MANGROVE HEALTH: AN EVALUATION BASED ON ANALYTIC HIERARCHY PROCESS FOR THE ZHENHAI BAY MANGROVE WETLAND PARK IN CHINA

XIANG, L. N.[1#] – CHEN, Z. J.[1#] – QU, M.[2] – ZHANG, H.[3] – CHEN, P.[3] – LI, R. B.[1] – SANG, K.[4*]

[1]*Guangdong Lingnanyuan Exploration and Design Co. Ltd, Guangzhou 510120, China*

[2]*Guangdong Forestry Survey and Planning Institute, Guangzhou 510520, China*

[3]*College of Horticulture and Landscape Architecture, Zhongkai University of Agriculture and Engineering, Guangzhou 510225, China*

[4]*School of Communication, Xiamen University Malaysia, Sepang 43900, Malaysia*

[#]*These authors contributed equally to the research*

[*]*Corresponding author*
e-mail: kun.sang@xmu.edu.my

(Received 25th Feb 2024; accepted 8th Jul 2024)

Abstract. Constructed parks for mangrove wetlands are considered crucial for preserving coastal ecosystems. However, several challenges confront the construction and maintenance of existing mangrove parks in the Great Bay Area of China, such as the survival rates of newly planted plants, declining plant diversity, and fluctuating quality of water and soil. While various methods exist for restoring mangrove wetland parks, there is a need for a health assessment of mangrove parks to quantify related health indicators. Previous studies mainly focused on individual species and the ecological functions of mangroves, neglecting the complexity of the overall health of communities. Based on the current situation of mangrove parks in the Great Bay Area, this paper proposes a methodology and workflow with Zhenhai Bay National Wetland Park as a study area, aimed at identifying potential health factors through field surveys on ecological communities and structures, biosafety, water and soil, and external threats and disturbances. Experiments and indicators were carried out for the evaluation, and the quantified results showed that the mangrove park had an average level of health, with the central area being more sensitive than the north and south parts. The assessment results can guide further landscape design, wetland restoration, and tourism planning, and serve as a reference for other health assessments for mangroves in similar urban areas.
Keywords: *mangrove, health assessment, wetland park, GIS, the Great Bay Area*

Introduction

Wetlands usually have high ecological values, diversity, and productivity, known as the "kidney" of the Earth. Among all kinds of wetlands, mangroves constitute a unique system characterized by woody communities in the intertidal land between coastal areas, involving mangrove vegetation, flora, fauna, water bodies, intertidal beaches, and some subsystems. The hydrological cycle within mangroves is intricate, featuring rapid material and energy exchange between the wetland and the sea, which is also accelerated by tidal cycles. Thus, a loss or excessive interference in the intertidal environment may result in the degradation or even extinction of mangroves (Wei, 2019; Zhang, 2020).

Due to the widely acknowledged importance of mangrove wetlands to nature and human societies, constructing both artificial or semi-artificial parks is considered one of the main methods to protect and utilize mangroves, which serve as specialized areas with multiple functions, such as water conservation, climate regulation, and habitat provision

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

(Sarhan and Tawfik, 2018). A rich diversity of mangroves is instrumental in increasing coastal biodiversity and maintaining regional security. As "coast guards", they act as a natural barrier against soil erosion, reducing the impact of sea waves on urban or suburban areas. The diverse vegetation in these wetlands forms a green corridor that can enhance the defense of a city against disasters (Liao, 2019). With rich biological resources, it is also a natural museum where researchers can study the environmental changes in coastal areas by examining the succession patterns of mangroves (Yasir et al., 2020), providing valuable educational experiences and mental rejuvenation for its users. The development of wetland parks can also foster public awareness of the environment and play a crucial role in safeguarding other endangered ecosystems (Rahadian et al., 2019).

Among Asian countries, China has experienced a consistent increase in mangrove wetlands due to a growing awareness of their scientific and conservation values. In response to the need for wetland preservation, the establishment of wetland parks has emerged as an effective strategy recognized by the government. Coastal cities in South China are actively constructing wetland parks dedicated to mangrove protection, becoming integral components of mangrove wetland restoration and conservation efforts. The Chinese Forestry and Grassland Administration aims to restore important mangroves, resulting in the establishment of 38 nature reserves with mangrove forests. Over 50% of mangrove forests are covered by nature reserves (Zhang, 2020).

Despite the significance, an acceleration of coastal urbanization and the expansion of urban activities, together with increased pressure from agriculture, have affected the mangrove wetland ecosystems (Zhang et al., 2021). Especially in recent decades, the impact of climate warming has added new challenges. Rising sea levels have influenced coastal beaches, prolonging inundation periods and causing a reduction in the reproductive areas of mangroves (Magarotto and Costa, 2021). Spreading across countries and regions, the global mangrove areas were decreasing, making the disappearance of mangrove wetlands the fastest among all types of wetlands (Valiela, 2001). The multifaceted threats necessitate attention and efforts to revitalize these invaluable ecosystems. The challenge in constructing mangrove wetland parks lies in addressing the health of mangroves because an improper ecological structure can lead to the declining mangrove diversity, fluctuating mangrove quality, withering or death of mangrove, as well as other potential ecological and environmental problems (Prasetya and Pur Bayti, 2017). As public spaces designed to fulfil human spiritual and environmental needs, mangrove parks should also strike a balance between recreational functions and ecological resilience.

Review of literature

The concept of “ecosystem health” has emerged and frequently discussed by scholars. Previously, it was proposed that a natural site can be regarded as "healthy" if it has an intact ecosystem. Later, more natural and social dimensions were considered to acknowledge the inseparable relationship between humans and nature (Bian et al., 2010; Charrua et al., 2020). Aligned with this concept, scholars have extended to assess the health of wetlands from more perspectives, such as water bodies, rivers, lakes, wetlands, coasts, etc. (Zhang, 2020). In the context of mangroves, a healthy state was proposed as the ability to maintain a stable community structure and successional functions and be capable of sustaining human well-being (Gilman et al., 2008). Due to their distinct characteristics and functions, health assessments of these wetlands have transitioned from simple indicators like water quality to comprehensive evaluations covering more aspects

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

and indicators, such as aquatic organisms, benthic invertebrates, as well as other social perspectives, such as aesthetics, services, etc. (Bai, 2016; d'Acampora et al., 2018; Rahadian et al., 2019; Fang et al., 2021).

Recent literature has revealed a multitude of studies on mangrove wetlands, concentrated on both micro and macro perspectives. Most research predominantly consists of experiments on the afforestation and restoration of mangroves (Kamali and Hashim, 2011; Van Bijsterveldt et al., 2021), with a few explorations focusing on the evaluation methods of mangrove wetland parks. Some case studies also offered theoretical support for the design and optimization of this study. Against this background, a comprehensive evaluation of the health of mangrove parks is needed, which should also be an integral part of the sustainable management of coastal ecosystems. By integrating the concept of healthy development of mangrove wetlands, related case studies, and regulations, an evaluation specifically for mangrove parks in China is designed. The significance of the health assessment lies in the following aspects: raising awareness and attention towards the protection of mangrove wetlands within urban areas; and providing theoretical and practical guidance for other mangrove parks, especially those in developed urban areas (Shao, 2019).

Methodology

The methodology in this research follows previous research cases and the Chinese national guidance, such as Mangrove Wetland Health Evaluation Technical Specification in China (LY/T2794-2017) (SFA, 2017; Fang et al., 2021). It is consisted of fieldwork and experiments, involving investigations into the coastal wetland parks, and testing the collected samples in the lab at the Zhongkai University of Agriculture and Engineering in China to examine various indicators of the study area. Multidimensional mangrove protection measures, ecological restoration strategies, and some national regulations were contained to ensure the rationality of evaluation, the evaluation system was designed and composed of four dimensions, including the community and structure of the mangrove wetland (C), soil and water (W), external threats and disturbances (E), and biosafety (B), further divided into 18 evaluation indexes (SFA, 2017). By identifying health problems in the wetland, this analysis provides crucial insights for the further development of Zhenhai Bay Mangrove Wetland Park and offers theoretical support for ecological restoration and landscape construction (Cao et al., 2020).

The detailed research steps are as follows (*Figure 1*): 1) Review relevant theoretical outcomes on the construction and ecological restoration of mangrove wetland parks; 2) Conduct field surveys to gather data from the mangrove park; 3) Construct a comprehensive health evaluation system for mangrove wetlands to assess the health status; 4) Decide the indexes' weights using the Analytic Hierarchy Process (AHP) method with experts; 5) Examine each indicator by quantifying the values in experiments; 6) Overlay data on a map and estimate the surrounding areas; 7) Conclude the findings and provide suggestions for mangrove wetland parks based on the health evaluation (*Figure 1*).

Study area

Situated in the coastal region of southern China (*Figure 2*), the Great Bay Area covers several provinces and cities, including Guangdong, Hong Kong, and Macao (GBA). As one of the most developed areas in China, it has nearly 82 million inhabitants. Similar to other urban areas, the GBA is facing a number of issues due to its fast urbanization,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

including the problems of ecological security, land use imbalance, etc. (Guo et al., 2021; Wang et al., 2021; Li et al., 2022; Nijhuis et al., 2023).

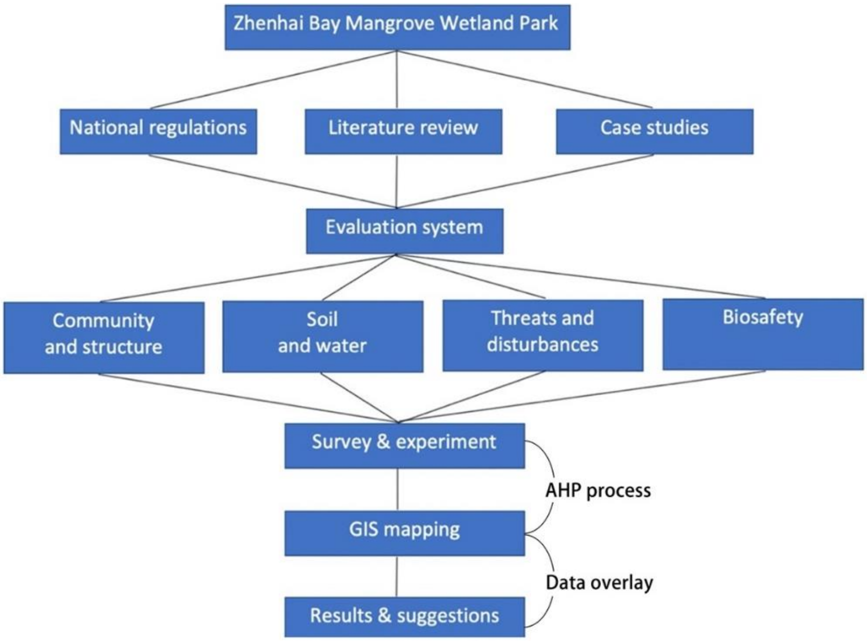

Figure 1. *Workflow of the study*

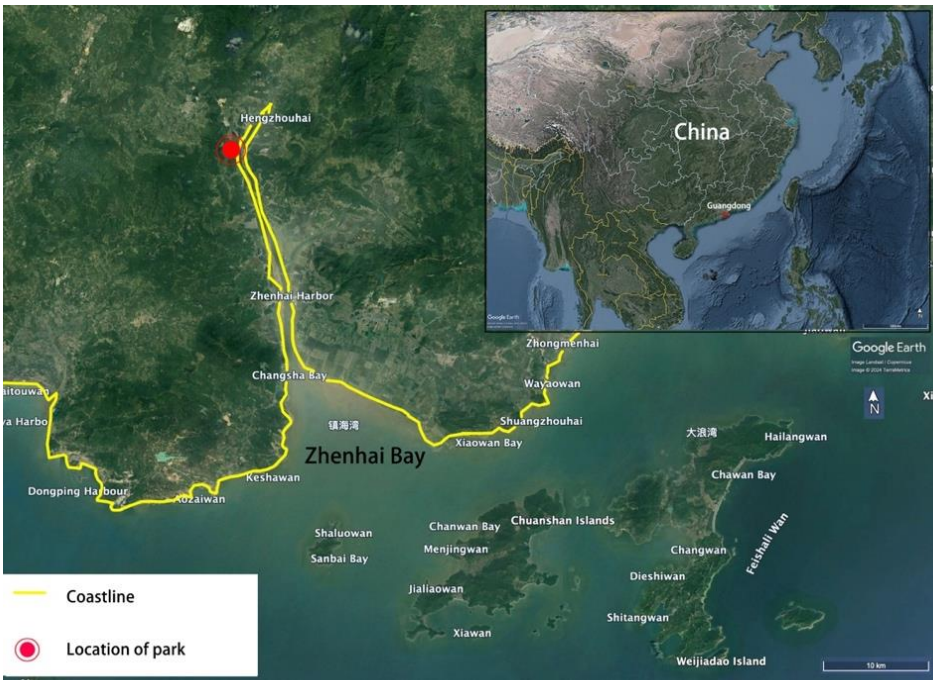

Figure 2. *Location of the Zhenhai Park in China*

The Zhenhai Bay Mangrove Wetland Park encompasses a total area of 549 hectares, with the wetland covering 515 hectares (93.8% of the whole park). The land in the park is predominantly flat, with a maximum elevation of 26 meters. The landscape is

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

characterized by intertidal beaches and mangrove swamps. Notably, mudflats and aquaculture ponds are concentrated there, constituting an area of 387 hectares, which accounts for 70.5% of the total wetland park area. Mangrove forests cover an area of 162.3 hectares (29.5% of the park). Mountains and hills, ranging from 4 to 26 meters, cover an approximate area of 1.71 hectares. Currently, this park is the largest wetland in the region, known as a "Sea Forest". The park plays an important role in maintaining regional ecological balance and biodiversity. The park can be divided into five sections: conservation area, restoration and reconstruction area, publicity and education area, and utilization and management service area. Due to its high ecological value, as well as its profound culture, historical heritage, and unique oyster industry, the park is acknowledged as a “National Wetland Park”. Because of the ecological and regional importance of this wetland, it has been selected as a study area to discuss the methodology of constructing a health evaluation.

Site investigation

During the research, ten rounds of fieldwork were conducted in 2022 to investigate the basic conditions of the mangrove park, including water quality and species. The mangrove park covers a vast area, and ecological sampling and the belt transect method (drawing transect lines and placing quadrats over them) were applied to study the park (Kenkel et al., 1989; Cao et al., 2002; Wheater et al., 2020). Due to the linear shape of the park, seven points were evenly distributed along the coastline to select the samples. The selected sample points are shown below, as well as some pictures taken along the fieldwork (*Figure 3*), following the requirement of arboreal area: 10 m×10 m, shrubs: 5 m×5 m, and herbs: 1 m×1 m (SFA, 2017). In each sample, the authors went to the sites to collect water and soil for testing.

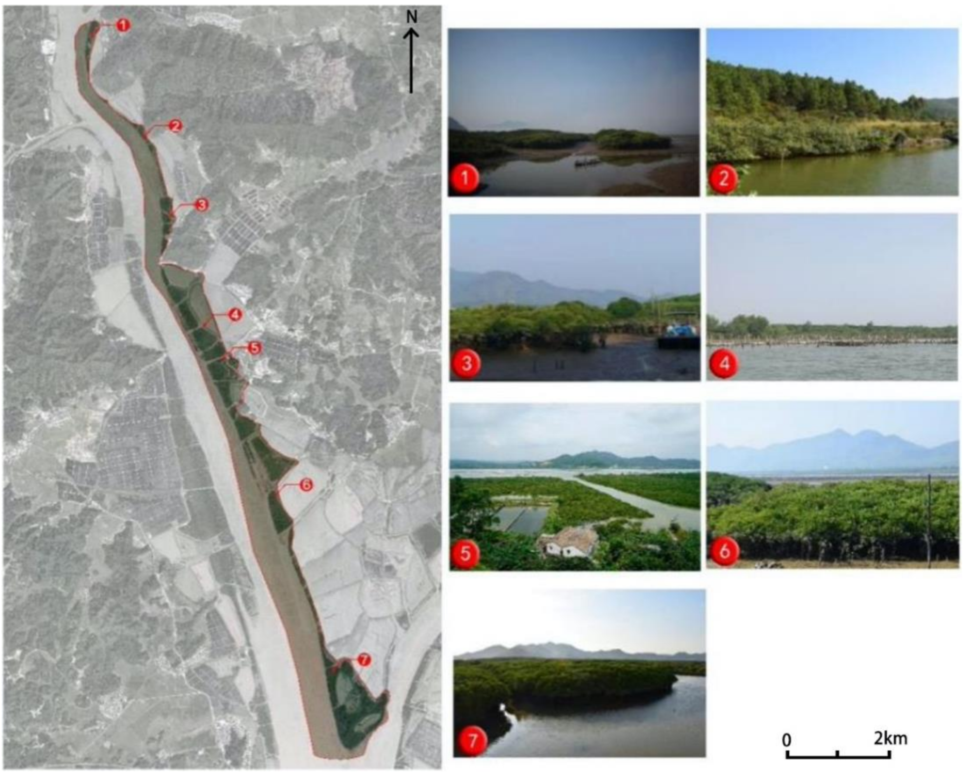

Figure 3. *Sample distribution and landscape photos*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

The water was obtained at a height of 5 cm from the surface of the water, with an interval of 10 days (in total three times). The sampling depth for soil was 20 cm from the surface, and one-inch-thick soil was sampled each time (in total three times). The sampling period was continued for one month (during the spring in 2022).

After the fieldwork, it was observed that the water quality in the park could basically meet the local water standards. However, pollution from industries in the surrounding area was also evident. Numerous aquaculture ponds were built but lacked standardized management, leading to the direct discharge of wastewater, which posed a significant threat to the health of the mangrove wetland by spreading pathogens. Some areas showed poor water quality due to abandoned ponds, where water stagnation led to deterioration. Meanwhile, sewage containing nitrogen and phosphorus, released without proper treatment, also significantly impacted the water quality within the park.

Health evaluation system

A comprehensive investigation of the Zhenhai Bay Wetland Park was conducted to assess its health. Technical regulations and case studies were followed, including the LY/T2794-2017 and other references in *Table 1*. This evaluation comprised four major dimensions: community and structure (C), water and soil quality (W), external threats and interference (E), and biosecurity (B), with 18 evaluation indexes included. The evaluation indicators were tested through field measurements, laboratory experiments, and statistical methods. The ecological indicators included naturalness, ecological integrity, proportion of dominant species, degree of depression, etc. Laboratory indicators included soil salinity, water pollution index, nutrient index, etc. Statistical data involved plant diversity, bird diversity, benthic animal diversity, wetland degradation, wetland reclamation, invasion area, disease species, disease area, tourists' arrivals, etc. Specific methods and tools were used for testing water and soil quality (*Table 2*). All experimental data were analyzed using statistical methods with Statistical Product and Service Solutions 27.0 (SPSS). A detailed explanation of every index is provided in *Table 3*.

Table 1. *Constructed evaluation system*

Dimensions	Index	References
Community and structure (C)	Naturalness (C1) Integrity (C2) Dominant species (C3) Crown density (C4) Plant diversity (C5) Bird diversity (C6) Benthic animal diversity (C7)	Ong & Gong, 2013; Vaghela et al., 2018 Faridah-Hanum et al., 2019; Fang et al., 2021; Hossain et al., 2021 Dayal et al., 2022; Zhao et al., 2022 Akram et al., 2023 And national guidelines: LY/T2794-2017; GB6920-1986; HJ535-2009; GB11913-1989; HJ828-2017; GB11893-89; HJ636-2012; GB17378.5; SFA 2017; MEE 2009
Water and soil quality (W)	Salinity (W1) Water index (W2) Nutrition index (W3)	
External threats and interference (E)	Wetland degradation (E1) Wetland reclamation (E2) Seawall construction (E3) Tourists' arrivals (E4)	
Biosecurity (B)	Invasive species (B1) Invasion area (B2) Disease species (B3) Disease area (B4)	

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

Table 2. *Testing method and tools of the mangrove health*

No	Index	Method	Guidelines	Tool type
1	pH	Glass electrode	GB6920-1986 (MEE, 1987)	Apure GRT1120
2	Nh3	Spectrophotometry	HJ535-2009 (MEE, 2010)	Shengaohua SH6600
3	DO	Electrochemical probe	GB11913-1989 (MEE, 2009)	Meacon MIK-DM2800
4	COD	Dichromate method	HJ828-2017 (MEE, 2017)	Yihua CODmax-II
5	TP	Spectrophotometric	GB11893-89 (MEE, 1990)	Shengaohua SH6600
6	TN	Spectrophotometric	HJ636-2012 (MEE, 2012)	Shengaohua SH6600
7	Salt	Salinometer	GB17378.5 (MEE, 1998)	Ruiming-SAB

Table 3. *Explanation of selected indexes*

ID	Units	5	4	3	2	1
C1	Ratio %	≥80	80~60	60~40	40~10	≤10
C2	Type	Intact	Minor intrusion	Deteriorated	Incomplete	Destroyed
C3	Ratio %	80>	80~60	60~40	40~20	<20
C4	Ratio %	100	100~80	80~60	60~40	<40
C5	Number	28	76	5~4	32	1
C6	Ratio %	>80	80~60	60~40	40~30	<30
C7	Ratio %	>80	80~60	60~40	40~30	<30
W1	Ratio %	10~25	25~35 or 10~5	35~40 or 5~3	3~1	>40 or <1
W2	Index value	<0.20	0.20-0.60	0.60-1.00	1.00-2.00	>2.00
W3	NI value	<1.0	1.0-2.0	2.0-3.0	3.0-4.0	>4.0
E1	Degradation rate %	<15	15~25	25~35	35~50	>50
E2	Reclamation rate %	<15	15~25	25~35	35~50	>50
E3	Construction rate %	0	<20	20~40	40~80	>80
E4	Number (person/ha)	0	<100	101-200	201~400	>400
B1	Number	0	1	2	3~4	>4
B2	Area %		<10	10~20	20~30	>30
B3	Number	0	1	2	3~4	>4
B4	Area %	0	<10	10~20	20~30	>30

The electrode method was for testing the pH value of water. It had two electrodes to measure the voltage difference generated. Colorimetry for measuring the NH3 in water was based on the reaction of Nessler's reagent with ammonium ions. The electrochemical probe method for dissolved oxygen (DO) was based on the theory that the current is proportional to the concentration of oxygen in water. The dichromate method was based on the process of potassium dichromate oxidizing reducing substances in water. For testing total phosphorus (TP) and total nitrogen (TN), the spectrophotometric method was used as a quantitative analysis of molecules depending on how much light is absorbed by the colored compound. A salinometer was a way to measure salinity because it can affect the electrical conductivity and the specific gravity of a solution.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

The water quality index (WQI) for water quality can be calculated by assessing four key indexes: pH, DO, TP, and ammonia nitrogen (NH3-N) (Qun et al., 2009; Lin et al., 2018; Zhang et al., 2020). The formula is:

$$WQI = \frac{1}{n}\sum_{i}^{n} Pi \quad \text{(Eq.1)}$$

In *Eq. 1*, the n means the number of water index, and Pi means the i-th concentration value of the tested index. Then, the nutrient index (NI) was according to the COD, TN, and TP. The calculation formula is (Zhu et al., 2010; Lin et al., 2018):

$$NI = \frac{C\,cod}{C'cod} + \frac{C\,tn}{C'tn} + \frac{C\,tp}{C'tp} \quad \text{(Eq.2)}$$

In Eq. 2, the C value means the tested concentration value of the index, and C' means the standard parameter of the index.

Weight decision

The data overlay and calculation required the weight of each index, which was an important part of this research. The method applied for assigning weight to indexes was the "AHP with expert method" (Saaty, 2004). Five experts from different fields were invited to discuss and compare the importance of each pair of indicators and assign an importance value to them (from 1 to 9). For example, 9/1 means the first indicator has significantly more importance than the second one; 1/9 means the second one is significantly more important than the first one, and so on (Song et al., 2010). According to the pairs of importance values, their weight can be calculated. For the four dimensions, the comparison was: B1/B2 – 2/1, B1/B3 – 4/1, B1/B4 – 6/1, B2/B3 – 2/1, B2/B4- 3/1, and B3/B4 – 2/1. The tested consistency value was 0.0034, which meant high consistency among the weight comparisons (Franek and Kresta, 2014). The AHP calculation results were as follows (*Table 4*).

Table 4. *Result of AHP weights*

Dimensions	Weightage	ID	Final weight in the system
Community and structure (C)	0.519	S1	0.084
		S2	0.013
		S3	0.063
		S4	0.152
		S5	0.109
		S6	0.038
		S7	0.063
Water and soil quality (W)	0.259	W1	0.153
		W2	0.080
		W3	0.028
External threats and interference (E)	0.140	E1	0.021
		E2	0.043
		E3	0.009
		E4	0.057
Biosecurity (B)	0.082	B1	0.006
		B2	0.055
		B3	0.006
		B4	0.020

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

Based on the calculated weights, the overall health condition (H) was proposed as below:

$$H = \sum_{ij}^{n} Pij * Wij \quad \text{(Eq.3)}$$

In *Eq 3*, n means the number of indicators. P means the value of each indicator, and W means the calculated weightage from *Table 2*. Following the equation, at last, the health situation of the mangrove park was qualified as follows.

Results

Community and structure

A total of 127 plant species were recorded in the Mangrove Park. Most of them were naturally grown, except for some plants in the supratidal zone that were artificially planted as fast-growing economic trees, such as Eucalyptus urophylla. Among all the species, there were 12 mangrove species (including four semi-mangrove species). The 12 mangrove species are listed below: *Acrostichum aureum, Heritiera littoralis, Sonneratia caseolari, Bruguiera gymnorhiza, Kandelia candel, Rhizophora stylosa, Hibiscus tiliaceus, Thespesia populnea, Excoecaria agallocha, Aegiceras corniculatum, Acanthus ilicifolius, and Avicennia marina*. Other species were also found in the park, including 101 species of animals, comprising nine species of amphibians, 14 species of reptiles, 74 species of birds, and four species of mammals. However, human activities have caused significant disturbance to habitats, with some habitats being occupied and destroyed, leading to a decline in ecological functions. Some other ecological risks were also identified, such as increased landscape fragmentation, which has led to a decrease in biological habitats.

The evaluation of communities and structures encompassed seven key indexes: naturalness, ecological integrity, dominant species, crown density, plant diversity, bird diversity, and benthic animal diversity. Among them, naturalness was determined by the percentage of undisturbed mangrove forests in relation to the total mangrove area; Ecological integrity was gauged by assessing the percentage of mangrove populations in low-tide, mid-tide, and high-tide zones within the surveyed area. Bird diversity was expressed as the percentage of birds in the park compared to the bird population of the region. Benthic diversity (benthic animals) was measured by the percentage of benthic biomass relative to the whole region. The results showed that sample one was mainly dominated by the species of *Aegiceras corniculatum, Kandelia candel, Acanthus Ilicifolius, Acrostichum aureum*; Sample two: *Avicennia Marina, Kandelia candel, and Aegiceras corniculatum*; sample three: *Petalless Sonneratia caseolaris, Acanthus Ilicifolius, and Acrostichum aureum*; sample four: *Acanthus Ilicifolius, Heritiera littoralis, and Thespesia populnea*; sample five: *Aegiceras corniculatum and Kandelia candel*; sample six: *Avicennia Marina, Kandelia candel, and Aegiceras corniculatum*; sample seven: *Avicennia Marina, Kandelia candel, and Aegiceras corniculatum* (*Table 5*).

Among all the samples, sites 6 and 7 exhibited the highest ecological completeness. Sample 6 had the highest proportion of dominant species, boasting 85% of all the mangrove plants. Sample 7 recorded an 80% degree of naturalness. Conversely, sample 5 exhibited a lower density and the least populated benthic fauna. Samples 6 and 7 also

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

showed higher degrees of plant diversity. The survey revealed close values across all the samples, except for site 4. In terms of biotope and structure, sample 4 displayed lower values compared to other sites. Thus, it indicated a lower variation in habitat and structure among the surveyed sites (1, 2, 3, 5, 6, and 7).

Table 5. *Evaluation score of the seven communities*

No.	C1 (type)	Value	C2 (%)	Value	C3 (%)	Value	C4 (%)	Value	C5 (n)	Value	C6 (%)	Value	C7 (%)	Value
1	Deteriorated	3	85	5	78	4	80	4	4	3	83	5	74	4
2	Deteriorated	3	55	3	70	4	50	2	4	3	83	5	70	4
3	Deteriorated	3	50	3	20	2	70	3	5	3	83	5	78	4
4	Destroyed	1	30	2	20	2	20	1	5	3	83	5	27	1
5	Deteriorated	3	55	3	40	2	40	2	3	2	83	5	72	4
6	Intact	5	85	4	50	3	80	4	6	4	83	5	74	4
7	Intact	5	75	4	80	4	80	4	6	4	83	5	70	4

Soil and water

The result (*Table 6*) showed that the soil salinity levels within the park remained stable (within 20‰ - 30‰), thereby providing a conducive environment for the growth of mangrove plants and semi-mangrove plants. For water quality, a higher value meant a worse quality. Sample 4 exhibited the highest water pollution index (0.94). Samples 4 and 5 had the highest nutrient index, exceeding 2.5. A higher nutrient value also meant a worse quality. Thus, within the elements of soil and water evaluation, samples 4 and 5 were associated with lower qualities, indicating potentially worse environmental conditions. In contrast, sample 1 was characterized by a lower index, which meant a better condition of soil and water.

Table 6. *Evaluation of soil and water in the park*

No.	W1 (‰)	Value (1-5)	W2	Value (1-5)	W3	Value (1-5)
1	23	5	0.67	4	1.94	4
2	20	5	0.73	3	1.97	4
3	27	4	0.71	3	2.28	3
4	29	4	0.94	2	2.51	2
5	24	5	0.83	3	2.64	2
6	30	4	0.72	3	1.98	4
7	29	4	0.76	3	2.28	3

External threats and disturbances

The wetland degradation rate was calculated as the proportion of salinization, sanding, and vegetation degradation within the assessment area to the total wetland area in the region. The wetland reclamation represented the percentage of the original mangrove wetland area that has been converted to other land use types, such as farmland or aquaculture ponds. The visitor quantity was measured as the number of visitors per hectare per day, obtained through visits to the management office. Meanwhile, the seawall construction was determined by assessing the percentage of seawall extension in relation to the extension of the coast where the mangrove wetland is situated (*Table 7*).

Table 7. *Evaluation score of mangrove threats and disturbances*

No.	E1 (%)	Value (1-5)	E2 (%)	Value (1-5)	E3 Visitor/ ha	Value (1-5)	E4 (%)	Value (1-5)
1	8	5	4	5	9	4	0	5
2	9	5	5	5	9	4	0	5
3	9	5	5	5	9	4	0	5
4	65	1	65	1	9	4	90	1
5	12	5	8	5	9	4	0	5
6	10	5	7	5	9	4	0	5
7	5	5	4	5	9	4	0	5

As is seen, sample 4 was characterized as an area of abandoned ponds, exhibited the highest rates of both degradation and reclamation. Based on inquiries, the park received approximately 5,000 visitors daily, with a density of about nine visitors/ ha. The seawall construction rate at sample 4 was notably high, standing at approximately 90% based on satellite images, and was assigned a value of 1. For the external threats and disturbances, sample 4 was distinctly assigned the lowest value, while the remaining sample sites showed minimal variations.

Biosafety

All data in this dimension were obtained from the survey of samples in the park. The original measured values and assigned values are as follows (see *Table 8*). Among these, Ba and B3 were counted by numbers, while B2 and B4 were measured as percentages of invaded areas.

Table 8. *Evaluation score of biosafety*

No.	B1 (n)	Value (1-5)	B2 (%)	Value (1-5)	B3 (n)	Value (1-5)	B4 (%)	Value (1-5)
1	2	3	7	4	2	3	3	4
2	2	3	12	3	2	3	7	4
3	2	3	12	3	3	2	3	4
4	3	2	25	2	3	2	10	3
5	2	3	9	4	3	2	6	4
6	2	3	7	4	2	3	6	4
7	2	3	7	4	2	3	3	4

In terms of biosafety, the prevalent invasive species identified in sample 4 were *Mikania micrantha, Spartina alterniflora, and Derris trifoliata*, covering 25% of the whole area. Regarding diseases, the species were predominantly featuring by *Lasiognatha mormopa,* and *Aglossa caprealis*. Sample 4 exhibited the largest area of pest damage, where nearly 10% of the plant leaves and stems displayed signs of insect attack (Chen et al., 2018; Chen et al., 2020). The other sample sites showed minimal variations compared to sample 4.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

Overall results and mapping

Overlaying all the indexes and calculating the health value in SPSS, the overall results are shown below (*Table 9*). With the help of Geographic Information System (GIS) software, the data were overlayed on a map using inverse distance weighted (IDW) interpolation, a method to determine values using a linearly weighted combination of samples. Based on the known calculated values, the surrounding points can be estimated (Bartier and Keller, 1996; Khouni et al., 2021). Thus, the rest areas of the park were drawn on the map, showing the estimated health values (*Figure 4*).

Table 9. *Overall evaluation score of the mangrove park*

Sample	1	2	3	4	5	6	7
C1	0.336	0.336	0.168	0.168	0.168	0.252	0.336
C2	0.038	0.038	0.038	0.013	0.038	0.063	0.063
C3	0.316	0.189	0.189	0.126	0.189	0.252	0.252
C4	0.606	0.303	0.455	0.152	0.303	0.606	0.606
C5	0.328	0.328	0.328	0.328	0.219	0.438	0.438
C6	0.190	0.190	0.190	0.190	0.190	0.190	0.190
C7	0.252	0.252	0.252	0.063	0.252	0.252	0.252
W1	0.767	0.767	0.613	0.613	0.767	0.613	0.613
W2	0.320	0.240	0.240	0.240	0.240	0.240	0.240
W3	0.110	0.110	0.083	0.055	0.055	0.110	0.083
E1	0.105	0.105	0.105	0.021	0.105	0.105	0.105
E2	0.216	0.216	0.216	0.043	0.216	0.216	0.216
E3	0.037	0.037	0.037	0.037	0.037	0.037	0.037
E4	0.286	0.286	0.286	0.057	0.286	0.286	0.286
B1	0.017	0.017	0.017	0.011	0.006	0.017	0.017
B2	0.221	0.166	0.221	0.111	0.221	0.221	0.221
B3	0.017	0.017	0.017	0.011	0.011	0.017	0.017
B4	0.081	0.081	0.081	0.061	0.081	0.081	0.081
Class	**4.243** average	**3.678** average	**3.536** average	**2.301** unhealthy	**3.384** subhealth	**3.997** average	**4.053** average

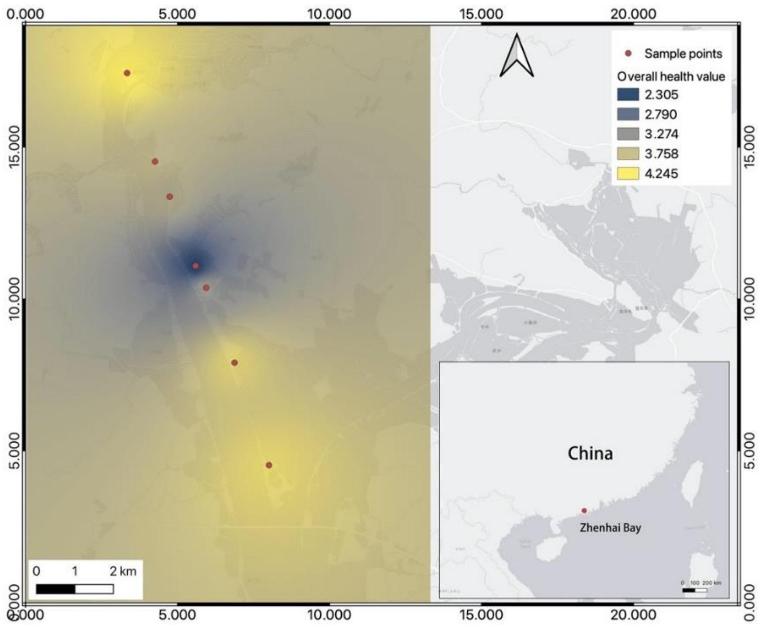

Figure 4. *Overall mapping of health value in the Zhenhai Park*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

According to the SFA standard, an overall value higher than 4.25 (85%>) is considered healthy; 3.50–4.25 (70%>) means an average condition; 3.0-3.5 (60%>) is subhealth, and a value lower than 3.0 (<60%) means an unhealthy system (SFA, 2017). At last, it can be concluded that Zhenhai Park revealed significant differences in external threats and disturbances among the sites, with the reclamation rate emerging as the foremost threat. Sample 4, with a reclamation rate of 65%, classified as a dangerous period for its health. Sample 4 showed worse levels in several factors, including biotic community and structure and soil and water environment indicators, all below-average values. Despite fluctuations in the overall water index and trophic status in the park, samples 1, 6, and 7 consistently maintained a healthier condition, positively correlated with their biotope structures. The primary external threat in the park remains the reclamation rate, while the number of visitors is still within a flexible range. Invasive plants and pests can potentially threaten the healthy development of mangrove forests. Sample 2 was rated as “average”, with the main factors affecting mangrove health being the degree of depression and invasive species. Sample 5 was rated as a subhealth category, with influencing factors including the degree of depression, invasive species, naturalness, nutrient status index, and disaster species. Spatially, the center of the park showed a less healthy situation, and the north and south parts were relatively healthier than the centre.

Discussions

The findings of this study are envisioned to contribute to the advancement of research in wetland park planning, specifically emphasizing the healthy development of mangrove. The objective is to address the inherent challenges in reconciling the restoration and protection of mangrove wetland parks with the spatial demands of human activities. It is anticipated that this research can offer valuable insights for the planning of mangrove wetland parks and other similar wetland parks in the future. The findings of this research are basically consistent with other investigations in the GBA, such as Fang et al. (2021). According to them, most attributes for the GBA wetlands were under a “sub healthy” grade, with good grades mainly from tree diversity, bird diversity, species habitat degradation rate, etc. The main factors affecting the health status were water, soil, vegetation, and animals.

Considering the relationship among the factors, it should be further discussed. For example, samples 2 and 5 were affected by invasive species and showed compromised community structures. It may suggest an influence between biosecurity and community structure (Kortz and Magurran, 2021). Sample 4 had a high reclamation rate and showed poor water and soil qualities. The number of visitors in sample 4 was also huge, which may suggest that these factors could not withstand a certain level of human interference (Baloch et al., 2023). These relationships should be further tested in more mangrove parks to verify.

This research also has certain limitations. The research methodology was mainly based on the synthesis of mangrove forestation and wetland ecological restoration techniques from other scholars and cases of mangrove wetland parks. The actual construction and ecological restoration effects will require continuous monitoring over an extended period. The development of mangrove wetland ecosystems is influenced by various factors, and mangrove wetland parks, being only a component of the mangrove protection system, have limitations in safeguarding mangrove ecosystems at a broader regional scale. Achieving the healthy development of mangrove ecosystems necessitates a holistic

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

approach, involving the coordination of regional development and addressing the intricate relationships among mangrove ecosystems, the surrounding environment, society, and the economy.

The applied weighting approach of AHP provides a quick and simple method for determining an area's critical components, but it also has drawbacks, such as the limited number of experts and the possibility of bias in their conclusions due to personal experiences. To address this issue, it is advisable to investigate other techniques for factor selection and identification. Therefore, for a more objective factor selection procedure, it is recommended to incorporate statistical models, such as structural equation modeling (SEM), etc. (Wang et al., 2022). Additionally, more spatial technologies, including social media crowdsourcing to monitor the wetlands in GBA, should be implemented for measuring ecological services, routinely checking the wetland conditions, and continually updating the regional wetland data for a better understanding from the perspective of normal park users (Sinclair et al., 2018).

As for the conditions of the bay area, it is necessary to formulate clear and effective management and protection measures for mangrove resources within the designated red line. A stringent prohibition of mangrove destruction activities should be enforced to safeguard and promote the quality development of mangrove forests. Cultivating a mangrove-based eco-industry is crucial, guiding local communities to scientifically understand and protect mangrove forests. Exploring the coupling mode of "restoration with aquaculture" in ponds can effectively protect and sustainably develop the mangrove wetland ecosystem and biodiversity. This coupling mode can extend to breeding ponds, promoting the regional expansion and development of mangrove forests, encouraging the long-term development of quantitative development and ecological aquaculture, and gradually guiding wetlands back to red forests. Furthermore, the implementation of eco-tourism, environmental education, and other eco-industries is proposed. This strategic approach aims to optimize the industrial structure, enhance the income of residents, and foster the protection and restoration of mangrove resources across societal, economic, and natural dimensions. The overall goal is to create a balanced and sustainable ecosystem, promoting harmony between human activities and mangrove wetland preservation.

Conclusion

The study delved into pertinent literature and examined classic cases of mangrove wetland parks. The evaluation of mangrove wetlands in Zhenhai Bay has led to the formulation and application of a wetland park protection framework grounded in the healthy assessment of mangrove ecosystems. The key conclusions drawn from this research include Mangrove in Zhenhai Bay is strategically situated at the intersection of land and water, where salt and fresh water coalesce. This unique positioning creates an evident edge effect, fostering diverse habitats for various organisms. The mangrove ecosystem exhibits high biodiversity, underscoring its significance in research and conservation efforts. The health status of mangrove forests in Zhenhai Bay Park was objectively analysed through field research and data collection in Zhenhai Bay. The ecosystem health assessment, guided by regulatory frameworks, identified prominent health risks and underlying causes. Among these are human activities, the presence of extensive breeding ponds, river and surrounding area aquaculture leading to water pollution and eutrophication, and biosafety concerns. The mapping results revealed the spatial distribution of the health, subhealth, and unhealth of the mangrove system. These

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

findings lay the foundation for setting objectives and directions for the future planning of other mangrove parks in the Great Bay Area. A comprehensive set of wetland park planning should be centred on the key aspects, encompassing designing intact biological communities and structures, ensuring soil and water environment quality, addressing external threats and disturbances, and implementing biosafety measures.

Acknowledgements. This research was supported by the National Natural Science Foundation of China (ID: 32100077), and Fujian Province Social Science Research Fund (ID: FJ2024C128).

REFERENCES

[1] Akram, H., Hussain, S., Mazumdar, P., Chua, K. O., Butt, T. E., Harikrishna, J. A. (2023): Mangrove health: A review of functions, threats, and challenges associated with mangrove management practices. – Forests 14(9): 1698.
[2] Bai, R. (2016): Ecosystem evaluation and protection countermeasures of Qiliyu Provincial Wetland Park in Taiyue Mountain, Shanxi. – Inner Mongolia Forestry Survey and Design 39(05): 61-63.
[3] Baloch, Q. B., Shah, S. N., Iqbal, N., Sheeraz, M., Asadullah, M., Mahar, S., Khan, A. U. (2023): Impact of tourism development upon environmental sustainability: a suggested framework for sustainable ecotourism. – Environmental Science and Pollution Research 30(3): 5917-5930.
[4] Bartier, P. M., Keller, C. P. (1996): Multivariate interpolation to incorporate thematic surface data using inverse distance weighting (IDW). – Computers & Geosciences 22(7): 795-799.
[5] Bian, J., Geng, L., Fang, R. (2010): Research on river health evaluation system. – China Rural Water Conservancy and Hydropower 09: 39-42.
[6] Cao, Y., Williams, D. D., Larsen, D. P. (2002): Comparison of ecological communities: the problem of sample representativeness. – Ecological Monographs 72(1): 41-56.
[7] Cao, H., Liu, S., Liu, S. (2020): Evaluation of mangrove ecosystem health and protection strategy in Huachang Bay, Hainan. – Zhongnan Forestry Survey and Planning 39(02): 16-19.
[8] Charrua, A. B., Bandeira, S. O., Catarino, S., Cabral, P., Romeiras, M. M. (2020): Assessment of the vulnerability of coastal mangrove ecosystems in Mozambique. – Ocean & Coastal Management 189: 105145.
[9] Chen, Q., Jian, S., Ma, K., Chen, P. (2018): Differences in macrobenthic faunal communities in mangrove wetland habitats (Zhanjiang, China) invaded and non-invaded by exotic cordgrass Spartina alterniflora. – Ecological Research 33: 1113-1123.
[10] Chen, Q., Xu, G., Wu, Z., Kang, P., Zhao, Q., Chen, Y., Lin, G., Jian, S. (2020): The effects of winter temperature and land use on mangrove avian species richness and abundance on Leizhou Peninsula, China. – Wetlands 40: 153-166.
[11] d'Acampora, B. H. A., Higueras, E., Román, E. (2018): Combining different metrics to measure the ecological connectivity of two mangrove landscapes in the municipality of florianópolis, southern Brazil. – Ecological Modelling 384: 103-110.
[12] Dayal, S., Waqa-Sakiti, H., Tabe, T., Hodge, S. (2022): An integrated evaluation of mangrove health and ecosystem value to local inhabitants: a blended ecological and sociological approach. – Pacific Dynamics: Journal of Interdisciplinary Research 6(1): 6-29.
[13] Fang, X. S., Liu, S., Chen, W. Z., Wu, R. Z. (2021): An effective method for wetland park health assessment: a case study of the Guangdong Xinhui National Wetland Park in the Pearl River Delta, China. – Wetlands 41: 1-16.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

[14] Faridah-Hanum, I., Yusoff, F. M., Fitrianto, A., Ainuddin, N. A., Gandaseca, S., Zaiton, S., Harun, N. Z. N. (2019): Development of a comprehensive mangrove quality index (MQI) in Matang Mangrove: Assessing mangrove ecosystem health. – Ecological Indicators 102: 103-117.
[15] Franek, J., Kresta, A. (2014): Judgment scales and consistency measure in AHP. – Procedia Economics and Finance 12: 164-173.
[16] Gilman, E. L., Ellison, J., Duke, N. C., Field, C. (2008): Threats to mangroves from climate change and adaptation options: a review. – Aquatic Botany 89(2): 237-250.
[17] Guo, H., Cai, Y., Yang, Z., Zhu, Z., Ouyang, Y. (2021): Dynamic simulation of coastal wetlands for Guangdong-Hong Kong-Macao Greater Bay area based on multi-temporal Landsat images and FLUS model. – Ecological Indicators 125: 107559.
[18] Hossain, M. S., Hossain, M. B., Rakib, M. R. J., Jolly, Y. N., Ullah, M. A., Elliott, M. (2021): Ecological and human health risk evaluation using pollution indices: A case study of the largest mangrove ecosystem of Bangladesh. – Regional Studies in Marine Science 47: 101913.
[19] Kamali, B., Hashim, R. (2011): Mangrove restoration without planting. – Ecological Engineering 37(2): 387-391.
[20] Kenkel, N. C., Juhász-Nagy, P., Podani, J. (1989): On sampling procedures in population and community ecology. – Vegetatio 83: 195-207.
[21] Khouni, I., Louhichi, G., Ghrabi, A. (2021): Use of GIS based Inverse Distance Weighted interpolation to assess surface water quality: Case of Wadi El Bey, Tunisia. – Environmental Technology & Innovation 24: 101892.
[22] Kortz, A. R., Magurran, A. E. (2021): Complex community responses underpin biodiversity change following invasion. – Biological Invasions 23(10): 3063-3076.
[23] Li, Q., Wu, J., Su, Y., Zhang, C., Wu, X., Wen, X., Chen, X. (2022): Estimating ecological sustainability in the Guangdong-Hong Kong-Macao Greater Bay Area, China: Retrospective analysis and prospective trajectories. – Journal of Environmental Management 303: 114167.
[24] Liao, B. (2019): Mangrove forests: Amphibious plants on China's coast. – Forest and Human 3: 100.
[25] Lin, X., Gao, S., Zhang, T., Liu, G. (2018): Research Progress and Application Status of Eutrophication Evaluation Method of Seawater. – Advances in Earth Science 33(4): 373-384.
[26] Magarotto, M. G., Costa, M. F. D. (2021): Mangrove Park of Recife: A century of extreme uses and abuses. – Regional Studies in Marine Science 42: 101654.
[27] Ministry of Ecology and Environment (MEE). (1987): Water quality-Determination of pH value-Glass electrode method. – Retrieved 10th September 2023 from: https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/198703/t19870301_66620.shtml.
[28] Ministry of Ecology and Environment (MEE). (1990): Water quality-Determination of total phosphorus-Ammonium molybdate spectrophotometric method. – Retrieved 10th September 2023 from: https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/199007/t19900701_67131.shtml?eqid=c97b68a7000045b10000000364709593.
[29] Ministry of Ecology and Environment (MEE). (1990): Water quality-Determination of total nitrogen-Alkaline potassium persulfate digestion UV spectrophotometric method. – Retrieved 10th September 2023 from: https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/201203/t20120307_224383.shtml.
[30] Ministry of Ecology and Environment (MEE). (1998): Marine Monitoring Code 5: Sediment Analysis. – Retrieved 10th September 2023 from: https://www.gbbz.net/text/Interpret/ba5ac18231dc9a7a.html.
[31] Ministry of Ecology and Environment (MEE). (2010): Water quality - Determination of dissolved oxygen-Electrochemical probe method. – Retrieved 10th September 2023 from: https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/200911/t20091106_181278.htm.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2205_41554172

[32] Ministry of Ecology and Environment (MEE). (2010): Water quality-Determination of ammonia nitrogen-Nessler's reagent spectrophotometry. – Retrieved 10th September 2023 from: https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/201001/t20100112_184155.shtml.
[33] Ministry of Ecology and Environment (MEE). (2017): Water quality-Determination of the chemical oxygen demand-Dichromate method. – Retrieved 10th September 2023 from: https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/201704/t20170410_409547.shtml.
[34] Nijhuis, S., Sun, Y., Lange, E. (2023): Adaptive Urban Transformation: Urban Landscape Dynamics, Regional Design and Territorial Governance in the Pearl River Delta, China. – Springer.
[35] Ong, J. E., Gong, W. K. (2013): Structure, function and management of mangrove ecosystems. – ISME Mangrove educational book series 2: 81.
[36] Prasetya, J. D., Pur Bayti, F. (2017): Mangrove health index as part of sustainable management in mangrove ecosystem at Karimunjawa National Marine Park Indonesia. – Advanced Science Letters 23(4): 3277-3282.
[37] Qun, M., Ying, G., Liu, Z., Tan, X. (2009): Application of comprehensive water quality identification index in water quality assessment of river. – WRI Global Congress on Intelligent Systems 1: 333-337.
[38] Rahadian, A., Leilan, F., Arafat, I. N. (2019): Ecosystem mangrove management in urban area: case study mangrove Kali Adem Jakarta Indonesia. – IOP Conference Series: Earth and Environmental Science 399(1): 012008.
[39] Saaty, T. L. (2004): Decision making-the analytic hierarchy and network processes (AHP/ANP). – Journal of Systems Science and Systems Engineering 13: 1-35.
[40] Sarhan, M., Tawfik, R. (2018): The economic valuation of mangrove forest ecosystem services: implications for protected area conservation. – The George Wright Forum 35(3): 341-349.
[41] Shao, S. (2019): Research on ecological restoration design of urban riverine wetland par. – Master thesis of Beijing Forestry University.
[42] Sinclair, M., Ghermandi, A., Sheela, A. M. (2018): A crowdsourced valuation of recreational ecosystem services using social media data: An application to a tropical wetland in India. – Science of the Total Environment 642: 356-365.
[43] Song, G., Chen, Y., Tian, M., Lv, S., Zhang, S., Liu, S. (2010): The ecological vulnerability evaluation in southwestern mountain region of China based on GIS and AHP method. – Procedia Environmental Sciences 2: 465-475.
[44] State Forestry Administration (SFA). (2017): Technical Procedure for Health Evaluation of Mangrove Wetland. – Retrieved 10th September 2023 from: http://sps.gdtbt.org.cn/noteshow-16646.html.
[45] Vaghela, B. N., Parmar, M. G., Solanki, H. A., Kansara, B. B., Prajapati, S. K., Kalubarme, M. H. (2018): Multi criteria decision making (MCDM) approach for mangrove health assessment using geo-informatics technology. – International Journal of Environment and Geoinformatics 5(2): 114-131.
[46] Valiela, I., Bowen, J. L., York, J. K. (2001): Mangrove Forests: One of the World's Threatened Major Tropical Environments. – Bioscience 51(10): 807-815.
[47] Van Bijsterveldt, C. E., Van Wesenbeeck, B. K., Ramadhani, S., Raven, O. V., Van Gool, F. E., Pribadi, R., Bouma, T. J. (2021): Does plastic waste kill mangroves? A field experiment to assess the impact of macro plastics on mangrove growth, stress response and survival. – Science of the Total Environment 756: 143826.
[48] Wang, H., Peng, Y., Wang, C., Wen, Q., Xu, J., Hu, Z., Jia, X., Zhao, X., Lian, W., Temmerman, S., Wolf, J., Bouma, T. (2021): Mangrove loss and gain in a densely populated urban estuary: lessons from the Guangdong-Hong Kong-Macao Greater Bay Area. – Frontiers in Marine Science 8: 693450.

[49] Wang, Y., Li, N., Zhu, J., Deng, Q., Hu, J., Xu, J., Zhou, J. (2022): Association between socio-ecological factors and leisure time physical activity (LTPA) among older adults in Sichuan, China: A structural equation modeling analysis. – BMC geriatrics 22(1): 1-8.
[50] Wei, S. (2019): Research on the design of urban wetland park combined with mangrove ecological restoration. – Master thesis of Beijing Forestry University.
[51] Wheater, C. P., Bell, J. R., Cook, P. A. (2020): Practical field ecology: a project guide. – John Wiley & Sons.
[52] Yasir, Y., Nurjanah, N., Nova, Y. (2020): Environmental communication model in Bengkalis's mangrove ecotourism development. – Journal ASPIKOM 5(2): 322-337.
[53] Zhang, R. (2020): Construction and Application of Evaluation System for the Effectiveness of Reclaimed Water Recharge Urban Landscape Water Body Ecological Health and Restoration Project. – Master thesis of Beijing Forestry University.
[54] Zhang, Y., Hou, K., Qian, H. (2020): Water quality assessment using comprehensive water quality index and modified Nemerow index method: A case study of Jinghui Canal, North China. – In IOP Conference Series: Earth and Environmental Science, August 21-23, 2020, Changchun, China, pp. 012125.
[55] Zhang, J., Yang, X., Wang, Z., Zhang, T., Liu, X. (2021): Remote sensing based spatial-temporal monitoring of the changes in coastline mangrove forests in China over the last 40 years. – Remote Sensing 13(10): 1986.
[56] Zhao, H., Wang, G., Song, Y., Zhao, Q. (2022): Evaluation of ecosystem health in Futian mangrove wetland based on the PSR-AHP model. – Applied Mathematics and Nonlinear Sciences 7(2): 985-998.
[57] Zhu, Y., Zeng, T., Yang, J., Tan, Y. (2010): Water quality assessment in Shashi of the Yangtze River by comprehensive water quality index. South-to-North Water Transfer. – Water Science and Technology 8(5): 122-124.