Interaction between the physicochemical characteristics of the water environment and the mangrove plant community

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Abstracts: To investigate the interactive effects of variables related to water environment physicochemical factors on the structure and function of plant communities in Nansha coastal wetlands, the ability of vegetation to characterize water quality under multiple ecological effects and the response and distribution of vegetation under different hydrological conditions.Using the Nansha coastal wetland in Guangzhou as the study area, 12 representative plant communities were selected and transient water harvesting was carried out in their groundwater, aquatic water and five water intakes and outlets. 17 water quality sampling sites, including background and control sections, were set up for field investigation.One-way ANOVA was used to analyze the indexes, and the RDA ranking in the linear model was selected by DCA to sort and analyze the plant community and environmental data. Use the Membership Function to comprehensively evaluate the environmental quality of different communities; Regression Analysis was used to model the elationship between plant communities and physicochemical factors in the water environment. The results showed that: (1) There were certain differences in physical and chemical factors of water environment between different communities of mangrove forests in Nansha coastal wetlands.Through the determination of water quality at various points, the average salinity of water body was 3.71, which belonged to brackish water, and the average TRB of water body was 14 mg/L, which belonged to medium turbidity. The concentrations of DO, COD and TP in some communities were too high, and the other indexes were within the limits. The water quality of the second phase is more polluted than the water quality of the first phase.(2) From the RDA analysis of plant communities and aquatic environment factors, there were different degrees of correlation between plant community distribution, species diversity and aquatic environment factors. (3) Use the Membership Function to evaluate the ecological environment quality of mangrove forests in Nansha coastal wetlands, and form a comprehensive evaluation system by constructing 5 first-level indicators and 26 second-level indicators.In terms of comprehensive wetland indicators, the Kandelia obovata community, Aegiceras corniculatum community, Bruguiera gymnorhiza community and Pongamia pinnata community had good ecological environment quality, followed by Cerbera manghas community, Laguncularia racemosa community and Sonneratia aperatala community. The second phase Sonneratia aperatala community, the second phase Talipariti tiliaceum community, and the second phase Pongamia pinnata community are poor and poor, all of which are in the second stage of wetlands. The interaction of mangrove plant communities and aquatic environment factors plays a key role in promoting the composition, structure and function of wetland ecosystems, and is essential for understanding the mechanisms of species coexistence, biodiversity conservation and forest management.

Keywords: Coastal wetlands; Aquatic environment; Biodiversity; Affiliation function; Regression equation

1. Introduction

More than 70 of the UN Sustainable Development Goals (2015-2030) are directly related to wetlands[1], while the"Convention on Wetlands of Importance Especially as Waterfowl Habitat"organises the fourth Ramsar Strategic Plan (2016-2014), which aims to enhance wetland conservation, restoration and wise use [2]. Current international research on wetland restoration mechanisms has evolved from focusing on the restoration process of single elements to a multi-objective and integrated restoration mechanism that combines micro-mechanisms and macro-processes [3], which integrates the assessment of the restoration mechanisms and effects of wetland functions such as flood control, water purification and biodiversity maintenance [4].

Wetland ecosystems have a unique hydrology, and although wetlands cover only 9.7% of the global land area [5], the high productivity and rich biodiversity are often effective in mitigating aquatic nitrogen pollution [6-8]. The variety and distribution of wetland plants depends on various environmental factors such as light, water temperature, substrate composition, external disturbances and the quality of water quality.Macrophytes have multiple ecological roles and the ability of vegetation to characterise water quality [9], with plants retaining nutrients, absorbing nutrients and releasing dissolved oxygen organic matter through submerged roots and leaves, which in turn affects water quality [10].The functional traits of plants can reflect their ability to adapt to changes in external environmental conditions [11]. Based on the response of wetland plants in terms of plant height and plant weight under different water gradients, the response and distribution of plants under different wetland hydrological conditions can be predicted [12], and thus the ecological niche differentiation of plants and the synergistic evolution between plants and their environment can be explored [13]. Wetland water table impacts are an important factor in the distribution patterns, species diversity and flora of wetland plant communities [14,15], with lower water tables causing a shift in wetland plant community types from aquatic to mesophytic [16]. Wetland plants resist anoxic conditions by forming aeration tissues and aeria*l roots, and their deep and extensive root systems and nutritional reproduction characteris*tics can also enhance adaptation to disturbance and the formation of dominant species [17]. Groundwater loading may buffer the effects of climate change on the structure of some wetland plant communities, and recharge water usually remains constant, resulting in a characteristic relatively stable plant community [18]. Studies have shown that the study of species composition, diversity and distribution of plant communities is an important component of wetland ecosystems, and such plant-based water environment assessment programmes are already in use in large areas of the world [19,20].

Domestic and international scholars have assessed the health of mangrove ecosystems in the coastal wetlands of Nansha, taking full account of the impact of rapid urbanisation in the Guangdong-Hong Kong-Macao Greater Bay Area on the mangrove ecosystem [21]. A comprehensive analysis was conducted for the functions and status of Nansha wetlands and their environmental carrying capacity [22]; the service functions of mangrove ecosystems in Nansha coastal wetlands were assessed on the basis of a survey on the status of wetland resources in the Nansha area [23]; a biological assessment of water quality in Nansha wetlands was conducted using the zooplankton diversity index situation [24]; and the status of wetland resources and community composition were examined [25,26]. However, studies on the interaction between mangrove communities and the aquatic environment under different community types have not been reported.The aim of this study was to assess the interactive effects of variables related to water environment physicochemical factors on the structure and function of plant communities in Nansha coastal wetlands through the relationship between plant community structure, biodiversity and hydrological related variables.

2. Materials and methods

2.1 Study area

This study is located in the Nansha coastal wetland scenic area in the Pearl River Delta, which is situated in the geometric centre of the Pearl River Delta economic zone, on the shore of the Lingding Ocean and the Pearl River estuary, surrounded by the sea on three sides, with an area of about 77 hm^2. By the northeast, southwest and central four major mouth gates such as Humen, Hongqimen and Jiaomen and the remaining about 16 main tributaries of the West and North rivers flowing through the territory, the total regional water resources are large 76.9 m^3/s, 6.64 million m^3/d [27]. The annual precipitation is 1,542 mm, the average annual precipitation in years of abundant water is 2,035 mm, the average annual precipitation in years of dry water is 1,095 mm, the average annual runoff is 1,051 million m^3, and the wetland water storage month is 1.1 billion m^3[28]. It belongs to the subtropical marine monsoon climate, with an annual frost-free period of 346 d, an average temperature of 21.8 □, and an annual sunshine time of 1,930 h. The natural vegetation is dominated by Rhizophoraceae, Araceae, Asteraceae and Primulaceae, and the main community types are *Sonneratia apetala* community,*Talipariti tiliaceum* community and *Phragmites australis* community and three other species, of which *Sonneratia apetala* community accounted for 86.72% of the total area [29]. The wetland is a polder formed on the basis of the original mudflats, and the water area accounts for 9/10 of the wetland area [30].

2.2 Sampling design

In this study, 12 plant community samples were selected from the artificial mangrove forest of Nansha coastal wetland, with a total of 180 samples (36 large samples and 144 small samples) as the research object.Transient water samples were extracted from the Nansha wetland system based on community characteristics to study the physicochemical parameters of the wetland ecosystem, estimate the effects of environmental variables such as hydrology on the diversity, taxa and biomass of the mangrove plant community, compare the water quality under different communities and make an analysis of their correlation.Using the plant community as a benchmark, groundwater and watershed water and five inlets and outlets were transiently harvested from 12 community sample sites, with a total of 17 water quality sampling sites, including background and control cross-sections (Fig 1).The background section is the inlet and outlet of 18 and 19 Chung（18 chung and 19 chung are river course names）, sample point 13-18 Chung 1, sample point 14-18 Chung 2, sample point 15-18 Chung 3, sample point 16-19 Chung 1, sample point 17-19 Chung 2, to investigate the background values of the water environment. The control section is the brackish freshwater within the Nansha Wetland Scenic Area. The sampling points were arranged for eight communities in Phase I and four communities in Phase II, namely Sample Point 1- *Laguncularia racemosa* community, Sample Point 2- *Aegiceras corniculatum* community, Sample Point 3- *Kandelia obovata* community, Sample Point 4- *Bruguiera gymnorhiza* community, sample site 5 - *Pongamia pinnata* community, sample site 6 - *Cerbera manghas* community, sample site 7 - *Phragmites australis* community, sample site 8 - *Sonneratia apetala* community, phase II sample site 9 - *Sonneratia apetala* community, sample site 10- *Talipariti tiliaceum* community, sample site 11- *Pongamia pinnata* community, sample site 12- *Phragmites australis* community, reflecting the dilution and purification of water bodies by mangrove communities in the Nansha wetland.

Fig 1. Distribution of water environment sampling sites in Nansha coastal wetland, Guangzhou

2.3 Vegetation and environmental variable sampling

From July to August 2022, the field investigation of Nansha coastal wetlands was carried out, and sample sites were selected according to the distribution of representative plant communities in the first period and phase II, including 8 samples in the first phase and 4 samples in the second phase, and reflected the basic characteristics of each plant community through the investigation of the plant ontology in the sample square. The large sample square measured the trees with a breast diameter greater than 5 cm, and calculated the relative growth of the upper layer (tree layer) in the forest. The small sample measured the plants with a breast diameter of less than 5 cm, and calculated the relative growth of the understory layer (shrub layer). All plants in the large sample (including the plants in the small sample) were measured one by one, and the relative growth of the whole layer (arbor layer + shrub layer) was calculated.

Water samples are collected at similar temperatures and are first washed three times with watershed water to avoid floating water bodies entering the collector during collection and to prevent disturbance of water sediments. A total of 17 sample points were set up, each sample point was divided into 3 sample plots, two water samples were collected from each sample plot, a typical section of the sample plot was selected and excavated ±30 cm until the groundwater seeped out, left for a period of time, the supernatant was taken into a bottle, marked and sealed.Water samples were also taken in the same manner at parallel locations to the groundwater extracted.Six groundwater samples and six water samples from each community, three replicates were taken at the inlet and outlet, for a total of 156 samples. 500 ml of each water sample was collected and transported to the laboratory in time for further analysis. Seventy-eight of the water samples were used to determine pH, turbidity (TRB), salinity, conductivity, dissolved oxygen (DO), chlorophyll a, redox potential, total dissolved solids (TDS), total phosphorus (TP), total nitrogen (TN), ammonia nitrogen (NH_3-N) and nitrate nitrogen (NO_3-N); the other 78 water samples were used to determine five-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD).pH, turbidity, salinity, conductivity, DO, chlorophyll a, Eh and TDS were determined using a water quality meter; TP was determined using the elimination ascorbic acid method; TN was determined using the low-range persulphate oxidation method; NH_3-N was determined using the low-range salicylic acid method; NO_3-N was determined using the cadmium reduction method and colourimetric analysis was carried out using a HACH spectrophotometer(Table.1).

Table 1. The physico-chemical parameters used to test water quality and their laboratory analysis methods used.

Parameters	Methods	Instrumentation	Reference
pH	/	Multi3510 - WTW Multi3510 IDS multiparameter water quality meter	/
Turbidity	/	Multi3510 - WTW Multi3510 IDS multiparameter water quality meter	/
Salinity	/	Multi3510 - WTW Multi3510 IDS multiparameter water quality meter	/
Electrical conductivity	/	Multi3510 - WTW Multi3510 IDS multiparameter water quality meter	/
DO	/	Multi3510 - WTW Multi3510 IDS multiparameter water quality meter	/
TDS	/	Multi3510 - WTW Multi3510 IDS multiparameter water quality meter	/
Eh	/	Multi3510 - WTW Multi3510 IDS multiparameter water quality meter	/
Chlorophyll-a	/	YSI Multi-parameter Water Quality Analyzer EXO2	/
TP	**USEPA PhosVer 3**	HACH DR6000 UV-Visible Spectrophotometer	/
TN	Activated Persulfate Oxidation	HACH DR6000 UV-Visible Spectrophotometer	/
NH_3-N	Low-range Salicylic Acid	HACH DR6000 UV-Visible Spectrophotometer	/
NO_3-N	Cadmium Reduction Method	HACH DR6000 UV-Visible Spectrophotometer	/
BOD_5	Dilution and Inoculation Method		HJ 505-2009
COD	Dichromate Method		HJ 828-2017

Table 2.“Surface Water Quality Standards ”(GB3838-2002)

Parameters	I	II	III	IV	V
pH			6～9		

DO≧	7.5	6	5	3	2
COD≦	15	15	20	30	40
BOD_5≦	3	3	4	6	10
NH_3-N≦	0.15	0.5	1	1.5	2
TP≦	0.02	0.1	0.2	0.3	0.4
TN≦	0.2	0.5	1	1.5	2

2.4 Data processing

2.4.1 Species Diversity

In order to measure the plant diversity of mangrove communities, the species composition of different communities was analyzed by using the α diversity index, and the formula was as follows:

Simpson index（D_{sim}）：

$$D_{\text{sim}} = 1 - \sum P_i^2$$

Where:

P_i-the proportion of the number of individuals of species i to the number of all plant individuals in the community, i=1, 2,...,S;

S - Total number of species species.

Shannon-Wiener index（D_{sw}）：

$$D_{\text{sw}} = -\sum P_i \ln P_i$$

Pielouindex(J)：

$$J = -\sum P_i \ln P_i / \ln S$$

2.4.2 Membership Function

(1) Establishing Judging Levels

In this study, there are 10 mangrove plant community eco-environmental quality factors set R, divided into plant growth R_1, vegetation diversity R_2, soil organic carbon content R_3, and water environment factor R4 and R5, i.e. R={R_1,R_2,R_3,R_4}.A subset of 5 first-order factors, containing a total of 26 second-order indicators: R_1={R_{11},R_{12}...R_{14}}; R_2={R_{21},R_{22}...R_{29}}; R_3={R_{31}}; R_4={R_{41},R_{42}...R_{46}}； R_5={R_{51},R_{52}...R_{56}}.

(2) Determining Membership Function

The function is used to determine the degree of affiliation of each indicator. The evaluation indicators involved in this study are divided into positive and negative relationships with changes in ecological and environmental quality, with positive indicators showing that the larger the indicator value, the better the ecological and environmental quality, and vice versa. Water environment physical and chemical factors COD, BOD_5indicator value the larger the water quality level is worse, so choose the affiliation function inverse indicators. The formula is as follows [31]:

a. Membership Function for positive indicators:

$$M(x_i) = \begin{cases} 0, & x_i = x_{\min} \\ \dfrac{x_i - x_{\min}}{x_{\max} - x_{\min}}, & x_{\min} < x_i < x_{\max} \\ 1, & x_i = x_{\max} \end{cases}$$

b. Membership Function for inverse indicators:

$$M(x_i)=\begin{cases}0, & x_i=x_{max}\\ 1-\dfrac{x_i-x_{min}}{x_{max}-x_{min}}, & x_{min}<x_i<x_{max}\\ 1, & x_i=x_{min}\end{cases}$$

Where：

$M(x_i)$ - the degree of membership of a single indicator;

x_i - ith indicator;

Xmin - community indicator minimum;

xmax - community indicator maximum.

2.5 Data analysis

Calculation of species diversity in mangrove communities in Nansha wetlands using the α diversity index. One-way analysis of variance (ANOVA) using SPSS 22.0 statistical software to analyse the mean measurements of the physical and chemical factors of the water environment in the 26 sample sites.Determining the size of the first axis of the Lengths of gradient by using the DCA in Canoco5 and selecting the RDA ranking in the linear model to rank the plant community and environmental data. An integrated assessment of the environmental quality of different communities through Membership Function.Graphic drawing using Oringin 2022.

3 Results

3.1 Different community structures and plant species diversity

There are 8 species of mangrove plants in Nansha coastal wetland, composed of true mangroves and semi-mangroves, belonging to 7 families and 8 genera. There were 52 species of shrub plants, belonging to 43 genera in 30 families, and there were similarities in sublayer plants in different communities, and most of them were terrestrial vascular plants, and fewer aquatic vascular plants. The most common species are *Acrostichum aureum*, *Alocasia odora*, *Ardisia elliptica*, *Bidens pilosa*, *Acanthus ilicifolius*, 5 dominant families have been identified, the largest family is Pteridaceae, followed by Rhizophoraceae, Araceae, Asteraceae, Primulaceae, Native plants accounted for 86.9% and exotic plants accounted for 11.8%, and the distribution of biomass and species reflected the difference in community indicators.

By comparing plant diversity and richness in the upper, lower and whole layers of different communities, *Aegiceras corniculatum* community (9) has the highest abundance, with the lowest being the second stage *Pongamia pinnata* community (2.67); the highest richness of the upper layer of the lower forest was the *Kandelia obovata* community (2) and *Bruguiera Gymnorhiza* community (2), the rest of the community is pure forest; The highest and lowest full-layer richness are *Aegiceras Corniculatum* community (10) with Phase II *Pongamia Pinnata* community (3). Analyzing the vertical structure of mangrove stands in Nansha coastal wetland, the plant diversity index of the upper layer of different communities showed a significant difference ($P<0.01$), except for the *Kandelia obovata* community and the *Pongamia pinnata* community (fig 2). The Shannon-Wiener index of the understory layer of different communities was very different ($P<0.01$), the species species of *Aegiceras corniculatum* community were more complex, and the Simpson index of the understory layer showed a significant difference ($P< 0.05$), and the dominance of the first stage plants was higher than that of the second stage plants. The Pielou index in the understory layer differed significantly ($P<0.05$) (fig 3). There was a significant difference in the Shannon-Wiener index in different communities ($P<0.05$), while the Pielou index in the mixed layer was not significantly different from the Simpson index ($P>0.05$), and the *Aegiceras corniculatum* community had the highest Shannon-Wiener index and the smallest was the *Laguncularia racemosa* community (fig 4).

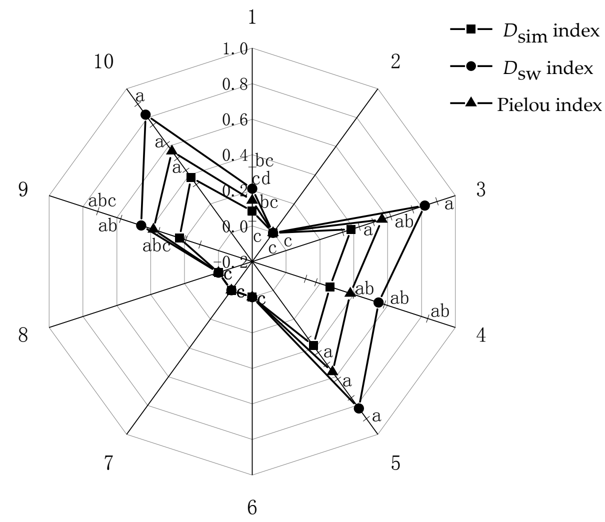


Fig 2. Comparison of upper layer biodiversity of mangrove communities in Nansha coastal wetland of Guangzhou

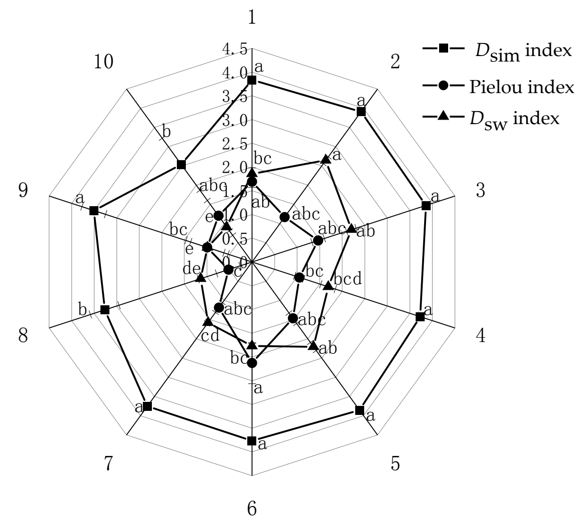


Fig 3. Comparison of understory biodiversity of mangrove communities in Nansha coastal wetland of Guangzhou

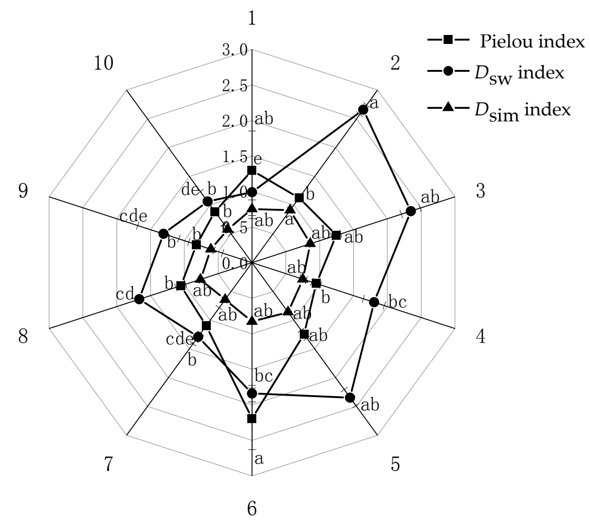
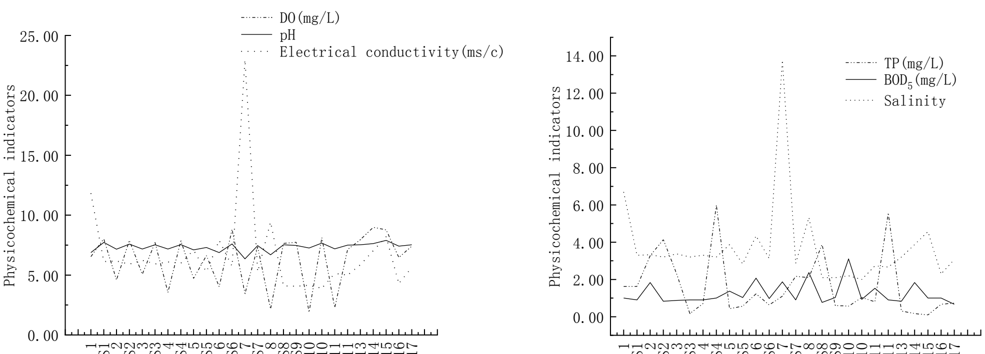


Fig 4. Comparison of full-layer biodiversity of mangrove communities in Nansha coastal wetland of Guangzhou

3.2 Changes and characteristics of physico-chemical parameters

Through the collection and measurement of groundwater, inlet and outlet water and background water in different communities of the Nansha wetland, the measured values of physical and chemical factors of water at each site are shown in Fig 5. There is some variability in the physicochemical factors of the water column at different sampling sites in the Nansha wetland. The salinity of the water at each site in the Nansha wetland was measured and the average value was 3.71, which is brackish freshwater, and the salinity of the groundwater was lower than that of the water.It shows that the coastal wetland waters of Nansha are indirectly influenced by the tidal changes of the sea, creating brackish freshwater. The low salinity of the groundwater suggests that there is some dilution of the salinity of the water column by the soil and plant roots.The average turbidity of the water body is 14 FNV, which is medium turbidity and the water is relatively turbid, indicating that there is more sediment, clay, inorganic and organic matter of microorganisms and other suspended matter in the waters of the Nansha wetland.The pH values ranged from 6.35 to 7.89, within the standard limits of 6 to 9, and there were no exceedances of the pH levels in the water bodies.

The water quality of the Nansha coastal wetland was evaluated and analysed according to the "Environmental Quality Standard for Surface Water" (GB3838-2002), and the results showed that the water body was of category 1-5 standards.The DO, BOD_5 and COD concentrations at each sample point reached the Class 1 standard, with mean values of 6.26 mg/L, 1.25 mg/L and 7.76 mg/L respectively, with individual indicators of BOD_5 reaching Class 3 water and Class 6 water, and there were large differences in the categories to which the DO indicators belonged in different communities. The average value of TP in the water body of Nansha coastal wetland is 0.35 mg/L, which meets the water quality standard of category 5; the average value of TN is 1.63 mg/L, which meets the water quality standard of category 5; the average value of NH_3-N is 0.28 mg/L, which meets the water quality standard of category 2; and the average value of NO_3-N is 0.05 mg/L. The mean pH value of the water was 7.33 and the water was generally neutral; the mean conductivity value was 6.74 ms/cm; the mean turbidity value was 17.76 FNV; the mean Eh value was 196.57; the mean TDS value was 6.74 g/L; and the mean chlorophyll-a value was 124.32 µg/L. The NH_3-N content of Nansha Binhai Wetland Phase II is high, plant decomposition produces nitrogen, there is water pollution, probably due to the lush growth of plants in Phase I can achieve effective decomposition, Phase II plant growth is poor, the rest of the indicators Phase I and Phase II are convergent.



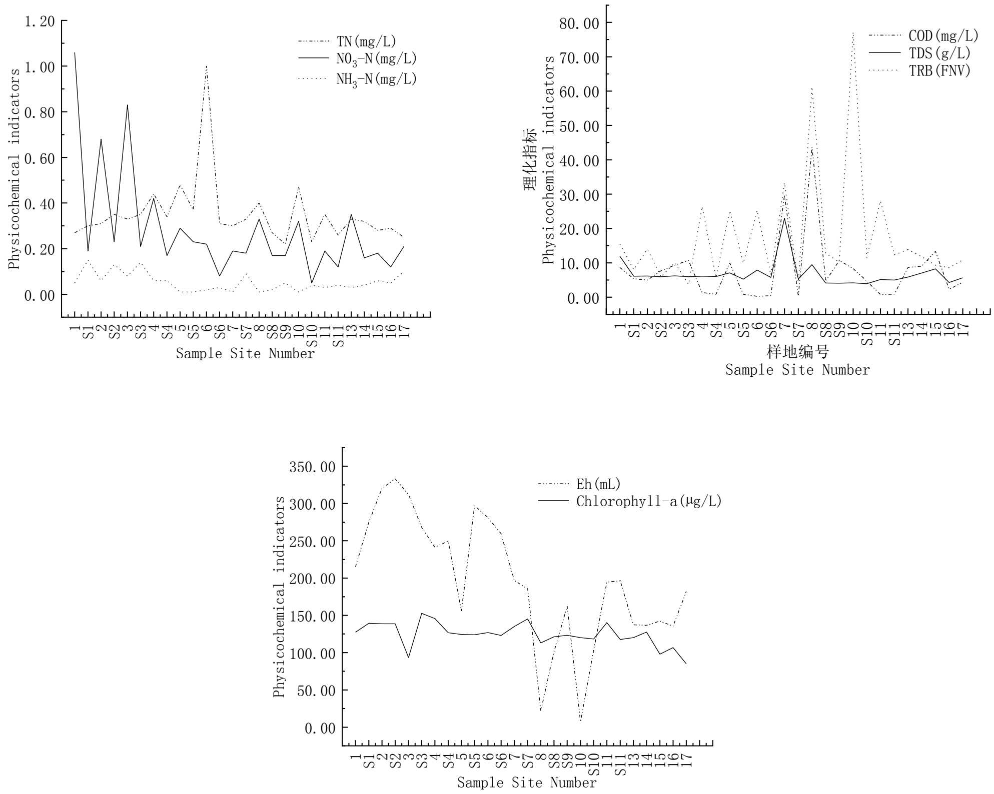


Fig 5. Comparison of physical and chemical factors of the water environment at different sites in Nansha coastal wetland, Guangzhou

Note: 1 to 10 denote plant community groundwater, S1 to S10 denote watershed water, and 13 to 14 are inlets and outlets.

3.3 Environmental gradients and their relationship with community metrics

3.3.1 Detrended correspondence analysis, DCA

The relationship between the environment and the plants and the interspecific relationships on a given environmental gradient are reflected by different models. There are usually two types of models, linear and single-peak, and the single-peak model is generally used for direct gradient analysis, while the linear model is considered if the results are not good. The model chosen is determined by analysing the size of the first axis of the Lengths of gradient, with a single-peak model being chosen above 4.0; between 3.0 and 4.0, either a single-peak model or a linear model can be used; below 3.0, a linear model is preferred. Therefore, the RDA ranking in the linear model was chosen for this study to analyse the plant community and environmental data.

3.3.2 Redundancy Analysis (RDA)

Based on Redundancy Analysis, the full RDA model using 14 environmental variables (Table.3) had a total variance of 20.304%, with 80.7% of the explanatory variance and 65.1% of the adjusted explanatory variance. The eigenvalue for ordinal axis 1 was 0.49, with a cumulative percentage of explained variation for species of 49.03% and a cumulative percentage of explained fitted variation for species-environment of 60.72%; the eigenvalue for ordinal axis 2 was 0.311, with a cumulative percentage of explained variation for species of 80.14% and a cumulative percentage of explained fitted variation for species-environment of 99.25%; the eigenvalue for ordinal axis 3 was 0.006, with a cumulative percentage explained variation of 80.74% for species and a cumulative percentage explained fitted variation of 100% for species-environment.The cumulative variation in species for the first three axes was 80.74% and the cumulative percentage of variation explained in the relationship between plant species diversity and water quality physicochemical parameters was 100%, thus showing that the first three ranking axes were well ranked to reflect most of the information, indicating a significant influence of water quality on wetland plant species diversity and distribution. By comparing the correlation between the physicochemical variables of the water environment and the diversity of plant species, the physicochemical parameters NH_3-N, TP and chlorophyll-a had a significant effect on the species (p<0.05), while the other physicochemical factors were not significant(Table.6). It can be seen that the hydrological variables have a strong influence on plant community structure and biomass, with varying correlations between each metric variable and the four environmental variables.

Table.3 Summary statistics of the first four axes of the coastal redundancy analysis (RDA) with community indicators and environmental variables in Nansha, Guangzhou (sampling date is December 2022)

	Axis 1	Axis 2	Axis 3	Axis 4	Total variance
Eigenvalues	0.49	0.311	0.006	0.15	1
CV of metrics data (%)	49.03	80.14	80.74	95.78	
Species-environment correlation	0.889	0.921	0.692	0	
CV of metrics-environment relationship (%)	60.72	99.25	100		
Sum of all eigenvalues					1
Sum of all canonical eigenvalues (full model)					0.957

Table 4. RDA analysis of plant communities and water environment factors in Nansha coastal wetland, Guangzhou

Variable	Explanatory volume（%）	Contribution（%）	*F*	*P*
NH_3-N	12.8	15.8	4.1	0.032
TN	10.3	12.8	3.6	0.054
TP	10.9	13.6	4.3	0.024
COD	5.2	6.4	2.1	\
Salinity	6.5	8.1	2.9	0.078
TDS	23.9	29.6	18.1	\
Chlorophyll-a	4.6	5.7	3.9	0.028
T.D.S	3.1	3.9	2.9	\
NO_3-N	3.4	4.3	3.6	\
DO	1.6	2.0	1.7	0.146
TRB	0.6	0.8	0.7	\
Oxidation-reduction Potential	1.3	1.6	1.4	0.156
BOD_5	0.7	0.9	0.8	0.418
pH	0.5	0.6	0.5	0.568

3.3.3 Analysis of RDA ranking plots of sample sites and water environment factors

The mangroves in the Nansha coastal wetland were classified into different plant community types according to the distribution of plant species in the sample plots, with three sample squares in each sample plot representing the plant community types(Fig 6). They are mainly distributed in the second, third and fourth quadrants, except for the communities represented by C3 and B1, which are distributed at the edge of the sorting axis, and the rest of the communities represented by each point are more concentrated in the sorting space, among which the correlation between the communities represented by A1 and B3, A10 and B9, C5, C6 and C10, and A8, B6 and B8 is high, and the communities represented by the other sample sites have some variability. Sample sites A1, B3, C1, B2, C3, A9, C7, B10 showed strong positive correlations with NH_3-N, NO_3-N, DO, TDS, Salinity, T.D.S, Eh, and significant negative correlations with TP, COD, BOD_5, TRB; sample sites B2, C2, C4, C9, B9, B10, A10, A7, B7, C7 A2, A3 showed significant positive correlations with pH, TN, Chlorophyll-a; sample points A4, A5, C10, C5, C6, B5, A8, B6, A6, C8, B4 showed significant positive correlations with COD, TRB, BOD_5, TP, and more negative correlations with NH3-N, NO_3-N, DO, TDS, Salinity, T.D.S, Eh.

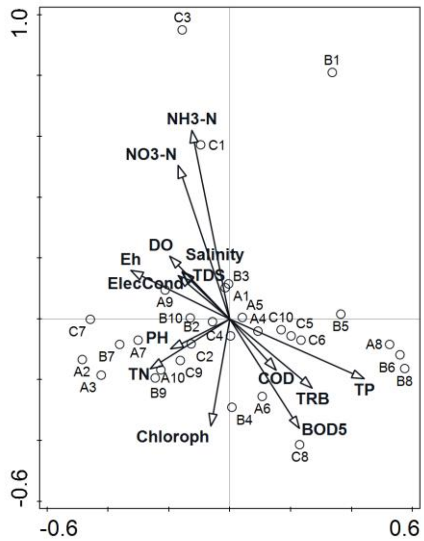


Fig 6. RDA ranking of sample sites and water environment factors in Nansha coastal wetland, Guangzhou

Note: A1, B1, C1 are three samples of the Laguangmu community; A2, B2, C2 are three samples of the Tongfa tree community; A3, B3, C3 are three samples of the autumn eggplant community; A4, B4, C4 are three samples of the Mullein community; A5, B5, C5 are three samples of the water yellow bark community; A6, B6, C6 are three samples of the sea mango community; A7, B7, C7 A8, B8 and C8 are three samples of the second phase of the sea mulberry community; A9, B9 and C9 are three samples of the second phase of the yellow hibiscus community; and A10, B10 and C10 are three samples of the second phase of the water yellow peel community.

3.3.4 RDA ranking analysis of plant diversity and aquatic environmental factors in Nansha wetlands

The RDA double-order diagram shows that the Simpson index and the Pielou index are in the first quadrant and the Shannon-Wiener index is in the fourth quadrant(Fig 7). Shannon-Wiener index was positively correlated with COD, TRB, TP, BOD_5, and significantly negatively correlated with NH_3-N, NO_3-N, DO, TDS, T.D.S, Salinity, Eh; Simpson index, Pielou index were significantly negatively correlated with pH, TN, and Chlorophyll-a were significantly negatively correlated.

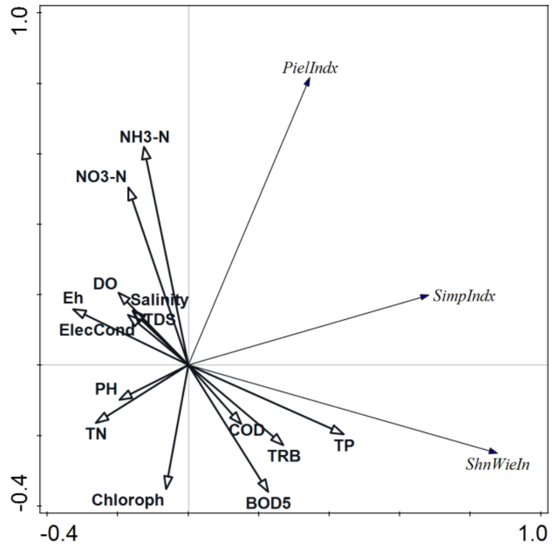


Fig 7. RDA ranking of plant diversity and water environment factors in Nansha coastal wetland, Guangzhou

Note: In the figure,PielIndx is Pielou index；SimpIndx is Simpson index and ShnwieIn is Shannon-Wiener index

3.4 Membership Function--Relationships between plant community structure,function (biomass) and hydrologically related variables

Five primary indicators and 26 secondary indicators were evaluated using affiliation function analysis to establish a comprehensive evaluation system(Table.5). The plant growth of the 10 mangrove communities in the coastal wetland was ranked in descending order: community 7 > community 8 > community 6 > community 1 > community 3 > community 4 > community 5 > community 10 > community 9 > community 2, with community 7 and community 8 growing the most and community 2 and community 9 growing the least. In plant diversity, the trend of the magnitude of D_{sim} and D_{sw} in the understorey was: community 2 > community 3 = community 5 > community 1 > community 6 > community 4 > community 7 > community 8 > community 9 > community 10, and the Pielou ranking in the understorey was: community 6 > community 1 > community 3 = community 5 > community 7 = community 10 > community 2 > community 4 > community 9 > community 8, with the highest D_{sim} and D_{sw} index for community 2 and the highest Pielou index for community 6; the lowest D_{sim} and D_{sw} index was for community 10 and the lowest Pielou index was for community 8. The diversity indices of the upper layers of the forest are all ranked as follows: community 3 = community 5 > community 4 > community 9 > community 1 > community 2 = community 6 = community 7 = community 8 = community 10. The highest diversity indices are for community 3 and community 5, and the lowest are for community 2, community 6, community 7, community 8 and community 10, all of which are pure forests. The D_{sim} index of the whole layer is as follows: community 2 > community 3 = community 5 > community 6 > community 7 > community 4 > community 1 > community 8 > community 9 > community 10, the highest D_{sim} index is community 2 and the lowest is community 10; the D_{sw} index of the whole layer is as follows: community 2 > community 3 = community 5 > community 6 > community 4 > community 7 > community 9 > community 8 > community 10 > community 1, the highest D_{sw} index is community 2 and the lowest is community 10; the Pielou index of the whole layer is as follows: community 6 > community 3 = community 5 > community 2 > community 8 > community 7 > community 9 > community 10 > community 1. The highest D_{sw} index is for community 2 and the lowest is for community 1; the trend of the Pielou index for the whole layer is: community 6 > community 1 > community 3 = community 5 > community 2 > community 8 > community 7 > community 4 > community 10 > community 9, the highest Pielou index is for community 6 and the lowest is for community 9.

At the level of soil organic carbon content, community 4 > community 2 > community 7 > community 6 > community 9 > community 1 = community 3 = community 5 > community 8 > community 10, with community 4 having the highest organic carbon Membership Function values and community 10 having the lowest organic carbon Membership Function values. Comparing the physicochemical factors in the water environment of the different communities, the highest CO value was for community 1 and the lowest was for community 10; the highest NH_3-N value was for community 1 and the lowest was for community 7; the highest TP value was for community 6 and the lowest was for community 1; the highest TN value was for community 2 and the lowest was for community 5; the highest COD value was for community 6 and the lowest was for community 8; the highest BOD_5 value was for community 1 and the lowest was for community 10. The mean value of the affiliation function indicates the ecological quality of each community, ranked as follows: Community 3 > Community 2 > Community 4 = Community 5 > Community 6 > Community 1 > Community 7 > Community 9 > Community 8 > Community 10, In terms of comprehensive wetland indicators, the *Kandelia obovata* community, *Aegiceras corniculatum* community, *Bruguiera gymnorhiza* community and *Pongamia pinnata* community had good ecological environment quality, followed by *Cerbera manghas* community, *Laguncularia racemosa* community and *Sonneratia aperatala* community. The second phase *Sonneratia aperatala* community, the second phase *Talipariti tiliaceum* community, and the second phase *Pongamia pinnata* community are poor and poor, all of which are in the second stage of wetlands.

Table 5. Membership function values of planted mangrove communities in Nansha coastal wetlands

Factors Tier 1 indicators	Number	Indicators Secondary indicators	Membership Function										
			Indicators	1	2	3	4	5	6	7	8	9	10
Plant Growth	R_1	Chest Height 3D Indicator	R_{11}	0.42	0.01	0.26	0.17	0.12	0.47	0.82	0.71	0.07	0.09
		Total number of understory species	R_{12}	0.63	2.62	1.00	0.87	0.25	0.37	0.75	0.50	0.75	0.00
		Total number of species in the whole layer	R_{13}	0.24	1.00	0.52	0.48	0.10	0.14	0.29	0.19	0.29	0.00
		Proportion of native plants	R_{14}	0.39	0.09	1.00	1.00	1.00	1.00	0.00	0.33	1.00	1.00
Plant Diversity	R_2	Understory D_{sim}	R_{21}	0.96	1.00	0.97	0.92	0.97	0.94	0.93	0.74	0.83	0.45
		Understory D_{sw}	R_{22}	0.63	0.95	0.77	0.57	0.77	0.60	0.53	0.35	0.29	0.26
		Understory Pielou	R_{23}	0.59	0.38	0.50	0.33	0.50	0.77	0.39	0.11	0.31	0.39
		Upper Forest D_{sim}	R_{24}	0.17	0.00	0.77	0.52	0.77	0.00	0.00	0.00	0.46	0.00
		Upper Forest D_{sw}	R_{25}	0.22	0.00	0.86	0.57	0.86	0.00	0.00	0.00	0.58	0.00
		Upper Forest Pielou	R_{26}	0.21	0.00	0.83	0.55	0.83	0.00	0.00	0.00	0.46	0.00
		Whole floor D_{sim}	R_{27}	0.66	0.88	0.81	0.67	0.81	0.77	0.68	0.52	0.47	0.43
		Whole floor D_{sw}	R_{28}	0.19	0.94	0.79	0.55	0.79	0.57	0.49	0.32	0.33	0.23
		Whole floor Pielou	R_{29}	0.38	0.32	0.37	0.25	0.37	0.73	0.29	0.31	0.20	0.23
Soil factor	R_3	Organic carbon content	R_{31}	0.42	0.68	0.42	0.83	0.42	0.58	0.63	0.34	0.50	0.12

Continued table:

Factors Tier 1 indicators	Number	Indicators Secondary indicators	Membership Function										
			Indicators	1	2	3	4	5	6	7	8	9	10
Community groundwater	R_4	CO	R_{41}	0.68	0.47	0.52	0.36	0.49	0.41	0.35	0.21	/	0.19
		NH_3-N	R_{42}	0.64	0.40	0.49	0.25	0.16	0.12	0.10	0.18	/	0.18
		TP	R_{43}	0.06	0.1	0.12	0.23	0.27	0.8	0.09	0.19	/	0.26
		TN	R_{44}	0.13	0.25	0.18	0.05	0.03	0.10	0.09	0.16	/	0.04
		COD	R_{45}	0.81	0.89	0.8	0.97	0.78	1.00	0.33	0.02	/	0.81
		BOD_5	R_{46}	0.99	0.97	0.99	0.99	0.98	0.96	0.97	0.96	/	0.94
Water area	R_5	CO	R_{51}	0.84	0.82	0.81	0.82	0.69	0.93	0.77	0.80	0.81	0.85
		NH_3-N	R_{52}	0.10	0.13	0.11	0.09	0.12	0.03	0.09	0.09	0.09	0.01
		TP	R_{53}	0.09	0.14	0.14	0.13	0.16	0.10	0.12	0.06	0.01	0.02
		TN	R_{54}	0.13	0.32	0.01	0.46	0.05	0.05	0.17	0.30	0.05	0.08
		COD	R_{55}	0.89	0.84	0.76	0.98	0.99	0.99	1.00	0.89	0.77	0.91
		BOD_5	R_{56}	0.99	1.00	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.99
		Mean value of the Membership Function		0.48	0.58	0.61	0.56	0.55	0.52	0.42	0.36	0.36	0.33

3.5 Regression equations of mangrove plant communities and water environment in Nansha coastal wetlands

3.5.1 Regression analysis between physical and chemical factors in the water environment

Linear regression equations, quadratic equations and logarithmic equations were fitted between the water environment factors in the Nansha coastal wetland by regression analysis (Table 6). There were significant differences in plant diversity and aquatic environment factors in different communities (P<0.05), and the explanatory ability of the explanatory variables of the regression equation was 0.136< R^2<1, DO and turbidity (R^2=0.615), TRB and redox potential (R^2=0.793), salinity and pH (R^2=0.819), conductivity and pH (R^2=0.888), DO and pH (R^2=0.888), BOD_5 and TRB (R^2=0.383), TDS and salinity (R^2=1), TDS and conductivity (R^2=1) were very significant differences (P<0.01). The fitting models of R^2>0.5 are: DO and turbidity (R^2=0.615), TRB and redox potential (R^2=0.793), salinity and pH (R^2=0.819), conductivity and pH (R^2=0.888), DO and pH (R^2=0.888), TDS and salinity (R^2=1), TDS and conductivity (R^2=1).

Table 6. Regression equations between the physical and chemical factors of the water environment in the Nansha coastal wetlands (n=30)

Independent variable (x) and dependent variable (y)	Regression Equation	R^2
DO and Eh	y=-45.684+115.969x-10.582x^2	0.317*
DO and Turbidity	y=62.901-27.388lg$x$	**0.615****
DO and TP	y=0.798-193x+0.018x^2	0.21*
DO and BOD_5	y=2.188-0.454lg$x$	0.32*
TRB and Eh	y=60.916-0.329x+0.001x^2	**0.793****
Eh and COD	y=-4.467x	0.424*
Eh and BOD_5	y=-85.262x	0.447*
Salinity and pH	y=611.786-166.711x+11.406x^2	**0.819****
Electrical conductivity and pH	y=969.015-263.315x+17.979x^2	**0.888****
DO and pH	y=965.907-262.384x+17.91x^2	**0.888****
COD and pH	y=1556.034-424.798x+29.129x^2	0.406*
TP and TRB	y=0.027+0.13lg$x$	0.15*
COD and TRB	y=-5.824+6.074lg$x$	0.136*
BOD_5 and TRB	y=-0.075+0.563lg$x$	0.383**
TDS and Salinity	y=0.218+1.83x-0.013x^2	**1****
CODand Salinity	y=1.791x	0.049*
TDS and Electrical conductivity	y=1.001x	**1****
COD and Electrical conductivity	y=1542-1.538x+0.098x^2	0.277*
COD and TDS	y=15.431-1.54x+0.098x^2	0.277*
NH_3-N and TN	y=0.134x	0.452*
Chlorophyll-a and TN	y=121.591+345.885x-2460.715x^2	0.215*

*Significantly correlated at the 0.05 level,**significantly correlated at the 0.01 level.strong correlations are marked bold at R^2 ＞ 0.5.

3.5.2 Regression analysis of plant diversity and water environment factors

By regression analysis of plant diversity, growth and aquatic environment factors in Nansha coastal wetlands (Table 7), plant diversity in different communities was significantly correlated with aquatic environment factors (P<0.05), and the explanatory ability of the explanatory variables of the regression equation was 0.026<R^2<0.676, and the Shannon-

Wiener index was significantly correlated with the Simpson index (P<0.01, R^2=0.676). The fitted models for R^2>0.5 are: Pielou index and Base area(R^2=0.591);Shannon-Wiener index and Simpson index (R^2=0.676).

Table 7. Regression equation of plant diversity (x) with water environment physicochemical factors (y) in Nansha coastal wetland (n=30)

Independent variable (x) and dependent variable (y)	Regression Equation	R^2
Simpson index and pH	y=-28.937+8.574x+0.617x^2	0.026*
Shannon-Wiener index and pH	y=-103.927+30.176x-2.147x^2	0.255*
Shannon-Wiener index and Salinity	y=2.425-0.407lg$x$	0.151*
Pielou index and Salinity	y=0.142+0.409x-0.025x^2	0.251*
Shannon-Wiener index and	y=-0.045x	0.432*
Pielou index and Electrical conductivity	y=-0.014+0.259x-0.009x^2	0.25*
Simpson index and TDS	y=0.464+0.068x-0.003x^2	0.262*
Shannon-Wiener index and TDS	y=0.595+0.263x-0.011x^2	0.239*
Pielou index and TDS	y=-0.093+0.273x-0.01x^2	0.256*
Pielou index and TN	y=0.995+0.441x-0.101x^2	0.226*
Shannon-Wiener index and COD	y=2.186-0.098x+0.002x^2	0.362*
Simpson index and Plant height	y=0.445+0.088x+-0.005x^2	0.224*
Pielou index and Base area	y=166.322x	**0.591***
Pielou index and Basal volume	y=0.536+0.041x	0.265*
Shannon-Wiener index and Chest height volume	y=1.271+0.068x-0.001x^2	0.321*
Shannon-Wiener index and Simpson index	y=2.7x	**0.676****
Pielou index and Simpson index	y=0.145+0.652x+0.929x^2	0.299*

*Significantly correlated at the 0.05 level,**significantly correlated at the 0.01 level.strong correlations are marked bold at R^2 ＞ 0.5.

4 Conclusion

4.1 Different community structures and plant species diversity

*There are 8 species of mangrove plants in Nansha coastal wetland, composed of true mangroves and semi-mangroves, belonging to 7 families and 8 genera.There were 52 species of shrub plants, belonging to 43 genera in 30 families, and there were simi*larities in sublayer plants in different communities, and most of them were terrestrial vascular plants, and fewer aquatic vascular plants. The most common species are *Acrostichum aureum*, *Alocasia odora*, *Ardisia elliptica*, *Bidens pilosa*, *Acanthus ilicifolius*, 5 dominant families have been identified, the largest family is Pteridaceae, followed by Rhizophoraceae, Araceae, Asteraceae, Primulaceae, Native plants accounted for 86.9% and exotic plants accounted for 11.8%, and the distribution of biomass and species reflected the difference in community indicators.

4.2 Analysis of physicochemical parameters of water environmental factors in different communities

There is some variability in the physicochemical factors of the water environment between different communities of mangroves in the Nansha coastal wetlands. In general, the water quality of the Nansha coastal wetland is good and falls within water quality standard 5 of the general landscape waters in the "Environmental Quality Standard for Surface Water" (GB3838-2002), with other classification criteria present for individual plant communities. The average salinity of the water body was 3.71, which is brackish fresh water; the average turbidity of the water body was 14 FNV, which is medium turbidity; the pH value ranged from 6.35 to 7.89, which is within the standard limit of 6 to 9. Turbidity and pH values in the water column were relatively stable at each point, with large differences at the remaining points. It shows that the Nansha coastal wetland is indirectly influenced by the tidal changes of seawater, and that the nutrient matrix and physicochemical composition of the groundwater stimulate and limit the various conditions for microbial life activities, affecting the growth volume and diversity of the plant community and the distribution of plant species.Of the 26 sample sites, the lowest pH value was in the groundwater of the *Sonneratia apetala* community at 5.35 and the highest value was in the 15# inlet and outlet at 7.89.DO concentrations in the water column varied considerably from site to site, with the highest value at the 14# inlet and outlet at 8.98 mg/L and the lowest concentration in the groundwater of the *Pongamia pinnata* community in Phase II at 1.89 mg/L. Five categories of water quality criteria were covered in the sampling of the different community samples. Overall, the higher water quality standard areas are at the inlets and outlets, indicating that there is some circulation turnover in the waters and that the waters are self-purifying and of good quality. The lower water quality standards are in the groundwater of the plant communities and there is some water contamination, with the *Sonneratia apetala* community, the Phase II *Sonneratia apetala* community, the *Phragmites australis* community, and the Phase II *Pongamia pinnata* community having greater contamination in the groundwater. The NO_3-N content of the water column ranged from 0.01-0.15 mg/L and did not exceed the standard. There was little variation in the comparison between the communities and the water column had a high self-purification capacity. Relatively high levels of NO_3-N at sample sites near wetland offices, where human disturbance drives biological movement and high levels of loading alter ecological communities.

NH_3-N levels tended to level off in the different community sample sites, with concentrations ranging from 0.05 to 1.06 mg/L, covering the four categories of water quality criteria with some variation.The highest NH_3-N content is in the 16# inlet and outlet, 0.12 mg/L; the lowest is in the Laguncularia racemosa groundwater, with 1.06 mg/L. The decay of plant residues decomposes a large amount of nitrogen, aggravating the pollution of the water body, and the NH_3-N content is high. The COD content of the water body was highly variable, in the range of 0.3 mg/L to 43.67 mg/L. Most of the sample sites fell within the water quality standard of Class 1, indicating a high degree of pollutant removal efficiency.The presence of *Sonneratia apetala* communities exceeding the standard limits may be due to the fact that *Sonneratia apetala* has a well-developed root system and that more oxygen is consumed by root (subterranean) respiration or soil respiration of plants within the community.

TP concentration values ranged from 0.22 mg/L to 1.0 mg/L, with the highest value in *Cerbera manghas* groundwater at 1.0 mg/L and the lowest value in *Talipariti tiliaceum* waters in Phase II at 0.22 mg/L. There were exceedances in *Bruguiera gymnorhiza* community groundwater, *Cerbera manghas* community groundwater, *Pongamia pinnata* community groundwater, and Phase II *Pongamia pinnata* groundwater, all in anaerobic soil conditions. Water levels, Eh and vegetation growth processes influence TP concentrations, which are released under anaerobic soil conditions and adsorbed into the soil matrix under aerobic conditions, while acting as a source and sink for TP. The BOD_5 content ranged from 0.67 mg/L to 3.1 mg/L, with all points falling within the Class 1 water quality standard.This shows that the water quality in the Nansha coastal wetland is good and that the water quality function of the wetland ecosystem dissipates the pollutant concentrations. Plant roots can couple organic matter decomposition with inorganic ion evolution, degrading organic matter through the energy of inorganic redox processes and changing the physical and chemical environmental characteristics of the water.

4.3 Analysis of the relationship between plant communities and water environment factors

The RDA analysis of plant communities and water environment factors at different sites shows that, with the exception of individual communities scattered at the edges of the ordination axis, each point represents a more concentrated distribution of communities in the ordination space. *Laguncularia racemosa* community, *Aegiceras corniculatum* community, *Kandelia obovata* community, *Sonneratia apetal* community, Phase II *Talipariti tiliaceum* community and Phase II *Pongamia pinnata* community were strongly and negatively correlated with NH_3-N, NO_3-N, DO, TDS, Salinity, Electrical conductivity, Eh were strongly positively correlated, and TP, COD, BOD_5, TRB were significantly negatively correlated; *Aegiceras corniculatum* community, *Bruguiera gymnorhiza* community *Aegiceras corniculatum* community, *Bruguiera gymnorhiza* community, *Kandelia obovata* community, *Sonneratia apetal* community, Phase II *Talipariti tiliaceum* community and Phase II *Pongamia pinnata* community were significantly and positively correlated with pH, TN, Chlorophyll-a; *Bruguiera gymnorhiza* community The *Bruguiera gymnorhiza* community, *Pongamia pinnata* community, *Cerbera manghas* community, Phase II *Sonneratia apetala* community and Phase II *Pongamia pinnata* community showed significant positive correlations with COD, TRB, BOD_5, TP, and more positive correlations with NH_3-N, NO_3-N, DO, TDS, Salinity, Eh Electrical conductivity, and Eh were strongly negatively correlated.

By RDA analysis of the species diversity index variables, the Shannon-Wiener index was positively correlated with COD, TRB, TP and BOD_5, and significantly negatively correlated with NH_3-N, NO_3-N, DO, TDS, conductivity, salinity and Eh; the Simpson index and Pielou index were significantly negatively correlated with pH, TN and chlorophyll-a.Species diversity and richness are mainly controlled by certain substances, and the length of the arrows indicates the proportion of the influence of aquatic environmental factors on aquatic plant diversity. It can be seen that NH_3-N, NO_3-N and TP content have a greater influence on plant diversity. The higher the DO concentration, the lower the TP, NH_3-N, NO_3-N, COD, BOD_5 and chlorophyll-a. The pH value is positively correlated with TN and NH3-N, and negatively correlated with the rest of the indicators, indicating that the rest of the indicators decrease as the pH value increases. The content of NH_3-N and chlorophyll a tended to decrease with increasing TRB concentration, while the content of TP, COD and BOD_5 increased with increasing TRB concentration. The increase in TDS and salinity content was followed by an increase in COD and BOD_5 content, which did not correlate with other physicochemical factors. As far as the easy-to-measure values (measured by on-site portable instruments) and difficult-to-measure values (measured values in laboratory physical and chemical experiments) are concerned, the approximate concentration trend of the difficult-to-measure values can be inferred through the easy-to-measure values in the subsequent studies with limited experiments, so as to improve the research efficiency.

4.4 Comprehensive evaluation results of the Membership Function method

Ecosystem quality assessment of Nansha coastal mangroves using Membership Function. Five primary indicators and 26 secondary indicators are constructed to form a comprehensive evaluation system, and the visual representation of the primary indicators is achieved through the quantitative study of the secondary evaluation indicators. Among the ten communities the largest plant growth is in the tall tree *Sonneratia apetala* community, as the larger plants are able to thrive in saturated soils with severe oxygen depletion, dominating the shallow ecosystem and becoming an important part of the ecological processes and biodiversity mix. The mangrove *Sonneratia apetala* is an exotic plant with a tendency to spread, and the formation of its dominant species means that the Nansha coastal wetland ecosystem is at some risk of invasion. The highest value of soil organic carbon content was found in *Bruguiera gymnorhiza* community and the lowest in *Pongamia pinnata* community. This indicates that ortho-mangroves have a stronger organic carbon storage capacity, and that the mangrove understorey soil is reductive, with its intricate root system producing secretions that decompose organic matter slowly and accumulate easily, promoting the formation of organic carbon.

In terms of the overall wetland indicators, the *Kandelia obovata* community, the *Aegiceras corniculatum* community, the *Bruguiera gymnorhiza* community and the *Pongamia pinnata* community have good ecological and environmental quality, all are located in the middle of the water and are weakly disturbed, except for the *Kandelia obovata* community, the *Aegiceras corniculatum* community, the *Bruguiera gymnorhiza* community and the *Pongamia pinnata* community have a certain degree of heavy metal pollution purification; the *Cerbera manghas* community, the *Laguncularia racemosa* community, the *Sonneratia aperatala* community is the second most important community, because it is located near the human activity area forest, on the other hand, because its root system is complicated, root respiration and soil respiration consume more oxygen, individual indicators have exceeded the standard, affecting the overall environmental quality; *Sonneratia aperatala* community, *Talipariti tiliaceum* community, *Pongamia pinnata* community are poorer and are all in Phase II. The water environment factor indicators, biodiversity, growth and soil organic carbon are all lower than in Phase I, indicating that the environmental quality of the plant community depends on various environmental factors and that the factors are synergistic with each other. Plants characterise water quality capacity through multiple ecological capabilities, and good water quality in turn has a direct impact on multiple environmental factors, forming a coexistence mechanism for wetland ecosystem function.

5 Discussion

5.1 Characteristics of different community structures and biodiversity

In this study, there were significant differences in plant community structure between different communities, and overall, communities with higher trophic levels and wetter soils had the greatest plant species diversity. The vertical structure of the forest layer and forest phase formed by the staggered height of trees and the layering of canopy are conducive to the reproductive symbiosis and adaptability of plants and improve biodiversity. The vertical structure of the forest layer and forest phase formed by the staggered height of trees and the layering of canopy are conducive to the reproductive symbiosis and adaptability of plants and improve biodiversity. The first phase of the wetland was built in 1999 and the second phase was constructed in 2008, and there were large differences in plant growth, and the older forest stands affected the nutrient cycle rate and carbon storage. The first stage of true mangroves is mostly and the second stage of semi-mangroves is most, and the research shows that the ecological benefits of true mangrove plants are higher than those of semi-mangrove plants and other associated plants. In the Nansha coastal wetlands, high TRB, eutrophication and other environmental factors limit plant diversity, mainly for species that can adapt to the current habitat[32]. Small changes in the physical environment will produce coherent biological responses, which will affect not only individual organisms but also biological genetics, and the niche differentiation and evolution mode of plants and the co-evolution of plants and the environment can promote the mutually beneficial symbiosis between various factors of coastal wetland ecosystems.

5.2 Comparative analysis of water environmental factors in different communities

Of the many influencing factors, hydrological conditions are the dominant variable in determining the structure and function of wetland ecosystems.In response to the problems in the water environment of the Nansha coastal wetland, the treatment of domestic sewage generated by the work and life of the wetland management office and wetland staff should be strengthened, the control of pollution sources should be enhanced and the TN concentration in the surrounding waters and plant communities should be reduced. The water quality in Phase II is more polluted than in Phase I. There is greater pollution in the *Sonneratia apetala* community in Phase I, the *Sonneratia apetala* community in Phase II and the *Phragmites australis* community in Phase II. Regular harvesting of *Phragmites australis* in wetlands and regular cleaning of *Sonneratia apetala* communities should be carried out to reduce the production of plant saprophytic components and reduce water pollution.The COD concentration at the sample site of the Sonneratia apetala community in Phase II exceeded the standard value because of its proximity to the wetland fish pond culture area, which has a high microbial content in the water body and requires a higher consumption of DO, and therefore the concentration exceeded the standard, and the management of the wetland fish pond culture area should be increased. The waters of the *Kandelia obovata* community, *Bruguiera gymnorhiza* community and *Pongamia pinnata* community have excessive water TP concentrations and eutrophication of the water column. It may be due to the inability of the aerobic section's phosphorus-polymerising bacteria to take up large quantities of dissolved phosphorus, poor sludge discharge and unsatisfactory sedimentation, producing an excess of TP. Sediment loading may also have a significant impact on the assemblage and diversity of aquatic plants and therefore nutrient loading to wetland waters sediments could be studied. There are implications for studying the relationship between macrophyte biodiversity and phytoplankton due to the high turbidity of the waters, which may promote phytoplankton growth. In recent years, there has been increasing interest in the ecosystem processes of water and carbon cycling in the wetland sector, where soil water content in the ecosystem carbon cycle has a differential impact on climate warming [33]. Soluble organic carbon may show an increasing or decreasing trend with varying hydrological conditions. Vegetation characteristics (density, species type and growth habitat) will influence the production, consumption and transport of CH_4 through microorganisms and enzymes, thus indirectly affecting CH_4 emissions [34], and the water and carbon cycles form a coupled and balanced mechanism that deserves more attention.

5.3 Analysis of the relationship between plant communities and water environment factors

The interactions between mangrove plant communities and aquatic environmental factors play a key role in driving the composition, structure and function of wetland ecosystems and are critical to understanding the mechanisms of species coexistence, biodiversity maintenance and forest management.The ability of plants to characterise water quality through multiple ecological effects and the community structure patterns of wetlands to alter species distribution and diversity under the influence of water quality are reflected in rich data on the interactions between plant communities and environmental factors in the Nansha coastal wetlands. The ability of plants to grow in different locations indicates the potential for different nutrient states to which plants are adapted, and more research is needed to establish better links between water levels, nutrient and sediment inputs, and macrophyte conservation needs. It is hoped that the plant community analysis will provide a baseline for monitoring plant diversity and environmental factors, and provide a convincing basis for the importance of biodiversity conservation and sustainable water use in the Nansha coastal wetlands.

Using Membership Function and Regression Equation to analyze between different environmental factors, 5 primary indicators and 26 secondary indicators are constructed to form a comprehensive evaluation system, and through the quantitative study of secondary evaluation indicators, the visual representation of primary indicators is realized. The analysis takes into account the amount of mangrove plant growth, plant diversity, water environment factors and soil factors, with the aim of determining the quality of the environment in multiple dimensions. In subsequent studies, the Membership Function score of the introduced plants can be reduced to 0 to ensure the proportion of native tree species, and better evaluate their environmental quality on the basis of stable community structure.The Linear Equation, Euadratic Equation and Logarithmic Equation were constructed using Regression Equation to calculate difficult values using easy-to-measure values in subsequent studies, reducing destructive sampling and balancing ecological conservation with substantive research. The model was developed not only to compare the environmental quality situation of different communities in this study, but also to provide some reference for the evaluation of ecological and environmental quality in other study areas.

5.4 Suggestions for rationalising the management of artificial mangroves

Suspended matter as the main pollutant in the water body, the N, P and MnO_4- index in the water body have a certain adsorption effect, after the adsorption of suspended matter settles too slowly will lead to the deterioration of the water body, or vice versa. The intricate root system of mangroves can promote the rapid settlement of large suspended particles and adsorb small suspended particles, reducing the residence time of suspended particles in the water column, but the tolerance of mangroves to suspended particles in the water system is limited, and different species of mangrove plants have different tolerances. In the selection of mangrove plants for ecological restoration of wetlands against pollution (inorganic nitrogen, heavy metals, etc.), *Avicennia marina*, *Kandelia obovata*, *Aegiceras corniculatum* as good types have a high absorption capacity for heavy metals, *Bruguiera gymnorhiza*, *Rhizophora stylosa* as good types, *Heritiera littoralis*, *Ceriops tagal*, etc. as average types.Studies have shown that *Ceriops tagal*, *Excoecaria agallocha*, *Egialitisannulata* are tolerant to heavy metals and that *Acanthus ilicifolius* is not suitable as a pollution resistant species [35]. The adaptability of different tree species to seawater salinity varies, with *Kandelia obovata* having a suitable seawater salinity of 7.5-21.2, *Sonneratia caseolaris* requiring a seawater salinity of <10 for seed germination, and other tree species having a ready salinity of Acanthus *ilicifolius, Rhizophora stylosa* for 8, *Ceriops tagal* for 0-15, *Aegiceras corniculatum*, *Rhizophora apiculata* for 8-15, and *Avicennia marina* for 0-30. According to the ecological relationships of plant growth, *Sonneratia apetala* can form compound mixed forests with *Kandelia obovata* and *Bruguiera gymnorhiza*, and community combinations of *Rhizophora stylosa* and *Avicennia marina* can form better results.

The removal rates of TN and TP in the artificial wetland with planting increased by 13.6% and 19.5% respectively compared to the state without plants. Some studies have shown that *Phragmites australis* has a higher capacity for N uptake in wetlands and *Iris tectorum* has a higher capacity for P uptake in wetlands . The highly productive Eichhornia crassipes also has a high uptake potential (about 350 kg P and 2000 kg N per year per 1 hm^2), while the potential of submerged plants is relatively small (100 kg P and 700 kg N per year per 1 hm^2 [36]. *Schoenoplectus lacustris*, *Zizania latifolia* and *Sagittaria trifolia* are good at removing BOD_5 and COD from water bodies. *phragmites australis*, *Typha orientalis* , *Photamogeton distinctus* and *Eichhornia crassipes*, *Schoenoplectus triqueter* can effectively treat wastewater and adsorb a variety of difficult to degrade organic pollutants. The oxygen-secreting capacity of the root system determines the ability of wetland plants to absorb and accumulate heavy metals in wastewater and substrates.The amount of aeration of the plant is also directly related to the depth of its growth and the extent to which the root system can expand in the substrate. The enzymes and other substances released into the soil by plant roots can degrade pollutants directly and very quickly. Certain secretions can also promote the growth of certain phosphorus- and nitrogen-loving bacteria, facilitating the release and conversion of N and P, thus indirectly increasing the purification rate.BOD_5, COD, TN and TP in wastewater are mainly removed by microorganisms growing on and near the root zone of aquatic plants. The biomass of plant roots is positively correlated with the activity of denitrifying bacteria, urease, acid and alkaline phosphatase, so species with more developed root systems should be selected, such as *Phragmites australis*, *Miscanthus floridulus*, *Acorus calamus* and *Reineckia carnea* [37]. Better water purification plants also include larger plant species with strong root systems and well-developed adventitious roots, such as *Typha domingensis* and *Typha angustifolia*, which have a greater rate of external oxygen uptake. *Acorus calamus* can release complexes that affect the growth of other species with a kleptoparasitic effect. The accumulation of N and P by plant organs is significantly correlated with root surface area. *Canna genaralis* and *Thalia dealbata* have larger root surface areas, and their nutrient uptake and storage rates are higher than those of other species, suggesting that root surface area can be used as one of the criteria for plant selection. Artificial wetlands have a large demand for carbon sources during water treatment, and plants can release many organic compounds through their root systems, which can act as an important source of carbon within the wetland.

Global assessments suggest that NCS (Natural Climate Solutions) could provide more than 1/3 of the mitigation potential needed to limit warming by 2030, and that such “nature-based climate solutions” are considered to be additional potential to the natural carbon sinks of ecosystems.To maximise the potential and wider environmental benefits of NCS, a multi-level governance strategy needs to be developed [38]. Explore the model of coupled coexistence of mangrove ecological restoration and aquaculture ponds to achieve "land into forest". Mangrove plant debris and root secretions facilitate the growth of microorganisms and plankton such as algae, which are a major food component for shrimps, crabs and shellfish, making them an important feeding ground for fish. A highly productive microbial community is formed in the ecosystem, which constantly converts the apoplankton into a source of N, P and other nutrients that become a source of supply for mangrove plants and other plants. This results in a food chain of mangrove apoplast-decomposer microorganisms-debris consumers (zooplankton and some benthic animals, etc.)-low-level predators (shrimps, crabs, shellfish, etc.)-high-level predators (mainly fish) [39]. The forested space is mainly used for aquaculture ponds, and a new model of "mangrove + eco-industry" is explored, with the mangrove system feeding the fish, shrimp, crab and shellfish in the aquaculture ponds to enhance the fishery industry[40] and realise the synergy between ecological and economic values. The ability of plants to grow in different locations indicates the potential for different nutrient states to which plants are adapted, and more research is needed to establish better links between water levels, nutrient and sediment inputs, and macrophyte conservation needs.Sediment loading may also have a significant impact on the assemblage and diversity of aquatic plants and therefore nutrient loading to wetland waters sediments could be studied. Community structure patterns in wetlands are influenced by water quality, altering species distribution and diversity. It is hoped that the rich data will reflect the interaction between plant communities and aquatic environmental factors in the Nansha coastal wetlands and provide a compelling basis for the importance of biodiversity conservation and sustainable water use in the Nansha coastal wetlands.

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