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Service value of wetland ecosystem in Sanmenxia Reservoir area

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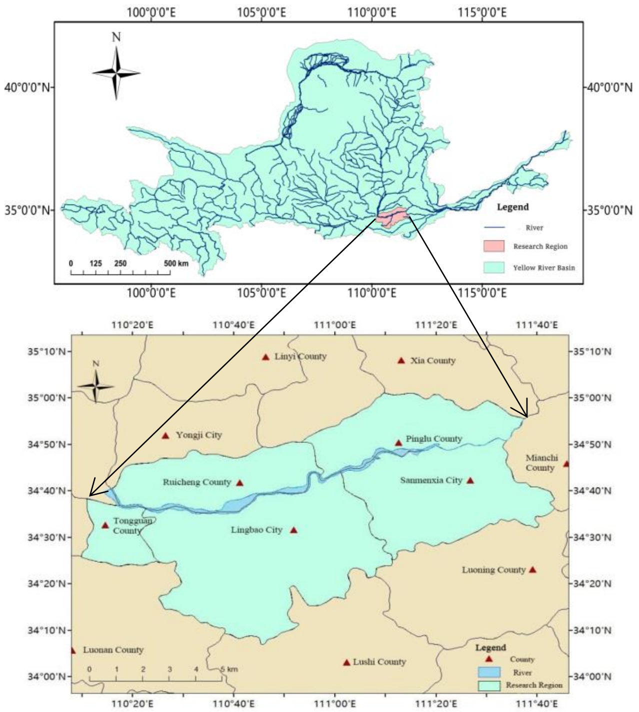
Graphical abstract



Abstract

The evaluation of wetland ecosystem service lays the foundation to the wetland protection and exploitation. Evaluating the ecological service of all types of wetlands scientifically and reasonably is critical to improving the quality of ecological environment and securing the regional ecological security. In the middle reaches of the Yellow River, a typical sediment-laden river wetland- Sanmenxia Reservoir area Wetland, is chosen as the research target. Based on the systematic analysis its unique formation process and ecological services, the biological resources are formed, including the value of supply service, regulation service, support service, and cultural service. The value of wetland ecological services was calculated by market value, opportunity cost, shadow engineering and substitution cost methods. The results show that the total value of wetland ecosystem service is worth about 80.86 billion yuan, and the dominant ecological services are regulation service and support service with the economic value of 46.49% and 50.85% respectively. The evaluation results make people more directly understand the importance of wetland leading ecological service and provide scientific basis for the protection and management of wetland in Sanmenxia Reservoir area.

Keywords: Sanmenxia Reservoir area wetland, wetland protection, wetland exploitation, ecosystem service, value assessment, evaluation method.

1. Introduction

As a unique ecosystem for water-land interaction, wetland not only provides food, medicine and other raw materials for production and living of human, but also creates and maintains the life support system of the earth and the environmental conditions necessary for human's survival (Ouyang *et al.,* 1999). Wetland ecosystems play an important role in flood controlling and drought relief, climate regulation, water conservation, flood regulation, land reclamation, biodiversity conservation, tourism and leisure. Therefore, it can bring significant ecological, economic and social benefits to humans (Brouwer *et al.,* 1999). Ecosystem's service refers to the natural environmental conditions and effects that human beings depend on for the ecosystems and in the ecological processes (Lu 2006). The evaluation on the value of ecosystem's service under each type of wetland is conducive to more direct identification of the leading services and ecological value of the wetland ecosystem. The direct monetary value highlights the importance of wetland to regional economic development (Humaira and Saima, 2018; Kong *et al.,* 2015; Sajil Kumar, 2020; Suhaili and Samsudin, 2018; Swodesh and Yuvraj, 2020).

Domestic and foreign scholars have done a lot of researches related to the evaluation on the value of wetland ecosystem services. Costanza (1997) *et al.* divided the global ecosystem into 16 types and divided the services of each ecosystem into 17 categories, including wetland ecosystems. For the first time, they used the United States, Indonesia and other countries as research targets for calculating the value of wetland ecosystem services, and then multiply the total area of global wetlands to estimate the total value of global wetland ecosystem services; Zorrilla-Miras *et al.* (2014) conducted research and analysis on the impact of land use on the wetland in the Doniana wetland in Spain. According to the results, land use change is the key to the loss of ecosystem service value; Xin *et al.* (2002) evaluate the service of wetland ecosystem in Panjin District of Liaohe Delta based on the method of GPS, field visit investigation, environmental economics, resource economics, fuzzy mathematics and other research methods. Hence, they obtained the service value of wetland ecosystem in this area is worthy of 6.213 billion yuan; Cui *et al.* (2016) divided the Zhalong wetland ecosystem services into two parts, the final service and the intermediate service. The value of the final service is regarded as the total value of the wetland ecosystem service. In addition, different evaluation methods, such as the market value method, the shadow price method and the travel expense method, are used. Ecological values are assessed in the form of monetization. The results show that, in 2011, the total value of Zhalong wetland ecosystem services was 67.94 billion yuan, and the intermediate service value was 47.15 billion yuan (Faiza *et al.*, 2018; Fikriah *et al.*, 2019; Md. Nazmul and Bo-Ching, 2019; Okoli *et al.*, 2018).

In this study, the research target was the typical multi-sediment river wetland-Sanmenxia Reservoir wetland in the middle reaches of the Yellow River. Based on the unique formation process and evolution law of the wetland in the Reservoir area, 10 representative ecological indicators and 2 unique ecological indicators (power generation and sediment transport capacity) were selected. A combination of environmental economics, resource economics and ecological economics (Xea *et al.,* 2007) are adopted for quantitative assessment of the four major services of the wetlands in the Reservoir area. The research results will help people to more directly recognize the importance of the wetland ecosystem's service in the Sanmenxia Reservoir area and provide a theoretical basis for the protection and management of wetland ecosystems and rational development and utilization. It has important scientific significance and practical value.

2. Overview of the study area

Based on the Yellow River's characteristics of a large amount of sand and mud, the Sanmenxia Reservoir Wetland (Tongguan-Sanmenxia) in the middle reaches of the Yellow River was selected as the study area (Figure 1). Sanmenxia Reservoir is located at the junction of Sanmenxia City, Henan Province and Pinglu County, Shanxi Province. It is between 108°45'-111°20' east longitude and 340°2l'-35°50' north latitude. It is the first comprehensive water conservancy and hydropower project for flood control, anti-flooding, water supply, irrigation and power generation on the mainstream of the Yellow River. The controlled drainage area is 688,000 km^2, accounting for 91.5% of the area of the Yellow River Basin (Cheng *et al.,* 1999). In the process of using the Sanmenxia Water Control Project for more than 50 years, the Reservoir area has formed a relatively stable ecological system. The most representative is the wetland ecosystem, which is the winter habitats of many rare waterfowls (Yang *et al.,* 2014). As the wetland in the Reservoir area is formed under effects of the special water and sand conditions in the middle reaches of the Yellow River and the different operating water levels in the Sanmenxia Water Control Project, the wetland types are rich and diverse, including river wetlands, beach wetlands, lakes and Reservoir wetlands, and marsh wetlands (Zhou *et al.,* 2015). In addition, with the change of Reservoir operation mode, the area of various types of wetlands also changed significantly.

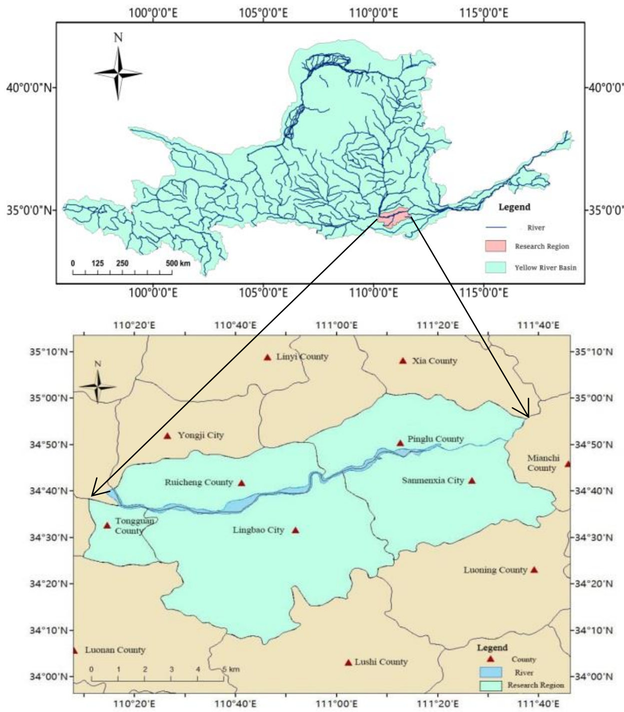


Figure 1. Schematic diagram of wetland research area in Sanmenxia Reservoir

3. Research method

3.1. Data source and method

3.1.1. Data sources

The various parameters cited in the calculation are originated from the observation data of the Sanmenxia Reservoir Wetland Hydrological Observatory (Tongguan Station and Sanmenxia Station), the meteorological data of the China Meteorological Network (Boyd *et al.,* 2019), the experimental data of the field survey and related departments. The obtained data is interpreted and processed by software such as ENVI and GIS, and the processing results are statistically analyzed.

3.1.2. Evaluation method

Fu Jiaoyan *et al.* (2007) combined the research results of ecological and environmental economics and divided the evaluation methods of wetland ecosystem service into income market evaluation, damaged market evaluation, inferential market evaluation and hypothetical market evaluation methods.

1. The income market assessment method means that the value generated by the wetland can be obtained through direct or indirect market transactions, including market value method, production service method, opportunity cost method and shadow engineering method;
2. The damaged market assessment is to obtain the indirect value by estimating the compensation cost due to the damage of the wetland, including the change of vitality method, the human capital law, the recovery cost method and the protection cost method;
3. Inferring the market assessment is to estimate the value of people's environmental preferences by observing people's market behavior, including expense expenditure method, travel expense method, hedonic value method, etc.;
4. Assume that market assessment is based on the lack of real market data or even indirect observation of people's market behavior (Meka-Mechenko *et al.,* 2017). It is necessary to establish a hypothetical market and conduct an assessment by investigating people's wishes to determine certain non-market goods or services. Value mainly includes the alternative cost method and the contingent valuation method.

Based on a comprehensive analysis of the ecological services provided by the wetland ecosystem in the Sanmenxia Reservoir area, this study selects the market value method (We, 1977), the carbon tax method (Zhou *et al.,* 2011), the opportunity cost method (Ding *et al.,* 2015), the shadow engineering method (Xea *et al.,* 2007), and the replacement. The cost method (Yan *et al.,* 2000), the outcome parameter method (Su *et al.,* 2012) and the travel expense method (Sutton *et al.,* 2002) and other commonly used value assessment methods of wetland ecosystem services at home and abroad, to assess the ecological services' value of the wetland in the Reservoir area.

3.2. Establishment of evaluation index system

According to the principle of ecological and ecosystem services, the characteristics of wetland ecosystem in Sanmenxia Reservoir area, and the characteristics of wetland ecosystem types, structures and ecological processes in the Reservoir area (Woodward *et al.,* 2001), the wetland ecosystem services of Sanmenxia Reservoir area can be divided into supply, adjustment, support, and cultural services. Then, from the unique geographical location and formation conditions of the wetland in the Reservoir area (Fidan *et al.,* 2016), 12 ecological indicators with representative and unique characteristics were selected, and the evaluation index system of wetland ecosystem service value in Sanmenxia Reservoir Area was built (Table 1).

Table 1. Evaluation index system of wetland ecosystem services in Sanmenxia Reservoir Area

Service classification	Evaluation index	Evaluation method
Supply service	Biological resources	Market value method
	Water resources	Market value method
	Power generation	Market value method
Adjustment service	Atmospheric regulation	Carbon Tax Law
		Market Value Law
	Climate regulation	Opportunity cost method
	Sand transport capacity	Market value method
	Regulate flood	Shadow engineering
	Purify water quality	Alternative cost method
Support service	Biodiversity conservation	Result reference method
	Maintain ecosystem integrity	Market value method
Cultural service	Teaching and research	Result reference method
	Leisure Travel	Travel cost method

4. Value assessment on the ecosystem service

4.1. Value assessment on the supply service

4.1.1. Biological resources

The biological resources provided by the Sanmenxia Reservoir Wetland ecosystem are mainly aquatic products and plant resources. The assessment formula of the biological resource value is:

$$V_1 = \sum T_i \cdot P_i \quad (1)$$

In the formula: V_1 is the total value of biological resources, unit: yuan; T_i is the output of the main biological resources of the wetland in the Reservoir area, unit: $t \cdot a^{-1}$; Pi is the market unit price of the corresponding biological resources, unit: yuan.

According to the investigation and evaluation on aquatic resources in the Yellow River wetland, the annual output of wetland aquatic products in the Sanmenxia Reservoir area is about 76,000 tons, and the annual output of reeds, about 5,700 tons. The average price of aquatic products monitored by the Ministry of Agriculture was selected as the price index (Nowak *et al.,* 2017). The average value of aquatic products was 16.33 yuan/kg. Based on the market price difference between general reed and fine reed in the market, the average market price range of the two was estimated to be 0.41 yuan/kg. Finally, the total value of the wetland biological resources in the Sanmenxia Reservoir area was 1,243.3 million yuan.

4.1.2. Water resources

Sanmenxia Water Conservancy Project is a comprehensive water conservancy project in combination of power generation, irrigation and flood control. It provides abundant power for Henan, Hebei and Shanxi provinces, irrigation water source for Henan province, and plays a major role in flood control in Henan and Shandong provinces (Lee and van der Heijden, 2019). At the same time, Sanmenxia Reservoir is also the main source of water supply for more than 300,000 people. The assessment formula of water resource value is as follows:

$$V_2 = \sum Q_i \cdot P_i \quad (2)$$

In the formula: V_2 refers to the total value of water resources, unit: yuan; Q_i means the water consumption of each industry, unit: $t{\cdot}m^{-3}$; Pi is the price of water unit in the corresponding industry, unit: yuan·m^{-3}.

The annual average water consumption of the Sanmenxia Reservoir is 450 million m^3, among which agricultural water supply and the industrial water supply accounts for 89% (400.5 million m^3) and 6% (27 million m^3) respectively, and the urban life takes 4% (18 million m^3). In Sanmenxia City, the residential water is 1.3 yuan/m^3, industrial water is 2.1 yuan/m^3, and agricultural water is 0.32 yuan/m^3. Finally, it is calculated that the supply value of wetland water resources in Sanmenxia Reservoir Area is 208 million yuan.

4.1.3. Power generation

The Sanmenxia Water Control Project is the first large-scale water conservancy hub built on the main stream of the Yellow River. It has comprehensive utilization benefits such as power generation, flood control and irrigation. The power generation value assessment formula is shown as follows:

$$V_3 = E \cdot R \cdot P \quad (3)$$

In the formula: V_3 is the total value of power generation, unit: yuan; E is the average annual power generation, unit: $Kw{\cdot}h$; R is the average line loss rate of the grid enterprise, unit: *%*; P refers to the average power price of national power generation enterprises, unit: yuan·$(Kw{\cdot}h)^{-1}$.

According to the statistics, after three renovations, the existing installed capacity of the Sanmenxia Hydropower Station reaches 400 MW, and the average annual power generation is 1.317 billion kw·h (Cheng *et al.,* 2019). The average annual line loss rate of national grid enterprises in 2013-2017 accounts for 6.45%, and the average on-grid price of power generation enterprises in China is 0.39 yuan/Kw·h. In summary, the total value of the wetland power generation in the Sanmenxia Reservoir area is 481 million yuan.

4.2. Value assessment on adjustment service

4.2.1. Atmospheric regulation

The wetland fixes the CO_2 in the atmosphere, releases O_2 into the atmosphere through the photosynthesis of large areas of the reed plants and other aquatic plants, hence regulating the atmosphere to reach the dynamic balance of CO_2 and O_2 in the atmosphere. The formula for evaluating the value of atmospheric regulation is:

$$\begin{aligned} M_1 &= 1.63 \cdot T \\ M_2 &= 1.2 \cdot T \\ V_4 &= \sum M_i \cdot P_i \end{aligned} \quad (4)$$

In the formula: V_4 is the total value of atmospheric regulation, unit: yuan; M_1 is the annual fixed CO_2 amount, unit: $t{\cdot}a^{-1}$; M_2 is the annual release of O_2; T is the annual plant production, unit: $t{\cdot}a^{-1}$; and P_i is the price of carbon fixation, unit: yuan·t^{-1}.

According to the current international standard for carbon tax rate and China's reality, the research takes China's afforestation cost of 250 yuan/t and average of 770 yuan/t based on the international carbon tax standard of 150 dollars/t as the carbon tax standards, the amount of CO_2 absorbed Sanmenxia Reservoir area wetland plants is 9291 t, and the value of CO_2 absorbed by wetland plants in Sanmenxia Reservoir area is calculated to be 715×10^4 yuan (Abdin *et al.,* 2018). The value of O_2 released by wetland plants in Sanmenxia Reservoir area is calculated by using the industrial manufacturing cost of oxygen as the shadow price. As the industrial oxygen cost is 400 yuan/t, the value of annual release of O_2 is calculated to be 274×10^4 yuan. Finally, the total value of the atmospheric regulation of the Sanmenxia Reservoir area is calculated to be 0.099 billion yuan.

4.2.2. Climate regulation

Wetland water is continuously released to the atmosphere through plant transpiration and water evaporation, thereby increasing air humidity and reducing air temperature to achieve climate regulation. The assessment formula for climate adjustment value is:

$$V_5 = \frac{E_z + E_s}{2} \cdot A \cdot P \quad (5)$$

In the formula: V_5 represents the total value of atmospheric regulation, unit: yuan; Ez refers to the plant evapotranspiration in the Reservoir area, unit: *mm*; Es is the water surface evaporation of the wetland in the Reservoir area, unit: *mm*; A means the water surface area of the wetland in the Reservoir area, unit :km^2; P is the unit price of water resources.

The Sanmenxia Reservoir area owns a large number of reeds in a wide distribution area. They are the main players in the transpiration of plants and the typical dominant plant species in the Reservoir area. In the study, the evapotranspiration of reeds is used as the transpiration of plants in the Reservoir area. The average annual evapotranspiration of the Sanmenxia Reservoir area is 1,056.59 mm; the evaporation of the wetland surface in the Reservoir area is the main source of water evaporation (Ingarao *et al.,* 2018). According to the observation data on the station in the study area, the average annual evaporation of the wetland surface in the Reservoir area is

1,732.85 mm. Based on ENVI software, the average surface area of the Sanmenxia Reservoir Wetland is interpreted to be 85 km^2; according to the water supply authority of Sanmenxia City, the water resource price is 1.3 yuan/m^3. Therefore, the total value of the climate regulation of the Sanmenxia Reservoir area is calculated to be 155 million yuan.

4.2.3. Sand transport capacity

With the people's improving understanding of social environment and water and sand resources and the development of economy and society, sediment resources are gradually recognized and widely used in production and practice (Khoo *et al.,* 2019). As an inexhaustible resource, sediment has great potential for development and utilization. The formula for evaluating the value of sediment transport capacity is shown as:

$$V_6 = S \cdot P \quad (6)$$

In the formula: V_6 is the total value of sediment transport capacity, unit: yuan; S is the average annual sediment transport, unit: $t \cdot a^{-1}$; P means the price of market neutral sediment, unit: $yuan \cdot m^{-3}$.

The average annual sediment transport volume of mainstream flow control hydrological station (Tongguan Station) on the Yellow River is 256 million tons. At present, the price of medium-sized sediment in the domestic building materials market generally ranges from 100-160 yuan/m^3, so the average value of 130 yuan/m^3 is taken. Therefore, the value of sediment transport capacity of the Sanmenxia Reservoir Wetland is 33.28 billion yuan.

4.2.4. Regulating flood

The formation of Sanmenxia Reservoir area wetland is closely related to the construction of the Sanmenxia water conservancy project. The formation of wetlands mainly depends on the application of water conservancy projects. The determination of the value of flood regulation in the Reservoir area also depends on the engineering data of the Sanmenxia Water Control Project. The formula for evaluating the value of flood regulation is:

$$V_7 = C \cdot P \quad (7)$$

In the formula: V_7 is the value of flood regulation, unit: yuan; C is the flood control capacity, unit: m^3; P is the price of building Reservoir capacity, unit: $yuan \cdot m^{-3}$.

The Sanmenxia Water Conservancy Project is located in the lower reaches of the middle reaches of the Yellow River. The controlled drainage area accounts for 91.5% of the total drainage area of the Yellow River and 89% of the inflow. It plays a huge role in flood control and regulation. After the reconstruction of the Sanmenxia Water Control Project, the highest flood control water level is 335 m, the flood control capacity is about 6 billion m^3, and the cost of constructing water conservancy facilities is 0.67 yuan. Therefore, the value of the flood regulation in the Sanmenxia Reservoir area is calculated to be 4.02 billion yuan.

4.2.5. Water purification

The herbaceous plants in the wetlands of Sanmen Reservoir area are lush, such as reeds, cattails, alfalfa and lotus, which can effectively purify the water of the reservoir. The sewage in the reservoir is mainly industrial wastewater and domestic sewage. There are more ammonium nitrogen and dissolved potassium phosphate in the water. These two inorganic nutrients can be easily absorbed by soil particles. The formula for evaluating the value of purified water is:

$$V_8 = W \cdot P \quad (8)$$

In the formula: V_8 is the value of water purification in wetland, unit: yuan; W is the amount of waste water discharged by the unit, unit: t; P is the operating cost of the sewage treatment plant, unit: $yuan \cdot t^{-1}$.

At present, the discharge of waste water from the Yellow River is 4.337 billion tons. The sewage discharge in the study area is 2.1% of the discharge of waste water from the Yellow River basin, or 91.1 million tons. At present, the operating cost for China's sewage treatment plant is between 0.51-3.01 yuan/t, the average operating cost is 1.38 yuan/t (the average construction cost is 0.37 yuan/t, the average sewage operating cost is 0.81 yuan/t, and the average treatment cost of sludge is 0.20 yuan/t) to evaluate the value of water purification in the Sanmenxia Reservoir area. Hence, the value of the purified water quality of the Sanmenxia Reservoir area is calculated to be 126 million yuan.

4.3. Value assessment on support services

4.3.1. Biodiversity conservation

The Sanmenxia Reservoir area is rich in wetland species and plays an important role in maintaining biological habitats and biodiversity. The formula for assessing the value of biodiversity conservation is:

$$V_9 = H \cdot P \quad (9)$$

In the formula: V_9 is the conservation value of wetland biodiversity, unit: yuan; H means the wetland area of Sanmenxia Reservoir area, unit: hm^2; P refers to the biological habitat value of wetland ecosystem per unit area, unit: $yuan \cdot hm^{-2}$.

The wetlands in the Reservoir area are abundant in animal and plant resources and are the winter habitats of many rare waterfowls. In this section, the bio-habitat value of the wetland ecosystem in China is estimated to be 2,203 yuan/hm^2 and the natural habitat value of the wetland ecosystem evaluated by Costanza *et al.* is US $304 /$hm^2$ (equivalent to RMB 2087.3 yuan/hm^2). The value is 2,145.2 yuan/hm^2. The wetland area of the Reservoir area is 18,450 hm^2.Hence, it is calculated that the conservation value of wetland biodiversity in Sanmenxia Reservoir Area is 0.4 billion yuan.

4.3.2. Ecosystem integrity

The Sanmenxia wetland ecosystem ensures the energy flow between the species within the system, the material circulation between the biomes and the environment, and maintains the normal process of species survival and evolution. The ecosystem integrity value assessment formula is:

$$V_{10} = Q_m \cdot P \tag{10}$$

In the formula: V_{10} represents the integrity value of wetland ecosystem, unit: yuan; Q_m is ecological water demand, unit: m^3; P means the unit price of water resources, unit: yuan·m^{-3}.

According to the literature, the minimum ecological water requirement of the Sanmenxia Reservoir Wetland is 16.835 billion m^3, the suitable ecological water requirement, 17.869 billion m^3, and the ideal ecological water requirement, 20.211 billion m^3. In order to maintain the integrity of the wetland ecosystem in the Sanmenxia Reservoir area and ensure the normal ecological services, this study uses a minimum water requirement of 16.835 billion m^3 and a water supply price of 1.3 yuan/m^3 provided by the Sanmenxia water supply authority. Therefore, the value of the wetland ecosystem integrity in the Sanmenxia Reservoir area is 21.86 billion yuan.

4.4. Value assessment on cultural service

4.4.1. Academic research

The value on education-oriented and scientific research provided by the Sanmenxia Reservoir area wetland is evaluated by the alternative cost method. The average value of education and scientific research value per unit area of wetland ecosystem is adopted to calculate the value of scientific and academic research in the Sanmenxia Reservoir area. The evaluation formula for academic and research value is:

$$V_{11} = H \cdot P \tag{11}$$

In the formula: V_{11} represents the academic and research value, unit: yuan; H is the wetland area of Sanmenxia Reservoir, unit: hm^2; P refers to the educational value of wetland per unit area, unit: yuan·hm^{-2}.

According to the average scientific research value of the wetland ecosystem per unit area in China and the average value of 3146.3 yuan/hm^2 for the evaluation of the global wetland ecosystem scientific research education by Costanza *et al.*, the educational research value of the wetland in the study area. The wetland area of the Sanmenxia Reservoir area is 18,450 hm^2. Finally, the academic and research value of the wetland in Sanmenxia Reservoir Area is calculated to be 58 million yuan.

4.4.2. Leisure travel

The wetlands of the Sanmenxia Reservoir area enjoy beautiful scenery, rare birds and colorful humanities landscapes. The natural resources and eco-tourism resources are combined to form a unique wetland natural human landscape with high tourism value. The value of leisure travel is calculated by using the travel cost method:

$$V_{12} = F_1 + F_2 + F_3 \tag{12}$$

In the formula: V_{12} is the total value of tourism, unit: yuan·a^{-1}; F_1 is the direct income of tourism (including tickets, hotel income, tourism goods expenditure and parking fee s), unit: yuan·a^{-1}; F_2 is travel expenses (transportation and accommodation costs), Unit: yuan·a^{-1}; F_3 is the travel time value (hourly wage standard ×total travel hours×40%).

According to the survey, the Sanmenxia Wetland receives 130,000 visitors a year, with an income of 113 million yuan, an average travel cost of 200 yuan, an average travel time of 1.5 days, and an average daily wage of 300 yuan. Therefore, the value of leisure tourism in the Sanmenxia Reservoir area is calculated to be 162 million yuan/year.

4.5. Discussion and analysis

Table 2 shows the services of different ecosystems in the Sanmenxia Reservoir area and their corresponding value. As the individual ecosystem services are based on the differences between the evaluation methods and data sources, there is a possibility that the evaluation results are lower than the actual ones. Through the evaluation of the 12 ecological indicators of the 4 major services of the Sanmenxia Reservoir area, the total value of the wetland ecosystem service in the reservoir area is 80.86 billion yuan, of which the proportion of the regulatory service value accounts for 46.49% among the four ecosystem services. The support service accounts for 50.85%, and the combined proportion of the two accounts for 97.34%. The ecological value of the two services accounts for almost all the ecological services of the wetland in the reservoir area. It can be seen from Table 2 that the main services of the Sanmenxia Reservoir Wetland are to maintain the integrity of the ecosystem > sediment transport capacity > flood regulation > biological resources > power generation > water resources > leisure tourism > climate regulation> water purification > academic and research > biodiversity conservation > atmospheric regulation. It can be seen that the main services of the Sanmenxia Reservoir Wetland are to maintain ecosystem integrity, sediment transport capacity, and flood regulation, which are worth 41.077 billion yuan, 33.28 billion yuan, and 4.02 billion yuan respectively.

5. Conclusion

The Sanmenxia Reservoir Wetland has an important ecological role, so the evaluation of the ecosystem service lays the foundation for the wetland protection and development and utilization of the Sanmenxia Reservoir area, and for ensuring the sustainable use of the wetland resources in the Sanmenxia Reservoir area. The study concluded that the total value of wetland ecosystem services in the Sanmenxia Reservoir area is 80.86 billion yuan, of which the service of the four ecosystem services accounts for 2.39% of the total value, the regulation service accounts for 46.49%, the support service accounts for 50.85%, and the cultural service accounts for 0.27%. The evaluation results show that the value of the wetland ecosystem service in the Sanmenxia Reservoir area is very considerable, and it also has significant ecological benefits and direct economic benefits. In particular, core services, such as maintaining ecosystem integrity, sediment transport capacity, and flood regulation are potential and intangible services that are easily neglected. If we only pay attention to the obvious economic value, it will inevitably result in the loss of the service value of the ecosystem and the destruction of the ecosystem. In recent years, with the rapid development of the economy, the urban development and construction process has accelerated. The wetland resources in the Sanmenxia Reservoir area are also disrupted by various factors, such as river pollution, destruction of animals and plants, and large-scale tidal flat wetlands being occupied as farmland. This directly leads to the decline of wetland ecological services and value reduction.

The Sanmenxia Reservoir area wetland ecosystem provides many ecological services. In this study, only 12 representative and unique ecological indicators were selected, and the value of the wetland ecosystem service in the Reservoir area was estimated. However, due to the lack of basic data and the lack of evaluation methods, the evaluation results vary. For example, in this study, the wetland tourism resources in Sanmenxia Reservoir area are unevenly distributed in this area. The value of wetland tourism service value in the Reservoir area is calculated by using the value of wetland leisure tourism per unit area. It is impossible to accurately assess the value of tourism services. In addition, in the assessment of biodiversity conservation and cultural research valued, the research methods and application parameters of Costanza commonly used in domestic wetland evaluation are adopted, which is difficult to directly reflect the ecological service value provided by the wetland ecosystem in the targeted area. In the future research, we should focus on the structural composition, specific services and changing processes of the wetland ecosystem in the Reservoir area, and explore the complex relationship between the ecosystem system and the economic system, in order to fully and accurately reflect the value of various ecological services provided by the Sanmenxia wetland ecosystem.

Since different types of wetland ecosystem services provide different services, appropriate evaluation methods should be adopted. As the research on the evaluation of wetland ecosystem services is gradually deepened, a more complete evaluation system and calculation method will be applied. It is hoped that policy makers and administration departments at all levels will use the data and analysis on this research in wetland protection and management to formulate and implement reasonable wetland protection policies and measures to promote the healthy and sustainable development of the wetland ecosystem throughout the Reservoir area.

Table 2. The value of wetland ecosystem service in Sanmenxia Reservoir Area

Services	**Value (billion)**		**Proportion (%)**	
Supply service	Biological resources	12.433	1.54	2.39
	Water resources	2.08	0.26	
	Power generation	4.81	0.59	
Adjustment service	Atmospheric regulation	0.099	0.01	46.49
	Climate regulation	1.55	0.19	
	Sand transport capacity	332.8	41.16	
	Regulate flood	40.2	4.97	
	Purify water quality	1.26	0.16	
Support service	Biodiversity conservation	0.4	0.05	50.85
	Maintain ecosystem integrity	410.77	50.80	
Cultural service	Academic and research	0.58	0.07	0.27
	Leisure Travel	1.62	0.20	
Total	808.6	100	100	

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