EVALUATING ECOSYSTEM SERVICES OF WETLANDS BASED ON AHP METHOD: A STUDY ON HUIYANG, GREATER BAY AREA IN CHINA

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Abstract. Wetland ecosystems can be effectively managed to produce sustainable services and benefits for human beings. Thus, it is considered as an essential component of Earth's life-support system. It has been studied quantitatively, but few studies have focused on exact local characteristics of various wetlands in Greater Bay Area (GBA) to continuously quantify the value of ecological services. Against the background of fast urbanization and wetland degradation in GBA, as a famous ecological core in China, Huiyang is of great importance for its ecological, social, and cultural functions in the whole region. Thus, this study aims to provide decision-making references for wetland protection and development in this area. All the wetlands in Huiyang, including mangroves, inland tidal flats, and coastal tidal flats, were included as research objects. Based on the investigated wetland resources, multiple methods were combined to study their wetland services, including pollution prevention cost, substitution cost, and travel expense calculation. Creatively, five factors were selected by Analytic Hierarchy Process (AHP) method: water purification, carbon fixation, shore protection, biodiversity conservation, and leisure tourism. After a comparison, the results showed that the total value of wetland ecosystem services in Huiyang was nearly 30.47 million dollars in 2020. Among the three types of services, the value of leisure tourism service was dominant, accounting for 95%. Among the five factors, the ranking sequence was: leisure tourism, carbon sequestration, biodiversity conservation, shore protection, and water purification. Based on the results, this paper provides a basis for more cities to scientifically measure the value of their wetlands, further utilize the wetland services in a more balanced way.

Keywords: *ecosystem service, wetland, landscape, value evaluation, biodiversity*

Introduction

Among all ecosystems, wetlands are one of the major ecosystems on Earth with high ecological and species diversity, as well as high biological productivity. According to statistics, the annual services value of wetland ecosystems reached 1.4 million US dollars/km^2 (Costanza et al., 1997), which was 15 times the value produced by forest ecosystems and 160 times that of farmland ecosystems. The aim of ecosystem services evaluation is to assess the changes in the stock of natural assets and calculate the value of these services in numerical ways, which can serve to improve ecosystem management

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(Vallecillo, 2019). The importance of wetlands to human society has been widely studied and recognized, especially their functions of regulating hydrological conditions, protecting wild species, purifying pollution, providing support for tourism and education, etc. (Gren et al., 1994; Mitsch and Gosselink, 2000; Chen et al., 2009). However, wetland systems are still facing many challenges and dangers. According to Valiela et al. (2001), as of the beginning of the 21st century, the global mangrove has shrunk by at least 35%, and estimated to continuously decrease by 25% by 2025. Since wetlands can deliver substantial social, economic, and environmental benefits globally, the importance of wetlands has been highly valued by countries all over the world. For example, in China, since the *National Congress* in 2017, the government emphasized the significance of protecting and developing wetlands on a national scale. The concept of "Green Water and Gold Mountains" was proposed to realize their ecosystem service values. It was also highlighted that evaluating wetland values in the form of monetization and measuring the effectiveness of wetland ecological construction is a crucial process to promote the realization of ecological products and developing sustainable wetlands (Meng et al., 2017).

In China, Guangdong province is located in the Guangdong–Hong Kong–Macao GBA, which is one of the largest and most populous urban areas in the world (an area of 56,000 km^2 with nearly 82 million of population). Similar to other urban areas, the GBA also faces many urbanization problems, such as the depletion of its ecological security and the imbalance between land and human beings, within the background of climate change and intense land use activities (Li et al., 2022). Building "ecological civilization" is one of the key priorities for the local government, as it has been chosen as one of the pilot locations for regional ecological civilization in China. A series of progress has been further expedited in this field. The province has carried out some measures to protect the wetlands and has successfully received many positive outputs in this region. With the publication of the *Administrative Measures for Wetland Parks in Guangdong Province* and the *Regulations on Wetland Protection of Guangdong Province*, it is observed that a hierarchical management system of wetland has been established, and more and more valuable wetlands are being studied by scholars from different perspectives, such as using satellite image for monitoring wetland changes (Guo et al., 2021), assessing and characterizing the carbon storage capacity of wetlands (Deng et al., 2022), and using Dual Environmental Evaluation for the spatial-temporal characteristics of the production-living-ecological spaces in GBA (Wu et al., 2021).

In the whole GBA, ecological sources accounting for nearly 13% of the total area, especially the south of GBA shows a good background of natural systems (Jiang et al., 2021). Huiyang, the southernmost part of Guangdong, is one of the tourist destinations in China famous for its wetland landscapes, and wetlands account for a large proportion of its territory (*Figure 1*). There are many scattered wetlands, such as the famous Daya Bay Mangrove Park, which is one of the top tourist destinations in China, with a total area of 176 ha and characterized by the mangroves with functions of ecological protection, sightseeing, and leisure activities (Xiao et al., 2019). The riparian zones account for 93.5%, inland mudflat with a percentage of 3.61%, and mangroves with a percentage of 2.89% (Zhao, 2017).

Due to the great ecological importance of Huiyang, investigating the status of wetland resources there and adopting suitable methods to decide the ecological indicators and calculate the value of ecosystem services will be beneficial to clarify its ecological

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products and provide basic support for establishing and improving their realization mechanism, as well as the success of ecological compensation (Li and Xu, 2021).

Figure 1. *Wetlands in Huiyang*

Review of Literature

"Ecosystem service" is defined as the various benefits that ecosystems and their biodiversity provide to humans through a wide range of ecological effects and processes, including direct and indirect, tangible and intangible benefits (Daily and Matson, 2008). However, in recent decades, humans have caused more negative impacts on ecosystems than in any previous period. Due to social progress and industrial development, ecosystem services have also been continuously degraded. Since 2005, the "Millennium Ecosystem Assessment (MEA)" has been assessing the consequences of ecosystem changes for human well-being. And it has been recognized that evaluating and quantifying ecosystem services is of great importance to meet the needs of economic development while slowing down the degradation of ecosystems.

The combination between ecology and economy was started from the late 20th century in China (Ma and Wang, 1984). Since then, scholars started to evaluate different natural places both ecologically and economically. Wu et al. (2003) conducted a comprehensive assessment of the ecological value for the Changjiang wetlands in China using the afforestation cost method combined with the cost substitution method (Wu et al., 2003). Yu et al. (2005) measured the forest ecosystem services in China, divided forest ecosystem services into eight categories, and constructed an evaluation index system for forest ecosystem. Continuously, Jiang et al. (2011) assessed 12 types of wetland ecosystem services in Chinese coastal basins and concluded that their total value was 59.87 billion dollars. Wang et al. (2017) calculated the ecosystem production of Aershan City (Northwest of China) and concluded that the total value was 7.84 billion dollars, of which regulation services accounted for 88.44%, cultural services 8.72%, and products services accounting for 2.83%.

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In recent years, both theoretical research and practical studies on evaluating ecosystem service value have made progress due to the introduction of different models and techniques. Evaluation methods have become more comprehensive, and the focus of studies has shifted from large-scale ecosystems to small-scale ecological sites, such as some specific forests, wetlands, and grasslands. However, there are still some shortcomings that are waiting for further studies. For example, the indicators for ecological evaluation are various and have been developed for many different systems, but how to build an evaluation system for Chinese wetlands has not reached a consensus; The value estimated without on-site investigation cannot be recognized by the market, and the price of environmental protection enforcement and ecological compensation is far lower than the value assessed by theoretical research. How to convert the estimated value into an actual transaction price is also a topic that needs further discussion. Further, there are still few studies on the ecological service function of urban wetlands in Huiyang area, especially focusing on evaluating the ecological service function in small detailed areas (Zheng, 2018; Yu and Hao, 2020).

To solve the problem of indicator selection, Saaty (1989) created the AHP method, a technique for supporting complex decision-making. The AHP technique provides a structure for making these determinations in a consistent manner and entails decomposing complex decisions into a hierarchy of criteria and alternatives, and then comparing each criterion and alternative using pairwise comparison matrices. Its advantages lie in providing a systematic and structured approach to decision-making, which can help to improve the quality of decisions made in evaluations. And it allows decision-makers to break down complex problems into smaller, more manageable components, making it easier to evaluate the relative importance of different criteria. The AHP method was also widely used in ecological evaluations, such as in the case of evaluating the Eco-environment quality (Ying et al., 2007) and ecological vulnerability (Wu and Tang, 2022).

Based on the literature review, aimed to quantify and compare the different ecological services to guide further wetland protection and development, this research used Huiyang district as a study area to propose a comprehensive evaluation process with the AHP method composed of several indicators for ecological services: regulating service, support service, and cultural service function. By using a comprehensive assessment methodology to calculate and measure the value of ecological service, this study provides a technological guidance for evaluating the performance of local development. The indicator selections followed both case studies and the Chinese governmental standard as references. Based on the calculated ecological values of Huiyang, further suggestions were also proposed. And the established evaluation system can also serve as a reference for other wetlands in this area to quantify their ecosystem services. Finally, it may also help people understand better the importance of the ecosystem to our life, motivating them to take part in preserving the ecological system and restoring the ecological services.

Materials and Methods

The entire working process is illustrated in *Figure 2*. Initially, the authors conducted a series of investigations in Huiyang to identify all the wetlands and collect basic geographic and environmental information. The second step involved establishing the evaluation system, which included compiling a list of ecological service indicators, referencing both the Chinese government standard and several case studies, such as the ecological accounting in China (Chen et al., 2014). Using the AHP method with expert

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opinions, the authors compared the importance of these indicators and selected the most important three indicators of ecology service: regulating, supporting and cultural service. After establishing the evaluation system with first layer of three indicators and second layer of five factors, the authors calculated each factor separately, using the equations recommended from other case studies. Ultimately, the authors obtained three service value and one overall value to guide further wetland development.

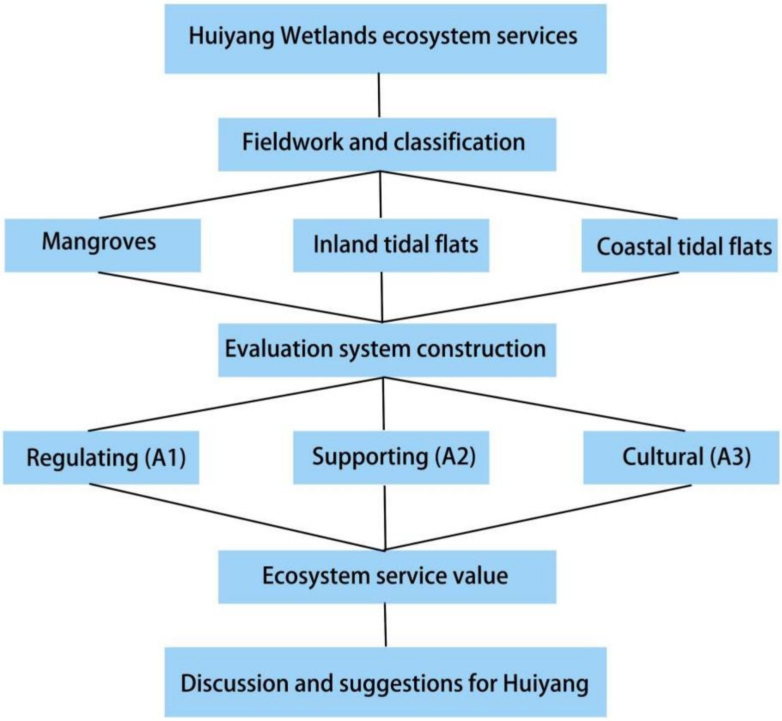

Figure 2. *Workflow*

Fieldwork

For the study area, Huiyang is located in the south of Guangdong Province, on the south bank of the middle and lower reaches of the Dongjiang River, and the eastern part of the Pearl River Delta. According to ten times of fieldwork conducted by the authors in 2020, the whole territory contains two huge regional wetlands (Guangdong Provincial Daya Bay Aquatic Resources Nature Reserve and the Provincial Mangrove Urban Wetland Park) with three main categories: mangroves, inland tidal flats, and coastal tidal flats. So, for a comprehensive evaluation, the study area (*Figure 3*) involves all the three types of wetlands. As is shown, in each wetland, samples points were selected according to the size and type of wetlands (due to data privacy issues, their specific shapes are not marked on the map), namely the inland tidal flats have five samples: Dakeng River - 1, Danshui River - 2, Danshui River - 3, Damao River - 4 and Pingshan River - 5 (the blue points on map). The only mangrove park was selected to study the mangroves in this area (in green color); And Xiaogui Bay, bay area of the Provincial Mangrove Park, and Daya Bay were selected to represent the coastal tidal flats (three yellow points).

Besides, other general natural and geographic data, including vegetation, water, and soil conditions, were also collected to ensure understanding of the current wetland situations.

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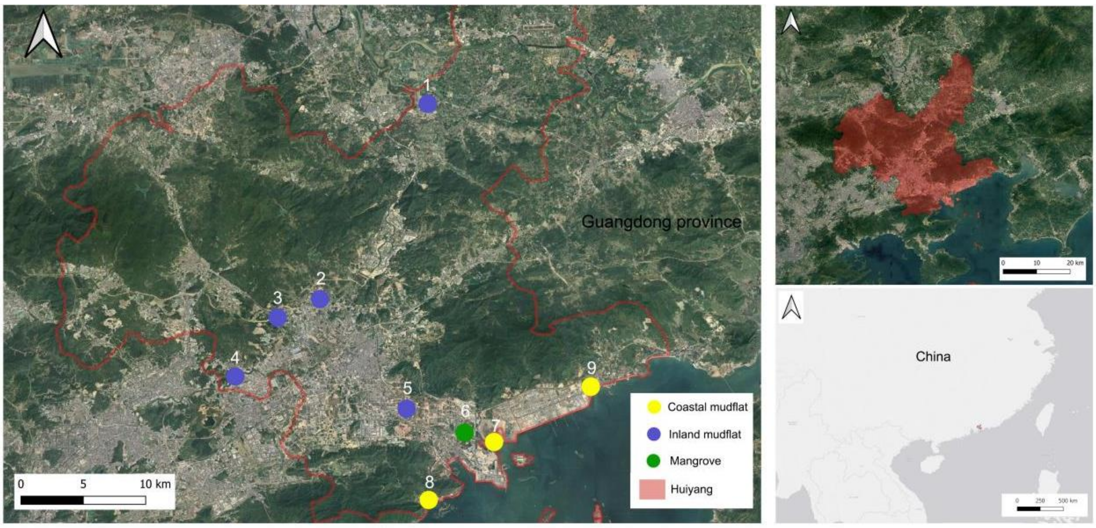

Figure 3. *Samples in Huiyang*

AHP and evaluation system

A national evaluation method, the *China Wetland Ecosystem Service Evaluation Specification (LY/T2899-2017)* (Forestry Administration, 2017), which is a standard for the evaluation process for various ecosystems, was published in 2017. Based on fieldwork data, this research mainly referred to this standard, as well as other case studies (Xin et al., 2005, 2006; Chen, 2007; Wu et al., 2010; Hu et al., 2015; Ding et al., 2016) to select the wetland indicators. The AHP method was then introduced, which involved listing popular ecological indicators and inviting five experts (from agriculture, geography, ecology, landscape architecture and forestry) to compare the importance between each pair. The experts were asked to give a value from 1/1 to 1/9 (or 9/1), with 1/1 indicating the same importance and 1/9 indicating that the second one is much more important than the first one. Six indicators were compared, namely provision, incubation, regulating, circulation, supporting, and cultural function. Using the AHP Calculator (https://bpmsg.com/ahp/ahp-calc.php), a matrix was built as shown in *Table 1*. The ranking for the priority of indicators was as follows: Cultural (33.5%), Support (30.7%), Regulating (21.4%), Provision (3.9%), Incubation (6.8%), and Circulation (3.7%). Thus, three indicators (provision, incubation and circulation) with limited importance for this area were eliminated and the top three indicators were retained (support, regulating and cultural) for the system construction.

Table 1. *Matrix for importance comparison*

Indicators	Cultural	Support	Regulating	Provision	Incubation	Circulation
Cultural	1	1/1	2/1	8/1	7/1	9/1
Support	1	1/1	1/1	7/1	8/1	9/1
Regulating	1/2	1/1	1/1	8/1	1/1	9/1
Provision	1/8	1/7	1/8	1/1	1/1	1/1
Incubation	1/7	1/8	1/1	1/1	1/1	1/1
Circulation	1/9	1/9	1/9	1/1	1/1	1/1

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Combined with the characteristics of wetland ecosystem in Huiyang, the three-wetland ecosystem service in Huiyang were finally divided into second level of factors: the regulating service can be reflected by water purification, carbon sequestration, shore protection; Support service were measured by biodiversity conservation; And cultural service function mainly includes one factor – leisure tourism. In all, there were five evaluation factors for the Huiyang wetland system. The specific interpretations and calculation methods are included in *Table 2* with references.

Table 2. *Wetland ecosystem service evaluation system for Huiyang*

	Indicators	Interpretation	Calculation	References
Regulating (A1)	Water purification (B1)	The value generated by reducing water pollutants through ecological processes such as absorption, transformation, and degradation.	Pollution prevention cost	(Trepel, 2010)
	Carbon fixation(B2)	The value of the function of reducing the concentration of carbon dioxide in the atmosphere by absorbing carbon dioxide to synthesize organic matter, fixing carbon in plants and soil.	Alternative costing	(Dong, et al, 2020)
	Shore protection (B3)	The functional value of avoiding or reducing seawall or coastal erosion by reducing waves.	Engineering alternative	(Orimoloye, et al., 2020)
Support (A2)	Biodiversity conservation (B4)	The value that underpins biodiversity conservation by providing long-term or short-term habitats for the reproduction, migration and habitation of rare and endangered waterbirds and other organisms.	Model evaluation	(Ye and Sun, 2021)
Cultural (A3)	Leisure tourism (B5)	The value of enriching knowledge and improving physical and mental health through the provision of recreational and leisure services.	Expense of tourism	(Li, et al, 2018)

After building of the evaluation system, then, each factor was calculated according to the rule explained as follows:

Water purification

The purification of water is one of the most important functions provided by wetlands. It is an effective and low-cost method for treating polluted water compared to chemical or physical treatments. The value of wetlands in terms of their water purification ability was estimated using pollution prevention cost method (Zhang et al., 2019). To facilitate data measurement, the purification function was estimated based on their ability to purify water discharged from local sewage treatment plants, particularly in terms of the costs of treating pollutants, including Ammoniacal nitrogen (NH3-N), total nitrogen (TN), total phosphorus (TP), chemical oxygen demand (COD), dissolved oxygen (DO), and pH values (Kazmierczak, 2001) (*Eq.1*):

$$W = \sum(Q_i - Q_j) \times t \times P_i \quad \text{(Eq.1)}$$

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In the formula: W is the value of wetland water purification (US dollar/year); Q_i is the concentration of the i-th pollutant (ton/m^3) in the water discharged from the sewage treatment plant (the selected five indexes); Q_j is the concentration of the j-th pollutant in the surface water after wetland purification (ton/m^3); t is the water discharge of sewage treatment plant (m^3); P_i is the treatment cost of the i-th water pollutant (US dollar/ton).

Carbon fixation

Usually, wetlands have anoxic soils, and the organic matters in wetland tend to be accumulated quite slowly. The storage capacity depends on the type and size of a wetland, vegetation composition, the depth of soils, the level of groundwater, nutrients, pH values, and other variables. As a result of soil erosion or the movement of leaves or other debris, carbon from upland areas is also carried into wetland soils. Wetlands also release carbon through normal seasonal variations (Whiting and Chanton, 2001). Thus, wetlands are called "Carbon warehouse" on the earth. The carbon fixation function is significant for the global carbon cycle. In this study, the carbon fixation value of wetlands was estimated by the substitution cost method (Dong et al., 2020). The carbon sequestration value of wetlands depends on the carbon conversion coefficient, carbon transaction price, and wetland carbon sequestration rate per unit, as well as the size of wetland areas. Thus, the three types of wetlands follow three different formulas (*Eqs. 2-4*):

Mangrove ecosystem:

$$V_1 = 3.67 \times 27.27 \times 10^{-3} \times 444.27 \times 10^{-3} \times SW = \sum(Q_i - Q_j) \times t \times P_i \quad \text{(Eq.2)}$$

Tidal flat ecosystem:

$$V_2 = 3.67 \times 27.27 \times 10^{-3} \times 235.62 \times 10^{-3} \times S \quad \text{(Eq.3)}$$

Swamp ecosystem:

$$V_3 = 3.67 \times 27.27 \times 10^{-3} \times 24.80 \times 10^{-3} \times S \quad \text{(Eq.4)}$$

In the formula: V is the carbon sequestration value of mangrove ecosystems, tidal flat ecosystems and swamp ecosystems (US dollar/year); S means the wetland area (m^2); The value 3.67 is the coefficient of Carbon conversion to CO_2. The carbon transaction price was based on the statistics by Guangzhou Carbon Exchange (CEEX) Website (CEEX, 2022). The carbon trading price reference is 4.09×10^{-3} (US dollar/kg); the carbon sequestration rate of mangrove wetland is 444.27×10^{-3} (kg/m^2/year); and the carbon sequestration rate of tidal flat wetland is 235.62×10^{-3} (kg/m^2/year); for moss peat swamp wetlands, it was 24.80×10^{-3} (kg/m^2/year) (Ouyang et al., 2013).

Shore protection

Due to their capacity to absorb the energy produced by ocean currents (a main reason caused erosion for shorelines), coastal wetlands function significantly to prevent coastline erosion (Carter, 1996). The way to measure can be verified according to type and location of wetlands. In this study, the value of shore protection was estimated by the engineering substitution method (Rao et al., 2015), and the price of artificially constructed seawalls was used to replace the ecological service value of wetlands (*Eq. 5*):

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$$V = \mathrm{C} \times \mathrm{L} \tag{Eq.5}$$

In the formula: V is the value of the shore protection (US dollar/year); C is the seawall cost per unit (US dollar/km); L is the length of the natural shoreline of the wetland (km).

Biodiversity conservation

Globally, many endangered species rely on wetlands, because wetlands can offer them short/long-term places for living and refuging. This service is regarded as biodiversity conservation of wetland. The conservation value of wetland biodiversity was estimated by a proposed evaluation model (Ye and Sun, 2021), which is composed by the conservation value of animal's diversity (V_1) and plant's diversity (V_2) (*Eqs. 6-8*):

$$\mathrm{V} = \mathrm{V}_1 + \mathrm{V}_2 \tag{Eq.6}$$

$$\mathrm{V}_1 = \mathrm{S}_1 \times \mathrm{L} \times 0.252016 \tag{Eq.7}$$

$$\mathrm{V}_2 = (1 + 0.1 \times (\mathrm{E} + \mathrm{B} + \mathrm{O})) \times \mathrm{S}_1 \times \mathrm{S}_2 \tag{Eq.8}$$

In the formula: V is the biodiversity conservation value (US dollar/year); S_1 is wetland area (m^2); L * 0.2523 is the global wetland animal habitat value per unit area (US dollar/m^2) (Costanza et al., 1997). E is the sum of the rare and endangered indices of all rare and endangered plants in the wetland; B is the sum of the endemic species of all plants; O is the sum of the age indices of all ancient trees; S_2 is the species loss (US dollar/ha).

Leisure tourism value

Significantly, wetlands also provide and support various leisure and tourism activities, such as canoeing, kayaking, animal photography, hunting, and fishing. Based on a previous study (Li et al., 2018) on wetland tourism, the calculation of leisure tourism value was proposed as follows (*Eq. 9*):

$$\mathrm{V} = \frac{\mathrm{C}_1}{\mathrm{C}_2} \times \mathrm{M}_\mathrm{i} \tag{Eq.9}$$

In the formula: V is the tourism value of the wetland (US dollar/year); C_1 is the annual tourism income of the county (US dollar/year); C_2 is the annual tourist number of the county (10,000 person/times/year); M is the number of visitors to the wetland in the year (10,000 person/times/year).

Results

According to the survey by author, among the three typical wetland categories in Huiyang, the inland tidal flat wetland areas account for 38.135 ha, the mangrove wetland areas have 30.501 ha, and the coastal tidal flat wetland areas are 987.842 ha (Ministry of Natural Resources, 2021). After all the calculation processes based on equation above, to sum up the five wetland evaluation factors, the final estimated value of wetland ecosystem services in Huiyang District was 30,465,413.64 US dollar/year (nearly 30.47 million dollar). Below, it explains the details results for each indicator and factor.

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Water purification

The water purification of Huiyang wetland was mainly reflected by the tidal flat ecosystem and inland tidal flats. The water quality survey mainly selected five water quality monitoring points, namely Dakeng River- 1, Danshui River - 2, Danshui River - 3, Damao River - 4 and Pingshan River - 5. According to the *Environmental Protection Tax Law of the People's Republic of China* (Ministry of Ecology and Environment MEE, 2018) and the *Decision of the Standing Committee of the Guangdong Provincial People's Congress on the Applicable Tax Amount of Environmental* Protection *Tax on Air Pollutants and Water Pollutants in Guangdong Province* (2017), the cost for dealing with ammonia nitrogen is 0.51 US dollar/kg; for total phosphorus treatment, it was 1.63 US dollar/kg, and the chemical oxygen demand treatment cost was 0.41 US dollar/kg.

The authors also went to the rivers to collect water sample for measuring the pollutants in water. The method was to collect water samples at a depth of 5 cm below the river surface. The samples were obtained ten times from the same locations at 30-day intervals (ten months from January to October 2020). After ten times of fieldwork in 2022, the contents of TN, COD, NH3-N, TP and DO were measured in the rivers (*Table 3*). According to the calculation of average value for ten months, the water quality was classified in to five classes from I-V (MEE, 2002). In this classification, a lower class means a better water quality and a higher class means a worse quality of water due to some pollution.

Table 3. *Water quality survey*

Sample	TN (mg/L)	COD (mg/L)	NH3-N (mg/L)	TP (mg/L)	DO (mg/L)	Class
1	1.67	19.17	1.13	0.19	6.89	III
2	11.33	24.09	0.69	0.16	6.15	IV
3	11.30	17.50	2.10	0.15	5.94	V
4	8.58	19.17	4.73	0.45	5.10	V
5	8.85	25.83	1.20	0.15	5.36	V

Based on the pollutants, the calculation was done to understand the costs of treating thses pollutants. At last, the annual sewage discharge volume of sewage treatment plant was 194 million m^3. Thus, the value of water purification service would be 11,015.97 US dollar/year.

Carbon fixation

After calculation, the contribution the three types of wetlands for the carbon fixation would be shown in the *Table 4*. And the total carbon fixation was 37,113.76 (US dollar/year).

Table 4. *Contribution of carbon fixation for each wetland type*

Items	Inland tidal flats	Mangroves	Coastal tidal flats
Area (ha)	38.135	30.501	987.842
Value (US dollar/year)	1,419.45	2,033.96	33,660.35

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Shore protection

Referenced on a real shore protection project in Huiyang (Huizhou Daya Bay Economic and Technological Development Zone, 2019), the length of the repaired seawall was 2.06 km, and the total investment was 15.97 million US dollar. It was estimated that the construction cost of the seawall per unit length in Huiyang was 7.75 million US dollar/km. And the construction cost of embankment was 0.16 million US dollar/km/year. At last, the whole shore protection value was 1,433,555.88 US dollar/year.

Biodiversity conservation

According to the International Union for Conservation of Nature (IUCN), the plants in Huiyang wetlands contained one endangered species, namely *Heritiera littoralis*, with an identification of “vulnerable species”. The sum of the endemic species indices of all plants in Huiyang was 180. And no ancient tree was found there. After calculation for the sampling sites, the biodiversity conservation in Huiyang wetlands was 30,696.67 US dollar.

Leisure tourism

Based on the formula proposed, the leisure tourism value in this area was mainly concentrated in “Daya Bay”, whose wetland types mainly involved mangroves and coastal areas. And the number of visits was about 500,000 person/year. As a result, the estimated value of leisure tourism in Huiyang was 28,964,049.30 US dollar/year.

Summary

Finally, the calculation results for each service category were shown in *Table 5*. As a result, among all the three ecological services, the final rank was: cultural services > regulating services > support services. The sequence for the five factors from higher to lower was: leisure tourism, carbon fixation, biodiversity conservation, shore protection, and water purification.

Table 5. *Ecosystem service value in Huiyang*

Type	Indicators	Value (US dollar)	Percentage (%)
Regulating	B1	11,015.97	0.01
	B2	37,111.76	0.12
	B3	1,433,555.88	4.70
Support	B4	30,696.67	0.10
Cultural	B5	28,964,049.30	95.07
Total		**30,465,413.64**	100

Discussions

The value of leisure tourism occupied the first place in the total value, which can be regarded as the core function in this area. Because the unique mangrove and coastal landscape enhance the leisure tourism value of wetlands in Huiyang. This result is consistent with previous research indicating that the leisure function accounted for the highest percentage of wetland ecological service (Scholte et al., 2015; Chen et al., 2018; Zhou et al., 2021).

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The second place is the shore protection function. It means that one of the most important services provided by coastal wetlands are that meaning of shore and coastal protection. Based on this conclusion, in the future, this area should emphasize its mangrove and coastal characteristics as a brand to attract more visitors and residents to enjoy the benefits provided by the wetland tourism. Then, the value of regulating and supporting services was found to be the lowest ones, accounting for only 5% of the total value. It is because most of the regulatory services are intermediate, reflected by ways of combination with other functions. Thus, in the future, how can the evaluation precisely divide different service functions is worthy of further discussions.

At last, the average value per unit of wetland ecosystem services in Huiyang District was 2.88 US dollars/$m^2 \cdot a^{-1}$, which is higher than the average value calculated from Liaoning Province (2.916 US dollars) (Gao et al., 2017), Guangdong Coastal Wetlands (0.42 US dollar) (Cao et al., 2009), Guangdong Haifeng area (1.09 US dollar) (Yi et al., 2018), and Zhanjiang Mangrove National Park (0.62 US dollar) (Haridan et al., 2016). To analyze the reason, some human factors have led to lower ecosystem service values in these areas. For example, coastal wetlands in Guangdong have suffered varying degrees of degradation in recent years due to urbanization, resulting in a serious loss of ecological service value. Guangdong Haifeng Wetlands mainly function to protect wild birds, but due to the construction of infrastructure in the wetland areas, negative impacts on the ecological function of this wetland have been observed, causing a lower ecological value. Zhanjiang mangrove has a large proportion of wetland surfaces, but their distributions are quite scattered, causing lower comprehensive benefits. An area with quite high ecological service value, the development experience of Huiyang can be a reference for other cities to learn. In the future, more research can be done to deeply analyze the wetland development strategy in Huiyang, which will provide valuable enlightenment to other similar areas in GBA, especially those areas with high wetland surfaces but lower services values.

Due to the complexity of ecological indicator and factors, an increasing number of methods are used for an objective selection of factors for the evaluation process. The AHP process in this paper is an easy and fast way to identify the key factors for an area. However, it also has its shortcomings, such as the limitation of expert number and their opinions may have some bias according to their own experiences. Some other methods for factor identification and selection should be studied to avoid this problem. Thus, it is recommended to introduce some statistical models such as the structural equation for a more objective process of factor selection (Wang et al., 2022). Furthermore, more quantitative, and spatial technologies should be introduced for ecological service measurement, regularly monitoring wetland conditions, and continuously updating wetland data, such as introducing big spatial data and social media crowdsourcing to monitor the wetlands in GBA, and to understand better the public perception on wetlands (Sinclair, et al, 2018).

Conclusions

Evaluating the services of wetland ecosystems is a complicated process which requires a combination of different data and methods. There are many ecological service items provided by different wetland ecosystems, and the services and benefits provided by wetland ecosystems have some particularities in difference cases. Thus, it is hard to define one universal way to evaluate all ecosystems. For those benefits not fully utilized, some

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reasonable compensations are necessary to continuously protect and effectively manage their resources. In this study, based on the proposed comprehensive evaluation method and the quantified values, the wetland ecosystem service value in Huiyang would be helpful in clarifying the comprehensive economic value of wetlands there, and provide a basis for the local government to formulate further policies on coastal wetland protection, development, and utilization. And clarifying a list of all ecological products and promoting the establishment of a trading system for ecological products can better serve regional ecological protection and development.

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