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Evaluation of Urban Wetland Ecosystem Service Value in Zhuzhou City

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ABSTRACT

Zhuzhou is an important part of the Changsha-Zhuzhou-Xiangtan city group in southern China. To grasp the economic benefits of urban wetland resources value in Zhuzhou City, strengthen wetland conservation and utilization, and ensure the sustainable development of cities, this paper takes Zhuzhou 2016 wetland remote sensing image interpretation map and multi-source data as the foundation, and build urban wetland ecosystem service evaluation system. Through deduplicate double counting, this paper evaluates the value of urban wetland ecosystem service in Zhuzhou City employing shadow project method, replacement cost method, travel cost method, conditional value method and other economic value evaluation methods. The results indicate: (a) The total value of urban wetland ecosystem services is $1,527,908,900 in 2016. (b) The ultimate value of urban wetland services ranked as follows: water storage regulation value ($539,566,265), climate regulation value ($424,930,361), tourism recreation value ($174,543,328), water supply value ($133,183,901), biological product value ($121,987,952), atmospheric composition regulation value ($92,111,687), soil erosion prevention value ($15,799,608), water purification value ($14,598,298), and aesthetic heritage value ($10,075,346); (c) The value of different types of wetlands ranked as follows: paddy fields ($526,111,672), riverine wetland ($526,111,672), ponds ($329,628,343), reservoirs ($149,275,241), wastewater treatment plant ($207,831/a); (d) The value per unit area of different types of wetlands ranked as follows: reservoirs ($240,919/ha), riverine wetland ($236,627/ha), pond ($145,693/ha), paddy fields ($26,551/ha) and wastewater treatment plant ($17,003/ha). The evaluation results reveal the great contribution of urban wetland system service to the Zhuzhou city with numbers, that not only provides data basis for wetland conservation and management but also provides a reference for the refined evaluation of urban wetland ecosystem service value.

INTRODUCTION

Wetland ecosystem services refer to the direct or indirect contribution of wetland ecosystems to human well-being and benefits (USEPA 2009, TEEB 2010). The study of wetland ecosystem services began in the middle and late 20th century. With the emergence of global environmental issues, this work has gradually become one of the hot topics of concern in ecology and economics. Numerous international organizations, experts and scholars have carried out a lot of research on wetland ecosystem services in terms of concept definition (Costanza et al. 1997, MA 2005, Wallace 2007, Boyd & Banzhaf 2007, Fisher & Kerry 2008, Fisher et al. 2008, Fisher et al. 2009), classification method (Daily 1997, De Groot et al. 2002, Woodward & Wui 2001, Brander et al. 2006, De et al. 2006), evaluation method (Costanza 2008, Adamus et al. 1987, Odum & Nilsson 1996, Turner et al. 2010, Hawkins 2003), and value evaluation (Hoekstra & Hung 2002, Nelson et al. 2009, Musamba et al. 2012, Jiang et al. 2015, De et al. 2012, Sun et al. 2018, Zhao & He 2018). Through many cases, it has fully revealed the multi-faceted ecosystem service functions and values provided by wetlands for human society. Among these wetland case types, natural wetlands outside the urban area are the main targets of ecosystem service value assessment research, while research on urban wetlands is relatively rare.

Wetlands are the birthplace of human "civilization" and are closely related to the beginning and decline of the city. On the one hand, wetlands provide many natural resources and material basis for the urban production and life, which provide a strong guarantee for the urban ecological balance and social development, while on the other hand, under the background of intensified global urbanization, human activities have caused serious disturbance and damage to wetlands, especially the shrinking area and increasing degree of fragmentation of wetlands within the urban area, and their ecosystem services are also affected in many aspects. The evaluation of urban wetland ecosystem service value is a process of quantitative evaluation of multiple service values of various types of wetlands within the city, which provides scientific data support for comprehensive protection and utilization of wetlands and sustainable development of the city (De et al. 2006).

At present, the economic value evaluation method is the most widely used one in many wetland ecosystem service evaluation methods. It is a quantitative assessment of the monetization of wetland ecosystem services. It not only reflects the impact of human activities on the structure and function of wetland ecosystem (Costanza et al. 2014), but also provides a basis for ecological compensation decision-making (Farley et al. 2010), and improves people's understanding of the importance of wetland ecosystem services (Braat et al. 2012).

Zhuzhou is an old industrial base in southern China. Its natural conditions are superior and its wetland resources are abundant. The Xiangjiang River flows through the city from south to north, dividing the urban area into two sides. In the past, the characteristics of traditional industries dominated by heavy chemical industry have caused huge consumption of natural resources in Zhuzhou City, which has caused a great impact on urban wetlands, serious water pollution, and the shrinking of wetland area and quantity. In the 21st century, Zhuzhou has become an important part of Changsha-Zhuzhou-Tan urban agglomeration, which is a demonstration area of "two-oriented society construction". Its urbanization process is intensifying and the urban area is expanding. Therefore, coordinating urban sustainable development and wetland conservation and utilization has become the focus of government and society. It is urgent to scientifically evaluate the value of wetland ecosystem services in Zhuzhou City, and provide a reference for management decision-makers. Based on the socio-economic environment of Zhuzhou City and the ecological characteristics of wetlands, this paper evaluates the value of urban wetland ecosystem services by various suitable economic value evaluation methods and reveals the wetland ecosystem services to provide urban survival and development with intuitive economic figures.

MATERIALS AND METHODS

Research Area Overview

Zhuzhou located in the east of Hunan province in China, in the west of Luoxiao Mountain Range, Nanling Mountains Range to the tilting area of Jianghan Plain, and the downstream of the Xiangjiang River water system, between the northern latitude 26°03'05"~28°01'07", east longitude 112°57'30"~114°07'15" (Fig. 1). Zhuzhou is a subtropical monsoon humid climate, four seasons, adequate rainfall, and rich in wetland resources. As of 2016, the total area of Zhuzhou (including city and counties) is about 11247.55 km^2, of which the urban area is located in the northwest of Zhuzhou with an area of 853.4k km^2 and a permanent resident population of about 4,016,300. This paper takes 2016 urban area (Zhuzhou City) as the specific research area, covering urban planning area and built-up area.

Classification of Urban Wetland in Zhuzhou City

The concept of urban wetlands does not currently have a scientific definition in a strict sense. The academic community

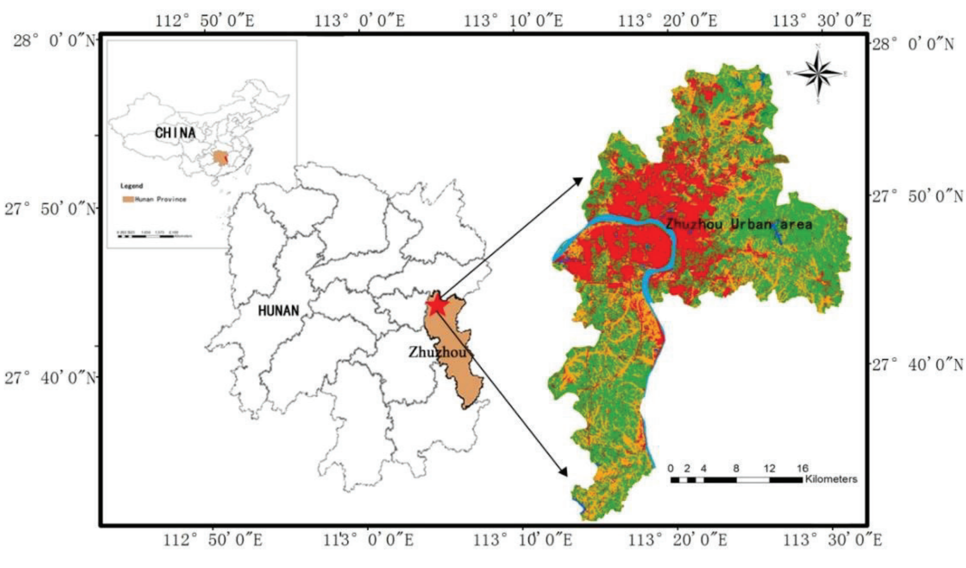

Fig. 1: Location of the study area.

Table 1: Classification of urban wetlands in Zhuzhou City.

Category	Primary type	Secondary type	Description
Urban wetland	Natural wetland	Riverine wetland	Permanent river, including rivers and their tributaries, stream, waterfall seasonal (has seasonal attributes) or intermittent (no obvious seasonal dependence) rivers, streams, floodplains (refers to the flood of flood-waters on both sides of the river)
	Artificial wetland	Reservoirs (area greater than 8ha)	Reservoir, lake, barrage, water storage area formed by the dyke, park wetland
		Pond (area less than 8ha)	Agricultural pond, water storage pond, Aquatic ponds such as fish and shrimp culture and small landscape water bodies
		Paddy fields	Rice fields, lotus, water bamboo fields, etc.
		Wastewater treatment plant	Sewage plant, treatment pool, oxidation pool, etc.

generally believes that urban wetlands refer to coastal and estuary, riverbanks, shallow lakes, water conservation areas, natural and artificial ponds, and wastewater treatment plants within urban areas. An ecosystem with a land-sea transitional nature (Wang & Lv 2007).

Based on the Ramsar Convention and the wetland classification system monitored by China's current wetland survey as the main basis, referring to "China's Land Use Status Classification" (GB/T 21010-2017), and other relevant norms, combined with the actual needs of the study, urban wetlands in Zhuzhou City are divided into natural wetlands and artificial wetlands. The specific classification and description are shown in Table 1.

Research Data Source

Data source and classification: The basic data of this paper mainly includes image data and statistical data. The main contents and sources are given in Table 2.

The Landsat 8 OLI remote sensing image data of Zhuzhou City come from the Geospatial Data Cloud Platform of the Chinese Academy of Sciences Computer Network Information Center (http://www.gscloud.cn); Zhuzhou City Administrative Border (2016), Zhuzhou City wetland Survey plaque data (2010) provided by Zhuzhou municipal forestry bureau; Zhuzhou City Google HD satellite map is downloaded from the internet employing 91 graphic assistant software.

Data interpretation: Based on the analysis software of ENVI5.3, ArcGIS10.4 and ecognition, and the object-oriented information extraction method, this paper finally obtained the classification and distribution of urban wetland in Zhuzhou city in 2016 (Fig. 2) and relevant data (Table 3).

Establishment of Evaluation System for Urban Wetland Ecosystem Service Value in Zhuzhou City

From the perspective of evaluating and managing ecosystems, the Millennium Ecosystem Assessment Classification System divides ecosystem services into four categories: supply services, regulatory services, cultural services and support services (Ma 2005), which is currently the most widely used wetland ecosystem service classification system. However, this classification system confuses the intermediate and ultimate services of wetland ecosystem, leads to double counting of ecosystem services, causes the unclear causal relationship between ecosystem functions and ecosystem services, and reduces the scientificity and applicability of wetland ecosystem services value assessment results (Boyd 2007, Johnston & Russell 2011, Nahlik et al. 2012, Ringold et al. 2013, Keeler et al. 2012, Wong et al. 2015). Therefore, the deduplication double-counting of ecosystem services has become the focus and difficulty of the refined assessment of

Table 2: Sources of data.

Classification	Data	Scope	Type	Time
Image data	Landsat 8 OLI	Row number 123/41	Landsat 8 OLI, 30m	07-23-2016
	Zhuzhou City wetland census spot	Zhuzhou City	Shapefile	2010
	Google Hd satellite maps	Zhuzhou City	TIFF	2016
Statistical data	Zhuzhou City administrative boundaries	Zhuzhou City	Geodatabase	2016
	Zhuzhou statistical yearbook	Zhuzhou City	Electronic document	2016
	Zhuzhou water resources bulletin	Zhuzhou City	Electronic document	2016

Table 3: Urban wetland types and acreage in 2016 in Zhuzhou City.

Urban wetland types	Area (ha)	Proportion (%)
Riverine wetland	2208.9	8.86
Reservoirs	619.6	2.49
Ponds	2262.5	9.08
Paddy fields	19819.9	79.52
Wastewater treatment plant	12.2	0.05
Total	24923.1	100

wetland ecosystem services and the optimal management of wetland ecosystem services (Jiang et al. 2015).

Due to the different scales and research purposes of ecosystems, wetland ecosystem services can exist in multiple classifications (Fisher et al. 2009, Costanza 2008) depending on the specific assessment environment and assessment objectives. Based on the classification of urban wetland in Zhuzhou City, this study takes the millennium ecosystem service classification as the main reference, conducts a comprehensive survey and analysis of Zhuzhou socio-economic environment and urban wetland ecological characteristics, and establishes the urban wetland ecosystem service evaluation system (Table 4) with the direct contribution to human benefits as the only criterion. Urban wetland ecosystem services are divided into ultimate services and intermediate services. The ultimate services include atmospheric composition regulation, climate regulation, water storage regulation, water purification, prevention of soil erosion, biological products, water supply, tourism, and aesthetic heritage. The sum of these services is the total value of the urban wetland ecosystem services in Zhuzhou City. Intermediate services include biodiversity, water conservation, and nutrient cycling, etc. These intermediate services contribute indirectly to human well-being through the ultimate service, and by excluding these intermediate services in the calculation of total value, double counting can be avoided.

CALCULATION PROCESS AND RESULTS

The value of urban wetland ecosystem services is a dynamic variable that changes with time and space. The evaluation process needs to indicate the time and region of its calculation. Based on the relevant basic data of urban wetland, this

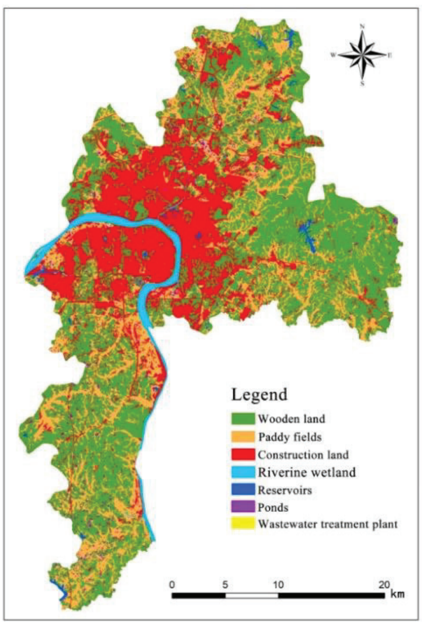

Fig. 2: Urban wetland classification in 2016 in Zhuzhou city.

paper uses Zhuzhou City as the research scope (853.4 km^2) in 2016 and uses the economic value evaluation method to calculate the ultimate service value and intermediate service value of urban wetland (all economic data is converted into 2016 prices based on the GDP deflator).

Final Service Value

Atmospheric composition regulation value: The adjustment value of atmospheric composition of urban wetland in Zhuzhou City mainly includes the value of oxygen release from wetland vegetation, soil carbon sequestration value and negative value of methane emission from paddy fields. It is mainly evaluated by the carbon tax value method and the market value method. The calculation equations are:

$$V_1 = V_C + V_t - V_f \quad \ldots(1)$$

$$V_C = C_1 \times P_1 \quad \ldots(2)$$

$$V_t = C_2 \times P_2 \quad \ldots(3)$$

$$V_f = C_3 \times P_3 \quad \ldots(4)$$

In the equations, V_1 is the value of the atmospheric composition of the wetland; V_c is the total value of oxygen release ($), C_1 is the total amount of oxygen released (t), P_1 is the price of oxygen release ($/t); V_t is the value of carbon sequestration of the soil ($), C_2 is Total carbon (t); P_2 is carbon sequestration price ($/t); V_f is the total methane released in paddy fields (kg), C_3 is the total methane release (t); P_3 is methane price ($/t).

(a) Wetland carbon sequestration and oxygen release positive benefits**:** *Soil carbon sequestration*: According to the relevant data, the carbon sequestration rate of the lake

Table 4: Assessment system of urban wetland ecosystem services in Zhuzhou city.

First level classification	Second level classification	Third level classification	Evaluation index and parameters	Wetland types included in the calculation	Evaluation method
Ultimate Service Value	regulation service value	Atmospheric composition Adjustment Value	Oxygen release, Carbon fixation, greenhouse gas emissions (Methane dominated)	Riverine wetland, Reservoirs, Pond wetlands, Paddy fields	Carbon tax value method, Industrial Oxygen production method
		Climate Adjustment Value	Temperature changes, humidity changes	Riverine wetland, Reservoirs, Pond wetlands, Paddy fields, Wastewater treatment plant	Shadow project method
		Water Storage Adjustment Value	Water storage, flood control and water yield regulation	Riverine wetland, Reservoirs, Pond	Shadow project method
		Water purification value	Removed quantity of N and P	Riverine wetland, Reservoirs, Pond	Replacement cost method
		Preventing soil erosion value	Reducing land waste, reducing soil fertility Loss	Riverine wetland, Reservoirs, Pond, Paddy fields	Replacement cost method
	Supply service value	Biological products value	Fish, rice, reed, etc.	Riverine wetland, Reservoirs, Pond, Paddy fields	Market value method
		Water supply value	Water consumption	Riverine wetland, Reservoirs	Market value method
	Cultural service value	Tourism recreation value	Travel cost, travel time cost, consumer Surplus	Riverine wetland, Reservoirs, Pond	Travel cost method
		Aesthetic heritage value	Willingness to pay, willingness to accept compensation	Riverine wetland, Reservoirs	Conditional value method
Intermediate Service Value		Biodiversity value	Diversity maintenance, habitat	Riverine wetland, Reservoirs, Pond	Result reference method
		Water conservation value	Surface water storage	River wetland, Reservoirs, Pond	Shadow project method
		Nutrient cycling value	Contents of N, P and K in Soil	Riverine wetland, Reservoirs, Pond, Paddy fields	Shadow price method

wetland is 190.2g/m^2·a (Song et al. 2011), and the soil carbon sequestration rate of the paddy fields is 380.78kg/m^2·a (Han et al. 2008).

Vegetation carbon fixation and oxygen release. Different ecosystems have different carbon fixation and oxygen release standards. In this study, the river wetland takes 0.22kg/m^2·a, and the lake wetland takes 0.15kg/m^2·a (Mei & Zhang 2007). The vegetation coverage index (NDVI) is extracted from the 2016 remote sensing image interpretation map of Zhuzhou City by ArcGIS and ENVI software. After the correlation calculation, the coverage area of non-paddy wetland plants is 2,994ha, which obtained the total carbon and oxygen release of wetland vegetation in Zhuzhou City.

Oxygen-releasing carbon price: According to the industrial oxygen production method, the price of oxygen release in 2016 is \$194.10/t. The carbon sequestration price adopts the carbon tax value method, and the 2016 conversion price is \$483.77/t.

***(b) Negative methane release from rice fields*:** Wetlands are important sources of greenhouse gas emissions such as methane, especially in rice fields where methane emissions are large (Song 2004). The paddy fields of Zhuzhou City (99% of rice fields) accounts for more than 80% of the total urban wetland area. Therefore, the economic value loss caused by methane emissions from rice fields is calculated as the economic value loss of greenhouse gas emissions from wetlands in Zhuzhou City. According to the relevant data, 0.36g/m^2·d is taken as the methane emission rate in the paddy field, and the methane emission in 410 months is taken as the total methane emission. The conversion price of methane in 2016 is \$0.19/kg (Shangguan et al. 1994).

(c) Taking the above data into the relevant equation for calculation, the atmospheric composition regulation value of urban wetland is \$92,111,687/a.

Climate regulation value: The climate regulation value of urban wetland in Zhuzhou City mainly includes temperature regulation and increased air humidity. It is mainly evaluated by the shadow engineering method. The calculation equations are:

$$V_2 = V_Q + V_h \quad \ldots(5)$$

$$V_Q = ET \div ER_{ac} \times P_e \quad \ldots(6)$$

$$V_h = EW \times PC_{ew}/m^3 \times P_e \quad \ldots(7)$$

In the equations, V_2 is the value of climate regulation (\$); V_Q is the value of temperature regulation (\$); ET is the heat absorbed by total evaporation (J); ER_{ac} is the energy efficiency ratio of the air conditioner; V_h is the value of air humidity (\$); EW is the amount of water evaporated (m^3); PC_{ew}/m^3 is the evaporation power consumption per cubic meter; P_e is the electricity price (\$/kWh).

***(a) Temperature regulation value*:** The annual evaporation of Zhuzhou City's waters relative to land is 14.3557×10^6 mm^3, which is selected 2.26×10^6 J/kg as the evaporation heat value of the water body. The energy efficiency ratio of the air conditioner is calculated according to 3.0, and the electricity price is \$0.09/kWh in 2016.

***(b) Increase the value of air humidity*:** The evaporation power consumption per cubic meter of water is converted into water vapour consumption of about 125 kWh as a parameter (Wu et al. 2016). The electricity price is taken at 2016 price of \$0.09/ kWh.

(c) Taking the above data into the relevant equation for calculation, the climate regulation value of urban wetland is \$424,930,361.45/a.

Water storage adjustment value: The water storage adjustment value of urban wetland in Zhuzhou City is mainly reflected in flood control and storage, regulation of water flow and flow rate, adjustment of regional water resources, etc., mainly adopted for evaluation by shadow engineering method and protection cost method. The calculation equation is:

$$V_3 = C \times V_i \quad \ldots(8)$$

In the equation, V_3 is the value of water storage adjustment (\$); C is the total amount of water storage regulation (m^3); V_i is the storage capacity per unit of water storage capacity (\$ /m^3).

According to the 2017 Statistical Yearbook of Zhuzhou City, the total water resources in Zhuzhou City in 2016 is 933×10^6 m^3. According to the "2001-2010 China Water Yearbook" data, the conversion cost of the unit storage capacity in 2016 is \$0.58/m^3. Taking the above data into the relevant equation for calculation, the water storage adjustment value of urban wetland is \$539,566,265/a.

Water purification value: The water purification value of urban wetland in Zhuzhou City is mainly reflected in the removal capacity of total nitrogen and total phosphorus in water by the wetland. It is mainly evaluated by the alternative cost method. The calculation equation is:

$$V_4 = N \times S \times V_N + P \times S \times V_P \quad \ldots(9)$$

In the equation, V_4 is the value of purification of wetland water (\$); N is the removal rate of nitrogen per unit area of the wetland; P is the removal rate of phosphorus per unit area of the wetland; S is the area of wetland (m^2); V_N is the treatment cost of nitrogen (\$/kg); V_p is the processing cost of phosphorus (\$/kg).

According to relevant data, the average removal rates of nitrogen and phosphorus per unit area of wetland are 3.98t/ha and 1.68t/ha, respectively (Jin et al. 2006). The total amount of nitrogen and phosphorus removed from the wetland water body is calculated based on the total area of urban wetland in Zhuzhou City. The conversion and treatment costs of N and P are \$0.44/kg and \$0.73/kg respectively in 2016. Taking the above data into the relevant equation for calculation, the adjusted water storage value of urban wetland is \$14,598,298.19/a.

Preventing soil erosion value: The preventing soil erosion value of urban wetlands in Zhuzhou City is mainly reflected in the reduction of land abandonment and soil fertility loss. It is mainly evaluated by the alternative cost method. The calculation equations are:

$$V_5 = V_{F^1} + V_{F2} \quad ...(10)$$

$$V_{F1} = S_t \times V_t \quad ...(11)$$

$$S_t = M \div D,\ \mathrm{M = P \times S} \quad ...(13)$$

$$V_{F_2} = S_t \times D \times R \times L_i \times V_i \quad ...(14)$$

In the equations, V_5 is to prevent the value of soil erosion (\$); V_{F1} is to reduce the value of land abandonment (\$); V_{F2} is to reduce the value of soil fertility loss (\$); S_t is to wasteland area (m^2); V_t is to reduce the cost of land abandonment per unit area (\$/ha); M is to reduce the total amount of soil erosion (m^3); D is the average thickness of soil topsoil (m); P is the depth of erosion (m), S wetland area (m^2); D is the average thickness of soil topsoil (m), R is the soil bulk density (g/), L_i is the content of the i-th nutrient element in the soil (kg), V_i is the price of the i-th element fertilizer (\$/t).

(a) Reduce land waste value**:** Referring to relevant data, the average value of grassland erosion depth is 25mm/a (Li et al. 2000), which calculates the total annual soil erosion of urban wetland is 6,277,500m^3 in Zhuzhou City. The average thickness of soil topsoil is 85mm, and the cost of reducing land per unit area is \$36.97/ha (Wu et al. 2015). The discounted price in 2016 is \$188.38 /ha.

(b) Reduce the loss of soil fertility**:** In this paper, the values of nitrogen, phosphorus and potassium nutrients are used to measure the value of wetland to reduce the loss of soil fertility. The bulk density of the soil is 1.2g/cm^3; the average content of nutrients in the soil surface is N=1.877g/kg, P=0.49g/kg, K=7.96g/kg (Li et al. 2006). The prices of nitrogen fertilizer, phosphate fertilizer and potash fertilizer in 2016 are \$189.17/t, \$100.39/t and \$265.85/t, respectively.

(c) Taking the above data into the relevant equation for calculation, the soil erosion value of urban wetland is \$16,911,762.05/a.

Biological product value: The biological products value of urban wetland in Zhuzhou City is mainly reflected in the value of freshwater animal products and rice. It is calculated based on the fishery output value and rice output value and is mainly evaluated by the market value method. The calculation equation is:

$$V_6 = V_y + V_d \quad ...(15)$$

In the equation, V_6 is the value of the biological product (\$); V_y is the output value of the fishery (\$); V_d is the output value of the rice (\$).

According to the 2017 Statistical Yearbook of Zhuzhou City, the total annual fishery output value in 2016 is \$27,480,422; the total output value of rice is \$94,507,530. Taking the above data into the relevant equation for calculation, the biological products value of urban wetland is \$121,987,951/a.

Water supply value: The water supply value of urban wetland in Zhuzhou City is mainly reflected in the value of water supply, including the provision of four types of water use, such as domestic water, industrial water, agricultural water, and public ecological water. It is evaluated by the market value method. The calculation equation is:

$$V_7 = \Sigma A_i \times P_i \quad ...(16)$$

In the equation, V_7 is the value of water supply (\$); A_i is the amount of water used for the i-th use (m^3); P_i is the market price of water for the i-type (\$ /m^3).

According to the 2017 Statistical Yearbook of Zhuzhou City, the total water consumption in 2016 is 67.854 × 10^6 m^3, of which the domestic water consumption is 71.84 × 10^6 m^3, the unit price is \$0.24/m^3, the industrial water consumption is 386.89 × 10^6 m^3, and the unit price is \$0.29/m^3; The water and public ecological water use are 140.44 × 10^6 m^3 and 79.37 × 10^6 m^3 respectively, and the unit price is \$0.02 /m^3. Taking the above data into the relevant equation for calculation, the supply value of the urban wetland water source is \$133,183,901/a.

Tourism recreation value: The tourism recreation value of urban wetland in Zhuzhou City is mainly reflected in the value of sightseeing and tourism in wetlands, the value of leisure and entertainment, the value of popular science education, and the value of health and fitness. This paper uses the Travel Cost Method (TCM) to evaluate the non-market value evaluation method of tourism resources based on consumer choice theory (Dong et al. 2011), which generally includes two parts: consumer expenditure and consumer surplus. Among them, consumer expenditure includes travel expenses and travel time value. This study passed the questionnaire survey (350 questionnaires are distributed, 334 valid questionnaires are returned, feedback rate is 95.43%) and analysis is obtained; consumer surplus is passed through consumers. The proportional relationship between the remaining and travel expenses is obtained. The equation for calculating the value of urban wetland tourism recreation is:

$$V_8 = a_1 + a_2 + a_3 \quad \ldots(17)$$

In the equation, V_8 is the value of tourism recreation for urban wetlands in Zhuzhou City; a_1 is expenditure for travel expenses; a_2 is value for travel time; a_3 is for consumer surplus.

***(a) Questionnaire statistics and analysis*:** Local tourist spending behaviour. Table 5 shows that urban wetland in Zhuzhou City are more attractive to surrounding residents, and the average length of recreation is 2 to 3 hours. More than half of the people who spend less than $5 per capita have a lower per capita consumption index.

Foreign tourists' consumption behaviour: It can be seen from Table 6 that the foreign tourists of urban wetland in Zhuzhou City mainly come from neighbouring cities, and there are many forms of self-driving tour; and the number of repeated play in the past three years is relatively low; the average playtime is 2 to 4 hours; the average cost per person is $5 to $15 is the main.

Table 5: Analysis of local tourists' consumption behaviour.

Issue	Options	Select the number of	Proportion (%)
How many kilometres are you from the wetland (park/scenic area)?	Within 3 km	83	28.23
	3-5 km	105	35.71
	5-10 km	84	28.57
	10-15 km	18	6.12
	15-20 km	2	1.02
	More than 20 km	1	0.34
How many times a year do you visit urban wetland (park/scenic area)?	Once	12	4.08
	Twice	21	7.14
	3 times	46	15.65
	4 times	32	11.22
	5 times	27	9.18
	6 to 10 times	64	21.77
	Once and twice a week	46	15.65
	Almost every day	45	15.31
How do you travel to urban wetland (park/scenic area)?	Walk	74	25.17
	Bus	107	36.39
	Self-driving	81	27.55
	A bicycle / battery car / motorcycle	19	6.8
	Taxi	12	4.08
How long did you spend in urban wetland (park/scenic area)?	Less than 1 hour	70	23.81
	2 to 3 hours	176	59.86
	3 to 4 hours	33	11.22
	4 to 5 hours	8	3.06
	6 hours and more	6	2.04
What is the cost of your visit to urban wetland (park/scenic area)?	Less than $5	174	59.18
	$5 to $15	76	25.85
	$15 to $30	29	9.86
	$30 to $45	8	2.72
	$45 to $75	5	1.7
	More than $75	2	0.68

***(b) Travel expenses*:** According to the preliminary questionnaire survey, the average daily travel cost of local tourists is $9.94, and the average daily travel cost of foreign tourists is $21.84. From this, the average daily travel cost of urban wetland in Zhuzhou City is about $12.35/person. In 2016, the total number of tourists in Zhuzhou City is 27.1579 million. The number of wetland tourists is estimated based on 30% of the total number.

***(c) Travel time value*:** Travel time value = number of visitors × total travel time × spent unit time opportunity wage cost. The travel time value is calculated according to the per capita disposable income of the urban population of Zhuzhou City $5546.39 in 2016, and the opportunity cost is calculated according to one-third of the wage cost (Chavas et al. 1989). The monthly working hours of tourists from all sources are 168 hours. The travel time of local tourists is calculated as 0.5 hours; the travel time of non-local tourists is calculated as 2 hours. Recreation time is calculated as 3 hours.

***(d) Consumer surplus*:** According to related research, consumer surplus is generally calculated at 40% of travel expenses (Li 2006).

(e) Taking the above data into the relevant equation for calculation, the tourism recreation value of urban wetland is $174,543,328.31/a.

Aesthetic heritage value: The aesthetic heritage value of urban wetland in Zhuzhou City is mainly reflected in the non-use value of the invisible resources such as culture, history, aesthetic sources and species in the wetland.

In this paper, the Conditional Value Method (CVM) is mainly used for evaluation. The value of urban wetland cultural heritage in Zhuzhou City is calculated by building a hypothetical market to know people's willingness to pay for non-market items (WTP) or to obtain wiliness to accept (WTA) (Zhuang 2006). Its calculation equation is:

$$V_9 = V_{wtp} \times A \qquad \ldots(18)$$

Table 6: Analysis of consumption behaviour of foreign tourists.

Issue	options	Select the number of	Proportion /%
How do you come to Zhuzhou City?	Self-driving	16	40
	Automobile	7	17.5
	Ordinary train	7	17.5
	High-speed rail/bullet train	8	20
	Aircraft	2	5
	Other	0	0
In the past three years, have you visited urban Wetland (Park / Scenic spot) in Zhuzhou City?	Once	11	27.5
	Twice	13	32.5
	Three times	9	22.5
	Four times	0	0
	Five times	4	10
	6-10 times	1	2.5
How long do you spend in urban Wetland (Park / Scenic spot) in Zhuzhou City?	10 hours and more	2	5
	Less than 1 hour	5	12.5
	2 to 3 hours	23	57.5
	3 to 4 hours	7	17.5
	4 to 5 hours	2	5
	6 hours and more	3	7.5
How much do you spend on visiting urban Wetland (Park / Scenic spot) in Zhuzhou City?	Less than $5	7	17.5
	$5 to $15	15	37.5
	$15 to $30	8	20
	$30 to $45	6	15
	$45 to $75	2	5
	More than $75	2	5

In the equation, V_9 is for the aesthetic heritage value ($); V_{wtp} is for the WTP value ($); A is the number of permanent residents in Zhuzhou City.

(a) CV questionnaire design**:** Relevant data are collected through the development of the wetland aesthetic heritage value questionnaire. Using a district survey, East area of Xiangjiang River issued 150 questionnaires and recovered 150 copies (including 4 unqualified questionnaires); West area of Xiangjiang River issued 200 questionnaires and recovered 200 copies (including 12 unqualified questionnaires). Besides, the survey covers all types of people.

(b) Analysis of survey results**:** To facilitate statistics, 3,674 pieces of valid 334 questionnaires are entered into Excel software to establish a CVM questionnaire database. As given in Table 7, the willingness to pay (WTP) produced two calculation results, one is the WTP average of $18.24, and the other is the WTP median value of $8.10. According to the actual situation, it is known that taking the arithmetic mean to calculate the per capita maximum willingness to pay will produce a higher error. Therefore, this paper obtained the WTP median value of $8.10 through the interpolation method and took it as the calculation standard of the paper's willingness to pay (WTP). Besides, the 2017 Yearbook shows that the resident population of Zhuzhou City is 1.2435 million in 2016.

Taking the above data into the relevant equation for calculation, the aesthetic heritage value of urban wetland is $10,075,300/a.

Intermediate Service Value

Biodiversity value: The biodiversity value of urban wetland in Zhuzhou City is mainly reflected in the important value its rich biodiversity provides for the balance of the regional ecosystem. In this paper, the achievement reference method is adopted, and its calculation equation is as follows:

$$V_{10} = V_c \times A \quad \ldots(19)$$

In the equation, V_{10} is for biodiversity value($); V_c is the value of wetland per hectare biodiversity ($/a); A is calculated urban wetland area (ha);

This paper studies the unit value of wetland biodiversity in the value of China's ecosystem services by Xie et al. (2015), and its 2016 conversion price is $2,892.92/ha·a. Taking the above data into the relevant equation for calculation, the biodiversity value of urban wetland is $1,981.89/a.

Water conservation value: The water conservation value of urban wetland in Zhuzhou City is mainly reflected in the water storage value of the wetland to the surface. This paper adopts the alternative cost method, and its calculation equation is:

$$V_{11} = \Sigma A_i \times D_i \times P_s \quad \ldots(20)$$

In the equation, V_{11} is for the conservation of water source value($); A_i is for each type of wetland area (ha); D_i is for each type of wetland storage depth (m); P_s is storage capacity of storage capacity ($/m^3).

According to the survey on the current situation of urban wetland resources in Zhuzhou City, with reference to the data of Zhuzhou City Water Resources Bulletin in 2017, the average depth of river wetland water storage in Zhuzhou City is 8m, and the average depth of water storage in the water storage area is 4m. The average depth of water is 2m; in 2016,

Table 7: Frequency distribution of sample willingness to pay.

WTP value ($)	Absolute frequency / person	Relative frequency (%)	Frequency of adjustment (%)	Cumulative frequency (%)
5	51	15.3	30.2	46.2
15	45	13.5	26.5	72.7
30	22	6.6	13.0	85.7
45	4	1.2	2.4	88.1
60	0	0	0	88.1
75	6	1.8	3.6	91.7
90	1	0.3	0.6	92.3
120	1	0.3	0.6	92.9
150	3	0.9	1.8	94.7
300	7	2.1	4.1	98.8
300 and above	2	0.6	1.2	100
Refusal to pay	164	49.2		
WTP average	18.24			
WTP median value	8.10			

Table 8: Value of urban wetland ecosystem service in Zhuzhou City.

Primary classification	Secondary classification	Tertiary classification	Value ($10^6·a)	Unit value ($10^3/ ha)	Proportion of total value (%)
Ultimate service value	Adjust service value	Adjustment value of atmospheric composition	92.1117	3.7	6.03
		Climate regulation value	424.9304	17	27.81
		Water storage regulation value	539.5663	21.7	35.31
		Water quality purification value	96.9327	0. 6	0.96
		Value of preventing soil erosion	16.9118	0. 7	1.11
	Supply service value	Biological product value	121.9880	4.9	7.98
		Water supply value	3.2002	5.3	8.72
	Cultural service value	Tourism rest value	26.2866	7	11.42
		Aesthetic heritage value	10.0753	0. 4	0.66
Total			1,527.9089	61.3	100.00
Intermediate service value		Biodiversity value	19.8189	-	11.43
		Water conservation value	142.6964	-	82.33
		Nutritional cycle value	10.8107	-	6.24
Total			173.326	-	100.00

the cost of the unit reservoir is \$0.58/m^3; the area of each type of wetland is shown in Table 3. Taking the above data into the relevant equation for calculation, the water conservation value of urban wetland in Zhuzhou City is \$142,696,482/a.

Nutritional cycle value: The nutritional cycle value of urban wetland is mainly reflected in the value of N, P, K and other nutrients in the utilization, conversion, movement and reuse of ecosystems. In this paper, the shadow price method and the soil bank nutrient retention method are used to evaluate the value. The calculation equation is:

$$V_{12} = S_t \times D \times R \times L_i \times V_i \quad \ldots(21)$$

In the equation, V_{12} is for the nutritional cycle value (\$); S_t is for the wetland area (m^2); D is for the soil topsoil average thickness (m); R is for the soil bulk density (g/cm^3); L_i is for the soil N, P, K nutrient content (kg); V_i is the price of N, P, K fertilizer (\$/t).

In this paper, the average thickness of soil surface layer in Zhuzhou City is calculated according to 85mm (Li et al. 2006), the bulk density of soil is 1.2g/cm^3, and the average content of nutrient elements in soil surface is N=1.877g/kg,

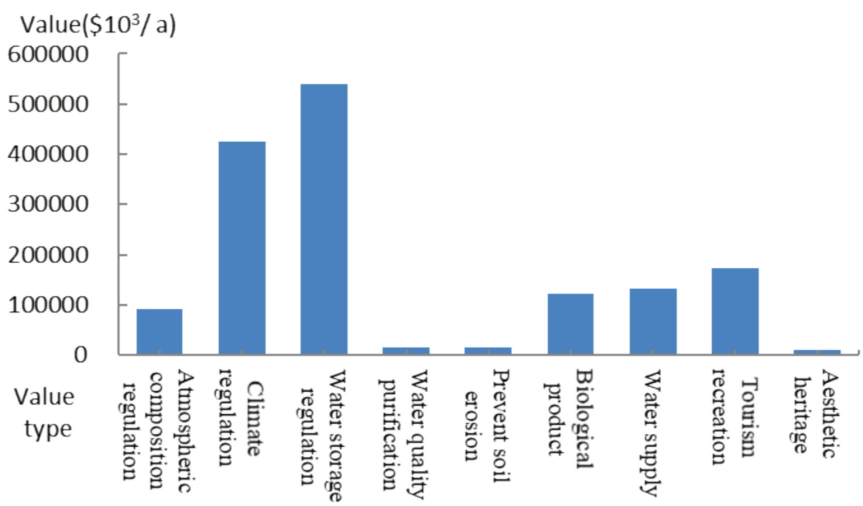

Fig. 3: Histogram of urban wetland value statistics.

P=0.49g/kg, K=7.96g/kg (Dong et al. 2011). The prices of nitrogen fertilizer, phosphate fertilizer and potash fertilizer in 2016 are \$189.17/t, \$100.39/t and \$264.49/t, respectively. Taking the above data into the relevant equation for calculation, the nutritional cycle value of urban wetland is \$10,810,707.8/a.

The total value of urban wetland ecosystem service in Zhuzhou City: The total value of urban wetland ecosystem service in Zhuzhou City is the sum of the ultimate service values of wetlands. The calculation equation is:

$$V_s = \Sigma_1^9 V_i \quad \ldots(22)$$

In the equation, V_s is the total value of service for wetlands (\$); V_i refers to the value of the i-type value (\$) in the ultimate service value.

After calculation, the ultimate service value of urban wetland is \$1,527,908,901; the intermediate service value of urban wetland is \$173,326,054. The total value of urban wetland ecosystem services in Zhuzhou City in 2016 is \$1,527,908,901 (Table 8).

Statistical analysis of urban wetland ecosystem service value in Zhuzhou City: The statistics of the ultimate service value of different urban wetland types in Zhuzhou City are shown in Table 9.

Analysis of the ultimate service values of urban wetland: The ultimate value of the urban wetland ecosystem services in Zhuzhou City is ranked as follows: Water storage regulation value>Climate regulation value>Tourism recreation value >Water supply value>Biological product value>Atmospheric composition regulation value> Preventing soil erosion value>Water purification value>Aesthetic heritage value, as shown in Fig. 3.

Analysis of the value of each type of urban wetland: The value of different types of urban wetland types in Zhuzhou City is as follows: Paddy fields>Riverine wetland>Ponds>Reservoir>Wastewater treatment plant, as shown in Fig. 4.

Analysis of unit area value of each type of urban wetland: The value per unit area of each type of urban wetland in Zhuzhou City is ranked as follows: Reservoirs>Riverine wetland>Pond >Paddy fields>Wastewater treatment plant, as shown in Fig. 5.

DISCUSSION AND CONCLUSIONS

Compared with previous wetland research, this paper focuses on urban wetland ecosystem services, and distinguishes the intermediate service value and ultimate service value of urban wetland ecosystem in the process of constructing service evaluation system, and comprehensively evaluates the direct contribution of the wetland ecosystem of Zhuzhou City to human welfare. From the perspective of the selection of evaluation indicators and methods, the evaluation results of this study are reasonable to some extent, and the value assessment methods are improved compared with the previous ones, providing a reference for the refined evaluation of urban wetland ecosystem service value.

However, part of the economic data has a long time, it has a certain impact on the evaluation results of the paper. Besides, it should be pointed out that deduplicate double-counting not only improves the accuracy and accuracy of ecological service value accounting but also provides a more scientific decision-making basis for urban wetland conservation and management. As a result, the wetland value can be

Table 9: The ultimate service values of different types of urban wetlands in Zhuzhou City.

Value types	Riverine wetland / $\$10^3$	Reservoir / $\$10^3$	ponds / $\$10^3$	Paddy fields /$\$10^3$	Wastewater treatment plant / $\$10^3$	Total value / $\$10^3$
Atmospheric composition regulation	3,059.8	14,325	10,025.3	77,594.2	-	92,111.7
Climate regulation	37,660.9	10,564	38,574.8	337,922.8	207.8	424,930.4
Water storage adjustment	241,412.1	53,647.1	244,507.1	-	-	539,566.3
Water purification	6,334	1,776.7	6,487.7	-	-	14,598.3
Prevent soil erosion	357.7	100.4	366.6	16,087.2	-	16,911.8
Biological product	11,923.3	3,344.5	12,212.6	94,507.5	-	121,988
Water supply	108,968.6	24,215.3	-	-	-	133,183.9
Tourism recreation	104,726	52,363	17,454.3	-	-	174,543.3
Aesthetic heritage	8,243.5	1,831.9	-	-	-	10,075.3
Total value of wetland	522,685.8	149,275.2	329,628.3	526,111.7	207.8	1,527,908.9
Proportion of the total value/%	34.21	9.77	21.57	34.43	0.01	100
Unit value/$\$10^3$/ ha	236.6	240.9	145.7	26.6	17	61.3

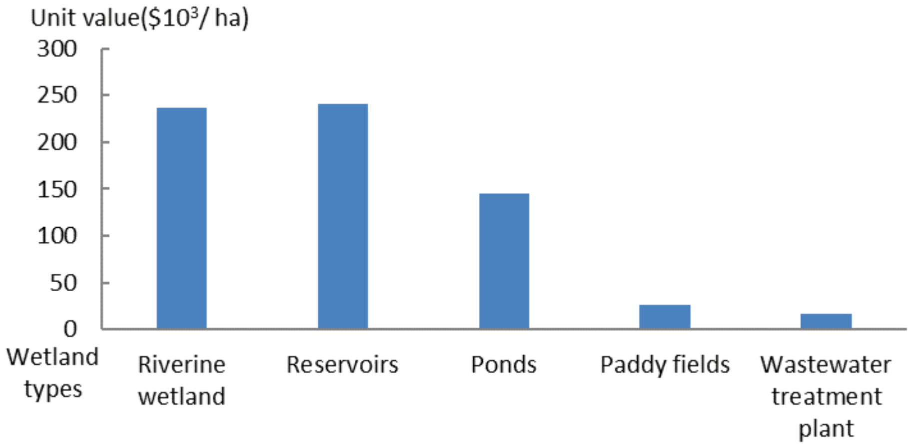

Fig. 4: Total value statistics of urban wetland types.

used to evaluate the results of science into city management decision-making system. For an important direction of urban wetland research and practical application, we need to further grasp the urban wetland ecosystem structure, process, function and service-related mechanism, clear the city spatial flow and transfer characteristic of wetland ecosystem services, clear the ultimate service directly linked with the beneficiaries, adopt more reasonable calculation, establish more scientific and comprehensive wetland ecological service evaluation system, make urban wetland ecosystem service research from the evaluation to the management practice.

Based on 2016, Zhuzhou wetland remote sensing image interpretation map, this paper establishes the urban wetland ecosystem service evaluation system according to the urban wetland classification in Zhuzhou City, combined with the field investigation and relevant basic data, and uses the economic value evaluation method to calculate urban wetland ecology system service value and comprehensive analysis of the evaluation results. The relevant conclusions are as follows:

(a) As of 2016, the total urban wetland area in Zhuzhou City is about 24,923ha, which is divided into five types: riverine wetland, reservoir, ponds, paddy fields, and wastewater treatment plants. The area of paddy fields is the largest, accounting for 19,820ha, accounting for 79.52% of the total urban wetland area. This indicates that as one of the main producing areas of rice in southern China, paddy fields is an important part of urban wetland in Zhuzhou City. It not only provides the city with material products but also plays an outstanding

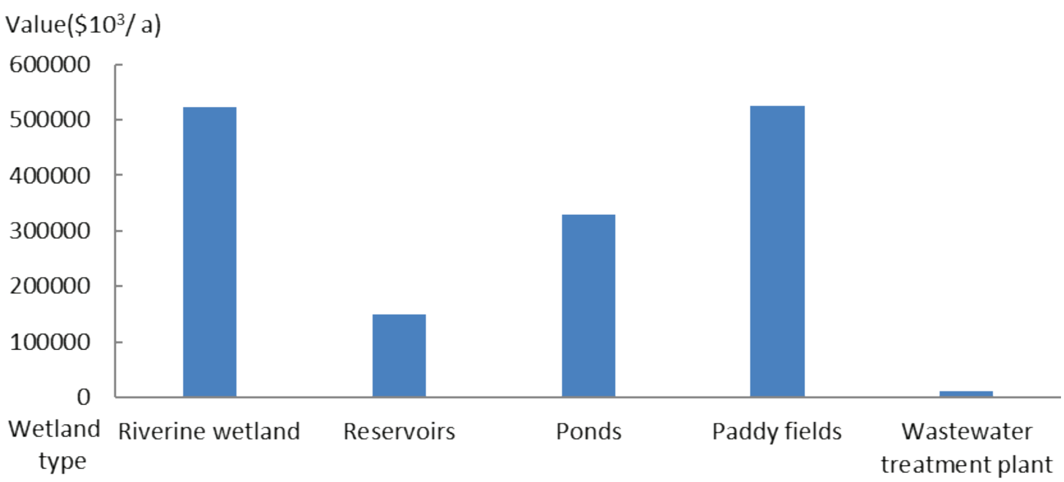

Fig. 5: Unit area value statistics of urban wetland types.

ecological service function. Therefore, it should continue to strengthen protection and management, and illegal occupation, ruin and destruction of paddy fields are strictly prohibited.

(b) In this paper, the urban wetland ecosystem service evaluation system in Zhuzhou City is constructed, and it is divided into ultimate service and intermediate service through deduplicate double counting. The ultimate service incorporates the total value calculation of wetland ecosystem services, while the intermediate services are excluded from the total value, which indirectly contributes to human well-being through the ultimate service. The evaluation index system provides an important direction for distinguishing the intermediate services (functions) and ultimate services of urban wetland ecosystems, and developing dynamic assessment and optimal management of urban wetland ecosystem ultimate services.

(c) In 2016, the total value of urban wetland ecosystem services in Zhuzhou City is about \$166,333,305.72, of which the ultimate service value was about \$166,333,305.72, the intermediate service value is about \$173,326,054.2. The urban wetland unit area ecosystem service value is about \$61,310.24/ha; The total value accounts for 8.63% of the total GDP of Zhuzhou City in the same year, which reveals the great contribution of wetland system services to urban development.

(d) The value of water storage regulation and climate regulation the largest among all ecological services of urban wetland in Zhuzhou City, which are about \$539,566,265.1/a and \$424,930,361.4/a, respectively. The sum of the two values accounts for 63.13% of the total value of urban wetland ecosystem services. This indicates that the urban wetland is the most important source of water vapour and climate regulators in Zhuzhou City, and water storage regulation and climate regulation are the core services provided by the wetlands to the city.

(e) Among all types of urban wetlands in Zhuzhou City, the value of paddy fields and riverine wetland is the highest, which is about \$526,111,671.7/a and \$522685813.3 /a, respectively. The sum of the two values accounts for 68.64% of the total value of urban wetland ecosystem services. Besides, the reservoir and the riverine wetland have the largest unit value, which is about \$240,918.67/ha·a and \$236,626.51/ha·a. This indicates that in the wetland conservation work of Zhuzhou City, riverine wetlands, especially the Xiangjiang River (the most important river in the region), should be the primary object, and the conservation of wetlands in reservoir wetland with large water areas should be strengthened, with the focus on guaranteeing their basic ecosystem service functions.

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