A LANDSCAPE EVALUATION METHOD FOR WETLAND PARK BASED ON GIS WITH ANALYTIC HIERARCHY PROCESS: THE STUDY OF TIANHE WETLAND PARK IN CHINA

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Abstract. Wetlands play a crucial role in sustaining the health of Earth's ecosystems, and wetland parks represent vital manifestations of wetlands, serving various functions in both urban and suburban areas. These parks not only provide essential ecological security, promote regional biodiversity, but also offer opportunities for leisure activities. Evaluating the landscape of wetland parks is invaluable in guiding their future development and supporting related eco-tourism initiatives. However, the rapid urbanization in the Pearl River Delta of southern China presents both challenges and opportunities for wetland parks in this area. Evaluation of wetland in this area has not received sufficient attention in academia. Therefore, this study aims to review landscape assessment techniques and explore the possibility of combining them with spatial technologies in this field. This paper introduced Geographic Information System (GIS) and the Analytic Hierarchy Process (AHP) as tools for analyzing wetland data. Landscape indices were selected based on previous research. A comprehensive wetland evaluation system was developed for the Tianhe Wetland Park in China, encompassing geographic, environmental, and social dimensions, which were investigated through fieldwork, experiment, and questionnaires to support the assessment process. Expert opinions were gathered to determine the significance of each metric in the system. Through data digitalization, rasterization, reclassification, and index calculation, the resulting values were reflected on an overall map. These findings allow for the analysis of relationships among landscape indices, thereby providing valuable insights for policymakers, managers, and stakeholders involved in the future development of wetland parks in this region.
Keywords: *wetland park, Guangzhou, landscape evaluation, Pearl River Delta, spatial method*

Introduction

"Landscape" has varying interpretations, as a multifaceted concept across different fields of study. It was defined as "the observable appearance of a region on the land resulting from human interactions with the environment" (Taylor and Lennon, 2012). It can be also conceptualized as intricate systems with varying interpretations based on observational attributes. Among all the landscape systems on Earth, wetlands stand out as unique and highly productive, known as the "kidney of the Earth". It is widely acknowledged that wetlands play a crucial role in sustaining ecological balance, providing habitat security, and promoting global biodiversity (Zedler, 2000). Especially in urban areas, wetland parks offer green and open spaces for leisure activities while serving as important sites for environmental education for the public. To gain a better understanding of wetland mechanism and to develop conservation strategies for wetlands, it is necessary to examine their various attributes and underlying driving factors. By analyzing those influencing factors, scholars can gain insights into the complex interactions between humans and nature and identify sustainable management approaches for these invaluable resources.

However, wetlands are facing a multitude of threats from external environment, such as global deforestation and desertification, leading to a rapid decline in wetland areas across many regions (Davidson et al., 2019). China, as a rapidly urbanizing nation in Asia, has witnessed significant losses of wetland systems over the past 50 years, particularly in metropolitan regions where expanding urban populations posed major threats to wetland biodiversity (Myers et al., 2000). Meanwhile, the degradation of wetland ecosystems carries severe consequences, including species extinction, climate change, and the loss of surface and groundwater, which can lead to violent conflicts over water supplies (Hu et al., 2017). As the demand for proximity to nature and clean resources increases, urban parks with special landscapes are being established in many countries to conserve, repair, to reconstruct a healthy urban ecosystem and to achieve both physical and spiritual well-being. Though some urban wetland parks may not meet expectations set by urban planners (Asomani-Boateng, 2019), many of them still provide a wide range of benefits, such as safeguarding metropolitan areas from natural disasters, filtering pollutants, providing food for humans and animals, and promoting economic growth through related wetland products (Liu et al., 2020). Given the immense importance and uniqueness of wetlands, numerous exceptional wetland parks have been developed, with the Chinese government alone recognizing over 900 national wetland parks, a number that continues to grow (Austin and Yu, 2016).

The Pearl River Delta in southern China stands as one of the most developed regions in the world, with highly urbanized areas like Hong Kong, Macao, Guangzhou, and Shenzhen, with a total population close to ten million (*Figure 1*). This region has emerged as a center for trade, finance, and manufacturing, experiencing rapid development since the 1970s. Scholars have engaged in extensive debates concerning the ecological and environmental quality, urbanization problems, as well as land use and land cover changes of this Delta (Xu et al., 2013; Wang et al., 2022). The parks there also encounter difficulties, such as a high degree of sensitivity, land fragility due to urbanization, etc. (Chen and Lin, 2013). Despite these challenges, the capital city Guangzhou possesses a well-developed river system and extensive water bodies, which provide a wealth of resources related to wetlands, harboring more than 30 artificial wetlands and one national wetland (Xu et al., 2018). Among these, the renowned "Tianhe Wetland Park (TWP)" comprises diverse lakes, grasslands, and woodlands, serving as an inclusive space that connects nature with rural resources and urban development zones. Given its central location within the area, this park has been chosen as a representative site to investigate the wetland landscape within the Pearl River Delta.

With the discussions above, this paper aims to construct a comprehensive methodology for evaluating the landscape of wetland park with the case of TWP in Pearl River Delta. This research holds significant implications and the evaluation process can serve as a valuable tool to address the following challenges: 1) identify potential future measures for regional ecological security and biodiversity conservation, 2) objectively and subjectively assess the current state of the wetland, aiding urban planning and the

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development of eco-tourism to enhance its future service quality and attract more visitors, and 3) lay the groundwork for a broader landscape evaluation of the entire region, offering an exemplary model for other southern cities grappling with similar challenges (Mu et al., 2021).

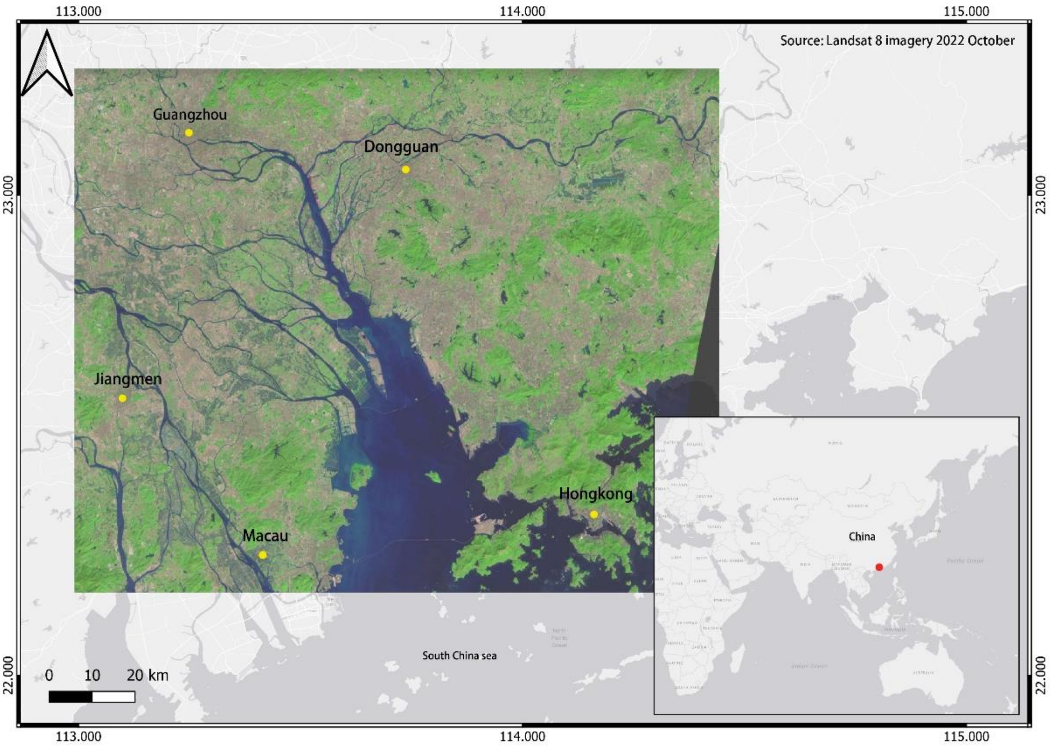

***Figure 1.** Landsat image of Pearl River Delta (source: https://www.usgs.gov/landsat-missions/landsat-8)*

Landscape evaluation

A comprehensive evaluation should encompass analysis from various dimensions of the landscape, employing different methods such as qualitative, quantitative, or a combination of both (Wang and He, 2006). Qualitative evaluation primarily focuses on factors such as historical context, economic significance, environmental concerns, and cultural heritage, among others, to identify existing issues and provide guidance for future development directions (Ozimek and Łabędź, 2013). On the other hand, quantitative evaluation emphasizes factors like ecology, plant functionality, pollutants, and land accessibility, utilizing data obtained from experiments and fieldwork to select appropriate indices that are then quantitatively calculated using suitable algorithms (Cavailhès et al., 2009). While previous quantitative evaluations were primarily focused on natural landscapes, there is an emerging trend of incorporating social and cultural factors into comprehensive landscape assessments, encompassing greenways, cultural routes, tourism resorts, and utilizing mixed methods to address diverse evaluation applications (Feng et al., 2020).

In recent decades, the advancement of spatial technologies, notably GIS, has expanded the scope of landscape evaluations. It enables data overlaying and diverse spatial analysis, making it a valuable tool for assessing landscape changes, land monitoring, and visual

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quality assessment (Fotheringham and Rogerson, 2013). Traditionally, empirical judgments and subjective questionnaire responses were common assessment approaches, often lacking precision and objectivity. Consequently, landscape research and evaluation have increasingly integrated spatial technologies, which offer advantages for wetland studies (Zhang et al., 2011; Liu and Nijhuis, 2020). Utilizing GIS to collect geographical data during the evaluation process can enhance objectivity compared to solely relying on cognitive approaches. Moreover, combining mathematical algorithms with GIS can yield more comprehensive and scientifically informed outcomes to guide future decision-making, rather than relying solely on the opinions of experts or visitors.

Despite the availability of various methodologies for evaluating and analyzing wetland landscapes, there are still some deficiencies in the current research. Existing studies primarily concentrate on natural aspects of wetlands using spatial calculations, employing Remote Sensing and GIS for monitoring biodiversity conservation and ecological conditions (Richardson, 2011; Garg, 2015). Water quality indicators such as dissolved oxygen (DO), ammonium nitrogen (NH3-N), chemical oxygen demand (COD), among others, have also been widely utilized to analyze wetland environments. However, there is a scarcity of case studies focused on the evaluation of urban wetland landscapes. Some studies have explored visitor perceptions of wetland plants through scenic beauty questionnaires (Tan and Peng, 2020), while others have examined wetland beauty based on descriptions in novels using electronic coding to understand readers' perspectives (Kiviat, 2021). Urban wetlands are complex entities comprising water bodies, wetland flora and fauna, visitor experiences and aesthetics, local culture, and various social and economic factors that influence the wetland. Consequently, a comprehensive evaluation method is still lacking for urban wetland landscapes, which effectively integrates natural data with cultural factors associated with wetland landscapes in cities.

Given the current situation, this paper aims to develop a comprehensive evaluation system for assessing wetland landscapes, encompassing aspects of culture, ecology, and scenic beauty, utilizing multiple tools to quantify the landscape value of park areas. The innovative aspect of this research lies in integrating landscape characteristics and cultural values into the assessment of wetland landscapes. Building upon this proposed method, future research can expand to include all wetland parks, providing a better understanding of the Pearl River Delta as a whole and measuring the value of the regional landscape.

Methodology

This study followed a GIS workflow (Fotheringham and Rogerson, 2013), which included data collection, processing, analysis, and mapping. It started by examining landscape assessment techniques and introduces GIS software as a tool for analyzing wetland data. Landscape dimensions and indices were selected based on relevant research and case studies to develop a wetland evaluation system. Fieldwork was conducted to gather geographic, environmental, and social data, aiding in the assessment process. The AHP, incorporating expert perspectives, was employed to determine the significance of each landscape metric in the system. The calculated values of the TWP were visualized on an overall evaluation map, from which recommendations for further management and studies can be derived (*Figure 2*).

The data collection process began by gathering information from three main perspectives: park data, environmental data, and geographic data. Park data was collected through a designed questionnaire, which helped identify relevant landscape indicators and

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indices. A comprehensive system was established, incorporating cultural, landscape, and ecological indicators, with multiple indices under each indicator to ensure a holistic assessment.

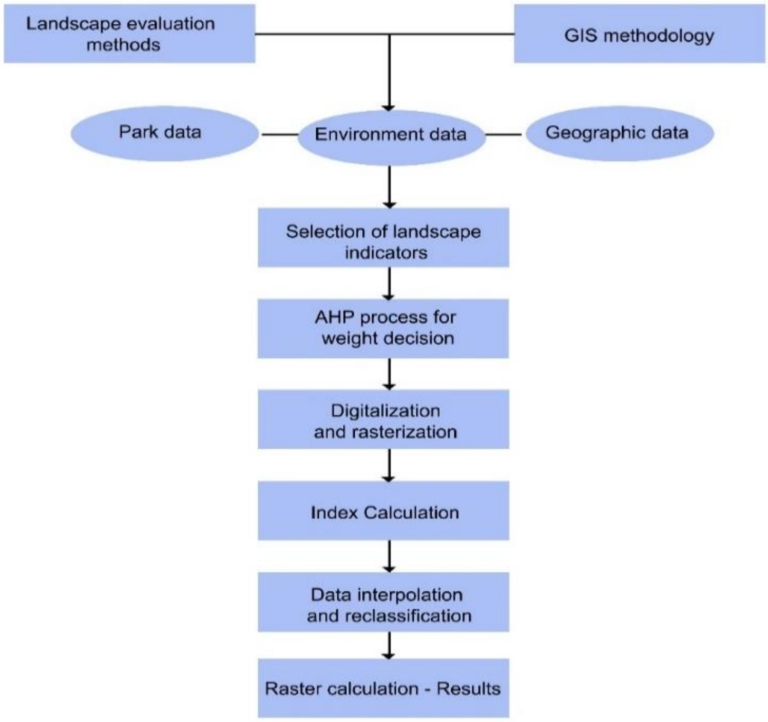

Figure 2. *Workflow*

During the AHP, experts' opinions were collected to determine the weight of each index in the system. For processing geographic data, satellite images were digitized and converted from raster to vector format, which were further rasterized to obtain the identified land use data. Subsequently, each index was calculated, and sample points were assigned values for interpolation using the Inverse Distance Weighted (IDW) method, covering the entire park area. Reclassification was also conducted to categorize each index into five classes, representing varying degrees of value.

Lastly, each index layer was overlaid with the expert-determined weights, resulting in the creation of a landscape evaluation map (Sung et al., 2001). The relationship between different indices can be examined using correlation methods (Pearson Correlation). Through the utilization of this approach, a comprehensive and objective evaluation of the wetland landscape was achieved, enabling the identification of areas with potential for improvement and informing future planning and development endeavors.

Study area

The study area, TWP, is situated in the Pearl River Delta of Guangdong Province, China (see *Figure 3*). This region experiences a subtropical maritime monsoon climate characterized by moderate temperatures and abundant rainfall. With its numerous river branches and natural wetlands, the park plays a vital role in preserving the regional biological diversity (Wang et al., 2014). However, the process of urbanization has resulted in several challenges, including habitat fragmentation, species loss, and

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ecosystem decline (Wu et al., 2021). To address these issues, TWP was developed as the first ecological park in Guangzhou City, incorporating the innovative concept of a "sponge city" (Yu, 2015). It emphasized the use of green infrastructure to regulate and purify rainfall, thereby enhancing water quality. Consequently, the park has become known as the "Green Necklace" of Guangzhou, successfully resolving pollution problems in the area. Moreover, its proximity to the local population enables easy access for nearby citizens to enjoy its beautiful landscapes and abundant resources.

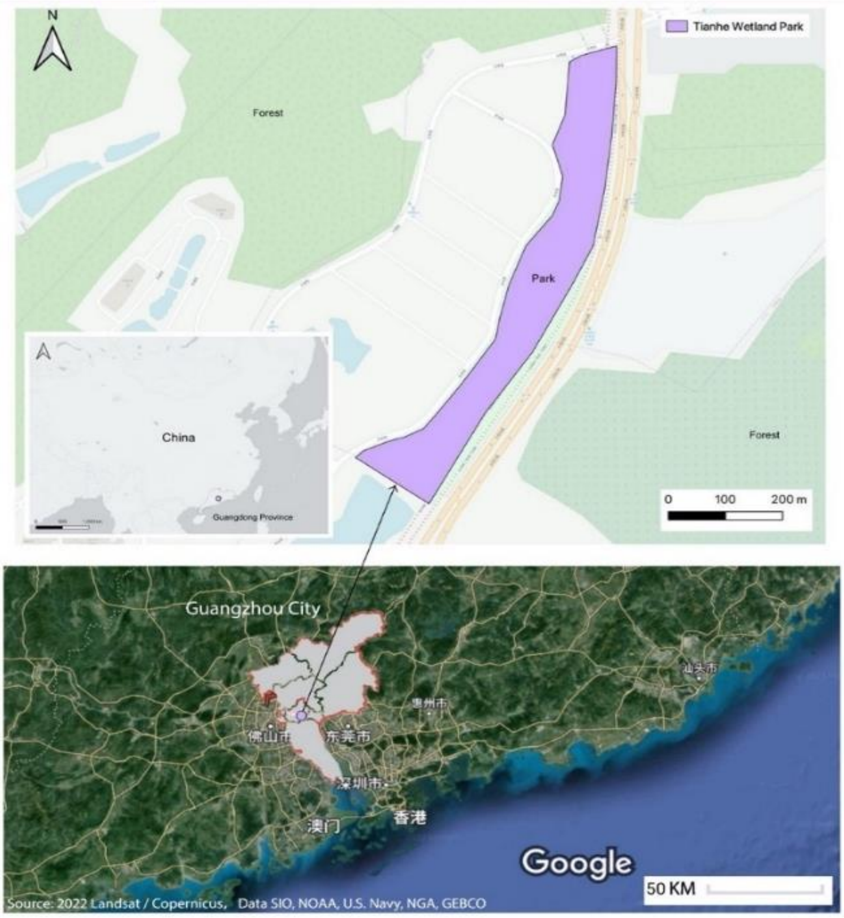

Figure 3. *Location of TWP in China*

The fieldwork for this study took place between 2019 and 2020, during which the researchers investigated the plant distribution and functional divisions within TWP. The park features a well-designed road system consisting of two main roads, as well as wooden platforms and various scenic spots that provide accessibility to visitors. In terms of plant diversity, the park is home to a total of 68 species of wetland plants, with emergent plants accounting for 60% of the overall count. Notable dominant species in the park include *Phragmites australis*, *Thalia dealbata*, *Taxodium distichum*, and *Syzygium jambos* (Ye, 2013).

However, a significant issue arises during the winter season when the fallen and decaying leaves of new plants become a source of pollution. This not only diminishes the park's natural beauty but also affects the activities of tourists. While a few studies have been conducted on TWP, such as analyzing social media comments to understand user

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expectations regarding ecosystem services (Zhai and Lange, 2020), the evaluation of the park's landscape quality by scholars has been lacking. Recognizing the need for effective zone management, Zhongkai Agricultural University was invited by the park to conduct a comprehensive study on the park's wetland landscape and provide recommendations for its future development.

Data collection

Data collection for this study involved three primary processes: questionnaire surveys, environmental measurements, and geo-data collection. Given the expansive spatial extent of the park (47 hectares), it was challenging to collect data from all locations. Consequently, thirteen sampling points were strategically selected to represent the overall condition of the park (*Figure 4*). These sampling points were chosen based on the distribution of ponds within the park, ensuring that at least one sampling point was measured for each pond.

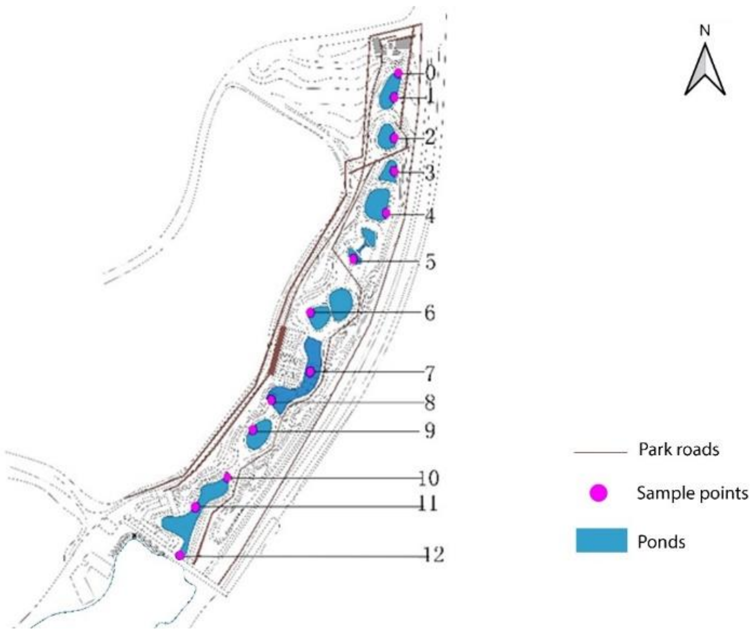

Figure 4. *Location of sampling points in the park*

To evaluate the present cultural state of the park, a questionnaire was designed and administered to respondents over a one-month period in April 2020. The questionnaire was primarily distributed through an online platform - Wenjuanxing (https://www.wjx.cn/, last accessed on 20 August 2022). It consisted of several landscape photographs of the sampled sites, aimed at assessing the park from three perspectives: landscape satisfaction, park characteristics, and park services. Upon viewing the provided photos, respondents were requested to evaluate each dimension through a single question, such as "Are you satisfied with the landscape beauty of this location?" A Likert scale was employed to allow respondents to provide a numerical rating ranging from 1 to 5. A rating of 5 indicated high satisfaction, while a rating of 1 indicated low satisfaction (1 = strongly dissatisfied, 2 = dissatisfied, 3 = neutral, 4 = satisfied, 5 = strongly satisfied). In total, 140 questionnaires were distributed, yielding 137 valid responses, and achieving a response rate of 97% (*Figure 5*).

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Figure 5. *Landscapes in the park (photos by authors)*

The environmental data was collected during ten fieldwork sessions conducted between April 2019 and January 2020, with a primary focus on the water bodies within the wetland park. Water samples were collected at a depth of five cm below the water surface. Sampling was carried out at regular intervals of 30 days from the same locations. The collected samples were analyzed for various parameters, including pH, dissolved oxygen (DO), total phosphorus (TP), total nitrogen (TN), ammonium nitrogen (NH3-N), turbidity (TU), chemical oxygen demand (COD), and microorganisms. These values were used to assess the water quality of the park. The water analysis primarily took place in a laboratory setting using an Ultraviolet-visible Spectrophotometer, a widely utilized tool in analytical chemistry that employs absorption spectroscopy. Furthermore, the presence of microorganisms in the water was assessed to determine its suitability for daily use and ensure safety.

For land data collection, satellite imagery was obtained from the website of MAXAR (https://www.maxar.com/products/imagery-basemaps, last accessed on January 15, 2020). MAXAR satellites provide high-quality images with resolutions ranging between 30 cm and 50 cm. These images offer exceptional clarity, accuracy, and detail, making them suitable for various geospatial analytic services, including land change detection, feature extraction, and object recognition. In this research, the acquired satellite imagery had a spatial resolution of 30 cm, enabling clear identification and digitization of land use within the wetland park. Land objects such as buildings, roads, and individual trees were distinctly discernible in the imagery.

Indicator's selection

Landscape indicators are widely recognized as an effective approach for assessing the quality of diverse landscapes (Uuemaa et al., 2009). In the case of wetland landscapes, which encompass both ecological and socio-cultural dimensions, a comprehensive assessment of the interactions between various landscape indicators within a specific context is essential to identify potential issues and opportunities within the park. Previous research has classified landscape indicators into six main categories: ecological, structural, visual, economic, historical, and social dimensions (Cassatella and Peano,

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2011). These indicators have been explored and utilized in various domains, including ecological, heritage, architectural, and urban studies.

For instance, in urban studies, indicators such as land use, urban growth, and fragmentation have been extensively studied to understand changes in urban landscape patterns (D'Eon and Glen, 2000; Jaeger et al., 2016). Landscape beauty has been assessed using landscape ecology indices such as patch density, edge density, and shape index (Franco et al., 2003). Water landscapes have been evaluated using indicators related to pollution and nutrient discharges (Wickham et al., 2003). Different landscape indicators have been selected and developed in various case studies to suit their specific research objectives. In the context of wetland park assessment, researchers have employed methodologies such as AHP and questionnaire surveys to evaluate the ecological impact, aesthetic value, and subjective perception of the plant landscape (Gao et al., 2022). Water quality, being a crucial aspect of wetland landscape assessment, can be measured using the Comprehensive Water Quality Identification Index (CWQII) (Cheng et al., 2022).

Based on site investigations, data availability, relevant case studies, and literature review (*Table 1*), the authors of this study developed an evaluation system for the wetland park, considering the perspectives of ecology, landscape, and culture. Each indicator was further divided into three indices to establish a comprehensive index system. The table below provides a list of the referenced studies. Subsequently, this evaluation system was applied to calculate the landscape value of the TWP.

Table 1. *Wetland landscape indices system*

Indicator	Indices	ID	Explanation	References
Ecology	Pollution	E1	CWQII value	Ban, et al., 2014
	Water safety	E2	Microbial communities	Guarin & Pagilla, 2021
	Diversity	E3	Simpson's diversity index	Sun, et al., 2019
Landscape	Edge	L1	Edge density	Tischendorf & Fahrig, 2000
	Patch	L2	Patch density	Uuemaa, et al., 2009
	Split	L3	Splitting index	Rodríguez-Loinaz, et al., 2015
Culture	Services	C1	Likert scale	Fairclough et al., 2018; Tsai Et al., 2010
	Characteristics	C2	Likert scale	
	User satisfaction	C3	Likert scale	

AHP for weight decision

In general, there are various methods to determine the weight of influencing factors, and among them, the AHP is an efficient and straightforward calculation approach. AHP serves as a decision-making tool that enables individuals to systematically evaluate and prioritize multiple criteria, leading to more informed decisions. It offers the advantage of saving time by collecting opinions from experts, as opposed to issuing questionnaires to users. In this process, the AHP approach was utilized to determine the weight of each index.

Five experts from diverse fields, including agriculture, architecture, geography, and environmental science, were invited to compare the relative significance between each pair of indices. They assigned values according to the AHP rule, which involves using numbers one to nine to indicate the significance. For instance, the expression 1/1 suggests

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that the first and second indices are of equal importance, while 9/1 implies that the first index is significantly more important than the second one. Conversely, 1/9 means that the first index is much less important than the second one (Saaty, 2004).

After thorough discussions, the importance sequence was determined, and the calculations were performed with the assistance of an AHP Online Calculator (https://bpmsg.com/ahp-online-calculator/, last accessed on January 15, 2021). The resulting weights for each index were as follows, arranged from higher to lower importance: Water quality - 29.5%; Species diversity - 21.2%; Water safety - 15.8%; Satisfaction - 13.1%; Characteristics - 8.1%; Services - 5.2%; Split - 3.8%; Patch - 2.0%; Edge - 1.4%. To assess the consistency of the calculation matrix, a measure of 8.7% was obtained, which is lower than the acceptable threshold of 0.1 (Leung and Cao, 2001).

Digitalization and rasterization

After the selection of indicators and the calculation of their weights, the land data needed to be processed for further use. The current image, which was obtained from MAXAR, was a raster containing the details of the park area (*Figure 6A*). The original imagery was digitized in QGIS 3.22. In the GIS environment, five main land elements were identified and drawn as vectors: roads, forests, water bodies, grasses, and hard surfaces (*Figure 6B*).

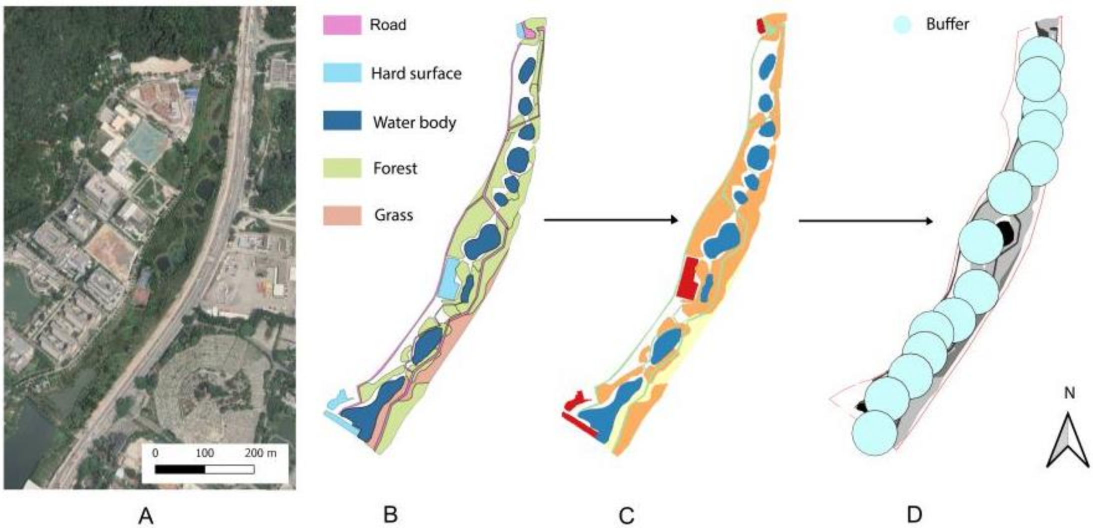

Figure 6. *digitalization and rasterization in GIS*

To facilitate the next step of data overlaying, the vector data had to be converted into a raster format. For this purpose, the "rasterize" tool in QGIS was applied (*Figure 5C*). This tool converted lines, points, and polygons into pixel-based rasters. During this process, values were assigned to the cells in the grid based on the attributes of the vector elements. The "nearest neighbor" algorithm was used for the rasterization process. Subsequently, a buffer zone with 50 meters was created around each sampling point to calculate the landscape indices within the sampling area (*Figure 5D*). This buffer zone served as a designated area where the landscape indices were computed. By processing the land data in this manner, various analyses could be conducted, and additional layers of information could be overlaid for further investigation and decision-making.

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Index calculation

To obtain the values of the indices in this research, several formulas were applied, and their meanings are explained as follows:

Firstly, the water safety index was primarily determined by the presence of microorganisms in the water, expressed as the number of microorganisms per 100 ml of water. The sample water was diluted, and the microorganisms were dispersed into single cells. Through cultivation, these single cells multiplied and formed visible colonies that could be counted. By considering the dilution factor, the estimated number of microorganisms in the sample could be determined. The observed number of coliform bacteria floras was found to be very low, indicating a safe situation for water use based on the standard set by the Chinese Ministry of Environmental Protection (CMEP) (GB3838-2002).

The CWQII is a factor used to assess the water quality in wetlands. It provides an objective measurement of water quality and is widely employed for comparing water quality across different rivers or various sections of the same river. The severity of pollution is reflected in a value determined by water indices such as pH, DO, TP, TN, NH3-N, COD, and TU. Each water index is calculated according to the standards outlined in GB3838-2002 and classified into five categories (1-5). A lower value indicates better water quality, with one representing the highest quality and five representing the poorest quality (CMEP, 2020). The formula used for calculating the CWQII was as follows:

$$Pm = \frac{Pi\ (high) - Pi}{Pi\ (high) - Pi\ (low)} * 10 \quad \text{(Eq.1)}$$

In the equation, Pi represents the actual measured value obtained from the site. Pi (high) and Pi (low) denote the two values within the interval close to the real value in the standard (refer to *Table 2*). The CWQII is then calculated as the average value of the computed indices, as shown in result table (field E1). The CWQII value ranges from 1 to 7, where 1-2 indicates higher standard quality, 2-4 represents average quality, 4-5 indicates lower quality, and grades 5-7 signify the worst quality. In the park, the water quality ranged from 4.0 to 5.5, indicating an average to poor quality. To ensure a clean and enhanced user experience with the wetland water, it is recommended that the reasons behind the poor water quality be further studied and addressed in the future park management.

Table 2. *Water quality standard*

Index (Unit)	**Class 1 (mg/L)**	**Class 2 (mg/L)**	**Class 3 (mg/L)**	**Class 4 (mg/L)**	**Class 5 (mg/L)**
DO	7.50	6.00	5.00	3.00	2.00
TP	0.02	0.10	0.20	0.30	0.40
TN	0.20	0.50	1.00	1.50	2.00
NH_3-N	0.15	0.50	1.00	1.50	2.00
COD	15.00	15.00	20.00	30.00	40.00
TU	0.05	0.50	1.00	2.00	3.00

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Next, Simpson's diversity (D) is a common index to measure biodiversity. It means the probability that the number of plants from the site twice in a row belongs to the same species. S is the number of plant species, and the ratio of the i (number of individuals of species) to the total number in the community (Pi). Then, the probability of randomly picking two individuals of species i is P_i^2 (Hopton et al., 2017; Begon and Townsend, 2021). The Simpson's diversity was shown in the result table (field E3), calculated as follows:

$$\mathrm{D} = 1 - \sum_{i=1}^{s} P_i^2 \quad \text{(Eq.2)}$$

The remaining indices were calculated using the QGIS plugin - Land-use change and ecosystem services (LecoS), which is a tool developed by the Humboldt University of Berlin. This plugin enables the analysis of land-use changes and their impact on ecosystems, as well as the assessment of landscape and ecological indicators. It proves particularly useful for quantifying carbon storage, water regulation, and biodiversity conservation. Among all the methods, three common indices were selected for analysis. The edge density index was calculated by dividing the number of edges by the maximum possible number of edges. The patch density index represents the number of patches divided by the total landscape area. And the splitting index (S) was calculated by the following equation, where a_{ij} is the patch area (m^2) and A is the total landscape area:

$$S = \frac{A^2}{\sum_{i=1}^{m} \sum_{j=1}^{n} a_{ij}^2} \quad \text{(Eq.3)}$$

Furthermore, the cultural indices were derived directly from the results of a questionnaire survey. During the survey, respondents were asked questions regarding park services, park characteristics, and landscape satisfaction related to 13 specific sites within the park. To enhance respondents' perception of the park's landscapes, landscape photos were provided by the authors. Based on the scores provided by the respondents, the average value for each site could be calculated. The cultural indices are listed in the result table as C1, C2, and C3.

Data interpolation and reclassification

In this step, the attribute table of the sample sites was linked to the corresponding sample points' locations in QGIS, displaying the nine surveyed and calculated factors. Interpolation techniques were then applied using GIS to predict values for the cells in a raster based on a small sample size of data points. This interpolation method allows for predictions of unknown values based on known geographic point data. In our study, we selected 13 sampling points within the park to predict the values of the nine factors in other areas. The IDW method was used for data interpolation (Arun, 2013; Burrough et al., 2015). As a local deterministic interpolation approach, it calculates the value as a distance-weighted average of samples in a neighborhood, with their influence decreasing as the distance from other points increases. *Figure 7* illustrates the interpolation results for three factors: Satisfaction (A), Water safety (B), and Species diversity (C).

To ensure comparability among the different indices, which were measured on different scales, a reclassification step was performed (Goodin and Henebry, 1997). Each

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raster layer representing an index was reclassified into five classes, assigning scores ranging from one to five (from lower to higher). Using five categories facilitates easy interpretation and understanding of differences, allowing for visualization using different colors or shades. This classification scheme effectively represents data variability without excessive complexity (Longley et al., 2005). *Figure 8* provides an example of the reclassification process, with (A) representing the original raster and (B) the reclassified raster. The classification mode followed the "Quantile" approach, which divides classes so that each class roughly contains the same number of features. The interpolation mode was set to discrete.

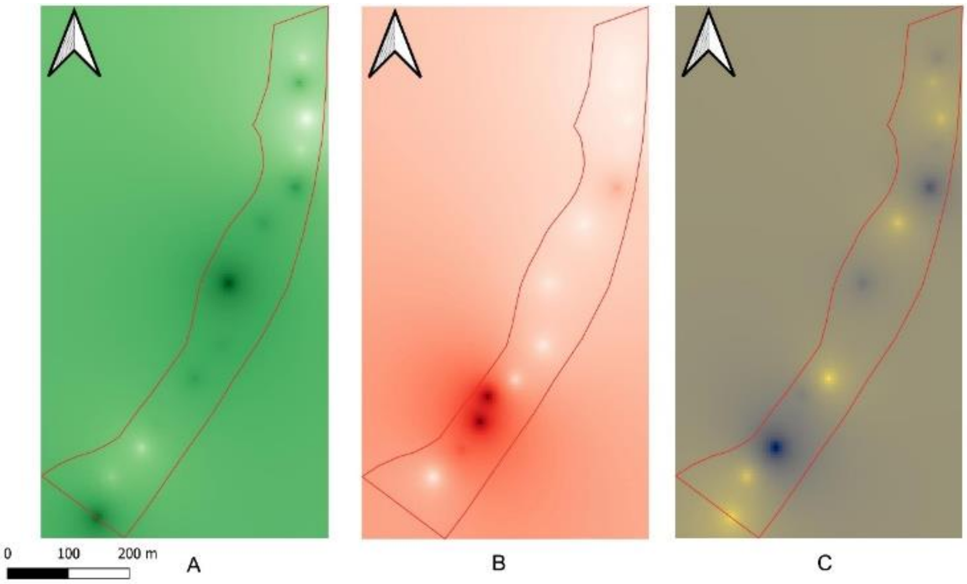

Figure 7. *Interpolation results*

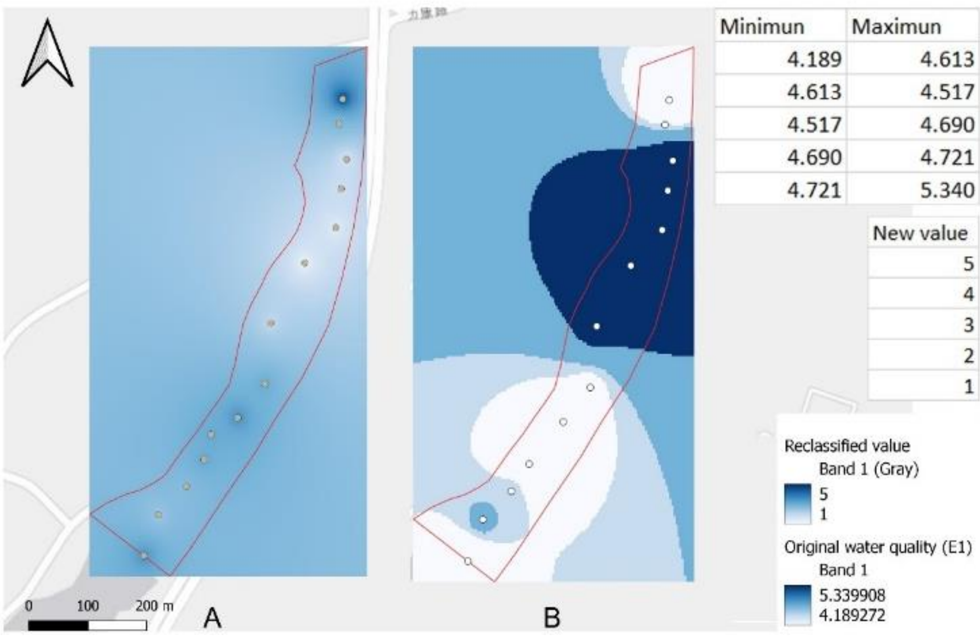

Figure 8. *(A) original raster; (B) reclassified raster*

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Raster calculation

Finally, in QGIS, the nine indices were overlaid using the raster calculator. The final landscape value (L) was calculated by multiplying each index by its corresponding weight and summing up the values. The formula for this calculation was as follows, where "i" represents the value for each index:

$$L = \sum i * weight \qquad \text{(Eq.4)}$$

Results

The overall values for the 13 sampling points are shown in the *Table 3*.

Table 3. *Result of index calculation*

ID	E1	E2	E3	L1	L2	L3	C1	C2	C3
0	5.437	61	0.445	0.050	0.00028	8.950	5.360	3.170	2.810
1	4.692	46	0.538	0.083	0.00057	6.470	4.160	4.530	3.330
2	4.307	82	0.572	0.067	0.00052	13.640	4.790	2.820	2.480
3	4.395	420	0.464	0.074	0.00069	16.770	2.410	3.180	2.880
4	4.236	1340	0.329	0.072	0.00044	4.490	3.060	4.350	3.470
5	4.165	100	0.586	0.039	0.00032	50.760	4.690	3.730	3.420
6	4.444	276	0.408	0.040	0.00016	7.960	4.980	4.060	3.850
7	4.831	200	0.474	0.025	0.00014	56.160	2.440	4.910	3.410
8	5.011	390	0.639	0.032	0.00018	17.760	3.290	4.730	3.430
9	4.64	565	0.469	0.051	0.00033	17.651	3.5991	3.773	3.229
10	4.670	2370	0.426	0.029	0.00041	14.650	3.520	4.110	2.900
11	4.570	130	0.158	0.041	0.00018	10.820	1.770	2.530	3.060
12	4.957	1370	0.593	0.058	0.00015	3.380	2.720	3.160	3.710

Based on the calculated values, we can observe the basic statistical description of the indices (*Table 4*), which includes the mean value, standard deviation (SD), maximum, and minimum values. Since the indices were measured on different scales, direct comparison or summation was not appropriate. To obtain an overall value, all the indices were rescaled. Following the raster overlay process, the values for the sample points are presented in *Table 5*. Furthermore, *Figure 9* provides an overall map of the landscape value in the park area, displaying both the area figure and a point graph.

Table 4. *Descriptive statistics*

	Mean	SD	Min.	Max.
E1	4.64	0.08	4.16	5.44
E2	565.42	1.24	46.00	2370.00
E3	0.47	0.27	0.16	0.64
L1	0.05	0.37	0.03	0.08
L2	0.0003	0.53	0.00014	0.00069
L3	17.65	0.94	3.38	56.16
C1	3.60	0.31	1.77	5.36
C2	3.77	0.20	2.53	4.91
C3	3.23	0.12	2.48	3.85

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Table 5. *Calculated landscape values*

ID	Final landscape value
0	2.48
1	3.49
2	3.82
3	3.07
4	2.61
5	4.02
6	3.523
7	3.05
8	3.59
9	3.16
10	1.83
11	2.23
12	4.21

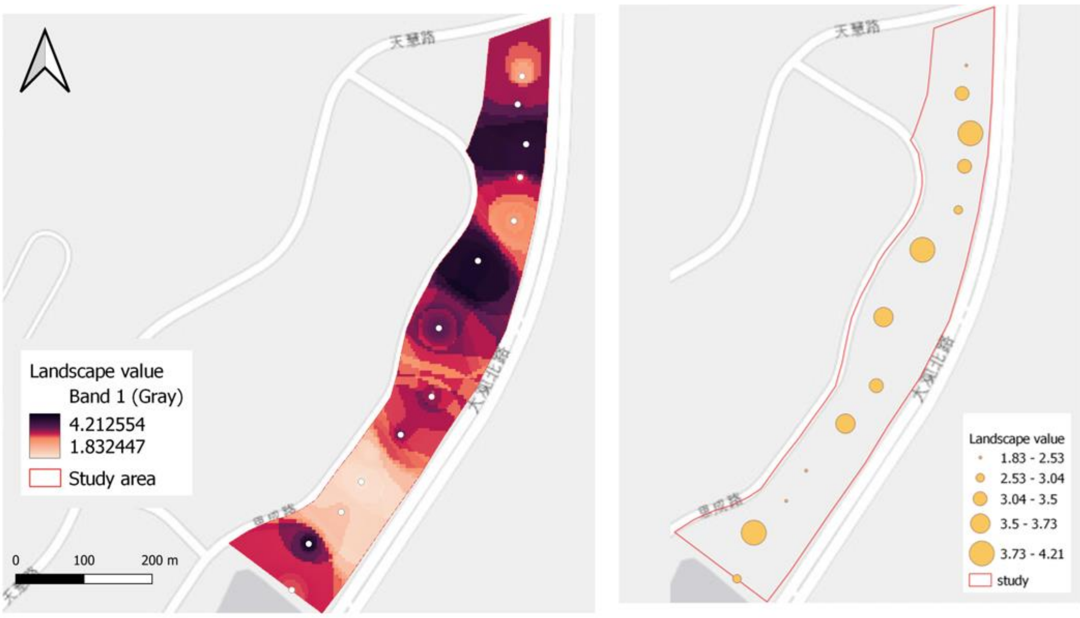

Figure 9. *Result of landscape value. (A) Area graph and (B) point graph*

The map presented below illustrates the landscape values in the park area. Darker colors and larger circles indicate higher landscape values, while lighter colors and smaller circles indicate lower landscape values. It can be noted that areas with higher landscape values are concentrated around samples 2, 5, and 11, with values ranging between 3.50 and 4.21. Moderate values are observed around samples 1, 3, 4, 7, 9, and 12, with values ranging from 2.53 to 3.50. Conversely, areas with the lowest landscape values are found between samples 9 and 10, with values ranging from 1.83 to 2.53.

Separately, for the nine topics, it can be summarized that the places with higher service values are sample 0 and 6, and lower values are observed in samples 10 and 12; For characteristics, higher values are observed in samples 8, 7, and 6, while lower values are around samples 2 and 10; Regarding satisfaction, higher values are observed in samples 6 and 12, whereas lower values are observed in samples 0, 2, and 3; For water quality,

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samples 0 and 8 have lower values, while sample 5 has a higher value; For water safety, samples 0, 1, and 2 have higher values, while samples 4, 10, and 12 have lower values; For species diversity, higher values are observed in samples 8 and 12, while lower values are observed in samples 4 and 11; Regarding edge density, higher values are observed in samples 3, 4, and 12, and lower values are observed in samples 0, 2, and 7; For patch density, higher values are observed in samples 2 and 11, while lower values are observed in samples 7 and 8; Finally, for the splitting index, higher values are observed in samples 0 and 3, while lower values are observed in samples 6 and 12.

Discussions and conclusion

Wetland parks exist within a complex context, being an integral part of its surrounding landscape. However, a universal evaluation method for wetland landscapes remains unsolved, with different cases focusing on different aspects and providing references for further landscape evaluations. Different regions, cities, or sites may prioritize various metrics in their planning processes, making it challenging to achieve a uniform landscape appraisal approach applicable to all types of landscapes and locations.

In this study, the quantification of landscape value in the context of wetland landscapes using indices such as patch, edge, and splitting indices has proven helpful in understanding the landscape pattern within a park. A higher value in these indices indicates a higher degree of fragmentation, which may result in biodiversity loss and changes in ecological functions within wetlands. The relationship between landscape fragmentation and its social impacts is still being debated by scholars (Zambrano et al., 2019). The research results primarily provide an overview of the values at selected sampling sites within the wetland park. Since the landscape quality of this park has not been studied in previous research, direct comparison with the results of other studies is not possible. However, some similarities can be observed between this study and other studies conducted in different Pearl River Delta parks (Fang et al., 2021). For example, the evaluation of water quality is consistently recognized as a crucial aspect in wetland park assessments. Certain factors, such as soil conditions and education services, were not considered in this study but should be included in future investigations.

Correlations between the landscape indices were also observed. For example, Pearson correlation analysis revealed moderate to strong correlations between L1 and L2 (0.74), C3 and L2 (-0.55), and L1 and L3 (-0.52). It is evident that the landscape indices (edge, split, and patch) are closely interrelated. Furthermore, a correlation between satisfaction and landscape patch density was observed. Previous research has tested the relationship between landscape preference and landscape structure, indicating that people tend to prefer landscapes with higher diversity, including a higher number of patches (Dramstad et al., 2006). However, in this study, the results indicated that areas with higher patch density received lower landscape values. Further investigation can focus on understanding whether landscape patch density influences the aesthetic perception of wetland users.

As an urban park, it is essential for the site to fulfill the needs of its visitors and users. Therefore, the cultural elements of a wetland park should also be assessed in the evaluation process. In this research, three indices, including park characteristics, services, and visitor satisfaction, were applied to evaluate the cultural aspects of the park. A higher cultural value indicates higher satisfaction, adequate services, and more distinct characteristics reflected in the park. Consequently, the evaluation outcomes have practical

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implications. Areas with lower ecological values should develop protective strategies to prioritize the functions of the wetland within the park. Places with lower cultural values should implement measures to improve service quality and introduce local characteristics to enhance user satisfaction. Sites with lower landscape values should address fragmentation issues, such as improving land use permeability.

To address the shortcomings of this research, it is important to acknowledge that the selection of indices was primarily based on case studies and references from previous research, given the limited number of studies focused specifically on wetland landscapes. To ensure a more scientific approach to indicator selection, the introduction of mathematical methods such as structural equation modeling could be considered, as it would help exclude unrelated factors (Xie et al., 2020). Furthermore, the evaluation of landscape satisfaction by users relied on subjective scoring based on landscape photos. This approach has limitations, as the quality of the evaluation is influenced by the selected photos and the technique of the photographer. Improving the method of quantifying visitors' perception of the landscape is an important area for further study. In future research, a focus on incorporating additional data sources will make the landscape evaluation more comprehensive and enable a better understanding of various aspects within a wetland landscape. For instance, the integration of big data from social media, including text and image data, could provide valuable insights into users' perceptions expressed on the internet. This approach would allow for the mining of additional landscape attributes (Li and Yang, 2022).

In conclusion, this research primarily explored three perspectives for assessing wetland landscapes: ecology, landscape, and culture. The proposed methodology combined GIS, questionnaires, experiments, and the AHP to calculate the landscape value in the buffer zone of TWP. After determining the weight of each landscape index using the AHP approach, each aspect was further categorized and represented by several indices. The total landscape value was then visualized on a digital map using GIS, effectively evaluating the wetland landscape in the park, and identifying areas with higher landscape values for future park planning. Modifications and development plans can be devised for areas with lower index values. The feasibility of applying the proposed methodology to other wetland parks will be further discussed, and future studies will aim to investigate the wetland landscape of the entire Pearl River Delta by examining larger areas.

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