected. Descriptions of each site are listed in Table 3. Treated effluent from Linpin Domestic Sewage Treatment Plant is discharged into a PTP (site 1). Effluent flowed into a VF wetland at site 2. A narrow FSF wetland and influent cascades were set up to treat effluents (site 3). Eventually, FWIs were set up for further purification (site 4). Finally, effluents flowed into an OP for recreation (site 5).

2.2.3. Shuijing Park

Shuijing Park, which is also an attraction for visitors to enjoy the cooler microclimate and semi-natural waterscapes in summer, is well-known for its charming waterscape along the reach. At outlets of stages in Shuijing Park, five sampling sites are designated. Introductions of each site are shown in Table 4. An urban river flows into the reach at site one and flows into a small-scale VF (site 2), then a narrow FSF at site 3. Later, FWIs were also set at site 4, and sewage flowed into an OP at site 5.

2.2.4. Yangbei Lake Wetlands

Yangbei Lake Wetlands, located west of Hangzhou City, has been constructed by locals as fishponds since the Tang Dynasty. Since then, Yangbei Lake Wetlands have been expanded and have become a significant irrigation water source in Fuyang District, Hangzhou City until the 1970s. Since the 1980s, the water quality of the lake has been severely degraded due to industrialisation and urbanisation in surrounding areas. In 2019, an EEL-oriented wetland eco-park was constructed to ease pollution.

At outlets of various stages in Yangbei Lake Wetlands, seven sampling sites were selected. Water is charged into CWs at site 1 and treated at the sediment pond (site 2). A series of FSFs is set at sites 3 and 4. FWI is constructed at site 5. An AP with some influent cascades (site 6) and an OP (site 7) are also built. Detailed introductions per site are shown in Table 5.

3. RESULTS

3.1. Hydrological and water quality indices

In-situ measurements of hydrologic factors and WQIs have been measured quarterly at each of the four constructed WQT wetlands. WQIs were improved significantly after the continuous purification process of the WQT wetlands (Table 6). To evaluate WQT effects per treatment stage, differences in WQIs were also calculated for treatment stages. Removal rates of Changqiao in summer (COD_{Cr} for 43.07%, NH_3-N for 72.03%, and TP for 74.44%) are the most remarkable among all sites, which also exceeded the results of *in-situ* monitoring in

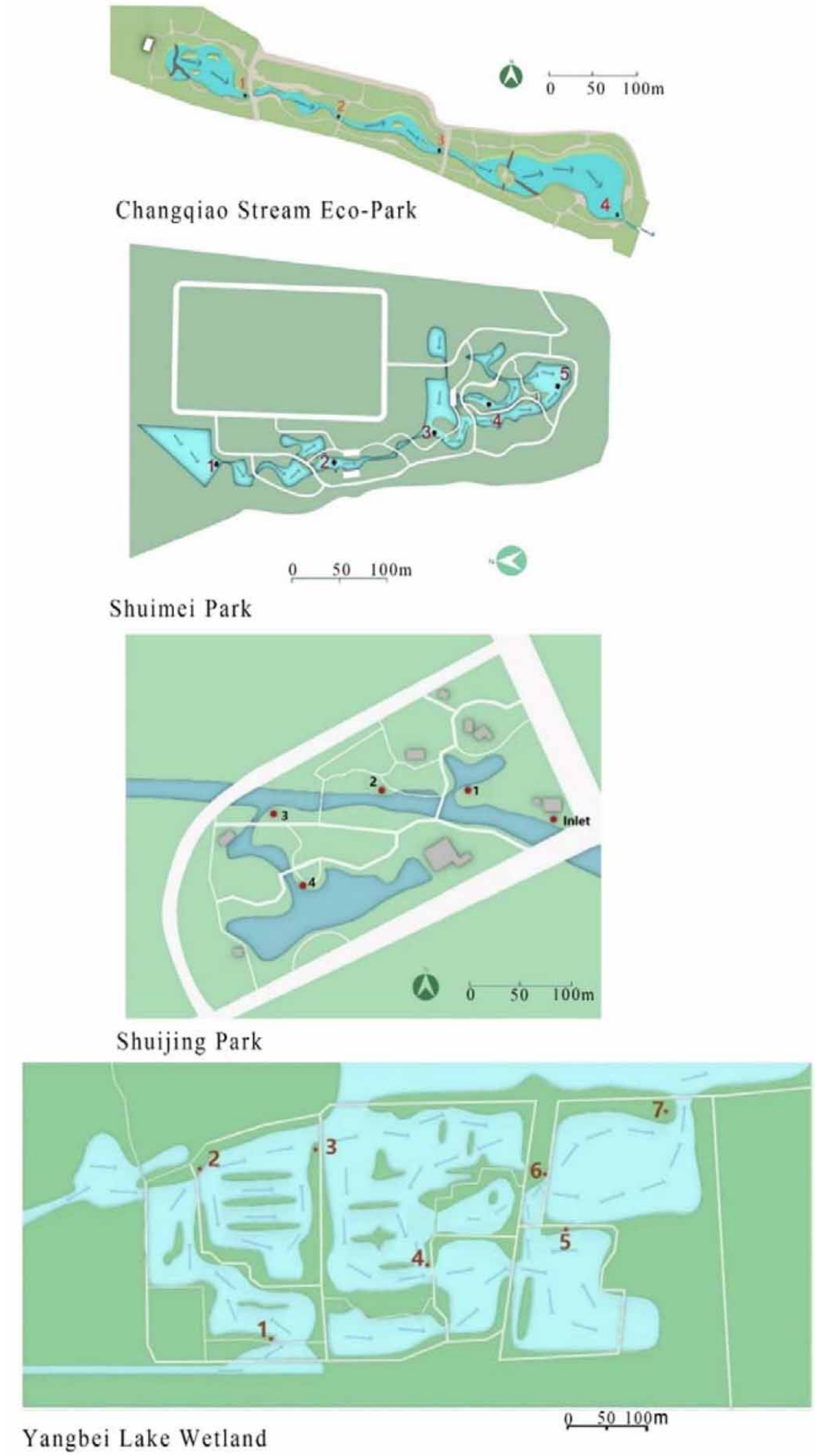


Figure 1 | The 2D map of four wetland parks.

homogenous small-scale sites (Czudar *et al.* 2011). From the statistics, we learned that there are undoubtedly significant differences in the WQT effects at diverse treatment stages in different seasons, while some remarkable phenomena and differentiators are discovered, which will be interpreted in Section 3.2.

Table 2 | Description of sampling sites in Changqiao Stream Eco-Park

Sampling site No.	**1**	**2**	**3**	**4**
Stages of treatment	Primary treatment pond (PTP)	Aeration pond with influent cascades (AP)	Free water surface wetlands (FWS)	Free water surface wetlands (FWS) + Floating wetland islands (FWI)
Vegetation	*Iris pseudacorus*, *Phragmites australis*, *Hydrilla verticillata*, *Ceratophyllum demersum*, *Lemna minor*	*Typha orientalis*, *Zizania latifolia*, *Phragmites australis*, *Vallisneria natans*, *Phyllostachys heteroclada*	*Cynanchum riparium*, *Nymphaea tetragona*, *Typha orientalis*, *Lythrum salicaria*, *Pontederia cordata*	*Thalia dealbata Fraser*, *Acorus tatarinowii*, *Sagittaria trifolia*, *Alisma plantago-aquatica*
Landscape form of the waterbody	A pond with weirs	A stream with multi-layer cascades	A pond with two tiny islands	A free water surface pond with one island
Length (m)	83	99	127	190
Area (m^2)	2,800	650	1,750	4,140

Table 3 | Description of sampling sites in Shuimei Park

Sampling site No.	**1**	**2**	**3**	**4**	**5**
Stages of treatment	Primary treatment pond (PTP)	Vertical flow wetland (VF)	Free water surface wetlands (FWS)	Floating wetland islands (FWI)	Ornamental pond (OP)
Vegetation	*Phragmites australis*	*Lolium perenne*, *Cyperus involucratus Rottboll*, *Calla palustris*	*Typha orientalis*, *Lythrum salicaria*, *Pontederia cordata*, *Sagittaria trifolia*	*Iris tectorum*, *Nymphaea tetragona*, *Lythrum salicaria*, *Cynanchum riparium*	*Nymphaea tetragona*
Landscape form of the waterbody	Artificial ponds with vertical revetment	A substrate bed allows sewage to flow from top to bottom	A stream with multi-layer cascades	A free water surface pond with one island	A pond for ornamental use
Length (m)	97	94	92	75	88
Area (m^2)	4,350	890	510	1,200	2,300

3.2. Analysis of water quality indicators

A typical hydrogeochemical method, known as water quality indices (WQIs), has been adopted as a valid indicator of water environment assessment. According to *The Standard Limits for Common Indicators of Surface Water Qualities in P. R. China* (GB 3838-2002), WQIs of surface water are further evaluated as follows.

DO is one of the significant factors in preserving the balance of the water ecological environment, especially for maintaining the survival of aquatic organisms. All the WQT wetlands in the research have been indicated for their apparent WQT effects on increasing DO levels. DO levels at outlets of all sites satisfied the class II standard in both summer and autumn and the class IV standard in winter at least.

COD_{Cr} is a comprehensive index representing levels of organic substances in the water body. COD_{Cr} levels at outlets of four wetland parks satisfied the class IV standards in summer while almost meeting the class V standard in winter. *Inter alia*, Shuijing Park presented the most notable performance in COD_{Cr} removal contributions in summer (51.99%) and autumn (44.63%). In contrast, the least noticeable COD_{Cr} removal performances in both summer and autumn occurred in Yangbei Lake Wetlands.

Table 4 | Description of sampling sites in Shuijing Park

Sampling site No.	1	2	3	4	5
Stages of treatment	Inlet	Vertical flow wetland (VF)	Free water surface wetlands (FWS)	Floating wetland islands (FWI)	Ornamental pond (OP)
Vegetation	/	*Cyperus involucratus* Rottboll, *Calla palustris*	*Typha orientalis*, *Lythrum salicaria*, *Pontederia cordata*, *Thalia dealbata* Fraser, *Juncellus serotinus*, *Nelumbo nucifera*	*Iris tectorum*, *Nymphaea tetragona*, *Lythrum salicaria*, *Acorus tatarinowii*	*Phragmites australis*, *Nymphaea tetragona*, *Juncellus serotinus*
Landscape form of the waterbody	Linear river	A substrate bed allows sewage to flow from top to bottom	Linear free surface waterbodies	A free water surface pond with FWIs	Some ponds for ornamental use
Length (m)	30	50	108	90	123
Area (m^2)	2,200	1,800	880	1,920	1,860

Table 5 | Description of sampling sites in Yangbei Lake Wetlands

Sampling site No.	1	2	3	4	5	6	7
Stages of treatment	Inlet	Sedimental pond (SP)	Free water surface wetlands (FWS1)	Free water surface wetlands (FWS2)	Floating wetland islands (FWI)	Aeration pond with influent cascades (AP)	Ornamental pond (OP)
Vegetation	–	*Phragmites australis*, *Ceratophyllum demersum*	*Typha orientalis*, *Lythrum salicaria*, *Thalia dealbata*	*Typha orientalis*, *Sagittaria trifolia*, *Thalia dealbata*, *Nelumbo nucifera*	*Nymphaea tetragona*, *Acorus tatarinowii*, *Taxodium distichum*	*Ceratophyllum demersum*	/
Landscape form of the waterbody	Linear river	Artificial ponds	Free surface waterbodies	Free surface waterbodies	A free water surface pond with FWIs	A narrow pond with influent cascades	A large pond for ornamental use
Length (m)	110	444	230	320	324	171	357
Area (m^2)	1,500	33,600	54,700	73,916	45,330	2,000	75,000

Removal of NH_3-N in four eco-parks was detected. The main WQT stages in all parks have corresponding effects on NH_3-N reduction. The water quality at the outlets of three wetlands meets class I standards in summer. The most remarkable performance occurred in Yangbei Lake Wetland in summer (95.50%). However, there are also some distinctive profiles. For Changqiao Park, increases in NH_3-N concentration have occurred in summer for indefinite factors. Besides, mean TP concentrations at all sites ranged from 0.05 to 0.45 mg/L in summer, 0.02 to 0.45 mg/L in autumn, and 0.19 to 0.42 mg/L in winter. TP levels at the WQT wetland outlets almost met class IV standards in both summer and autumn but did not comply with class V standards at all outlets in winter. However, due to the limitation of *in-situ* survey, biological indicators have not been included.

3.3. Correlation between the WQI and hydrological factors

For dynamic wetland ecosystems with WQT techniques, the EEL method operates in a 'design-monitoring-evaluation-adjustment-management' process, differing from the qualitative approach of other high-modified and

Table 6 | Hydrological and water quality indicators of four eco-parks

	Seasons	pH	DO (mg/L)	COD_{Cr} (mg/L)	Temp (°C)	NH_3-N (mg/L)	TP (mg/L)	V (m/s)
Changqiao site No. 1	Summer	8.10 ± 0.02	7.66 ± 0.23	96.03 ± 1.44	24.84 ± 0.24	0.13 ± 0.01	0.18 ± 0.01	0.12
	Autumn	9.13 ± 0.06	4.22 ± 0.03	84.67 ± 4.16	20.63 ± 0.06	0.27 ± 0.03	0.23 ± 0.02	0.09
	Winter	8.43 ± 0.08	3.63 ± 0.21	103.33 ± 3.21	7.07 ± 0.15	0.31 ± 0.02	0.23 ± 0.03	0.10
Changqiao site No. 2	Summer	8.07 ± 0.13	7.60 ± 0.52	83.10 ± 4.91	25.47 ± 0.12	0.15 ± 0.02	0.15 ± 0.02	0.13
	Autumn	8.94 ± 0.01	6.19 ± 0.20	69.67 ± 2.52	20.87 ± 0.06	0.24 ± 0.01	0.21 ± 0.01	0.20
	Winter	8.39 ± 0.01	4.27 ± 0.15	84.67 ± 3.06	7.37 ± 0.12	0.15 ± 0.00	0.22 ± 0.03	0.15
Changqiao site No. 3	Summer	7.90 ± 0.02	8.26 ± 0.12	78.67 ± 14.27	24.53 ± 0.12	0.10 ± 0.02	0.10 ± 0.02	0.22
	Autumn	8.77 ± 0.02	7.02 ± 0.19	65.00 ± 3.00	20.10 ± 0.02	0.13 ± 0.02	0.16 ± 0.01	0.15
	Winter	8.46 ± 0.01	5.39 ± 0.12	73.00 ± 1.73	7.23 ± 0.06	0.20 ± 0.05	0.19 ± 0.02	0.15
Changqiao site No. 4	Summer	8.19 ± 0.06	8.43 ± 0.06	54.76 ± 2.07	23.63 ± 0.21	0.01 ± 0.00	0.01 ± 0.00	0.15
	Autumn	8.66 ± 0.02	7.25 ± 0.02	53.50 ± 1.11	19.93 ± 0.12	0.10 ± 0.02	0.15 ± 0.02	0.15
	Winter	8.23 ± 0.02	5.40 ± 0.10	70.67 ± 1.15	7.40 ± 0.03	0.14 ± 0.01	0.18 ± 0.02	0.10
Shuimei site No. 1	Summer	7.42 ± 0.05	5.50 ± 0.17	84.00 ± 4.9	28.03 ± 0.45	0.20 ± 0.02	0.35 ± 0.02	0.15
	Autumn	7.86 ± 0.02	5.33 ± 0.15	88.33 ± 1.15	20.43 ± 0.40	0.23 ± 0.03	0.37 ± 0.03	0.05
	Winter	8.19 ± 0.02	3.77 ± 0.15	83.67 ± 2.08	7.57 ± 0.15	0.24 ± 0.02	0.34 ± 0.01	0.05
Shuimei site No. 2	Summer	7.31 ± 0.01	5.13 ± 0.15	76.33 ± 1.32	28.20 ± 0.57	0.10 ± 0.01	0.30 ± 0.01	0.10
	Autumn	7.57 ± 0.03	6.24 ± 0.01	75.67 ± 3.51	20.07 ± 0.00	0.17 ± 0.02	0.33 ± 0.02	0.05
	Winter	8.07 ± 0.03	4.07 ± 0.15	80.00 ± 4.00	7.13 ± 0.06	0.23 ± 0.02	0.29 ± 0.03	0.05
Shuimei site No. 3	Summer	7.13 ± 0.02	5.63 ± 0.12	62.00 ± 9.42	27.90 ± 0.08	0.10 ± 0.01	0.30 ± 0.02	0.05
	Autumn	7.20 ± 0.02	6.35 ± 0.07	66.67 ± 2.52	21.33 ± 0.06	0.12 ± 0.01	0.32 ± 0.03	0.10
	Winter	7.97 ± 0.02	4.67 ± 0.15	71.33 ± 2.08	7.30 ± 0.17	0.18 ± 0.03	0.24 ± 0.01	0.15
Shuimei site No. 4	Summer	7.28 ± 0.01	6.23 ± 0.29	55.60 ± 5.44	28.4 ± 0.16	0.23 ± 0.01	0.25 ± 0.02	0.25
	Autumn	7.09 ± 0.01	6.44 ± 0.16	66.33 ± 3.79	22.07 ± 0.06	0.20 ± 0.02	0.27 ± 0.04	0.25
	Winter	7.94 ± 0.01	4.73 ± 0.06	68.00 ± 3.61	6.70 ± 0.17	0.24 ± 0.02	0.22 ± 0.02	0.15
Shuimei site No. 5	Summer	7.16 ± 0.00	6.26 ± 0.06	50.33 ± 3.68	26.97 ± 0.05	0.25 ± 0.02	0.15 ± 0.02	0.40
	Autumn	7.15 ± 0.02	6.23 ± 0.03	72.33 ± 2.08	22.60 ± 0.00	0.24 ± 0.02	0.18 ± 0.03	0.20
	Winter	7.90 ± 0.03	4.73 ± 0.12	65.67 ± 4.93	7.87 ± 0.21	0.22 ± 0.05	0.21 ± 0.01	0.20
Shuijing site No. 1	Summer	9.27 ± 0.01	6.13 ± 0.15	93.06 ± 1.53	32.33 ± 0.12	0.37 ± 0.01	0.32 ± 0.02	0.10
	Autumn	8.63 ± 0.02	5.63 ± 0.06	93.33 ± 4.16	20.23 ± 0.06	0.37 ± 0.03	0.30 ± 0.00	0.12
	Winter	9.19 ± 0.04	3.97 ± 0.09	88.20 ± 0.92	7.77 ± 0.15	0.38 ± 0.03	0.33 ± 0.03	0.10
Shuijing site No. 2	Summer	8.26 ± 0.03	6.60 ± 0.36	70.03 ± 4.00	30.43 ± 0.06	0.28 ± 0.02	0.26 ± 0.02	0.15
	Autumn	7.55 ± 0.01	5.63 ± 0.03	87.00 ± 2.65	19.90 ± 0.17	0.32 ± 0.03	0.27 ± 0.03	0.14
	Winter	8.30 ± 0.03	4.13 ± 0.07	85.67 ± 2.52	7.70 ± 0.00	0.35 ± 0.01	0.29 ± 0.02	0.12
Shuijing site No. 3	Summer	7.92 ± 0.03	7.37 ± 0.06	53.67 ± 3.21	32.34 ± 0.31	0.19 ± 0.01	0.13 ± 0.02	0.35
	Autumn	7.51 ± 0.01	5.77 ± 0.03	65.33 ± 3.79	20.57 ± 0.21	0.25 ± 0.01	0.17 ± 0.02	0.32
	Winter	7.34 ± 0.01	4.29 ± 0.03	74.00 ± 2.00	7.60 ± 0.17	0.29 ± 0.01	0.23 ± 0.02	0.25
Shuijing site No. 4	Summer	7.58 ± 0.02	7.73 ± 0.15	40.33 ± 1.53	31.03 ± 0.12	0.13 ± 0.04	0.11 ± 0.01	0.30
	Autumn	7.47 ± 0.07	6.00 ± 0.26	55.67 ± 4.16	20.20 ± 0.10	0.16 ± 0.01	0.16 ± 0.01	0.37
	Winter	7.42 ± 0.07	5.03 ± 0.02	67.67 ± 3.51	5.63 ± 0.21	0.24 ± 0.03	0.21 ± 0.01	0.20
Shuijing site No. 5	Summer	8.00 ± 0.04	8.01 ± 0.17	44.67 ± 2.52	30.30 ± 0.10	0.11 ± 0.01	0.12 ± 0.01	0.20
	Autumn	7.67 ± 0.07	6.47 ± 0.06	55.00 ± 3.61	19.63 ± 0.12	0.13 ± 0.01	0.15 ± 0.03	0.15
	Winter	7.44 ± 0.01	5.14 ± 0.08	65.67 ± 3.06	6.37 ± 0.23	0.23 ± 0.02	0.19 ± 0.01	0.10
Yangbei site No. 1	Summer	8.41 ± 0.05	5.50 ± 0.26	81.67 ± 2.52	29.37 ± 0.06	0.45 ± 0.16	0.45 ± 0.04	0.30
	Autumn	8.27 ± 0.02	5.23 ± 0.25	102.33 ± 8.14	20.07 ± 0.06	0.44 ± 0.02	0.46 ± 0.02	0.20
	Winter	8.94 ± 0.12	2.27 ± 0.12	94.67 ± 4.16	7.23 ± 0.21	0.46 ± 0.02	0.42 ± 0.02	0.13
Yangbei site No. 2	Summer	7.95 ± 0.08	5.60 ± 0.17	90.33 ± 4.40	28.80 ± 0.00	0.45 ± 0.02	0.35 ± 0.04	0.15
	Autumn	8.22 ± 0.02	5.47 ± 0.12	84.67 ± 3.06	20.23 ± 0.06	0.32 ± 0.02	0.38 ± 0.01	0.20
	Winter	8.64 ± 0.02	2.80 ± 0.10	94.33 ± 1.15	6.63 ± 0.15	0.41 ± 0.01	0.39 ± 0.02	0.13
Yangbei site No. 3	Summer	7.83 ± 0.01	6.02 ± 0.17	84.67 ± 3.79	29.47 ± 0.12	0.36 ± 0.01	0.21 ± 0.01	0.15
	Autumn	7.74 ± 0.01	6.13 ± 0.15	82.33 ± 2.08	20.87 ± 0.06	0.28 ± 0.01	0.30 ± 0.04	0.20
	Winter	8.64 ± 0.02	3.23 ± 0.16	85.67 ± 2.52	6.77 ± 0.15	0.36 ± 0.02	0.33 ± 0.03	0.14
Yangbei site No. 4	Summer	7.56 ± 0.02	6.60 ± 0.20	76.67 ± 1.53	29.07 ± 0.06	0.25 ± 0.03	0.13 ± 0.04	0.35
	Autumn	7.72 ± 0.03	6.67 ± 0.12	75.33 ± 2.52	20.60 ± 0.00	0.24 ± 0.01	0.28 ± 0.01	0.28
	Winter	7.89 ± 0.01	3.90 ± 0.10	7.67 ± 3.06	6.27 ± 0.06	0.33 ± 0.02	0.32 ± 0.03	0.17

(*Continued.*)

Table 6 | Continued

	Seasons	pH	DO (mg/L)	COD_{Cr} (mg/L)	Temp (°C)	NH_3-N (mg/L)	TP (mg/L)	V (m/s)
Yangbei site No. 5	Summer	7.22 ± 0.03	7.03 ± 0.06	66.77 ± 1.76	29.43 ± 0.06	0.13 ± 0.02	0.10 ± 0.02	0.28
	Autumn	7.70 ± 0.02	7.10 ± 0.10	74.67 ± 2.52	20.53 ± 0.06	0.19 ± 0.02	0.23 ± 0.02	0.23
	Winter	7.75 ± 0.02	4.17 ± 0.15	73.67 ± 2.08	6.60 ± 0.20	0.30 ± 0.02	0.28 ± 0.01	0.16
Yangbei site No. 6	Summer	7.71 ± 0.01	7.10 ± 0.20	67.67 ± 1.53	30.03 ± 0.06	0.12 ± 0.01	0.05 ± 0.04	0.33
	Autumn	7.74 ± 0.01	7.27 ± 0.12	72.33 ± 2.08	20.87 ± 0.06	0.17 ± 0.02	0.17 ± 0.02	0.30
	Winter	7.86 ± 0.02	4.67 ± 0.21	73.00 ± 2.00	6.63 ± 0.15	0.30 ± 0.02	0.21 ± 0.02	0.17
Yangbei site No. 7	Summer	7.80 ± 0.03	7.37 ± 0.12	62.67 ± 1.53	30.10 ± 0.10	0.05 ± 0.01	0.02 ± 0.01	0.25
	Autumn	7.87 ± 0.02	7.07 ± 0.06	72.67 ± 1.15	20.77 ± 0.06	0.17 ± 0.02	0.14 ± 0.02	0.25
	Winter	8.17 ± 0.07	4.23 ± 0.06	72.33 ± 2.52	6.67 ± 0.12	0.27 ± 0.03	0.20 ± 0.01	0.11

artificial waterscapes. A Pearson correlation test analysis is necessary to determine the direct linear correlation between hydrological factors, including water temperature, flow velocity, and length of reach, and their contribution to the removal of various pollutants. The Pearson correlation test was conducted using a Python programme that utilised Matplotlib and Pandas packages. The analysis aimed to identify linear correlations between three key hydrological factors and the contributions to pollutant removal. The hypothesis testing method is adapted, and involves calculating the p-value of the non-correlation of two variables under the condition that the null hypothesis is valid, i.e., assuming that the two variables are not correlated. If $p < 0.05$, it indicates that there is a significant linear correlation between the two variables. The results are listed shown in Table 7.

Table 7 | Correlation analysis among hydrological factors and pollutant removal contributions of different treatment stages

WQT stages	WQIs/Hydrological factors	DO		COD_{Cr}		NH_3-N		TP		pH	
	Indices	*R*	*p*	*R*	*p*	*R*	*p*	*R*	*p*	*R*	*p*
AP	Temp	−0.276	0.001	0.166	0.001	−0.078	0.001	0.021	0.001	−0.054	0.001
	Velocity	0.603*	0.036	0.242	0.035	0.034	0.000	−0.148	0.000	−0.042	0.214
	Length	0.444	0.008	−0.868**	0.006	−0.378	0.001	−0.826**	0.001	0.657*	0.001
FSF	Temp	−0.141	0.000	−0.019	0.000	−0.335	0.000	−0.539*	0.000	−0.136	0.000
	Velocity	0.060	0.000	−0.220	0.000	−0.749**	0.000	−0.522*	0.000	−0.385	0.000
	Length	0.131	0.003	−0.460	0.000	0.049	0.000	−0.120	0.000	−0.394	0.000
FWI	Temp	0.581*	0.000	−0.542*	0.000	−0.308	0.000	−0.088	0.000	−0.391	0.000
	Velocity	0.515*	0.020	−0.351	0.000	0.137	0.000	0.129	0.000	−0.164	0.008
	Length	0.099	0.000	0.017	0.000	−0.688*	0.000	−0.633*	0.002	−0.324	0.029
VF	Temp	0.200	0.001	−0.770*	0.000	−0.789*	0.001	−0.571*	0.001	−0.013	0.001
	Velocity	−0.384	0.595	−0.329	0.018	−0.165	0.000	0.369	0.000	−0.861**	0.004
	Length	0.088	0.000	−0.189	0.000	−0.392	0.000	−0.302	0.000	−0.812**	0.000
OP	Temp	0.338	0.023	0.303	0.000	0.311	0.000	−0.083	0.000	0.283	0.000
	Velocity	0.215	0.000	−0.294	0.544	0.262	1.119	−0.772**	0.000	−0.306	0.523
	Length	−0.288	0.001	−0.219	0.000	0.465	0.000	−0.008	0.000	0.167	0.000

**High correlations; *Significant correlations.

We found some specific correlations between individual factors and the removal contribution of per WQT stages for all sites, which can be concluded as follows.

(1) For stages of APs, length of reach is the major influential factor for COD_{Cr} ($p = -0.868$), TP ($p = -0.826$), and pH ($p = 0.657$). Velocities of water are related to increases in DO ($p = 0.603$).
(2) For stages of FSFs, both water temperature ($p = -0.539$) and velocities of water ($p = -0.522$) are often related to TP removal contributions, while NH_3-N removals are affected by velocities ($p = -0.749$).
(3) For stages of FWIs, increases in DO levels show positive relations to both temperature ($p = 0.581$) and velocities ($p = 0.515$), while COD_{Cr} removal contributions are related to temperature ($p = -0.542$). Removal of NH_3-N and TP are associated with the length of reaches ($p = -0.688$ and -0.633, respectively).

(4) For stages of VFs, COD_{Cr}, NH_3-N, and TP removal contributions are affected by the waterbodies' temperature ($p = -0.770$, -0.789, and -0.571, respectively). Decreased pH is related to velocities ($p = -0.861$) and lengths of reaches ($p = -0.812$), indicating the valid capabilities to balance the pH of the water body.
(5) For stages of OP, TP removal contributions positively relate to velocities of waterbodies ($p = -0.772$), while none of the other factors indicated more related aspects.

4. DISCUSSION

4.1. Removal contributions by single-type WQIs

4.1.1. Dissolved oxygen (DO)

It is noticed that DO variations per treatment stages in wetland systems demonstrated their similarities. DO increasing trends are closely related to seasons (summer > autumn > winter). For summer, DO levels often rose during AP, VF, and FWS treatment stages. DO increases are processed during both stages of AP and FSF in autumn and winter.

The engineering parameters of wetlands, namely gradients, water velocity, and water temperature, appear to affect DO levels. Additionally, DO concentrations may be elevated by the photosynthesis of aquatic plants and the respiration of (micro)organisms. The reoxygenation reaction is an essential process for introducing oxygen into the water. Interactions between oxygen molecules in water frequently occur due to partial pressure gradients in the gas phase and a concentration gradient in the liquid phase. Therefore, more frequent turbulence in water bodies will decrease these gradients and improve oxygenation during the summer. However, stagnant water surfaces during autumn and winter will hinder oxygenation. Thus, extending the reach lengths of APs and FSFs will enhance reoxygenation in both seasons.

4.1.2. COD_{Cr}

It is observed that variation trends of COD_{Cr} concentration at most treatment stages are almost similar, except for some stages of Yangbei Lake in winter. Removal trends of COD_{Cr} are related to seasons (summer > autumn > winter). The most significant removal effect occurred in FWS and FWI in the summer. The stage of AP in Changqiao presents positive results in removing COD_{Cr} (13.46%), while the AP in Yangbei Lake is explicitly non-effective (1.10%). However, distinctive profiles of COD_{Cr} removal contributions are found in autumn. VFs in Shuijing (6.78%) and Shuimei (14.33%) indicated more apparent effects. Removal contributions of FSFs and FWIs in all sites were respectively weaker. As for winter, removal rates of COD_{Cr} in all sites were minimised to the most limited ranges. Vegetation growth in the second half of all wetland parks was weaker than in the first half section. These phenomena can be elucidated as follows.

COD_{Cr} can be deposited, biodegradable, and transformed by assimilation through aerobic processes (Imfeld *et al.* 2009). During summer, photosynthetic rates were increased at all sites for higher temperatures and sufficient O_2 production. Biodegradation rates of COD_{Cr} reached a maximum with frequent microbial activities (Wang *et al.* 2023). Meanwhile, the O_2 transfer capacities of the depleted vegetation decreased in autumn. Plants and microbials were almost suppressed in winter of low temperatures. Integrated VF–FSF-resisted impact pollution loads of COD_{Cr}, while OPs presented negative, which may be caused by exogenous pollution as obstacles. Thus, COD_{Cr} removal efficiencies were inhibited.

4.1.3. NH_3-N

NH_3-N removal primarily depends on plant uptake in constructed WQT wetland systems (Czerwionka *et al.* 2012). It is noticed that the total NH_3-N removal was seasonally dependent in all sites, i.e., summer > autumn > winter. Meanwhile, hybrid VF–FSF wetlands can enhance NH_3-N removal rates. Some anomalies in variations of NH_3-N levels were observed in Shuimei Park. NH_3-N levels in this park first decreased swiftly and then increased. FSF + FWI and OP had noticeable adverse effects on NH_3-N removal due to the scarcity of aquatic plants and the dominion of extraneous pollutants. It was also found that APs and some FWSs revealed inexplicit NH_3-N reduction.

Vegetations also optimise the hydraulic environment for microorganisms by releasing oxygen in root zones. Thus, dense vegetation attributed to noticeable NH_3-N removals in the summer. Total removal efficiencies are affected by the withering of plants and disappearance of microorganisms as decomposition of organic nitrogen can reduce NH_3-N removal rates. Furthermore, ammonia nitrogen is removed from substrates through filtration, adsorption, and sedimentation. On the surface, microorganisms may also conduct nitrification and denitrification processes (Jiang & Chui 2023). Additionally, isolate-set FWIs tend to be ineffective at promoting nitrification due to the constraining effects on oxygen transportation. Root zones can create microenvironments that support microbial communities and provide organic carbon sources for aerobic bacteria, leading to an increase in the structure and abundance of the microbial community (Di Luca *et al.* 2019). Studies have suggested that integrating FWIs with VFs and/or FSFs can be an effective method of improving WQT efficiencies.

4.1.4. Total phosphorous (TP)

Phosphorus is one of the reliable chemical nutrients for algae to grow in water. Water-soluble reactive phosphorus (SRP) is absorbed and transformed by plants. TP was removed through three parallel pathways, i.e., substrate fixation, plant uptake, and microbial action. Each component contributes differently, i.e., substrate > vegetation > microbes (Wang *et al.* 2017). Total NH_3-N removals are also observed to be closely related to seasons. It is indicated that TP removal rates of VF, FSF, and FWI in winter are much lower than those in summer. These phenomena are further explained as follows.

Absorption and sedimentation are both dominant for TP removal. Rahman *et al.* (2020) have noted that TP removal depends on multiple influences, i.e., sorption and complexation by vegetation, sedimentation, and biochemical action by microorganisms, while the deposition of suspended particles removes particulate P. Vegetations enhanced treatment efficiencies of WQT wetlands by absorbing and releasing O_2 and transforming organic matters to promote microbial degradation. O_2 release from roots and secretion of organic matter often promote microbial degradation. It has been suggested that the accumulation of organic P and the concentration of TP in aquatic plants aligns with prior research (Wang *et al.* 2023). The growth and reproduction rates of phosphorus-accumulating bacteria are also affected by temperature. In semi-anoxic environments, DO concentrations in wetland beds decrease and thus limit bacterial growth. As a result, there is a shift from phosphorus uptake during winter to phosphorus releases.

4.2. Correlation between hydrological factors and WQIs

Several rules can be concluded for the correlation between hydrological factors and WQIs.

(1) Water temperatures ultimately impact WQT effects for all stages.
(2) Lengths of reaches are frequently related to the removal processes of TP. Longer reaches with meanders will be of help to promote TP removal.
(3) NH_3-N and decreases in pH. Velocities of waterbodies are frequently related to DO, TP and decreases in pH, which occurs with interactional effects of VF > FSF, and AP > FSF.
(4) Several EEL measures effectively promote COD_{Cr}, NH_3-N, TP removal, and DO level rises, i.e., increasing lengths of AP, VF, FSF, and accelerating AP velocities, FSF, FWI, and OP.
(5) The effluent concentration decreases from the previous stage to the latter, irrespective of the season. Removal of NH_3-N occurs primarily in the first half section, mainly in the first 1/4 section in summer, and gradually decreases among later stages in winter. TP occurs primarily in the first 1/4 section in summer and the first half section in winter. The plant role is high in the first section. Eventually, the phosphorus is removed by plant harvesting and substrate replacements.
(6) Nutrient abundance in the water is explicitly higher at the inflow, thus, the rate of microbial degradation of organic matter is higher, resulting in a noticeably faster COD_{Cr} reduction. Once the sewage flows into the latter part of the wetland, the organic matter degradation rate reaches a certain level and the reaction rate decreases.
(7) During preliminary aeration, numerous microorganisms proliferate in the form of activated sludge. If tailwater is directly discharged into the VF or SSF, it may obstruct the flow paths. Therefore, the AP or FSF should be installed between the AP and SSF/VF to avoid blockage.

4.3. Explanations of differences among parks

Most of the treatment stages investigated in the study were discovered to have contributed to the improvement of WQIs, especially as their successful outcomes were recorded during the summer season, which aligns with findings from another *in-situ* monitoring cases (Li *et al.* 2009; Wang *et al.* 2021a, 2021b). However, significant differences in winter were observed among the wetland parks despite the noted hydrological factors. Compared with other sites, Shuijing Park and Yangbei Lake Wetlands have sustained their removal rates, which were also attributed to their different EEL measures. These perceptible differences can be explained as follows.

The activities of nitrifying and denitrifying bacteria have an impact on the removal rate of NH_3-N. The denitrification rate varies seasonally due to physiological and biochemical changes that occur in the microenvironment surrounding the root zones of vegetation. A lower rate of denitrification was observed during winter, which is consistent with other assessment programmes in southern China (Wang *et al.* 2021a, 2021b; Jiang & Chui 2023). Therefore, while the nitrification efficiency may remain high in low-temperature conditions, the denitrification rate limits the overall nitrogen removal in the WQT wetland, and vice versa. Both parks have larger planting areas. As a result, the vegetation roots have a greater ability to transport oxygen, enabling the maintenance of aerobic environments throughout the winter. The substantial surface area of the Yangbei Lake Wetland and the Shuijing Park, combined with their enhanced fluidity, creates an insulating effect that provides the perfect environment for the growth of aquatic plants during winter. Additionally, stages of AP exhibit more favourable eutrophic conditions, while ample DO in the upper strata of the water in VFs creates a suitable atmosphere for nitrification.

It is observed that the removal of COD_{Cr} and TN in FSFs is positively correlated with the inflow concentration, while the removal of TP is negatively correlated with the sewage inlet concentration, which is consistent with earlier studies (Mohd Noor *et al.* 2014; Zhu *et al.* 2023). Nonetheless, the effluent discharged from the FSF displays a significant concentration of nitrate nitrogen. The oxygen in the SSF predominantly originates from the oxygen released by the roots, and reduced oxygen levels may impede the efficiency of the nitrification process. Deeper sections within the SSF bed profile differ and alter from an aerobic to anaerobic environment, thereby promoting denitrification, as reported by Khan *et al.* (2022). The oxygen in the SSF predominantly originates from the oxygen released by the roots, and reduced oxygen levels may impede the efficiency of the nitrification process. However, the system's sustainability is upheld through VN-denitrification during times of insufficient carbon source. Nonetheless, it is important to consider that the VF beds are deeper and more prone to clogging during maintenance.

4.4. EEL-oriented guiding principles for WQT landscaping

4.4.1. EEL optimisation according to WQT methods

The findings demonstrate that the WQT contributions of all parks during specific seasons and stages were poor. Although VFs successfully completed nitrification, they were not reliable for denitrification reactions. Therefore, hydrologic engineering measures should be taken to optimise external physical geographical conditions of wetlands. To achieve sustainable and resilient landscaping, EEL projects for wetland parks must consider the various aspects of geo-ecological principles. Landscape architects should design suitable treatment facilities with proper composition of landscape elements, such as substrates, flow patterns, and vegetation.

By adopting the WQT measures, most treatment processes can be integrated into hybrid treatment stages of wetlands. Firstly, current deflecting elements, e.g., swales and microtopography, can promote the differentiation of flows, enhancing aeration and promoting higher DO levels. Secondly, by constructing low ditches along shores, lower sections of the streambed can be widened to promote the natural migration of (micro)organisms, which will enhance the removal of NH_3-N and TP. Thirdly, it is believed that VFs are usually more effective in COD_{Cr} removal and nitrification than HFs and FSFs in existing monitoring programmes (Abou-Elela *et al.* 2013; You *et al.* 2023), while VFs in this study have failed to present their ideal effects, probably for the limited tidal VFs prohibiting sufficient oxygen from penetrating, for their limited areas and inadequate detention time, which should be optimised by proper local-scale geospatial arrangements. Besides, waste-derived substrates are viable alternatives having fertilising effects with the potential for nutrient recovery, which is suitable for growing ornamental plants in wetland EEL projects (Sharma 2023).

4.4.2. Adaption of proper planting design

The conspicuous removal effects of organic matter, i.e., N and P, is one of the distinguishing features of WQT wetlands. It is noticed that higher planting with higher densities is effective in reducing TSS and COD_{Cr} and increasing pH in the aquatic environment, which is essential for improving water transparency, which has correspondent with existing studies in the southern region in P.R. China (Xiang *et al.* 2022). Different plants should be arranged accordingly for distinctive WQT stages. Some native plants in the southern region of P.R. China often present effects on dephosphorization, i.e., *Hydrocharis dubia* in winter and *Eichhornia crassipes* in summer (Wang *et al.* 2021a, 2021b). It is found that adequate aquatic plant communities are effective in VFs. They are also effective for SSF wetlands. Additionally, higher planting density led to higher WQT effects, corresponding to studies conducted in a horizontal SSF (Shruthi & Shivashankara 2022; Rohaningsih *et al.* 2023). Emergent plant communities provide more shaded areas. The presence of floating vegetation in the FSFs and FWIs will enhance biodiversity while preventing the growth of algae. According to the results of WQI assessment, we recommend *Phragmites australis* as the most proper aquatic plant for total nitrogen removal from sewage in all the parks. The roots of this plant absorb pollutants in water, transport oxygen, and create 'anaerobic-hypoxic-aerobic' microenvironments.

Besides, lower water temperatures primarily affect the removal rates of VFs. Therefore, we recommend improving the insulation of the WQT wetland by covering the surfaces of the SSF and VF with insulating material during the winter period. Consistency in these measures will help improve the performance of the wetland. Additionally, to promote stable WQT effects, particularly for smaller-scale sites, we advise increasing the depth of the primary treatment unit and extending the hydraulic retention time.

4.4.3. Integration with multifunctional design and adaptive management

Located in Hangzhou, four eco-parks in the study are adjacent to the core water systems of the city, containing many cultural and natural attractions. Non-point source pollution loads can be recurrently reduced by utilising the filtering and wastewater interception functions of constructed hydro-ecosystems, which can improve riparian landscapes (Huang *et al.* 2022). In a local geo-ecological scale, landscape architects should concentrate on integrating diverse functional layers, i.e., substrate layer, vegetation layer, waterbody layer, and WQT stages.

For adaptive ecosystem service management, EEL-oriented goals for multifunctional WQT wetlands should not be assessed by their state of completion but rather for the sustainability and resilience to deal with future uncertainties. Although the water quality improvement effect of the four eco-parks was significant, the landscape effect at some nodes is recommended to be optimised. Strategies of multifunctional landscape design should be optimised, which will help to enhance divergent functions to limited spaces with EEL measures for their management. We believe that proper-designed constructed WQT wetland parks should present multiple characteristics, i.e., environmental, sociocultural, and economic benefits. The four benefits mentioned above are summarised in Table 8. It is indicated that Changqiao Park and Shuimei Lake Wetland offered more generous social, cultural, and economic benefits. The EEL-oriented design of Shuijing Park and Yangbei Lake Wetlands should be improved to seize further sustainable development opportunities, i.e., natural education and social interaction.

Table 8 | Multi-aspect benefits of four WQT wetlands

Benefits		Changqiao	Shuimei	Shuijing	Yangbei Lake
Environmental	Improving water qualities	*	*	*	*
	Serving as green infrastructures	–	*	–	*
	Reducing floods	/	/	–	*
	Abundant vegetations	*	*	*	*
	Providing wildlife habitats	–	*	/	*
Sociocultural	Social interactions	*	–	–	–
	Improving aesthetics	*	*	*	*
	Recreational opportunities	*	*	*	*
	Natural education	*	*	–	/
	Reuse cultural heritages	–	/	/	–
Economic	Use of green materials	*	*	–	–
	Save treatment costs	*	*	*	*
	Tourism values	*	–	–	*

*Suitable; – partly suitable; / not suitable.

4.5. Further implications

From an ecological perspective, the author suggests that the findings will be beneficial for improving water quality in WQT stages as one of the ecosystem services provided by EEL projects of WQT wetland parks. Landscape architects and civil engineers are recommended to adopt some principles to optimise WQT wetlands. The diversity and landscape character of plants should be considered in practical EEL-oriented wetland design. Emergent, floating, and submerged plants should be arranged in communities based on their effectiveness in removing contaminants. Hybrid wetlands should also be arranged based on their WQT efficacy. During WQT wetland EEL projects, adaptive management of dynamic EEL should be considered. By enhancing EEL variability, semi-natural wetland ecosystems can progress from an initial state to a more stable ecosystem and potentially reach a stable state. Furthermore, WQT wetlands have been identified as highly promising landscape tools as they can serve multiple biodiversity-friendly functions and create semi-natural habitats within urban wetlands.

4.6. Limitations

Some limitations of the study are also noticed, listed as follows.

Firstly, in terms of the scope, the research focus on the practical EEL projects of urban WQT wetland, whereas EEL projects for other types of urban waterbodies, including rivers, streams, and reservoirs, are not considered. Also, for EEL projects in other regions of the world, specific empirical studies should be further conducted by multi-discipline researchers.

Secondly, the indicators in the empirical experimental methods did not include biological indicators, especially for plant diversity. Plants in the CWs often offer their functions for water quality maintenance, and the plant diversity in the WQT stages has a direct relationship with water qualities and hydrological conditions (Júnior *et al.* 2023). Therefore, further research on the interrelations among the plant biological indicators and the WQIs is needed.

Thirdly, other factors such as water depth and carbon source (Zhu *et al.* 2023) may influence nutrient concentrations in CWs, which should be considered for future homogeneous *in-situ* assessments. Despite WQI monitoring of different types of specific CWs (Salah-Tazdaït & Tazdaït 2023), further research into the hybrid wetland system's mechanism is required.

Finally, for large-scale urban CWs and river wetlands, the dataset of WQIs and hydraulic factors could further integrated into a geographic information system (GIS). This integration would also be applicable for landscape architects and environmental geographers to analyse and visualise the data using geodesign techniques and geoinformatics methods (Li *et al.* 2022).

5. CONCLUSION

To identify the WQT effects of constructed WQT wetland parks for practical EEL projects, WQT performances of various treatment stages of four typical WQT wetland parks in Hangzhou City have been studied, all of which are indicated to achieve integrated EEL performances. *In-situ* measurements affirmed that all WQT wetland parks contributed to the removals of COD_{Cr}, NH_3-N, and TP and rises of DO. The increasing DO, and decreasing COD_{Cr}, NH_3-N, TP, and pH levels are explicitly related to seasons (summer $>$ autumn $>$ winter). Hydraulic factors, including the velocity, the temperature, and the length of waterbody, have affected comprehensive treatment performances in all seasons. Guidance for urban constructed wetland EEL projects should be further optimised, i.e., optimising the EEL measures according to WQT principles, adapting appropriate planting designs, and integrating with multifunctional design. These findings will be helpful for improving the efficacy of WQT wetland parks as one of the ecosystem services provided by the urban sustainable EEL projects.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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