FUZZY-SET QUALITATIVE COMPARATIVE ANALYSIS OF WETLAND GROSS ECOSYSTEM PRODUCT: THE CASE OF HUADUHU WETLAND PARK IN CHINA

XIANG, L.[1#] – YAO, S.[1#] – HUA, W.[1] – ZHANG, H.[2] – JIANG, J.[3] – CHEN, Q.[3] – CHEN, C.[1] – CHEN, P.[2] – SANG, K.[4*]

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

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

[3]*Guangdong Forestry Survey and Planning Institute, Guangzhou 510520, 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 28th Apr 2025; accepted 26th Jun 2025)

Abstract. With concept of ecological civilization, developing countries are trying to create systems for the quantification and monetization of ecosystem services. However, the relationships among different factors that influence the ecological product value remain unclear. To promote the development of ecological product value of wetland parks, this study takes the Huaduhu National Wetland Park in China as the study subject and conducts an evaluation based on accounting guidelines. Utilizing the alternative cost method, the ecological product values of Huaduhu Park were calculated from a temporal perspective, considering services such as water conservation, soil conservation, flood storage, carbon fixation and oxygen release, air purification, water purification, climate regulation, species conservation, leisure travel, and landscape value. Innovatively, this research applied Fuzzy-set Qualitative Comparative Analysis (fsQCA) to test the selected indices in the system. As a result, the monetary value of the ecosystem services was 122.67 million USD in 2020, and 155.71 million USD in 2023. The core factors were carbon fixation and oxygen release and air purification. The park has comprehensive ecological functions and notable cultural services compared to other regions. Thus, future research will build upon the accounting values, focusing more on dynamic wetland monitoring, modeling of biophysical processes, and related areas.
Keywords: *wetland, ecosystem, accounting, GEP, Guangzhou, landscape*

Introduction

Wetlands are ecosystems that are distributed globally with special hydrological processes. As an ecotone between terrestrial and aquatic areas, they are regarded as a landscape with the highest biological diversity on Earth (Grossmann and Lindsay, 2017). Since the 1950s, the importance of wetlands for human survival and societal progression has been gradually realized, with rising concerns about their sustainable protection and development. To protect the wetlands and related resources, countries around the world signed several international agreements accordingly, such as *The Convention on Wetlands, The Global Wetland Outlook*, etc. Scholars from developed countries have valued the significance of wetlands for a long time, accumulating experiences in the restoration of degraded wetlands, construction of artificial wetlands, and reconstruction of wetland habitats (Davis and Ogden, 1994; Seilheimer et al., 2009). For example, in

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

Europe, various wetland habitats are being effectively protected, covering approximately 174,400 km^2 (4.5% of the EU territory) (Verhoeven, 2014). In Asia, the wetland situation is not very optimistic. The region has experienced significant wetland loss, with nearly 80% of wetlands threatened by land conversion and urban development, particularly in Indonesia, China, and Myanmar (Murray et al., 2022).

Among all the Asian countries facing ecological issues, China is known for its vast territory with various types of landscapes, as well as wetland ecosystems. With the aim of "Ecological Civilization and Green Development" proposed by China, a series of measures have been announced, such as the Five-Year Plan for the Construction of Ecological Civilization. According to the government report by China Global Television Network - CGTN (2022), China has over 600 nature reserves for wetlands and 1,600 artificial wetland parks, 64 of them recognized as Wetlands of International Importance. The central government has invested approximately $2.73 billion in over 4000 projects for wetland protection and restoration since the 21st century. It is also actively participating in global wetland protection initiatives, such as the establishment of the International Mangrove Center in China.

Wetland ecological problems have top priority, and the realization and transformation of the value of wetland ecological service has become a hot topic in academia. Similar to other ecosystems, the benefits that people obtain from wetlands are known as "Wetland Ecological Services (WES)". It covers: flood control, water replenishment, land stabilization, storm protection, sand & nutrient retention, etc. (Xu et al., 2020). For assessing wetlands, Ecosystem Service Accounting (ESA) is a framework to measure the benefits they provide, integrating ecological data with economic and social perspectives to help policymakers make better decisions about resource management (UN, 2021). Currently, many countries are following The System of Environmental-Economic Accounting (SEEA) framework. The main indices include Ecosystem Condition Index (ECI), Natural Capital Stocks (NCS), Environmental Protection Expenditure (EPE), Carbon Footprint (CF), etc. And the developing countries like Brazil, China, India, Mexico, and South Africa are also trying to build their own ecosystem accounting (UN, 2021). However, significant challenges need to be solved, including data availability, funding and resources, and a lack of awareness of the wetland benefits, which may hinder its successful implementation and localization (Wu et al., 2016). And the relationships among different indices in the accounting system should also be discussed further.

Wetlands bring not only visual enjoyment but are indispensable assets that support biodiversity, mitigate climate change, and enhance the quality of human life (Yuan and Liu, 2001; Zhang and Lv, 2006; Tang, 2010). Valuing or accounting wetland ecosystem services is crucial for understanding their benefits to both nature and human well-being. Since wetlands provide essential services and recreational opportunities, assigning a monetary value to these services can better appreciate their importance and advocate for their conservation. The evaluation of wetland parks has also expanded from ecological focus to more economic and social perspectives (Ren et al., 2009; Hou and Qiao, 2013). Localizing SEEA can enhance political will and stakeholder engagement by demonstrating the direct benefits of wetland accounting for national development goals, further promote regional cooperation and knowledge sharing, and help developing countries to learn from other experiences and practices. Against this background, the research objectives this research are: 1) to construct a comprehensive ES evaluation system for one representative wetland park in Southern China; 2) to quantify and compare the indicators from a spatial-temporal way in the case of Southern Chinese wetland parks.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

Literature review

Ecosystem service accounting

The concept of ES was introduced and classified by Constanza (1997) and Ehrlich and Ehrlich (1981). Scholars (e.g. De Groot et al., 2002; Pearce, 2014) further developed new systems from the perspective of direct, indirect and selective ecological values. The UN Millennium Ecosystem Assessment (MA) project was started in 2001. Later, Nelson et al. (2010) applied the economic model -- Integrated Valuation of Ecosystem Services and Trade-offs (INVEST) to analyze and simulate the dynamic evolution of different water ecosystems; Mengist et al. (2022) analyzed the value of EC through land use conditions and made predictions based on it. Based on the mentioned theories, more different ecosystems were evaluated according to the ES concept, such as agricultural (Lal, 2013), forests (Jin et al., 2005), grasslands (Zhao et al., 2004), marine ecosystem (Chen et al., 2006) and so on. To expand the indirect services into system, Cultural Ecosystem Services (CES) was also proposed from the social perspectives, including the satisfaction, cognition, leisure and entertainment, aesthetic experience, etc. (Cheng et al., 2019). Recently, it is also expanding to focus more on the spiritual and emotional needs of users, such as the feelings of crowdedness, scariness, and perceived noises (Daily, 2013; Loc et al., 2018).

Based on the studies of ecosystem functions, services, and benefits, the concept of Gross Ecosystem Product (GEP) was defined as the sum of the monetary value of products and services produced, aimed to measure the economic output of an ecosystem (Fisher et al., 2008; Wei et al., 2021). Scholars (e.g. Ouyang et al., 2018) incorporated GEP into the SEEA framework with more comprehensive indicators, encompassing ecosystem regulation, agricultural offerings, ecological tourism, etc. Successfully, The International Union for Conservation of Nature (IUCN) also recognized this concept, and other scholars, such as Rokicki et al. (2024) combined the Modular Applied GeNeral Equilibrium Tool (MAGNET) with GEP in the European projects. The GEP projects in China covered more than 10 provinces, 50 cities, and more than 160 counties, such as Lishui, Zhejiang, etc. (Ouyang et al., 2020; Zhang et al., 2023). As is seen, GEP accounting focuses more on the specific value of ecological products or services in economy, which can further improve the public and decision makers' understanding of the value of ecosystem services, thereby promoting ecological protection and sustainable development, and helping to assess the economic value of ecosystem services, which is of great significance for ecological compensation and ecological product trading. But the previous methodology and cased mainly focused on limited time and spatial span, which caused a lack of social and market consistency. New evaluation methods and practices are needed to expand the spatial and temporal scale for GEP. And more cultural dimensions should also be considered in the current GEP (Jiang, 2017; Li et al., 2023).

Services interaction

Studying the relationships among factors that shape ecosystem service accounting is essential for effective management strategies. Scholars identified that forest and grassland elements are determinant keys for the trade-off between carbon sequestration and water production services (Feng et al., 2020). Among various natural drivers, rainfall can intensify the accounting value, whereas forest reduction and grassland expansion may influence it negatively. Socio-economic factors such as income levels also play significant roles in GEP. For example, Warchold et al. (2021) found that income, location,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

and population provided a positive impact for the implementation of the eco-sustainable goals. The MA also provided evidence, highlighting that fisheries are a crucial source of protein for people in developing nations, but increased fishery production led to a decline in other ecosystem services (World Resources Institute -WRI, 2005). However, among the factors of water conservation, soil conservation, flood storage, carbon fixation and oxygen release, air purification, water purification, climate regulation, species conservation, etc., the relationships are under-emphasized. Further comparative studies are needed from both longitudinal and latitudinal aspects, namely to compare different case studies and expand to a spatial-temporal study for the GEP.

FsQCA

To solve the limitation, FsQCA has gained attention in ecological research over the past few years, offering a methodological framework for analyzing multiple relationships and identifying the complex conditions that influence the occurrence of a given outcome. It is a method that builds bridges between qualitative and quantitative methods, allowing for an understanding of how various conditions combine to produce specific outcomes (Lee, 2014). Compared to traditional regression analysis, which solves linear relationships between independent and dependent variables, FsQCA can explain well non-linear and non-additive interactions. And it provides multiple combinations of conditions can lead to the expected outcome, offering rich insights into the unique characteristics of each case. And it can help to understand better the changes across a small or intermediary number of cases. More and more researchers from different disciplines are using this methodology (Lee, 2014). It is also introduced in ecological and environmental studies, recently.

For example, Hartmann et al. (2022) identified the pathways leading to high levels of adoption for ecological innovation in transportation; Lai et al. (2024) employed FsQCA to examine the factors contributing to high levels of ecological tourism in the Yangtze River Delta, revealed that financial support from the government and economic development are crucial for achieving high ecological security. As is seen, the application of FsQCA can provide valuable insights for policymakers and practitioners to investigate the construction of ecological civilization, identifying the key factors that influencing more the results. Thus, it is selected to choose this method to expand the scale of previous GEP accounting.

Methodology

To solve the mentioned problems, this study adopts a quantitative evaluation combined with FsQCA trying to measure the GEP for a period (2020-2023) in Guanzhou, China. By constructing an ecological product value accounting system in China, selecting natural products and cultural products as indicators, using alternative market method to calculate the monetary value of these products, it selected the of Huaduhu National Wetland Park (as “the Wetland Park” in the following contents). The alternative market methods can help policymakers and managers make decisions more effectively by providing estimates of the value of non-market goods and services, flexibly applied according to different environments and conditions and adapt to different accounting needs and reduce variable bias (Comte et al., 2022). The technical route of the research is: (1) collect relevant data and conduct investigations in the park; (2) establish a specific GEP accounting system;

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

(3) conduct physical quantity accounting; (4) conduct monetary accounting; (5) calculate the overall GEP; (6) compare factors by FsQCA.

Study area

The wetland park (23°21′53″ - 23°23′44″N, 113°12′07″ - 113°15′39″E) is in the center of Guangzhou province as an important corridor between the urban areas and other regions. It locates in the southern subtropical monsoon climate zone, and its climate is characterized by high temperatures and abundant rainfall throughout the year. The regional resident population (Huadu district) is 1.7 million, one of the most populated areas in China. The park was rated as a national scenic area in 2016; in 2021, it was named a National Wetland Park. The park serves as a crucial habitat for biodiversity conservation, with a rich variety of flora and fauna, including protected species. Enhancing the urban ecological environment, transforming a former industrial site into a lush ecological park, it also has the function of raising public awareness and education on wetland protection through various activities. Boosting the local economy, the park attracted over eight million visitors each year, offering cultural and recreational benefits, representing a new urban identity for the region. Studying the park is essential for assessing the value of ecosystem services, optimizing ecological restoration strategies, innovating in public education, and exploring sustainable urban development models, making it a valuable case study for urban sustainability and ecological management. But currently, the environmental condition of the park extremely fragile, with excessive human interference, improper use of water resources, alien species invasion, etc. which caused lots of damage to the wetland community structure, resulting in reverse succession, and other potential threats to the local ecological security (Zhai and Lange, 2020). The location of this park is shown as in *Figure 1*.

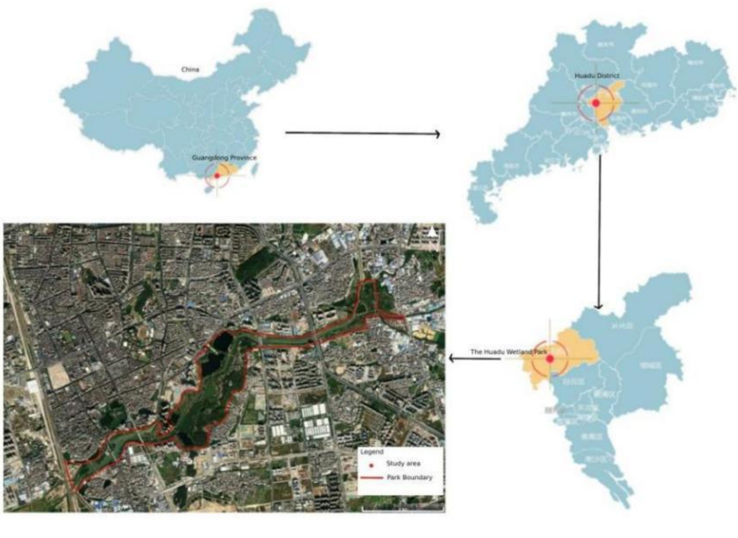

Figure 1. *Park location in China (Figure by authors)*

Data source

The data in this research came from various sources, as listed below. The general provincial data involved several statistical bulletins and statistical yearbooks (as explained in the following indicators). The air environment and meteorological data were

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

collected from monitoring stations, including precipitation, temperature, wind speed, air pollutants, etc.; water quality data came from the local environmental monitoring station (Huadu district in Guangzhou), as well as the fieldwork and experiment by the authors; soil data came from Chinese soil map and regional databases (https://data.isric.org/, last accessed 20 March 2024) and fieldwork; cultural services data came from questionnaires and field investigations; Other spatial data (like shape-file of geographic extents) came from the Resource and Environmental Science and Data Center of the Institute of Geographic Sciences and Natural Resources Research in China (http://english.igsnrr.cas.cn/, last accessed 20 March 2024).

The questionnaire is divided into four sections to capture cultural data: demographics include age, gender, education level, occupation, living area, and income; user patterns include types of activities, frequency and duration of visits, and motivations for visiting. The third part is the cost measurement, including travel cost from home ($0–10, $11–30, $31–50, over $51), and one-way travel time from home (<30 mins/ 31–60 mins/ 1–2 hrs/ Over 2 hrs). At last, the opening questions are also included, such as suggestions for improving accessibility or reducing travel barriers to the wetland park. The questionnaire was designed followed several studies (Liu et al., 2019; Heagney et al., 2019). It was approved by expert evaluation in Zhongkai University of Agriculture and Engineering. After a pilot test during January 2020, the formal questionnaire publication was during May - July 2020 and May - July 2023 for dynamic data collection.

Sampling method

The Park overs a total area of 260.4 hm^2, including water bodies (49.34 hm^2) and green vegetation (110.58 hm^2). Because of the linear shape of study area, eight sampling points were evenly distributed along the park to do the investigation (*Figure 2*). The selected sample points followed the requirement by the State Forestry Administration: arboreal area (100 m^2), shrubs (25 m^2), and herbs (1 m^2) (State Forestry Administration -SFA, 2017). And the sampling period was conducted in June - October 2020 and June - October 2023 (each year 10 times of site visiting). The process was carried out in accordance with the National Technical Guidance for site soil and groundwater sampling of volatile organic compounds (HJ1019-2019) (Ministry of Ecology and Environment -MEE, 2019) and Technical Specification for Water Quality Sampling (SL187-96) (WEMC, 1997). Data analysis was done in the lab at the Zhongkai University of Agriculture and Engineering, China.

Figure 2. *Sample distribution*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

Site investigation

The investigation group was composed by three professors from the field of environmental science, landscape architecture, and horticulture, as well as several master and PhD students from the Zhongkai University of Agriculture and Engineering. According to the initial investigation (*Figure 3*). The fieldwork showed that the water quality of the park was also maintained at a standard level. According to *Appendix 1-3*, eight sampling points exhibits distinct spatial variations. The soil exhibits moderate moisture levels and acceptable bulk density. The heavy metals in the soil of each sample point did not exceed the standard. For water quality, sampling points 1, 3, 4, and 5 show relatively high levels of ammonia nitrogen, Total Nitrogen (TN), and Chemical Oxygen Demand (COD), indicating some degree of pollution, while points 2, 6, 7, and 8 have relatively lower levels of these indicators, reflecting better water quality. Among them, points 7 and 8 stand out for their low COD and turbidity values, suggesting clearer water. The Total Protein (TP) levels are relatively uniform across all points, and the pH values are within the normal range. DO levels are relatively stable, with slight fluctuations. Overall, points 1, 3, 4, and 5 require more attention to water quality improvement, whereas points 2, 6, 7, and 8 demonstrate relatively good water quality conditions. The pollution problems need to be solved, which influenced badly the formal function and park services.

Figure 3. *Site investigation photos (soil sample- left; water sample -right)*

Then, the authors found that there were 165 species of vertebrates in the selected sample points, which were identified by the botany experts from the Zhongkai University of Agriculture and Engineering. Among them, there are 12 species of national protected animals, with dominant plants communities: *Panicum repens, Phragmites australis, Polygonum hydropiper, Commelina communis, Vallisneria natans, Lemna minor,* etc (Wu and Raven, 2010; Zhou et al., 2007).

Accounting indicators

The accounting indices were selected mainly based on previous case studies (Ouyang et al., 1999; Ouyang, 2018; Wu, 2022; Hao et al., 2022) and the *Technical Guidelines for Calculating Gross Terrestrial Ecosystem Product* (DB33/T2274-2020, DB3311/T139-2020, DB52/T1608-2021) (MEE, 2020; Administration for Market Regulation - AMR, 2021). The innovation of this research lies in a periodical investigation from 2020 to 2023. Both natural ecosystem services and cultural ecosystem services were considered in the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

selection after consultation with related scholars and professors. The accounting included both physical and monetary sections, with two categories (environmental and cultural) and 10 indicators: water conservation, soil conservation, flood storage, carbon fixation & oxygen release, air purification, water purification, climate regulation, species conservation, leisure travel and landscape value. Each indicator was further divided into several indices for the site measurement. The construction of the evaluation system was also validated by external experts (a group of three professors from agriculture, environmental science and landscape architecture). The details of the selected indicators and their meanings are explained in *Table 1*.

Table 1. *Accounting method*

Category	Indicators	Units	Monetary accounting	Reference
Environmental regulation	Water conservation (E1)	mm	Alternative market (Construction costs of water conservancy facilities)	AMR, 2021; MEE, 2020; Ouyang, 2018; Wu, 2022; Hao et al., 2022
	Soil conservation (E2)	MJ·mm·hm^{-2}·h t·hm^{2}·h·hm^{-2}·MJ^{-1}/mm^{-1}	Alternative market (Construction costs of soil conservation facilities)	
	Flood storage (E3)	mm	Alternative market (Reservoir construction costs)	
	Carbon fixation & oxygen release (E4)	gC/m^{-2}/a^{-1}	Alternative market (Carbon trading price)	
	Air purification (E5)	kg/a	Alternative market (Air purification costs)	
	Water purification (E6)	mg/L kg/a	Alternative market (sewage treatment costs)	
	Climate regulation (E7)	refer to table 2	Alternative market (Electricity costs for artificial temperature and humidity control)	
	Species conservation (E8)	number	Alternative market (costs for species conservation)	
Cultural services	Leisure (C1)	Person/year	Alternative market (Travel expenses)	
	Landscape value (C2)	m^2	Alternative market (Land value increment)	

Further, for each indicator, the calculation method is as below

Water conservation

Water conservation service means the function of the wetland ecosystem to enhance the water process, such as water regulating, recharging, expanding available water resources, etc. The quantity of water conservation was represented by the value of local precipitation and evapotranspiration. And the monetary value of water conservation can be calculated from the alternative market method. Namely, the formula for calculating the value is explained as follows:

$$V_{wc} = Q_{wr} \times C_{we} \quad \text{(Eq.1)}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

In the formula 1, V_{wc} is the monetary value of water conservation (dollar/a); Q_{wr} is the total amount of water quantity in the study area (m^3/a); C_{we} is the price of Reservoir construction and maintenance (dollar/m^3) instead. The price referred to the data published by the Guangzhou Water Resources Trading Market Price (https://swj.gz.gov.cn/, last accessed 20 December 2024), and the unit value is 4.96 dollar/m^3.

Soil conservation

Soil conservation is the function to protect soil from rainfall erosion, improving soil resistance, and maintaining soil quality. The monetary value of ecosystem soil conservation (V_{sc}) (dollar/a) can be obtained from the V_{sd} (value of reducing sediment deposition - dollar/a) and V_{dpd} (value of reducing non-point source pollution - dollar/a) (Ouyang, 2018). The calculation formula is as follows:

$$V_{sc} = V_{sd} + V_{dpd} \quad \text{(Eq.2)}$$

$$V_{sd} = \lambda \times (\frac{Q_{sr}}{p}) \times c \quad \text{(Eq.3)}$$

$$V_{dpd} = \sum_{i=1}^{n} Q_{sr} \times C_i \times P_i \quad \text{(Eq.4)}$$

In the formula 2-4, Q_{sr} is the value of soil conservation; c is the reservoir dredging project cost (dollar/m^3); p is the soil bulk density (t/m^3); λ is the sedimentation coefficient; i is the nutrients such as nitrogen and phosphorus in the soil; n is the number of nutrient species; C_i is the nutrients such as nitrogen and phosphorus in the soil (%); Pi is the treatment cost (dollar/kg). The soil bulk density p is 1.38 t/m^3, and λ of the reservoir is 0.24 (Yu et al., 2020); the unit cost of reservoir dredging project c is 8.57dollar/m^3. The content of soil nutrients in Guangdong Province is: total nitrogen 1.64 g/kg, alkali-hydrolyzable nitrogen 151 mg/kg, phosphorus 1.30875 g/kg, potassium 13.9875 g/kg; the price of potassium chloride fertilizer is 0.54 dollar/kg (Yu et al., 2020), the treatment costs of nitrogen, phosphorus, and potassium are: 0.5 dollar/kg, 1.6 dollar/kg, and 0.54 dollar/kg.

Flood storage

The function of flood regulation and storage refers to the vegetation and soil structure of the wetland, which can retain a large amount of precipitation and transit water, reduce and delay the flood peak to alleviate the disaster and loss caused by the flood season (Liao, 2019). The value can be represented the flood storage capacity of the ecosystem (C_{fm}) multiplied by the construction cost and maintenance cost of the reservoir project (C_{we}). The formula is as follows:

$$V_{fm} = C_{fm} \times C_{we} \quad \text{(Eq.5)}$$

In the formula 5, the construction cost and maintenance cost of the reservoir per unit capacity is 0.87 (dollar/m^3).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

Carbon fixation

Ecosystem carbon sequestration refers to the function of wetland ecosystems to absorb CO_2 in the atmosphere and fix it in plants or soil in the form of organic matter. This function is conducive to reducing the concentration of carbon dioxide in the atmosphere and slowing down the greenhouse effect. The formula for calculating the value of carbon fixation and oxygen release (V_q) is according to the value of carbon sequestration value (V_C) and value of oxygen released by the ecosystem (V_{op}) as follows:

$$V_C = Q_{CO_2} \times C_C \tag{Eq.6}$$

$$V_{OP} = Q_{OP} \times C_O \tag{Eq.7}$$

$$V_Q = V_C + V_{OP} \tag{Eq.8}$$

In the formula 6-8, Q_{co2} it is the total carbon sequestration of the wetland ecosystem (CO_2/ton/a); C_C is the carbon price (dollar/t). Q_{OP} is the amount of (oxygen/ton/a); C_O is the price of oxygen production (dollar/a). The average value of the carbon tax rate of 150 dollars/t and the afforestation cost of 250 dollar/t, and the exchange rate is 642.47 dollar/t (ICAP, 2023).

Air purification

Air purification refers to the function of the ecosystem to hold, absorb, filter and decompose atmospheric pollutants (SO_2, NO_2, and PM2.5), and improve the atmospheric environment. The calculation of air purification is based on the difference between the theoretical absorption and purification of air pollutants by the ecosystem and the pollutants in the air measured by the monitoring station, and the actual amount of air pollutants purified by the ecosystem can be obtained (Ouyang, 2018). The calculation formula of air purification value is as follows:

$$V_a = \sum_{i=1}^{n} Q_R \times C_i \times K \tag{Eq.9}$$

In the *Formula 9*, V_a is the value of the air environment purification of the ecosystem (dollar/a); Q_R is the purification amount of air pollutant (t/a), i is the category of air pollutants; n is number of the types of air pollutants; C_i is the treatment cost of the air pollutants (dollar/t); K is the fee adjustment coefficient. According to MEE (2023), the K value is 1.2, and C_i is calculated according to the cost of treatment of industrial gas waste (0.08 dollar/kg).

Water purification

Water purification refers to the function of purification of water pollutants through the absorption and decomposition of wetland ecosystems. The calculation of this indicator is mainly based on monitoring data, and according to the composition and concentration changes of pollutants in the water body, an appropriate indicator is selected for calculation. According to the indicators of water quality control in the Standard (GB3838-

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

2002), ammonia nitrogen, chemical oxygen demand, total phosphorus and other indicators are selected as the evaluation indicators of purified water body.

$$V_w = \sum_{i=1}^{n} Q_{wpi} \times C_i \tag{Eq.10}$$

In the formula 10, V_w is the value of water purification in the ecosystem (dollar/a); Q_{wpi} is the amount of water pollutants of the i-th purified value (t/a); C_i is the cost of the i-th water pollutant (dollar/t); n is the number of pollutant categories. At last, based on the sample points, COD, ammonia nitrogen, total phosphorus, and total pollutants are 8,072,020 kg; 88,792.22 kg; 121,080.3 kg respectively. And the control cost for the pollutants are: 0.4 dollar/kg, 0.5 dollar/kg and 1.6 dollar/kg.

Climate regulation

Ecosystem climate regulation service refers to the ecological function of vegetation transpiration and water surface evaporation to increase air humidity and reduce temperature to adjust the local climate of the ecosystem. The index selected the energy consumed in the process of evapotranspiration. The calculation formula of climate adjustment value is as follows:

$$V_t = Q \times P_e \tag{Eq.11}$$

In the formula 11, V_t is the value of ecosystem climate regulation (dollar/a); Q is the total energy consumed by the ecosystem to regulate temperature or humidity (kWh/a); P_e is the local electricity price (dollar/kWh). The local electricity price comes from the "Guangzhou Electricity Price List" issued by the Guangzhou Development and Reform Commission (2019), and the average value of all types of electricity consumption P_e is 0.1 dollar/kWh.

Species conservation

Species conservation service refers to the function of the ecosystem to provide habitats for rare and endangered animal and plant species, affect their activities, reproduction and other behaviors, and thus play a role in conservation. Species diversity is the basic structural and functional unit of biodiversity, which can provide necessary species and genetic resources for community succession and biological evolution in ecological sequence. Using the Shannon-Wiener index to divide the conservation cost per unit area and calculate the value of species conservation services. There are four endangered animal species, three vulnerable animal species, one endemic plant species and one ancient tree in this area. And the formula is:

$$V_{\text{bio}} = G_{\text{bio}} \times S \tag{Eq.12}$$

In the *Formula 12*, V_{bio} biodiversity value (dollar/a); S means species conservation value (dollar/ha/a^{-1}). According to the GEP Guidelines and Shannon-Wiener index in the park, the conservation cost per unit area is 1,907.14 dollar/hm^2/a.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

Leisure value

Leisure services refer to the cultural benefits that human beings obtain from the ecosystem through leisure entertainment, aesthetic, scientific and educational experiences, etc. The calculation formulas are:

$$V_r = \sum_{j=1}^{J} N \times TC_j \quad \text{(Eq.13)}$$

$$TC_j = T_j \times W_j + C_j \quad \text{(Eq.14)}$$

In the *Formulas 13-14*, J mean the location, n means the number of tourists (annual number of visitors in 2020 and 2023 was provided by the park management office). Other data were from the questionnaire: TC_j means the average travel cost from local area; T_j means the travailing time; Wj means the average travel cost from local areas; C_j means the travelling cost from other areas.

Landscape value

Landscape value service refers to the function of the ecosystem to provide landscape experience for human beings, thereby improving the value of surrounding land and real estate. The calculation formula of landscape value is as follows:

$$V_a = A_a \times P_a \quad \text{(Eq.15)}$$

In the formula 15, V_a is the landscape value (dollar/a); A_a is the total influenced area (km^2); P_a is the increasing value because of the park ($dollar/km^2/a^{-1}$). The house selling price is 2774 $dollar/m^2$; the average house increasing price is 3,091.57 $dollar/m^2$, and the unit increasing price is 383.01 $dollar/m^2$.

FSQCA

To compare the GEP factors, the study introduced the FsQCA method. The selected software is FsQCA 4.1, developed by the University of California, Irvine (https://sites.socsci.uci.edu/~cragin/fsQCA/software.shtml, last accessed 20 March 2024). It is an open and free software for scientists to use. Fuzzy set is a conventional set is comparable to a binary variable (1 and 0) (Ragin, 1987). The key steps to run the software include: data preparation, deciding fuzzy set scores, verifying consistency and coverage (Kwiatek et al., 2022). To make sure a consistent comparison, other GEP following the same standards were searched. Five national parks' GEP values were obtained: Three-River-Source National Park (West of China), Hainan Tropical Rainforest National Park (South of China), Wuyishan National Park (Center of China), Giant Panda National Park (Southwest of China) and Northeast Tiger Leopard National Park (Northeast of China), as well as the case study area Huaduhu park in Guangzhou. The common indicators in these parks are E1-E7 (Du et al., 2023). Each indicator's value and the overall natural GEP value were turned into 0-1 as the fuzzy set according to the threshold of 0.95, 0.55 and 0.05 in each dataset.

At last, two measures need to be tested for the relationship between each indicator and the GEP value: consistency and coverage. Consistency means the degree to which cases with the constitutive characteristic. A higher the consistency indicates a stronger

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

relationship; Coverage measures how much a consistent subset covers the superset. It is interpreted as the degree to which the cause is relevant to the effect. A higher the coverage means a higher importance of the causal configuration (Thygeson et al., 2012).

Results

According to site investigation, the quantity for each indicator were carried out, respectively in 2020 and 2023. The results are shown in *Table 2*. All the data were obtained from official publications, listed in the data source section. Based on each item's quantity and unit price (convert from Chinese Yuan to US dollar: one US dollar equals to 6.62 Chinese Yuan, an average value from 2010 to 2024 https://www.macrotrends.net/2575/us-dollar-yuan-exchange-rate-historical-chart, last accessed 20 December 2024), the values can be assessed for the GEP accounting. Since the accounting methods were properly the same for 2020 and 2023, the calculation examples only explained the data in 2023. The results for 2020 were listed with the calculated tables. The details of each indicator's accounting are listed as followed:

For the year 2023, the final calculation result of water conservation monetary value is 7,502,600.43 dollar/a. The soil conservation value is 2,528,325.08 dollar/a. The flood storage value V_{fm} is 1,733,130.43 dollar/a. The V_Q value is 305,403.71 dollar/a. The V_a is 915,070.10 dollar/a. The result of Q_{wp} is 4,059,217.01 kg/a. The climate adjustment value is 30,676,700.10 dollar/a. The calculation result of species conservation value V_{bio} is 1,422,461.57 dollar/a.

For questionnaire results, the authors used purposive and random sampling methods, namely inviting the visitors around the park to join the survey. The ethical considerations included informing the participants of the academic purpose and privacy of this research. At last, from 2020 to 2023, 195 and 203 valid questionnaires were successfully collected. In total, the demographic information is as below: in terms of age, the majority of visitors were between 18-34 years old, accounting for 43.2% of the total, followed by those aged 35-50 (31.6%). Regarding gender, female visitors (51.8%) slightly outnumbered male visitors (48.2%). The education level of the visitors was relatively high, with 65% having a college degree or above. Workers and students made up the largest proportion of visitors (82.3%) in terms of occupation. Most visitors lived within the same city as the park (75.5%). For user patterns, walking, bird-watching, and picnicking were the most popular activities. The majority of visitors came to the park weekly, and typically stayed for 1-2 hours per visit. And the motivations for visiting were relaxation, family/friends gathering, or nature appreciation. Through questionnaire survey, it is concluded that the average travel cost of tourists in Huadu District is 19.57dollar/person/a, and the average travel cost of tourists outside of Huadu District is 24.28 dollar/person/a; There are 1,279,779 tourists from Huadu district, and 426,593 tourists from other areas (in 2023). The calculation of leisure value V_r is 87,182,948.60 dollar/a. At last, the landscape value V_a is 21,940,314.40 dollar/a.

Comparisons

The detailed table for all the accounting is listed in *Table 3*. Overall, in 2020, the total GEP value of the Wetland Park was 122.67 million dollar (5.01 million dollar/ha). Among them, the environmental and cultural service accounted for 37.62% and 62.38% respectively. In 2023, the total GEP was 155.71 million dollar (average of 6.47 million dollar/ha). Among them, the environmental and cultural service accounted for 29.921%

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

and 70.079%, respectively. Thus, it can be seen that from 2020 to 2023, the total GEP has been increased sharply by 1.26 times.

Table 2. *The physical quantity of each item (2020 - 2023)*

Indicators	Explanation	Unit	2020 (yearly)	2023 (yearly)
E1	Precipitation	mm	1,889.3	1,860.65
	Evapotranspiration (ground)	mm	253.845	256.683
	Evapotranspiration (water surface)	mm	349.188	353.470
E2	Rainfall erosion	$MJ\cdot mm\cdot hm^{-2}\cdot h$	10,376.8	10,376.8
	Soil erosion (Minnesota Pollution Control Agency - MPCPA, 2025)	$t\cdot hm^{2}\cdot h\cdot hm^{-2}\cdot MJ^{-1/}mm^{-1}$	0.0034 (Slightly Erodible)	0.0034 (Slightly Erodible)
	Slope gradient	NA	8.5267	3.7426
	Vegetation cover	NA	0.0364	0.3639
	Soil and water conservation factor	NA	0.1612	0.1612
E3	Rainfall	mm	7,735.5 (Heavy)	7,986.3 (Heavy)
	Surface runoff	mm	960	960
E4	Carbon fixation rate of forests	$gC/m^{-2/}a^{-1}$	0.79	0.79
	Carbon fixation rate of lakes	$gC/m^{-2}/a^{-1}$	56.67	56.67
	Carbon fixation rate of other types of water	$gC/m^{-2}/a^{-1}$	400	400
	Carbon Conversion coefficient	NA	32/44	32/44
E5	Sulfur dioxide emissions	kg/a	14,740.143	10,013.036
	Nitrogen oxide emissions	kg/a	55,092.164	48,396.343
	PM2.5 emissions	kg/a	33,979.184	36,714.467
	Sulfur dioxide retention	kg/a	4,823,034	4,823,034
	Nitrogen oxide retention	kg/a	3,569,951.916	3,569,951.916
	PM2.5 retention	kg/a	598,652.475	598,652.475
	Sulfur dioxide equivalent value	NA	0.95	0.95
	Nitrogen oxide equivalent value	NA	0.95	0.95
	PM2.5 equivalent value	NA	4	4
E6	COD concentration	mg/L	2	2
	Ammonia nitrogen concentration	mg/L	0.016	0.022
	TP concentration	mg/L	0.02	0.03
	COD	kg/a	8,072,020	8,072,020
	Ammonia nitrogen	kg/a	64,576.16	88,792.22
	TP	kg/a	80,720.2	121,080.3
E7	Internal/external temperature difference	°C degree	1,411.81	2,138
	Ecosystem volume	m^3	13,413,354	13,413,354
	Air specific heat capacity	$J/(m^3/degree)$	1.003×10^3	1.003×10^3
	Electricity consumption for converting $1m^3$ of water into steam	kW·h	125	125
	Heat of volatilization	J/g	538.8	538.8
	Total evaporation	m^3	1,047,506.96	1,047,506.96
E8	Number of endangered species	NA	4	4
	Number of ancient trees	NA	1	1
C1	Number of tourists	Person/year	1,706,372	4,190,000
C2	Affected property	m^2	803,203.4	57,000.0

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

Table 3. *The accounting results*

Item	Index Explanation	unit	2020 (single indicator)	2023 (single indicator)	2020 (Total/ dollar)	2023 (Total/ dollar
E1	Reservoir construction and maintenance cost	dollar/m³	4.96	4.96	7,502,600.57	7,117,142.86
E2	Total nitrogen	kg	53,562.92	53,562.92	361,189.28	361,189.28
	Total phosphorus	kg	39,140.40	39,140.40		
	Total potassium	kg	418,320.12	418,320.12		
	Nitrogen treatment cost	dollar/kg	0.50	0.50		
	Phosphorus treatment cost	dollar/kg	1.60	1.60		
	Potassium treatment cost	dollar/kg	0.54	0.54		
E3	Reservoir construction and maintenance cost	dollar/m³	0.87	0.87	1,732,888.86	1,733,130.43
E4	Carbon trade price	dollar/t	91.71	91.71	305,403.714	305,403.714
	Oxygen producing price	dollar/t	142.85	142.85		
E5	Air pollution control cost	dollar/kg	0.08	0.8	904,919.28	915,070.10
	Adjust coefficient	NA	0.17	0.17		
E6	COD control cost	dollar/kg	0.40	0.40	3,785,777.43	4,059,217.01
	Nitrogen control cost	dollar/kg	0.50	0.50		
	Total phosphorus control cost	dollar/kg	1.60	1.60		
	COD pollutant equivalent	kg	1,153,145.71	1,153,145.71		
	Ammonia nitrogen pollutant equivalent	kg	80,720.20	110,990.27		
	Total phosphorus pollutant equivalent	kg	322,880.8	484,321.2		
E7	Electricity price	dollar/degree	0.10	0.10	30,136,251.40	30,676,700.10
E8	Shannon-wiener index	dollar/hm²/a	1,907.14	1,907.14	1,422,461.57	1,422,461.57
C1	Travel expense by local	dollar/person/a	21.28	19.57	34,766,729.10	87,182,948.60
	Travel expense from other area	dollar/person/a	17.57	24.28		
	Tourists’ arrival from the district	person/a	1279779	3142500		
	Tourists’ arrival from the other areas	person/a	426593	1047500		
C2	Average house price	dollar/m²	2,774.71	2,708.57	41,757,532.70	21,940,314.40
	House price increase	dollar/m²	2,826.71	3,091.57		
	House price increase/unit	dollar/m²	51.85	383.01		
Total (dollar)					122.67 million	155.71 million
Average (dollar/a)					471,807.69	598,844.61

After transformation as fuzzy set, the results are shown in *Table 4*. Then, single and a combination of indicators were set to see if they can influence significantly the outcome variable (GEP). Each park contained two data (two periods). The values (0-1) meant representations of vague information by assigning membership degrees to elements in the data-set. The statistical test results of consistency and coverage are shown in *Table 5*. In the table, the symbol of “~” means a lack of that tested condition.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

***Table 4.** Fuzzy set for all the parks*

Fuzzy set	E1	E2	E3	E5	E6	E4	E7	GEP
Case 1	0.91	0.53	0.52	0.05	0.96	0.05	0.63	0.04
Case 2	0.91	0.53	0.51	0.05	0.96	0.05	0.64	0.04
Case 7	0.75	0.51	0.06	0.97	0.85	0.97	0.37	0.36
Case 8	0.75	0.5	0.07	0.97	0.85	0.97	0.37	0.36
Case 4	0.37	0.03	0.96	0.56	0.81	0.35	0.55	0.49
Case 5	0.5	0.95	0.05	0.71	0.44	0.93	0.48	0.5
Case 3	0.35	0.07	0.95	0.53	0.8	0.35	0.53	0.51
Case 6	0.43	0.95	0.04	0.76	0.45	0.95	0.49	0.54
Case 9	0.05	0.08	0.53	0.62	0.56	0.52	0.95	0.81
Case 10	0.05	0.08	0.53	0.62	0.56	0.55	0.95	0.81
Case 11	0.95	0.93	0.93	0.07	0.05	0.51	0.05	0.95
Case 12	0.96	0.93	0.93	0.07	0.04	0.5	0.05	0.95

***Table 5.** The result of FsQCA*

Necessary Conditions	Coverage		Consistency
E1	0.675		0.699
~E1	0.862		0.681
E2	0.650		0.622
~E2	0.619		0.575
E3	0.694		0.663
~E3	0.508		0.473
E4	0.689		0.726
~E4	0.600		0.500
E5	0.705		0.663
~E5	0.697		0.660
E6	0.532		0.613
~E6	0.982		0.721
E7	0.741		0.705
~E7	0.796		0.743
Sufficient conditions (Parsimonious solution)	Raw Coverage	Unique coverage	Consistency
E5	0.663	0.039	0.705
~E7	0.743	0.139	0.796
E4	0.726	0	0.689
solution coverage:	0.940		
solution consistency:	0.681		
Conditions (Intermediate solution)	Raw Coverage	Unique coverage	Consistency
E7*E6*E5*E3*~E2*~E1	0.385	0.292	0.960
~E7*E4*~E6*E5*~E33*E2*~E1	0.261	0.022	1.00
~E7*E4*~E6*~E5*E3*E2*E1	0.226	0.144	1.00
~E7*E4*E6*E5*~E3*E2*E1	0.305	0.066	0.862
solution coverage:	0.767		
solution consistency:	0.925		

Among all the natural indices, the parsimonious solution of FsQCA found that the combination of E5 with E4 and lack of E7 explains 94% of the outcome cases with 68.9% consistency. And the intermediate solutions found that: the combination (Climate regulation, Water purification, Air purification, Flood storage, Lack of soil conservation, Lack of water conservation) explains 38.5% of the outcome cases with high consistency

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

(96%). This combination (lack of climate regulation, Carbon fixation & oxygen release, Lack of water purification, Air purification, Lack of flood storage, Soil conservation, Lack of water conservation) explains 26.1% of the outcome cases with good consistency (100%). The combination (Lack of climate regulation, Carbon fixation & oxygen release, Lack of water purification, Lack of air purification, Flood storage, Soil conservation, Water conservation) explains 22.6% of the outcome cases with perfect consistency (100%). The combination (Lack of climate regulation, Carbon fixation & oxygen release, Water purification, Air purification, Lack of flood storage, Soil conservation, Water conservation) explains 30.5% of the outcome cases with high consistency (86.2%). The overall solution coverage is 0.767 and solution consistency is 0.925. The overlapped element was the present of E5, E4 and absence of E7. Thus, they are the core conditions to lead to a higher GEP. The result met the criteria that the consistency should be higher than 0.8 and coverage should be be higher than 0.6. So, the analysis was valid (Rihoux and Ragin, 2009).

Discussion

Selected indicator system

According to the GEP results in Huaduhu, the ranking of indicator in 2020 was: landscape value > leisure > climate regulation > water conservation > water quality purification > flood regulation and storage > species conservation > air purification. In 2023, the highest value was coming from the tourism. Each of the indicators were sharing similar values from 2020 to 2023. The clear changes were from tourism values, which increased 2.5 times. This change might be caused to be the Covid-19 pandemic (Stata, 2021; Gera and Kumar, 2023). After the pandemic, there was an increasing trend of ecotourism and responsible behaviors. Tourists were more inclined to travel domestically, and their perception of health risks, expectations of corporate social responsibility, and willingness for sustainable tourism behaviors have been increased (Škare et al., 2021).

Comparing the indicators, it is clear that leisure values always accounted for the highest percentage (55% in 2023). Thus, cultural service including leisure and landscape value are the most important functions and services that provided by the park and generated highest economic outcomes. Compared with general park visitors, there is a higher demand for cultural services in wetland parks, especially for aesthetic value and entertainment value. These services are directly related to the experience and satisfaction of visitors. Thus, the park should enhance it characteristic through some measures, such as increasing educational and interpretive programs, to help visitors better understand the ecological and cultural importance of wetlands, thereby increasing their participation in and appreciation of the wetland park’s cultural services. It can also be enhanced by encouraging community participation and traditional management practices, which only helps preserve and pass on local natural heritage, but also provides unique cultural experiences (Guan et al., 2023).

For natural services, the ecosystem services provided by wetland parks are comprehensive, among which climate regulation services are often closely related to other services such as water resource protection and water purification, the three ones contributed significantly. For example, wetlands regulate climate through water circulation and vegetation cover, and affect water quality and quantity (Yang et al., 2023). Thus, the climate regulation had the highest value. Further, future wetland park design and construction can enhance the significant services as well as the ignored functions (E2,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

E4, E5, and E6), such as selecting plants with strong air purification functions, and increasing forest and herbaceous plants cover for a better carbon sequestration.

Comparison with case studies

The research also compared the GEP value with other studies (Guangzhou Haizhu National Wetland Park by Liu et al. (2022) and Huizhou Zhenhai Bay Wetland Park by Xiang et al. (2024). The results showed that the three wetland parks have a higher GEP than the Huaduhu park, which were GEP value 1,671,428 and 72,857 dollar/a, respectively. The differences can be caused by the different target of the wetland parks. Compared with other parks with similar sizes (Zhenhai Bay Wetland and Huangshui National Wetland Park in Xining, Qinghai), Huaduhu wetland still has its own strengths. The local ecological function was obvious, concentrated to the regulating service, and the cultural service function was most significant, so the monetary value per unit area was quite high. The highest average value was from the Guangzhou Haizhu National Wetland Park (2.5 time of the Huadu wetland park), due to its unique geographical location, biodiversity, scientific and educational programs provided. Thus, the other parks can obtain some experiences of the Haizhu National Wetland Park. It can also be seen that other provinces have different strategies, such as the west regions with more problems of wind and sand erosion, with more focuses on the the functions of soil conservation.

Core conditions in natural service

The FsQCA results for natural ecosystem services empathized that air purification and carbon fixation & oxygen release are significant in GEP. Wetland plants and microorganisms in ecosystems absorb and decompose pollutants to maintain the health and stability of the ecosystem. These functions may improve overall ecosystem health by reducing pollution and maintaining atmospheric balance, which leads to more resilient and productive ecosystems. It is crucial for protecting biodiversity and ensuring the overall functionality of ecosystems. Thus, ecosystems can better adapt to climate change, maintaining productivity and economic value despite other shortcomings (Blum, 2017). The results are consistent with previous ones, such as Wang et al. (2022). They stated that value of regulation services (carbon sequestration, oxygen emissions, water production, etc) contributed more to the regional GEP in China. Scholars also emphasized that wetland parks can increase the vegetation coverage to enhance their air purification, such as planting a diverse range of aquatic communities, and establishing buffer zones around wetland parks with dense vegetation (Mander et al., 2017). Re-routing tidal floodwaters, converting environments to functional wetlands, and constructing river diversions will be beneficial to improve the carbon fixation & oxygen release for wetlands. Some plants can be considered because of a strong ability of daily carbon fixation, such as *Metasequoia glyptostroboides* (Lei et al., 2024).

Limitation and future research

The study focuses primarily on quantitative measures and may overlook qualitative aspects of ecological and cultural services that are harder to quantify but equally important. The geographical and climatic differences between the wetland parks and other regions used for comparison also pose a challenge, as these factors significantly influence the ecological functions and service values. The reliance on specific indicators for cultural services, such as heritage and recreational values, may not encompass the full spectrum

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

of cultural benefits provided by the wetland parks. Future research should aim to address these limitations by incorporating more recent and comprehensive data, standardizing calculation methods, and including qualitative assessments of ecological and cultural services. Expanding the indicators to capture a broader range of cultural and ecological benefits and considering the unique geographical and climatic contexts of each wetland park will provide a more comprehensive understanding of their values. And longitudinal studies that track changes over longer time and the impact of conservation and management practices will be crucial in assessing the long-term sustainability and effectiveness of these wetland parks. It is also necessary to further improve the form and content of the questionnaire survey or explore a more effective calculation method of leisure value. Thus, future studies will focus more on dynamic wetland monitoring, decision support, modeling of biophysical processes, and more other indicators. For example, introducing participatory Geographic information system (GIS) will provide more accurate and comprehensive evaluations of the ecological and cultural service values of wetland parks, ultimately supporting better conservation and management strategies.

Conclusion

Based on the evaluation of the status quo of planning and construction of Huaduhu National Wetland Park and the evaluation of ecosystem grades, this study uses ecological product value accounting to evaluate the results of planning and construction of the national wetland park. Taking the products and services provided by the ecosystem as the benchmark, the wetland quantitatively evaluates the effectiveness of park construction, analyzes, and identifies the parts that need to be optimized and improved in the study area, and proposes improvement strategies. The main conclusions are as follows: Through the accounting of the value of the ecological products of Huaduhu National Wetland Park, the ecological system of the National Wetland Park can be effectively and comprehensively evaluated from a quantitative perspective. From the level of ecological assessment and the ecological characteristics of the research area, based on the principles of protection, systematization, scientific rationality, and openness and development, and combining various methods, the adjustment service products and cultural service products are selected as evaluation indicators. The monetary value of the ecosystem services in 2020 was 122.67 million USD/ha, and in 2023. Comparisons are made within the evaluation system as well as with other previous cases. Overall, the Wetland Park possesses comprehensive ecological functions and notable cultural services. The innovation of this research lies in a combination of GEP with FsQCA for a comparison from spatial-temporal perspective, which provide references for future wetland management and landscape planning.

Implications of the research

The research presented herein not only contributes to the scientific community but also resonates with the broader audience concerned with ecological conservation and sustainable development. Theoretically, it extends the discourse on ecosystem valuation by adopting a comprehensive approach to assess the GEP of Huaduhu National Wetland Park. It holds a holistic perspective, considering both the environmental and cultural services that wetlands provide, thus enriching the theoretical framework of ecosystem accounting. This research will inspire future studies to delve deeper into the complexities of ecosystem services, challenging the traditional narratives that often overlook the non-market values of nature. The findings of this study carry significant weight for policymakers and conservationists. Similar parks can protect the integrity of the structure and function of the ecosystem, maintain the healthy development of wetlands, and prevent wetland degradation. The protection of wetland ecosystems, ecological water replenishment, and the improvement of wetland protection rates all have higher requirements.

To strengthen water system, it is necessary to start with water quality improvement and water source and flow treatment, such as implementing sewage projects, take measures to intercept sewage and flow, control industrial wastewater discharge, treat domestic sewage, and prevent pollutants from flowing into the water system; improve water quality by using biological measures such as releasing fish fry, which can also increase the supply of material products; restore wetland vegetation, appropriately plant aquatic plants with strong water purification capabilities, and improve pollutant purification capabilities; increase water quality monitoring, strengthen water quality monitoring and management. And the parks should give full play to its unique resource advantages and tap the potential value of cultural services, focusing more on scientific research education and cultural popularization. Establishing a science popularization and education system in the wetland park, use various facilities and active publicity to display the history, causes, and resources of wetlands, carry out various science popularization activities, enhance the public's awareness of wetland protection, and attract the public to participate in wetland protection, thereby improving the value of maintaining recreation, and exploring scientific research education and cultural popularization functions, using cultural tourism to drive the development of the surrounding economy.

Acknowledgement. This research was supported by Research and application of key technologies for sewage treatment and utilization in forest eco-tourism sites (Guangdong Forestry Science and Technology Fund: GHS2019005 2019-19); Modern high-quality and efficient agricultural planning and technical services (Rural Revitalization Project of Guangdong Science and Technology Department: KA1810302).

REFERENCES

[1] AMR. (2021): Technical Specifications for Calculating Gross Ecosystem Product (GEP). – Retrieved 10th November 2024 from: https://amr.nanjing.gov.cn/ztzl/bzhzl/njsdfbzqwgk/202106/t20210623_2976410.html.

[2] Blum, J. (2017): Contribution of ecosystem services to air quality and climate change mitigation policies: the case of urban forests in Barcelona, Spain. – In: Urban Forests, pp. 21-54. Apple Academic Press.

[3] CGTN. (2022): China's Wetlands Protection Law takes effect. – Retrieved from: https://news.cgtn.com/news/2022-06-01/China-s-Wetlands-Protection-Law-takes-effect-1aZ5V5g5h0U/index.html.

[4] Chen, S., Zhang, Z., Ma, Y. (2006): China's marine ecosystem service function and value assessment research plan. – Advances in Earth Sciences 11: 1127-1133.

[5] Cheng, X., Van Damme, S., Li, L., Uyttenhove, P. (2019): Evaluation of cultural ecosystem services: A review of methods. – Ecosystem Services 7(C): 1-11.

[6] Comte, A. C., Campagne, S., Lange, S., Bruzón, A. G., Hein, L. (2022): Ecosystem accounting: Past scientific developments and future challenges. – Ecosystem Services 58: 01486.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

[7] Costanza, R. (1997): The value of the world's ecosystem services and natural capital. – Nature 387(6630): 253-260.

[8] Daily, G. C. (2013): Nature's services: Societal dependence on natural ecosystems (1997). – In: The Future of Nature. Yale University Press, pp. 454-464.

[9] Davis, S., Ogden, J. C. (1994): Everglades the ecosystem and its restoration. – CRC Press.

[10] De Groot, R. S., Wilson, M. A., Boumans, R. M. J. (2002): A typology for the classification, description and evaluation of ecosystem functions, goods and services. – Ecological Economics 41(3): 393-408.

[11] Du, A., Shen, Y. Q., Xiao, Y., Ouyang, Z. Y. (2023): Research on accounting of ecological products value in National Parks. – Acta Ecologica Sinica 43(1): 208-218.

[12] Ehrlich, P. R., Ehrlich, A. H. (1981): Extinction: the causes and consequences of the disappearance of species. – Random House.

[13] Feng, Q., Zhao, W., Hu, X., Liu, Y., Daryanto, S., Cherubini, F. (2020): Trading-off ecosystem services for better ecological restoration: A case study in the Loess Plateau of China. – Journal of Cleaner Production 257: 120469.

[14] Fisher, B., Turner, K., Zylstra, M., Brouwer, R., de Groot, R., Farber, S., Ferraro, P., Green, R., Hadley, D., Harlow, J., Jefferiss, P., Kirkby, C., Morling, P., Mowatt, S., Naidoo, R., Paavola, J., Strassburg, B., Yu, D., Balmford, A. (2008): Ecosystem services and economic theory: integration for policy-relevant research. – Ecological applications: a publication of the Ecological Society of America 18: 2050-2067.

[15] Gera, R., Kumar, A. (2023): Impact of COVID-19 on Tourism Destination Resilience and Recovery: A Review of Future Research Directions. – In: Dube, K., Nhamo, G., Swart, M. (eds.) COVID-19, Tourist Destinations and Prospects for Recovery. Springer, Cham.

[16] Grossmann, M. M., Lindsay, D. J. (2017): A new species of clausophyid calycophoran siphonophore (Cnidaria: Hydrozoa), *Kephyes hiulcus* sp. nov., widely distributed throughout the world's oceans. – Zootaxa 4250(1): 43-54.

[17] Guan, D., Ran, B., Zhou, L., Jin, C., Yu, X. (2023): Assessing and transferring social value of ecosystem services in wetland parks based on SolVES model. – Ecological Indicators 157: 111300.

[18] Guangzhou Development and Reform Commission (2019): Electricity price of Guangzhou. – Retrieved 10th November 2024 from: https://www.shanwei.gov.cn/swdpb/zxgk/201911/92c15ae1ab904fbfb7e93b8fd19b1694/files/85460ce1f31146acb019e23e6442f644.pdf.

[19] Hao, C., Wu, S., Zhang, W., Chen, Y., Ren, Y., Chen, X., Zhang, L. (2022): A critical review of Gross ecosystem product accounting in China: Status quo, problems and future directions. – Journal of Environmental Management 322: 115995.

[20] Hartmann, J., Inkpen, A., Ramaswamy, K. (2022): An FsQCA exploration of multiple paths to ecological innovation adoption in European transportation. – Journal of World Business 57(5): 101327.

[21] Heagney, E. C., Rose, J. M., Ardeshiri, A., Kovac, M. (2019): The economic value of tourism and recreation across a large protected area network. – Land Use Policy 88: 104084.

[22] Hou, Y., Qiao, J. (2013): Social Benefit Evaluation of Harbin Qunli Wetland Park. – Chinese Horticultural Digest 29(04): 105-106.

[23] International Carbon Action Partnership (ICAP). (2023): Progress in global carbon markets: 2023 annual report. – Retrieved 10th November 2024 from: https://icapcarbonaction.com/system/files/document/230417_ES_CHI.pdf.

[24] Jiang, W. (2017): Ecosystem services research in China: A critical review. – Ecosystem Services 26: 10-16.

[25] Jin, F., Lu, S., Yu, X. (2005): Service function and value evaluation of forest ecosystem in China. – Journal of Applied Ecology 8: 1531-1536.

[26] Kwiatek, P., Papakonstantinidis, S., Thanasi-Boçe, M., Limani, E. (2022): Learning styles in group composition: Evidence from a marketing simulation. – Marketing Education Review 32(1): 33-44.

[27] Lai, S., Zhang, M., Su, Z. (2024): Optimizing tourism ecological security: a study based on NCA and FsQCA methods. – Environment, Development and Sustainability.
[28] Lal, R. (2013): Enhancing ecosystem services with no-till. – Renewable Agriculture and Food Systems 28(2): 102-114.
[29] Lee, S. S. (2014): Using fuzzy-set qualitative comparative analysis. – Epidemiol Health 36: e2014038.
[30] Lei, Z., Wang, Q., Xiao, H. (2024): Carbon Fixation and Oxygen Release Capacity of Typical Riparian Plants in Wuhan City and Its Influencing Factors. – Sustainability 16(3): 1168.
[31] Li, F., Wang, F., Liu, H., Huang, K., Yu, Y., Huang, B. (2023): A comparative analysis of ecosystem service valuation methods: Taking Beijing, China as a case. – Ecological Indicators 154: 110872.
[32] Liao, W. (2019): Liping Gross Ecosystem Product (GEP) Accounting Research. – Guizhou University.
[33] Liu, W. Y., Chen, P. Z., Hsieh, C. M. (2019): Assessing the recreational value of a national forest park from ecotourists' perspective in Taiwan. – Sustainability 11(15): 4084.
[34] Liu, T., Yao, J., Zhu, J. (2022): Research on Planning Strategies for the Protection and Utilization of Ecological Space in Central Areas of Super Megacities from the Perspective of Preservation and Appreciation of Natural Resource Assets-Taking Guangzhou Haizhu National Wetland Park as an Example. – Shanghai Urban Planning 5: 52-59.
[35] Loc, H. H., Diep, N. T. H., Tuan, V. T., Shimizu, Y. (2018): An analytical approach in accounting for social values of ecosystem services in a Ramsar site: A case study in the Mekong Delta, Vietnam. – Ecological Indicators 89: 118-129.
[36] Mander, Ü., Tournebize, J., Sauvage, S., Sánchez-Perez, J. M. (2017): Wetlands and buffer zones in watershed management. – Ecological Engineering 103: 289-295.
[37] MEE. (2019): Technical guideline for site soil and groundwater sampling of volatile organic compounds. – Retrieved 10th November 2024 from: https://www.nssi.org.cn/nssi/front/110322173.html.
[38] MEE. (2020): Technical Guidelines for Calculating Gross Terrestrial Ecosystem Product (GEP). – Retrieved 10th November 2024 from: http://www.caep.org.cn/zclm/sthjyjjhszx/zxdt_21932/202010/W020201029488841168291.pdf.
[39] MEE. (2023): Construction Environmental Pollution Last Year Report. – Retrieved 10th November 2024 from: https://sthjj.gz.gov.cn/attachment/7/75137513189/9343740.pdf.
[40] Mengist, W., Soromessa, T., Feyisa, G. L. (2022): Estimating the total ecosystem services value of eastern fromomontane biodiversitu hotspots in response to landscape dynamic. – Environmental and Sustainability Indicators 14: 100178.
[41] MPCPA. (2025): Soil erodibility. – Retrieved 10th June 2025 from: https://stormwater.pca.state.mn.us/index.php?title=Soil_erodibility.
[42] Murray, N. J., Worthington, T. A., Bunting, P., Duce, S., Hagger, V., Lovelock, C. E., Lucas, R., Saunders, M. I., Sheaves, M., Spalding, M., Waltham, N. J., Lyons, M. B. (2022): High-resolution mapping of losses and gains of Earth's tidal wetlands. – Science 376: 744-749.
[43] Nelson, E. J., Daily, G. C. (2010): Modelling ecosystem services in terrestrial systems. – F1000 Biology Reports 2: 53.
[44] Ouyang, Z., Wang, R., Zhao, J. (1999): Ecosystem service function and its ecological economic value evaluation. – Journal of Applied Ecology 5: 635-640.
[45] Ouyang, Z. (2018): Gross Ecosystem Product GEP and Ecological Assets Accounting for Ecological Compensation. – Beijing: Science Press.
[46] Ouyang, Z., Lin, Y., Song, C. (2020): Accounting Research on Gross Ecosystem Product (GEP) -Taking Lishui City, Zhejiang Province as an Example. – Environment and Sustainable Development 45(06): 80-85.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

[47] Ouyang, Z., Song, C., Zheng, H. (2020): Using gross ecosystem product (GEP) to value nature in decision making. – Proceedings of the National Academy of Sciences 117(25): 14593-14601.
[48] Pearce, D. W. (2014): Blueprint 4: capturing global environmental value. – Routledge.
[49] Ragin, C. C. (1987): The Comparative Method. Moving Beyond Qualitative and Quantitative Strategies. – University of California Press.
[50] Ren, L., Wu, C., Yue, W. (2009): Emergy analysis of ecological and economic benefits of Xixi National Wetland Park. – Journal of Ecology 29(03): 1285-1291.
[51] Rihoux, B., Ragin, C. (2009): Qualitative Comparative Analysis (QCA) and Related Techniques. – Sage Publications.
[52] Rokicki, B., M'barek, R., Grammatikopoulou, I., La Notte, A., Van Alphen, M., Van Zeist, W., Bartelings, H., Polman, N. (2024): Gross Ecosystem Product in macroeconomic modelling. – Publications Office of the European Union.
[53] Seilheimer, T. S., Mahoney, T. P., Chow-Fraser, P. (2009): Comparative study of ecological indices for assessing human-induced disturbance in coastal wetlands of the laurentian great lakes. – Ecological Indicators 9(1): 81-91.
[54] SFA. (2017): Technical Procedure for Health Evaluation of Mangrove Wetland. – Retrieved 10th December 2023 from: http://sps.gdtbt.org.cn/noteshow-16646.html.
[55] Škare, M., Soriano, D. R., Porada-Rochoń, M. (2021): Impact of COVID-19 on the travel and tourism industry. – Technological Forecasting and Social Change 163: 120469.
[56] Statista. (2021): Global tourism and travel expenditure from 2008 to 2021. – Retrieved 10th November 2024 from: https://www.statista.com/statistics/271550/global-tourism-and-travel-expenditure/.
[57] Tang, M. (2010): Research on the Evaluation System of Urban Wetland Parks in Northwest China-Taking Lanzhou Yintan Wetland Park as an Example. – Journal of Shandong Agricultural University 41(01): 80-86.
[58] Thygeson, N. M., Solberg, L. I., Asche, S. E., Fontaine, P., Pawlson, L. G., Scholle, S. H. (2012): Using fuzzy set qualitative comparative analysis (fs/QCA) to explore the relationship between medical "homeness" and quality. – Health Serv Res. 47(1): 22-45.
[59] United Nations. (2021): Introduction to SEEA Ecosystem Accounting. – Retrieved from: https://seea.un.org/introduction-to-ecosystem-accounting.
[60] Verhoeven, J. T. (2014): Wetlands in Europe: perspectives for restoration of a lost paradise. – Ecological Engineering 66: 6-9.
[61] Wang, L., Su, K., Jiang, X., Zhou, X., Yu, Z., Chen, Z., Wei, C., Zhang, Y., Liao, Z. (2022): Measuring Gross Ecosystem Product (GEP) in Guangxi, China, from 2005 to 2020. – Land 11(8): 1213.
[62] Warchold, A., Pradhan, P., Kropp, J. P. (2021): Variations in sustainable development goal interactions: Population, regional, and income disaggregation. – Sustainable Development 29(2): 285-299.
[63] Water Environment Monitoring Center (WEMC). (1997): Technical Specification for Water Quality Sampling (SL187-96). – Retrieved 10th November 2024 from: https://www.las.ac.cn/front/book/detail?id=ef7fb43ade95d46f9b3bb407e8acce8d.
[64] Wei, B., Zhu, L., Yu, L. (2021): The Concept and Accounting Pilot of Gross Ecosystem Product (GEP). – China Assets Appraisal 10: 66-70.
[65] WRI. (2005): Ecosystems and Human Well-Being: Wetlands and Water Synthesis. – Retrieved 10th November 2024 from: https://biblioteca.cehum.org/bitstream/123456789/143/1/Millennium%20Ecosystem%20Assessment.%20ECOSYSTEMS%20AND%20HUMAN%20WELL-BEING%20WETLANDS%20AND%20WATER%20Synthesi.pdf.
[66] Wu, Z., Raven, P. H. (2010): Flora of China. – Missouri Botanical Garden Press.
[67] Wu, H., Dan, X., Wang, L. (2016): Review and Prospect of Wetland Park Construction in China. – Forestry Resources Management 2: 39-44.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

[68] Wu, S. (2022): Research on the Construction and Testing of Ecological Product Value Realization Evaluation Index System. – Master thesis of Sichuan University of Social Sciences.
[69] Xiang, L., Chen, Z., Qu, M., Zhang, H., Chen, P., Li, R., Sang, K. (2024): Mangrove Health: An Evaluation Based on Analytic Hierarchy Process for the Zhenhai Bay Mangrove Wetland Park in China. – Applied Ecology & Environmental Research 22(5): 4155-4172.
[70] Xin, K., Xiao, D. (2002): Estimation of service function value of wetland ecosystem in Panjin area. – Journal of Ecology 8: 1345-1349.
[71] Xu, X., Chen, M., Yang, G., Jiang, B., Zhang, J. (2020): Wetland ecosystem services research: A critical review. – Global Ecology and Conservation 22: 01027.
[72] Yang, L., Zhang, Z., Zhang, W., Zhang, T., Meng, H., Yan, H., Shen, Y., Li, Z., Ma, X. (2023): Wetland Park Planning and Management Based on the Valuation of Ecosystem Services: A Case Study of the Tieling Lotus Lake National Wetland Park (LLNWP), China. – Int J Environ Res Public Health 20(4): 2939.
[73] Yu, M., Jin, H., Li, Q. (2020): Accounting research on Gross Ecosystem Product (GEP) in Chenggong District. – Western Forestry Science 49(03): 41-48.
[74] Yuan, X., Lu, J. (2001): Study on benthos resources of island wetlands in the Yangtze Estuary. – Journal of Natural Resources 1: 37-41.
[75] Zhai, X., Lange, E. (2020): Using Social Media to Explore Perceptions of Ecosystem Services by Nature-Based Solution Projects. – Landscape Architecture Frontiers 8(3): 58-68.
[76] Zhang, X., Lv, X. (2006): A review on the evaluation of wetland ecosystem services. – Forestry Resources Management 5: 81-86.
[77] Zhang, L., Chen, X., Liang, T. (2023): Research progress, problems and prospects of ecological product value accounting in China. – Research of Environmental Sciences 36(4): 743-756.
[78] Zhao, T., Ouyang, Z., Zheng, H. (2004): Grassland Ecosystem Service Function Analysis and Evaluation Index System. – Journal of Ecology 6: 155-160.
[79] Zhou, H., Li, F., Wang, W. (2007): Fauna Sinica. – Chinese Science Press, Beijing.

APPENDIX

Appendix 1. *Water quality*

Samples	Ammonia nitrogen (mg/L)	TN (mg/L)	TP (mg/L)	COD (mg/L)	DO (mg/L)	Turbidity (NTU)	pH
1	1.709	1.942	0.062	21.333	3.137	2.123	6.87
2	1.015	0.955	0.032	20.000	4.420	2.565	6.99
3	1.495	1.485	0.058	30.667	3.121	1.860	7.13
4	1.684	1.707	0.061	29.333	3.305	2.325	7.24
5	1.647	2.050	0.056	22.667	3.160	1.860	7.42
6	1.152	0.969	0.057	20.000	4.230	1.860	7.49
7	1.273	1.177	0.028	17.333	3.483	0.310	7.39
8	1.442	1.390	0.054	16.000	4.592	0.620	7.41
Average	1.427	1.459	0.051	22.167	3.681	1.690	7.24

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249

Appendix 2. *Heavy metal*

Samples	As g/kg	Cd g/kg	Cr g/kg	Cu g/kg	Ni g/kg	Pb g/kg	Zn g/kg	Results
1	3.846	0.036	148.210	51.336	31.298	59.725	135.005	not exceed
2	1.282	0.044	27.964	13.361	4.962	58.140	28.815	not exceed
3	3.419	0.102	67.114	23.910	0.000	45.455	46.958	not exceed
4	3.419	0.000	0.000	2.110	3.053	18.499	12.273	not exceed
5	3.847	0.000	83.893	59.072	17.176	32.241	137.140	not exceed
6	0.000	0.090	0.000	12.66	0.000	28.54	22.41	not exceed
7	7.690	0.060	67.110	5.630	11.450	0.000	20.280	not exceed
8	18.800	0.000	0.000	0.000	0.000	22.200	27.750	not exceed
Average	5.288	0.041	49.287	21.009	8.492	33.100	53.829	not exceed

Appendix 3. *Soil quality*

Samples	Dry weight (g)	wet weight (g)	ratio (g/m$^{3)}$	water (%)
1	140.350	163.957	1.404	16.117
2	123.480	144.710	1.235	17.196
3	148.230	173.087	1.482	16.767
4	152.660	178.360	1.527	16.861
5	129.300	150.883	1.293	16.717
6	127.560	149.357	1.276	17.113
7	144.020	168.250	1.440	16.847
8	138.610	162.317	1.386	17.111
Average	138.028	161.365	1.380	16.928

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_82258249