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Assessing the Changes of Ecosystem Services in the Nansi Lake Wetland, China

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Abstract: Wetlands provide many essential ecosystem services for human well-being. The ecological assessment of wetland ecosystem services is problematic and thus is an important focus in the field of ecological research. In this study, an ecological assessment system containing the ecosystem product value, ecosystem regulation service value, and ecosystem cultural service value was established to calculate the gross ecosystem product in the Nansi Lake Wetland, China. Based on remote sensing images, field studies, and literature reviews, the gross ecosystem product was estimated for the years 1985, 1992, 2005, 2011, and 2017. The results showed that the gross ecosystem product of the Nansi Lake Wetland increased from 40.91×10^8 USD in 1985 to 46.28×10^8 USD in 2017. The gross ecosystem product of the altered wetlands increased by about 8.5 times with a rising linear relationship, while natural wetlands presented a nonlinear relationship. Furthermore, except for the changes in climatic condition, anthropogenic interference factors such as coal mining activities, farming practices, and government policies have promoted significant services in the Nansi Lake Wetland over the past 30 years. This study could provide important insight into the ecological assessment of wetland ecosystems and thus inform policy for the protection and better use of wetland resources.

Keywords: wetland ecosystems; ecosystem services; gross ecosystem product; Nansi Lake Wetland

1. Introduction

Wetlands constitute important and valuable global ecosystems [1–3], providing basic living conditions for humankind, animals, plants, and other living organisms [4,5]. Moreover, they play an irreplaceable role for human well-being [6–10]. However, with the intensification of human pressures, especially the acceleration of industrialization and urbanization, the conversion and intensification of land to agriculture [11], the area of wetlands is sharply decreasing worldwide [12–15]. Furthermore, the large amounts of pollutants entering wetlands from human activities have caused a serious degeneration of the function and structure of wetland ecosystems [16–18].

The ecological assessment of wetland ecosystem services has been widely considered [19–26]. In the classification of wetland ecosystem services, the Millennium Ecosystem Assessment divided ecosystem services into provisioning, regulating, cultural, and support services [10]. The functional and economic valuation of wetlands have both been taken into consideration [25,26]. As ecosystem services have a direct impact on decision making, their economic value has become more important [27–31]. Rahman et al. [19] assessed the wetland services for the improved development of decision-making in the mangroves of coastal Bangladesh. Gandarillas et al. [32] adopted the ecosystem serve framework combined with economic valuation to assess five major wetland services of high mountain wetlands. Li and Gao [24] estimated the ecosystem services valuation of a lakeside wetland park beside Chaohu Lake in China. Woodward and Wui [23] evaluated the relative value of different wetland services using a meta-analysis. Some studies have used different methods for determining the economic value of wetland ecosystems such as market value method [23], shadow engineering method [24,33], carbon tax method [34], contingent value method [35], amongst others [36]. These studies provided good references in the classification of wetland ecosystem services and different methods of calculation for the ecological assessment of wetland ecosystems.

Gross ecosystem product (GEP) is a similar economic concept to gross domestic product (GDP), and applied as a practical tool using specific indicators to measure the gross ecosystem product [37]. GEP was first proposed by Hannon in 1985 [38]. By calculating the value of ecosystem products and services provided to humans, GEP indicators can measure the health of ecosystems [39]. The particular concept of GEP and accounting systems were further defined by Ouyang et al. [40] and Ma et al. [41]. Ouyang et al. [40] pointed out that GEP mainly refers to the total value of the direct and indirect use values of ecosystem goods and services including the ecosystem provision value, ecological regulation services value, and ecological culture services value. Ma et al. [41] highlighted two critical points in GEP accounting: changes of ecosystem services and the economic benefits of products from ecosystem-provided services. While there remain some deficiencies of unified indicators of GEP that assess the degree of change in the ecological assessment of wetland ecosystem services, the quantitative assessment of the function and operation of wetland ecosystems through changes in GEP has become a feasible approach [42,43].

To improve wetland ecosystem assessment systems and enrich case studies in wetlands around the world, the purposes of this research are as follows: (1) to establish a reasonable ecological assessment system of wetland ecosystem services, based on GEP, in the Nansi Lake Wetland, China; (2) to estimate the ecological assessment of the Nansi Lake Wetland ecosystem services in the years, 1985, 1992, 2005, 2011, and 2017; and (3) to analyze the characteristics of the spatiotemporal variations of the Nansi Lake Wetland ecosystem services.

2. Materials and Methods

2.1. Study Area

The Nansi Lake Wetland is located in Shandong Province in Eastern China (116°34′–117°21′ E, 34°27′–35°20′ N) [44] and contains various types of wetlands: lakes, rivers, swamps, ponds, paddy fields, building lands, and other lands (Figure 1). It has a continental climate, with warm temperate and semi-humid monsoon regions. Precipitation has an uneven spatial and temporal distribution. The annual average temperature of the wetlands is 13.7 °C, and the average annual sunshine hours are 2273 h [45].

Nansi Lake is the largest freshwater and shallow eutrophic lake in North China, providing abundant wetland and biological resources [24]. Water resources can supply Weishan County and the surrounding counties, cities, and districts with industrial and agricultural production. Plant resources include phytoplankton, submerged macrophytes, floating-leaved macrophytes, and emergent macrophytes. Furthermore, floating-leaved macrophytes are dominated by *Trapa bispinosa* and *Euryale ferox*. Emergent macrophytes are mainly composed of *Phragmites australis* and *Nelumbo nucifera*. Fish resources are dominated by *Cyprinus carpio*. The population in the Nansi Lake Wetland is mainly engaged in agricultural production based on cofferdam breeding and rice planting. At the same time, the Nansi Lake Wetland port logistics industry is developed and is one of the important hubs of the south-to-north water transfer project [46]. Moreover, the Nansi Lake Wetland is rich in coal resources, and coal mining activities occur under the lake [47].

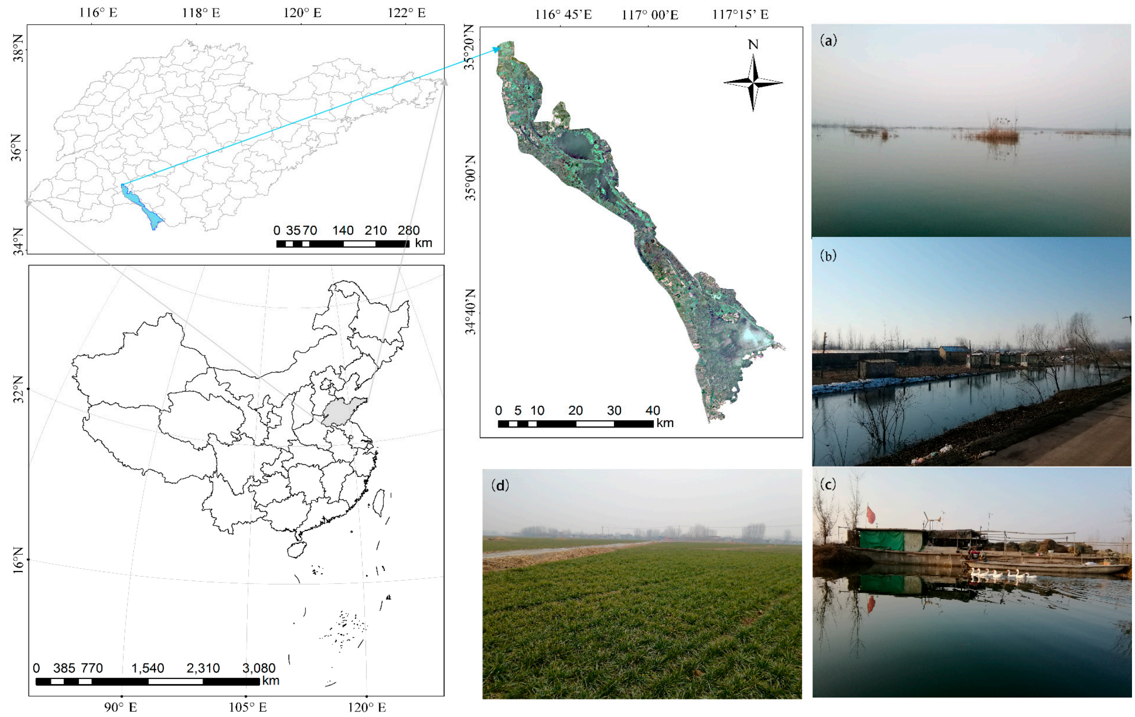

Figure 1. Location of the study area and landscape photos in the Nansi Lake Wetland. (**a**) Lakes; (**b**) Rivers; (**c**) Ponds; (**d**) Paddy fields.

2.2. Ecological Assessment Systems of Wetland Ecosystem Services in Nansi Lake Wetland, China

The assessment of wetland ecosystem services in the Nansi Lake Wetlands involved estimates of gross ecosystem product (GEP) [40,41]. Furthermore, this study considered the individual characteristics, structure, and ecological processes. The ecosystem service accounting index of the GEP of Nansi Lake Wetland was divided into three major categories and nine smaller classes [48–51]. The functions of wetland ecosystem products include water and biological resources. The functions of wetland ecosystem regulation services are divided into five kinds: climate adjustment, water conservation, soil and water conservation, flood regulation, and water purification. In addition, the functions of wetland ecosystem cultural services include entertainment and cultural education.

The accounting framework for the GEPs of the Nansi Lake Wetland is shown in Figure 2. It was divided into four steps. First, the ecosystem product values (EPVs) were calculated by obtaining the output and price of water and biological resources in the Nansi Lake Wetland (Equation (1)). Second, we assessed the ecosystem regulation service values (ERVs) of the Nansi Lake Wetland by obtaining the quantity and price of five regulation services (Equation (2)). Third, we accounted for the ecosystem cultural service values (ECVs) of the Nansi Lake Wetland by obtaining the functional quantity and price of entertainment and cultural education (Equation (3)). Finally, the values of the GEPs of the Nansi Lake Wetland was summed up by the product value, regulation service value, and cultural service value (Equation (4)).

$$\mathrm{EPV_S} = \sum\nolimits_{i=1}^{n} \mathrm{EP_i} \times \mathrm{P_i}, \quad (1)$$

$$\mathrm{ERV_S} = \sum\nolimits_{j=1}^{m} \mathrm{ER_j} \times \mathrm{P_j}, \quad (2)$$

$$\mathrm{ECV_S} = \sum\nolimits_{k=1}^{l} \mathrm{EC_k} \times \mathrm{P_k}, \quad (3)$$

$$\mathrm{GEP_S} = \mathrm{EPV_S} + \mathrm{ERV_S} + \mathrm{ECV_S}, \quad (4)$$

where $\mathrm{GEP_S}$ is the value of the wetland gross ecosystem product; $\mathrm{EPV_s}$ is the value of the wetland ecosystem products; $\mathrm{ERV_s}$ is the value of the wetland ecosystem regulation service; $\mathrm{ECV_s}$ is the value of the wetland ecosystem ecological cultural service; EP_i is the output of the i-th product of the wetland ecosystem; P_i is the price of the i-th product of the wetland ecosystem; ER_j is the functional quantity of the j-th ecosystem regulation service; P_j is the price of the j-th ecosystem regulation service function; EC_k is the functional quantity of the k-th ecosystem cultural service; and P_k is the price of the k-th ecosystem cultural service function. The detailed accounting indicators and equations are shown in Table 1. The values of the GEPs were calculated using the United States dollar (USD).

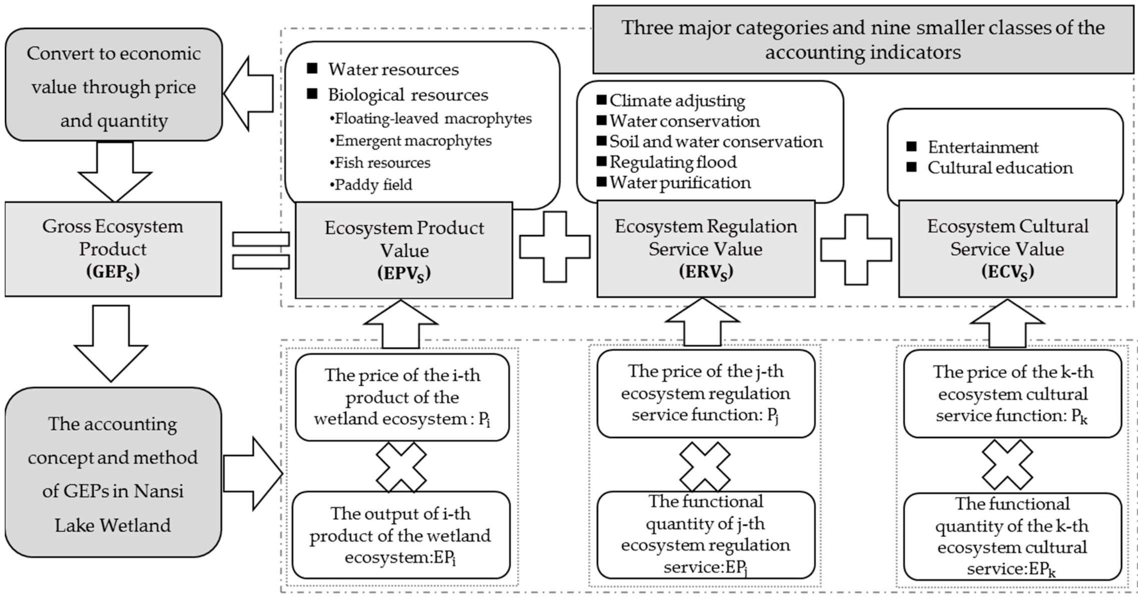

Figure 2. The accounting framework for the GEP of the Nansi Lake Wetland.

Table 1. Accounting indicators and formulas for the gross ecosystem product in the Nansi Lake Wetland [1].

Accounting Indicators			Formula	Description	Method
EPV_S	Water resources		$V_s = S \times H \times \overline{P_s}$	V_s is the value of water resources; S is the wetland area; H is the average depth of the wetland water resources; and $\overline{P_s}$ is the average cost of farmland irrigation and the price of waterworks [39].	Market Value Method
	Biological resources	Floating-leaved macrophytes	$V_{sf} = \sum(Q_{if} \times P_{if})$	V_{sf} is the value of the floating-leaved macrophytes; Q_{if} is the i-th floating leaf plant biomass; and P_{if} is the unit price of the i-th floating leaf plant [49].	
		Emergent macrophytes	$V_{sts} = \sum(Q_{it} \times P_{it})$	V_{sts} is the value of the emergent macrophyte; Q_{it} is the i-th emergent plant biomass; and P_{it} is the i-th emergent plant cost [49].	
		Fish resources	$V_{sy} = Q_y \times P_y$	V_{sy} is the fish production value; Q_y is the fish resource biomass; and P_y is the average unit price of the fish product [48].	
		Paddy field	$V_{ss} = Q_s \times P_s$	V_{ss} is the value of the paddy field; Q_s is the rice yield; and P_s is the rice price [48].	
ERV_S	Climate adjusting		$V_q = V_{gc} + V_{sy}$ $V_{gc} = Q_{gc} \times P_{gc}$ $V_{sy} = Q_{sy} \times P_{sy}$	V_q is the value of climate adjusting; V_{gc} is the value of fixed CO_2; V_{sy} is the value of releasing O_2; Q_{gc} is the amount of fixed CO_2; P_{gc} is the cost of the afforestation of CO_2; Q_{sy} is the amount of O_2 released; and P_{sy} is the cost of O_2 released [52].	Carbon Tax Method & Industrial Oxygenation Method
	Water conservation		$V_h = S_{max} \times R \times P_{sk}$	V_h is the value of water conservation; S_{max} is the maximum lake area of Nansi Lake; R is the average surface runoff of Nansi Lake; P_{sk} is the average cost of constructing a cubic meter of reservoir [51].	Shadow Engineering Method
	Soil and water conservation		$V_{stb} = S \times h \times R_1 \times R_2 \times P_{hf}$	V_{stb} is the value of soil and water conservation; S is the wetland area; h is the medium depth of erosion without vegetation; R_1 is the soil bulk density; R_2 is the average content of soil nutrients; and P_{hf} is the price of fertilizer [51].	Alternative Value Method
	Regulating flood		$V_t = Q_t \times P_{sk}$	V_t is the value of regulating flood; Q_t is the maximum amount of flood season of Nansi Lake; and P_{sk} is the average cost of constructing a cubic meter of reservoir [50].	Shadow Engineering Method
	Water purification		$V_{sz} = S_l \times P_l$	V_{sz} is the value of water purification; S_l is the area of *Phragmites australis* distribution; and P_l is the purification value of the unit *Phragmites australis* [1].	Expert Estimation Method
ECV_S	Entertainment		$V_x = S_x \times P_x$	V_x is the value of entertainment; S_x is the landscape distribution area to entertain; and P_x is the unit value of entertainment [1].	Expert Estimation Method
	Cultural education		$V_w = S \times P_w$	V_w is the value of cultural education; S is the wetland area; and P_s is the unit value of cultural education [1].	

Note: [1] The phytoplankton and submerged macrophytes are the main food for fish; they are duplicated with the value of fish resources when accounting for the gross ecosystem product, so they are not calculated.

2.3. Data Collection and Processing

In this research, data were obtained from three channels: interpreting remote sensing images, using field surveys, and reviewing the literature.

Remote sensing images were used for the classification of landscape type, the calculation of landscape area, and the estimation of water depth inversion. They were selected mainly from Landsat5 TM and Sentinel-2 data. The remote sensing images from 1985, 1992, 2005, and 2011 were interpreted from Landsat5 TM images, and the images of 2017 were obtained from Sentinel-2 data. To better interpret the changes in the Nansi Lake Wetland, the most vigorous season of vegetation growth was selected from June to September, when cloud cover was less than 10%. ENVI 5.3 software was used for the atmospheric correction of remote sensing images. Landsat images, corrected by the FLAASH atmospheric correction method, were used. Sen2Cor images were used for the Sentinel-2 images. Landsat images covered the entire study area without inlays. However, as the Sentinel-2 images did not contain all the research areas, the three scene images with the same shooting date were spliced, and finally, uniform cutting was performed using the vector boundary of the nature reserve.

Field surveys from 5 to 20 January 2018 were implemented by the Nansi Lake Wetland Ecological Investigation Team of the China University of Mining and Technology. The team investigated the current ecological environment in the Nansi Lake Wetland (Figures S1 and S3). The following data were obtained by collating the average cost of irrigation farmland and the price of waterworks; the average unit price of the fish product; unit price of the floating-leaved macrophytes and the emergent macrophytes; rice price; average cost of constructing a cubic meter of the reservoir; and price of fertilizer (Table S1). Those field data, which were used to calculate the gross ecosystem product, were gathered through face-to-face interview surveys with local residents (Figure S2).

Other data were collected from reviewing the literature [49,53]. These data were the floating-leaved macrophytes and emergent macrophytes biomass; fish resource biomass; rice yield; maximum lake area; average surface runoff of Nansi Lake; medium depth of erosion, without vegetation; soil bulk density; average content of soil nutrient; the maximum amount of flood season of Nansi Lake; area of *Phragmites australis* distribution; and area used for entertainment and cultural education (Tables S2 and S3).

All of the analyses were conducted using ENVI 5.3 (ESRI, San Diego, CA, USA) and SPSS 20.0 (IBM, New York, NY, USA). Charts and graphs were constructed using ArcGIS 10.2 (ESRI, San Diego, CA, USA), Origin 9.1 (OriginLab, Northampton, MA, USA) or the R project (R Development Core Team, Vienna, Austria).

3. Results

3.1. Timing Variation of the Gross Ecosystem Product in the Nansi Lake Wetland

According to the ecological assessment systems of wetland ecosystem services in the Nansi Lake Wetland and the data obtained from the remote sensing images, field surveys, and the literature, the gross ecosystem product (GEP) of the Nansi Lake Wetland was estimated for the years 1985, 1992, 2005, 2011, and 2017 (Table S4).

The GEPs of the Nansi Lake Wetland increased by more than 5.37×10^8 USD in 2017 when compared with 1985. The variation in GEPs showed a wave-like trend. GEPs rose from 40.91×10^8 USD in 1985 to 42.41×10^8 USD in 1992, then fell to 38.32×10^8 USD in 2005. After 2005, they showed an upward trend and reached 46.28×10^8 USD in 2017 (Figure 3a).

The ecosystem product value (EPV) fluctuated during the years of the study. Overall, the EPVs accounted for 15–21% of the GEPs. The value of biological resources was one of the core value functions of the EPVs. The value of water resources doubled from 1.16×10^8 USD in 1985 to 2.14×10^8 USD in 2017. Furthermore, the EPVs showed a downward trend from 1992 to 2005, similar to the declining variation of GEPs (Figure 3b).

The ecosystem regulation service value (ERV) comprised more types and complex changes, accounting for 61–66% of the GEPs in the Nansi Lake Wetland. There was a significant decline from 1992 to 2005, which was due to the significant decline in the value of water purification functions. The value of climate adjusting was maximal at 3.55×10^8 USD in 1985, then declined, reaching its lowest of 2.24×10^8 USD in 2005, and then increased to 3.02×10^8 USD in 2017. The value of water conservation showed an overall growth trend, which peaked at 2.14×10^8 USD in 2011. This change was similar to the value of water purification, but with a peak of 3.74×10^8 USD in 2017. Moreover, the value of soil and water conservation increased from 4.82×10^8 USD in 1985 to 5.29×10^8 USD in 2017. However, there was no change in the value of flood regulation function, since this calculation was estimated using the maximum amount of flood season in Nansi Lake (Figure 3c).

The ecosystem cultural service value (ECVs) increased a little overall from 1985 to 2017. The value of entertainment functions increased in a wave pattern, reaching its lowest of 3.78×10^8 USD in 2011 and peaking at 4.28×10^8 USD in 2017. The value of the entertainment function was consistently higher than that of cultural education (Figure 3d).

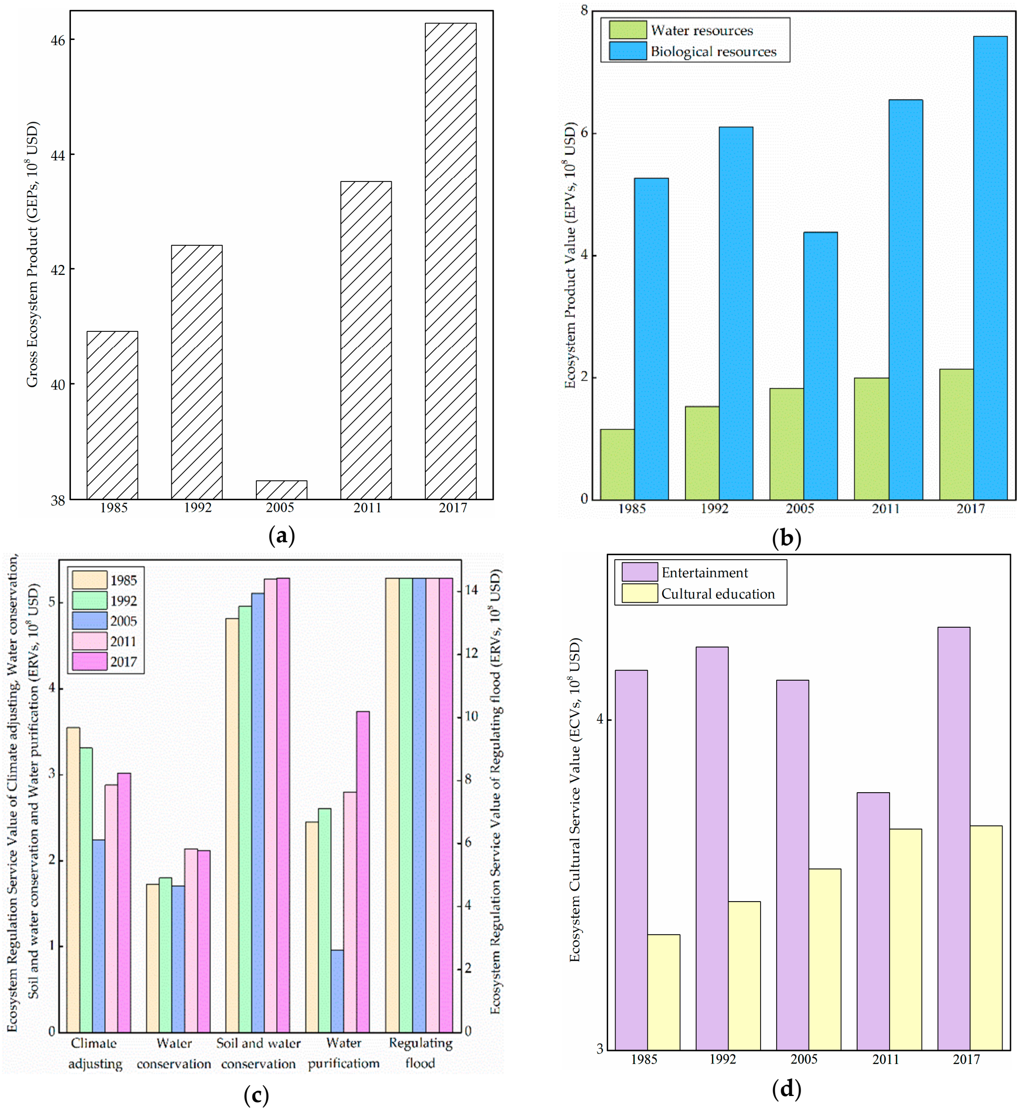

Figure 3. Variations of the gross ecosystem product in the Nansi Lake Wetland. (**a**) Gross Ecosystem Product, GEPs; (**b**) Ecosystem Product Value, EPVs; (**c**) Ecosystem Regulation Service Value, ERVs; (**d**) Ecosystem Cultural Service Value, ECVs.

3.2. Spatial Variation of the Gross Ecosystem Product of the Nansi Lake Wetland

In this study, the landscape types of the Nansi Lake Wetland were classified by interpreting the remote sensing image data. According to the Ramsar Convention [54] and WET health tool box [55], Nansi Lake Wetland was divided into seven landscape types: lakes, rivers, swamps, ponds, paddy fields, building lands, and other types of land uses (Table 2). Lakes, rivers, and swamps were classified as natural wetlands. Ponds and paddy fields were classified as altered wetlands. The landscape classification map is shown in Figure 4. During recent years of human disturbance, the landscape of the Nansi Lake Wetland has undergone tremendous changes. The area of lakes and swamps has decreased, while the area of ponds and paddy fields has been extended (Table S5).

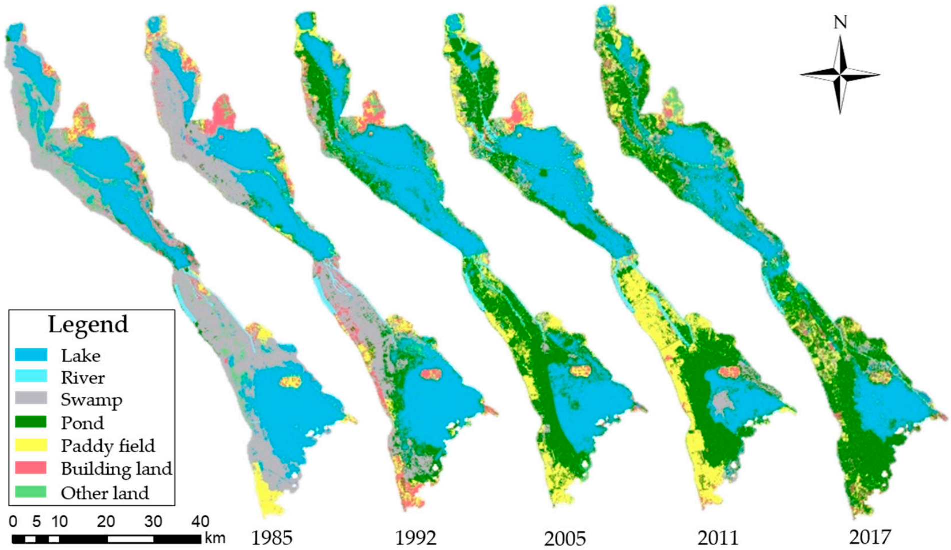

Figure 4. Landscape type classification map in the Nansi Lake Wetland (landscape changes in the years 1985, 1992, 2005, 2011, and 2017 are shown from left to right).

Table 2. Classification and definition of landscape types in Nansi Lake.

Wetland Type	Landscape Type	Definition
Natural wetlands	lakes	Permanent freshwater lake, with an area greater than 8 hm^2.
	rivers	Perennial or seasonally flowing waters of natural formation or artificial excavation.
	swamps	A large area of low-lying water and overgrown mud.
Altered wetlands	ponds	Land use area formed by composite artificial ecosystems such as drainage channel and fish pond.
	paddy fields	Cultivated land used to grow aquatic crops such as rice and lotus root.
Non-wetland landscape	building lands	Construction, mining, transportation and other land use types.
	other land uses	Other types of land use such as bare land.

The value of the flood regulation function was estimated using the maximum amount of the flood season in Nansi Lake, but could not be well divided in terms of natural wetlands and altered wetlands, so areas for these types were considered together. Compared with lakes, rivers, and swamps, the values of water conservation and water purification services in altered wetlands were neglected because of their relatively small values. Furthermore, when the biomass of animal and plant resources was divided into natural wetlands and altered wetlands, this was mainly calculated according to the proportion of the wetland area. As *P. australis* and *N. nucifera* (the main components of the emergent macrophytes) are mainly grown in natural wetlands, the biomass of the emergent macrophytes in altered wetlands was ignored. Moreover, the yield of paddy fields was incorporated into the gross ecosystem product calculation of the altered wetlands (Tables S6 and S7).

From 1985 to 2017, the GEPs of the natural wetlands were always higher than those of the altered wetlands. The GEPs of the altered wetlands increased sharply year by year, while the GEPs of the natural wetlands showed an upward trend, after a period of decline in 1992. The GEPs of the altered wetlands increased about 8.6-fold, changing from 1.37×10^8 USD in 1985 to 11.74×10^8 USD in 2017. However, the GEPs of natural wetlands showed a downward trend from 25.12×10^8 USD in 1985, but their value has gradually recovered in recent years and reached 20.12×10^8 USD in 2017 (Figure 5a).

The value of all kinds of ecological service types of the altered wetlands showed a rising tendency (Figure 5b). The value of entertainment increased significantly from 0.07×10^8 USD in 1985 to 2.18×10^8 USD in 2017, a more than 30-fold rise. The value of soil and water conservation changed from 0.38×10^8 USD in 1985 to 3.01×10^8 USD in 2017, which was the highest percentage of the total value in the altered wetlands. Except for the value of entertainment, which had a linear increase, the others were maximal in 2011. Furthermore, the changes in all values were relatively stable after 2011, apart from the increase in the entertainment value in altered wetlands.

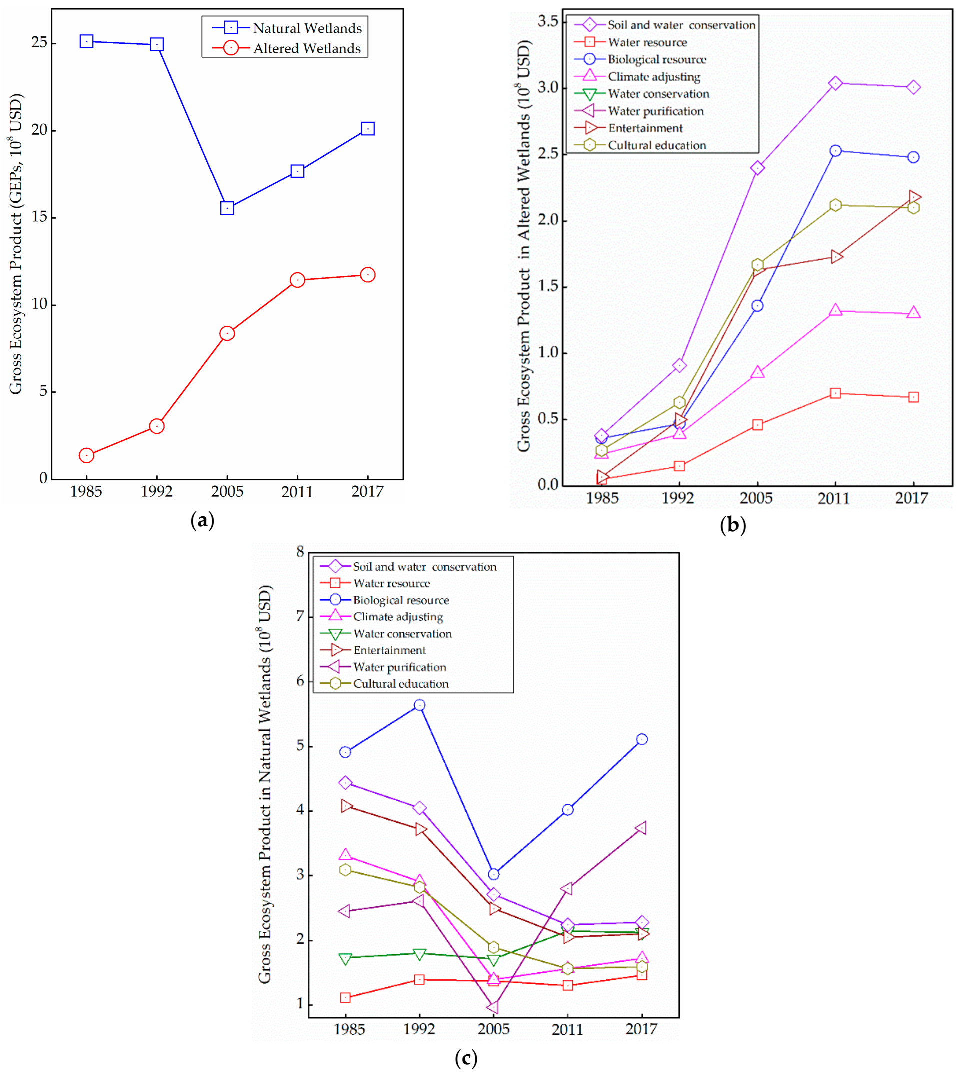

Figure 5. Comparison of gross ecosystem product in natural and altered wetlands. (**a**) Gross ecosystem product in natural and altered wetlands; (**b**) Gross ecosystem product in altered wetlands; (**c**) Gross ecosystem product in natural wetlands.

The value of ecological service types of the natural wetlands showed a more complicated trend than that of the altered wetlands. The values of the water resources, biological resource, water conservation, and water purification all increased, then decreased, and finally increased again. Moreover, the value of soil and water conservation, entertainment, and cultural education decreased. Except for the value of regulating flood, the value of biological resources comprised about 25% of the largest percentage. However, water resources had the smallest proportion of about 7% in natural wetlands. Taken together, all product values of the natural wetlands increased in 2017 (Figure 5c).

4. Discussion

In this study, it was found that wetland ecosystem services have changed in both time and spatial scales in the Nansi Lake Wetland. During the period from 1992 to 2005, the gross ecosystem product of the Nansi Lake Wetland decreased markedly. Previous studies found that changes in climatic conditions might play an important role in these changes, which would make future efforts to manage wetlands more complex [56–58]. It has been reported that the extreme drought at Nansi Lake in 2002 caused lakes to dry up and blocked rivers, which indicated a reduction in characteristic wetland diversity, vegetation degradation, and wetland landscape changes [59,60].

Moreover, there are abundant coal resources under Nansi Lake. Since 1992, a large number of companies have been licensed for coal mining. Coal mining activities under the lake have had a tremendous impact on the biological resources of the wetlands, especially water pollution, the reduction of the biomass of phytoplankton, and a decline in the yield of *P. australis* [61–63]. For example, the biomass of phytoplankton decreased from 2629 tons in 1992 to 2111 tons in 2005, and the production of *P. australis* decreased from 86,230 tons in 1992 to 31,700 tons in 2005. The large reduction in *P. australis* production has affected the water purification function of the Nansi Lake Wetland, which has directly caused a reduction of the regulation service value in Nansi Lake.

However, this is different from the downward trend value of ecosystem services found by the research results concerning mining areas [64,65]. Although the study area was affected by coal mining activities under the lake, the value of the gross ecosystem product was not affected much. Coal mining under the lake leads to an increase in water depth and water storage capacity, which might promote the growth of floating or submerged aquatic plants. The water level in the wetlands has changed, and the water depth has increased. A number of submerged aquatic plants were able to grow after the increase in water depth, resulting in the recovery of gross ecosystem product.

The gross ecosystem product of the Nansi Lake Wetland has gradually increased since 2005. These changes have mainly been due to the influence of the government on the Nansi Lake Wetland. In 2003, the Nansi Lake Water Resources Administration was established as a provincial nature reserve by the Shandong Provincial government. The overall goal is to protect the typical lake wetland ecosystem [55]. In recent years, a series of policies have been introduced by the Nansi Lake Water Resources Administration, for example, the Ecological Environmental Protection Program (2011–2015), Nature Reserve Management Regulations, Water Pollution Control Scheme, and Ecosystem Control Scheme.

A comparison of the gross ecosystem product of natural wetlands and altered wetlands showed that the gross natural wetland ecosystem product showed a similar trend as the gross ecosystem product in the Nansi Lake Wetland. The gross altered wetlands ecosystem product increased year by year. This area is a traditional farming area that has been affected by human activities such as reclamation for a long time. More and more, swamps and tidal flat wetland are being replaced by ponds and rice fields. The area of ponds has increased significantly since 1992, rising from 18 km^2 to 549 km^2, an increase of 531 km^2 (Table 3).

The increase in the area of ponds and paddy fields directly affects the product value of the Nansi Lake Wetland. Moreover, because a large number of natural wetlands have been replaced by altered wetlands, the increased gross ecosystem product of altered wetlands was much greater than the reduced ecosystem value of natural wetlands. This indicated that altered wetlands play an increasingly important role in driving the growth of the gross ecosystem product of the Nansi Lake Wetland.

Table 3. Variation of altered wetlands in Nansi Lake (km^2).

	1985	1992	2005	2011	2017
Pond	18	125	412	435	549
Paddy field	70	85	144	270	148

The results of the wetland ecological services value in Nansi Lake in this study showed both similarities and differences to other research results (Table 4). The accounting indicators of the ecological functions used by the authors are basically the same as those used by other researchers [48–51]. However, there are two main differences. First, the authors did not consider the biological habitat (Evaluation index ⑧ in Table 4) as a service factor for the evaluation of the Nansi Lake Wetland ecosystem services. This is mainly because the gross ecosystem product usually does not include eco-supporting service functions. Supportive service capabilities support the functionality and ecological adjustment of products and not directly for human well-being, and the role of these functions can be reflected in the product functions and adjusting functions, so the calculations should not be repeated. Second, Nansi Lake is the main source of the drinking, agricultural, and industrial water of the surrounding cities. The value of water resources (Evaluation index ① in Table 4) cannot be ignored. Therefore, the calculation results in this paper were relatively high, which was different from the index system and calculation method as chosen by other scholars working on the Nansi Lake Wetland [48,50,51]. Moreover, when calculating the value of the ecological assets of the Nansi Lake Wetland, the influence of inflation factors was taken into account. In this study, the 2017 constant price was the base year for calibration.

Table 4. Differences to other studies on the assessment of wetland ecological services in the Nansi Lake Wetland [1].

Base Year	Results (10^8 USD)	Evaluation Index	Reference
Average 2005–2008	32.91	②③④⑤⑥⑦⑧⑨⑩	[50]
2010	14.45	②③④⑤⑥⑦⑧⑨⑩	[51]
2012	19.51	②③④⑤⑦⑧⑨⑩	[48]
2005	38.32	①②③④⑤⑥⑦⑨⑩	This study
2011	43.52	①②③④⑤⑥⑦⑨⑩	This study
2017	46.28	①②③④⑤⑥⑦⑨⑩	This study

Note: [1] According to the literature and the existing evaluation practices, the accounting indicators of the value of the ecological functions in the Nansi Lake Wetland were divided into ten categories: ① water resources; ② biological resources; ③ climate adjustment; ④ water conservation; ⑤ flood regulation; ⑥ water purification; ⑦ soil and water conservation; ⑧ biological habitat; ⑨ entertainment; and ⑩ cultural education. Ordinal numbers in the table are the indicators used in the previous studies and in this study.

5. Conclusions

In this study, remote sensing image data, field research data, and literature data were used to estimate the changes of gross ecosystem product in the Nansi Lake Wetland. The study presents the following conclusions:

First, a complete and suitable system for the ecological assessment of wetland ecosystem services in the Nansi Lake Wetland was established. In this assessment system, there were three indicators and nine sub-indicators. The ecosystem product value was divided into water resources and biological resources. The ecosystem regulation service value contained climate adjustment, water conservation, soil and water conservation, flood regulation, and water purification. The ecosystem cultural service value comprised entertainment and cultural education.

Second, the gross ecosystem product (GEPs) of the Nansi Lake Wetland estimated for 1985, 1992, 2005, 2011, and 2017 increased from 40.91 × 10^8 USD in 1985 to 46.28 × 10^8 USD in 2017. The ecosystem regulation service value occupied the largest part, accounting for about two-thirds of the total economic value of the Nansi Lake Wetland. The ecological value of altered wetlands increased from 1.37 × 10^8 USD in 1985 to 11.74 × 10^8 USD in 2017, while natural wetlands presented a nonlinear relationship, which first decreased to 15.54 × 10^8 USD in 2005, and then increased to 20.12 × 10^8 USD in 2017.

In addition, human activities, especially coal mining under the lake and changes in climatic conditions, played important roles in the ecological services changes in the Nansi Lake Wetland. Therefore, in order to ensure the sustainable development of the Nansi Lake Wetland and human social economy, the rational utilization and effective protection of existing wetlands, under the guidance of the accounting of the gross ecosystem product, is recommended.

It is anticipated that the results of this research will provide new insight into the future of the ecological assessment of wetlands. This information will assist stakeholders in the scientific management of the Nansi Lake Wetland and attract more attention to the utility of its resources.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/11/4/788/s1, Figure S1: Current ecological environment in the Nansi Lake Wetland; Figure S2: Field surveys with different respondents in the Nansi Lake Wetland; Figure S3: Questionnaire on the current ecological environment in the Nansi Lake Wetland; Table S1: The average price of various ecosystem products and service functions in the Nansi Lake Wetland; Table S2: Average biomass of biological resources in the Nansi Lake Wetland; Table S3: Other related indicators of regulation service in the Nansi Lake Wetland; Table S4: Variation of gross ecosystem product in the Nansi Lake Wetland; Table S5: Landscape type classification area in the Nansi Lake Wetland; Table S6: Variation of gross ecosystem product of natural wetlands in the Nansi Lake Wetland; Table S7: Variation of gross ecosystem product of altered wetlands in the Nansi Lake Wetland.

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