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DYNAMIC EVALUATION AND SPATIAL MAPPING OF WETLAND ECOSYSTEM SERVICES VALUE - A CASE STUDY ON NANJING JIANGBEI NEW AREA

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Abstract

Based on the interpretation of LUCC data, through the correction of basic equivalent value and value equivalent coefficient, this study sets up the evaluation system based on value transfer method, and realizes the dynamic evaluation of wetland ecosystem services value in Jiangbei New Area, i.e., the value of wetland ecosystem services in Jiangbei New Area was RMB 6,060.77 million, RMB 9,244.62 million and RMB 7709.68 million respectively in 2002, 2009 and 2017, which show obvious fluctuation characteristics, and regulation services was the core value, among which flood and waterlogging regulation service value accounted for the highest. At the same time, this study introduces ESCI and ESSI analysis to quantitatively express the change in the evaluation data of wetland ecosystem services value from 2009 to 2017 in the study area with special raster data and realizes the visualization of value change with spatial mapping so as to compare and analyze the gain and loss of ecological function and effectively identify the main loss areas of wetland ecological function. The research methods used in this study are suitable for the research on wetland ecosystem of urban spatial scale, and can be relatively convenient for dynamic evaluation of wetland ecosystem services value and its changes, so as to effectively support urban ecological resource management decision-making.

Key words: evaluation, Nanjing Jiangbei new area, spatial mapping, urbanization, wetland ecosystem services

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1. Introduction

As an important ecosystem unit, the wetland provides a variety of ecological services for human life and economic development, such as water conservation, flood and waterlogging regulation and storage, material supply, soil and water conservation, atmospheric regulation, environmental purification and maintenance of biodiversity (Azous and Horner, 2000; Keddy, 2010; Lepage, 2011a, 2011b; Parker et al., 2019; Sharma et al., 2015; Sullivan et al., 2014; Wei et al., 2018). Since the 20th century, the cumulative reduction and degradation area of the global wetlands has exceeded 50 %. At present, the wetland area is still generally under the threat of shrinking and structural fragility (Ehrenfeld, 2000; Gardner et al., 2015; Millennium Ecosystem Assessment, 2005; Jessop et al., 2015; Kentula et al., 2004; Šabić et al., 2018; Sica et al., 2016; Zorrilla-Miras et al., 2014). Studies have shown that the greatest threat to wetland resources comes from human activities (Davidson, 2014; Hu et al., 2017; O'Connell, 2003; Panahandeh et al., 2018), while agricultural production and urbanization are the most important manifestations (Ehrenfeld, 2000; Gibbs, 2000; Gong et al., 2012; Niu et al., 2012).

With the rapid economic growth, the total area of wetlands in China has decreased from 5,687,000 km^2 in 1952 to 212.5,000 km^2 in 2014 (Cao et al., 2018), during which from 2003 to 2014 alone, the area of wetlands occupied and threatened by urban expansion increased nearly tenfold (Geng, 2014; Yang

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et al., 2018). The conservation and restoration of wetland resources is the key to the sustainable development of cities. Under the background of rapid urbanization, scientific evaluation and dynamic monitoring of wetland ecosystem value is the premise of formulating reasonable wetland resource management policy (Zhang et al., 2017a).

At present, in the field of research on ecosystem services, the main work involves two parts, one is the evaluation of ecosystem services value, and the other is the development of ecosystem management tools and practical research.

In the field of evaluation, based on previous studies and discussions (Costanza and Mageau, 1999; Costanza et al., 1997, 2014; Daily, 1997; de Groot et al., 2002), Millennium Ecosystem Assessment proposed a guiding classification scheme for ecosystem services, and implemented and guided the corresponding evaluation work (Millennium Ecosystem Assessment, 2005; Nelson, 2005). In recent years, some scholars have carried out special research on the evaluation of wetland ecosystem services in China, with such spatial sizes as the nation, watershed, estuary and cities (groups) (Cao et al., 2018; Hu et al., 2017; Li and Gao, 2016; Song et al., 2015; Yang and Liu, 2018; Zhang et al., 2014, 2017a). However, due to data and methodological issues, the current evaluation and dynamic monitoring of wetland ecosystem services in specific urban areas is too insufficient to provide adequate support for specific urban planning and management policy (Zhang et al., 2017a). In the field of development and practice of ecosystem management tools, value research provides a basis for comparison of ecosystem services functions and evaluation of the implementation effect of ecosystem policy (Jim and Chen, 2009; McPherson et al., 1997; Tyrväinen and Miettinen, 2000). At the same time, with the application of 3S technology in the research of ecosystem services, spatial mapping method can realize the visual quantitative evaluation of specific spatial ecosystem services, and has become an effective means to guide the practice of ecological management (Brown and Fagerholm, 2015; Daily and Matson, 2008; Daily et al., 2009; Kareiva et al., 2011; Tallis and Polasky, 2009). Egoh et al. (2008) used the spatial mapping method to analyze the relationship between five ecosystem services in South Africa; Onaindia et al. (2013), based on GIS-assisted techniques, used spatial mapping and spatial consistency analysis to study the trade-offs and synergies among biodiversity maintenance, carbon storage and runoff regulation in the Urdaibai Biosphere Reserve, Spain; Zhang et al. (2017b) used quantitative biophysical surrogate indicators to assess ecosystem services capacity in 11 eco-functional regions of China, and discussed their spatial-temporal characteristics through spatial mapping.

Although the mapping method of ecosystem services provides a visual tool for ecosystem management decision-making, there are still requirements for credibility, saliency and reasonableness in its use (Hauck et al., 2013). In addition, objectives, costs, temporal and spatial scales, evaluation methods, data authenticity and other factors of management decision-making also significantly affect the accuracy of the mapping results of ecosystem services (Eigenbrod et al., 2010). Although the ecological management decision-making of regional scale is more common, but currently most of the researches are from the national, watershed and other macro-scale, the effective monitoring on the value of local ecosystem services and its spatial and temporal changes is insufficient (Zhang et al., 2017b). Some scholars also pointed out that most of the existing studies on the mapping of the ecosystem services use the common alternative model methods, and the used data also lack the corresponding testing technology (Alam et al., 2016; Martínez-Harms and Balvanera, 2012). Therefore, it is necessary to further explore the mapping of urban wetland ecosystem services under the regional spatial scale. By optimizing the mapping methods, the mapping accuracy can be improved, so as to better serve the policy-making and investment decision-making of urban wetland resources protection.

On the basis of Costanza (1997, 2014) and others' research, Chinese scholar Xie Gaodi has continuously improved the system evaluation method based on ecosystem services value equivalence per unit area, and constantly raised the reliability of the evaluation results (Xie et al., 2008, 2010, 2015a, 2015b), which provides a foundation for establishing an efficient evaluation method for urban wetland ecosystem services.

In order to realize the visualization of temporal and spatial changes in the value of wetland ecosystem services at the urban regional scale, taking Nanjing Jiangbei New Area as an example, this study uses the land use/cover change data based on remote sensing image interpretation and the revised value conversion method to evaluate the value of wetland ecosystem services in the study area, and adopts the ecosystem services change index (ESCI) and ecosystem services index (ESSI) to quantitatively calculate the spatial and temporal changes in the value of wetland ecosystem services in the study area with spatial raster data and analyze the mapping.

2. Materials and methods

2.1. Overview of the study area

Nanjing Jiangbei New Area is located between 118°21'~119°03' east longitude and 30°51'~32°27' north latitude. It consists of three administrative units: Pukou District, Liuhe District and Baguazhou (subordinate to Qixia District). The area is 2,451km^2, accounting for 37% of the total area of Nanjing (Fig. 1).

There are many rivers, reclamation areas and lakes in the new district and the wetland resources are very rich. In recent years, due to the impact of human activities such as rapid urbanization and excessive reclamation, wetland resources have been destroyed significantly. In 2014, the overall urbanization rate of the area was 66.3 %. According to the *Jiangbei New*

Area Master Plan (2014-2030), the urbanization level of the whole district will reach 90% by 2030. The rapid urbanization progress of Jiangbei New Area will continue in the future, and the wetland resources in the district will still face great threats to human activities. Therefore, while keeping economic development, Jiangbei New Area urgently needs long-term effective monitoring of wetland resources so as to provide a basis for scientifically formulating wetland conservation and restoration policies.

2.2. LUCC data

LUCC data analysis has become an effective way to monitor wetland changes through remote sensing means (Frohn et al., 2012). In this study, the classification accuracy is improved by using the comprehensive discrimination method combining image spectral information and auxiliary information to further raise the accuracy of wetland spatial information acquisition in the study district.

The study uses remote sensing data with no cloud and similar months in 2002, 2009 and 2017 (Table 1). This series of image data have proven to be from a reliable source of information in the field of researches on wetland ecosystem services in China (Han et al., 2015; Zhu et al., 2018). The image correction is performed with the WGS-1984 coordinate system and UTM projection and the pre-processing such as radiation correction, geometric correction and cropping of the region of interest is performed before the data are used.

Based on the distribution and type of wetlands in Jiangbei New Area of Nanjing and the full consideration of the judgement characteristics of remote sensing image information, this study proposes the classification system of wetlands in Jiangbei New Area (Table 2). According to the analysis of the spectral characteristics, geometric features and environmental conditions of the main wetland types, the decision tree model is constructed by first dividing the district and then identifying the type (Fig. 2). The water body coverage area is identified with the third component KT_3 after K-T transformation, and the wetlands are classified and extracted according to the area and shape characteristics (the paddy wetland area is subject to the statistical yearbook of each year). The results of remote sensing extraction and classification are shown in Fig. 3 and the wetland area of each type is shown in Table 3.

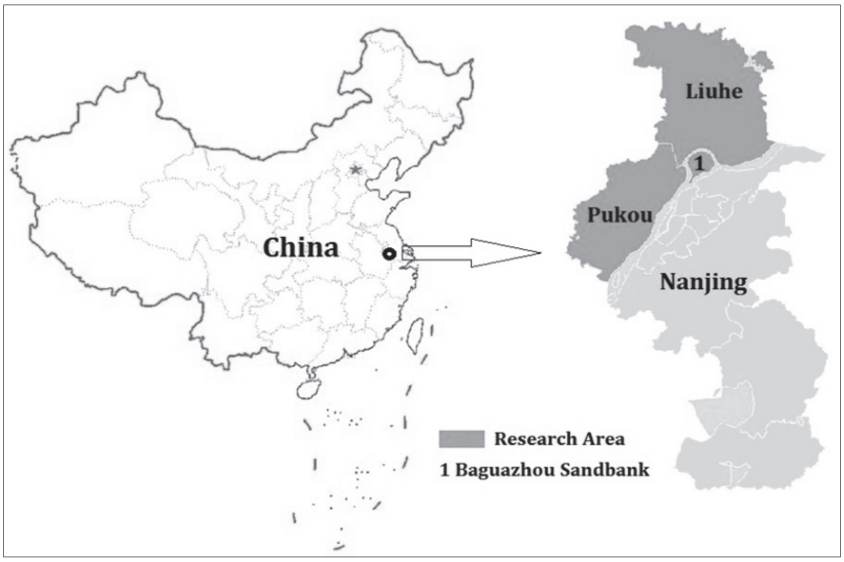


Fig. 1. Location of Jiangbei New Area in Nanjing

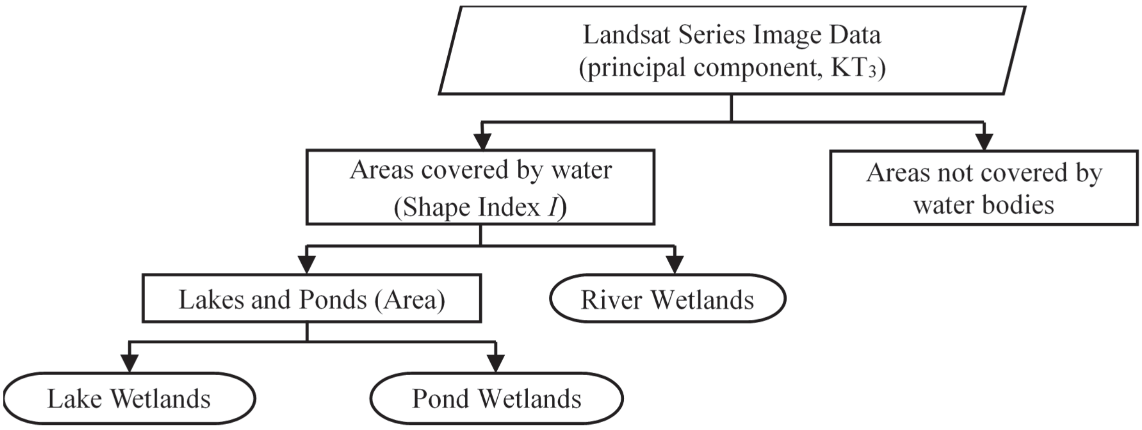
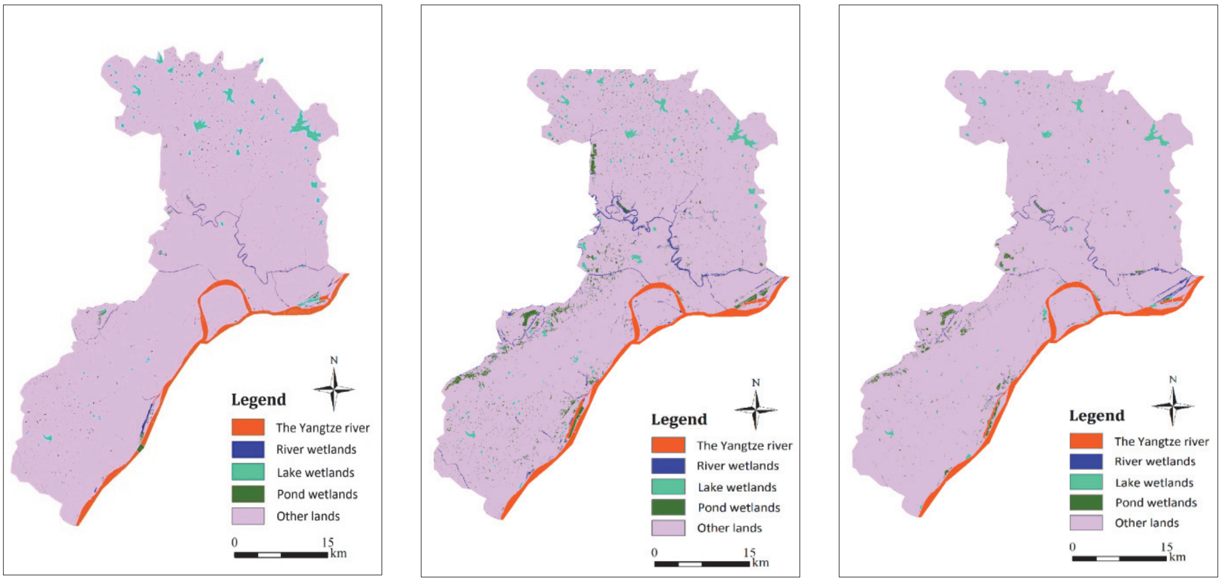


Fig. 2. Decision tree model for wetland information classification and extraction



(a) (b) (c)

Fig. 3. Remote sensing interpretation results of wetlands in Jiangbei New Area: (a) 2002, (b) 2009, (c) 2017

Table 1. Remote sensing data used in the study

Satellite/Sensor	*Number of wavelengths*	*Resolution (m)*	*Date of Obtain*	*Track Number*
Landsat7 ETM	7	30	2002-10-08	120/38
Landsat5 TM	8	30	2009-10-03	120/38
Landsat8 OLI	11	30	2017-10-09	120/38

Table 2. Wetland classification system in Jiangbei New Area

Type of Wetland	*Main Features*
Lake Wetland	a large area of planar water, including lakes, large reservoirs, etc.
River Wetland	regional permanent freshwater rivers
Pond Wetland	mainly refers to a small area of aquaculture water, irrigation reservoirs, etc.
Paddy Fields	mainly refers to paddy fields, also includes a small amount of cultivation of lotus root, artemisia and other aquatic plants arable land

Table 3. Statistics of wetland area in each year of Jiangbei New Area

Wetland Types	*Regions*	*2002*		*2009*		*2017*	
		Area (hm^2)	*Proportion (%)*	*Area (hm^2)*	*Proportion (%)*	*Area (hm^2)*	*Proportion (%)*
Lake Wetland	Pukou	408.38	0.45	500.22	0.55	375.23	0.41
	Liuhe	2145.69	1.44	2658.78	1.79	2602.37	1.75
	Baguazhou	38.61	0.69	29.05	0.52	23.02	0.41
	Jiangbei N.A.	2592.68	1.06	3188.05	1.30	3000.62	1.22
River Wetland	Pukou	274.54	0.30	598.05	0.66	222.66	0.24
	Liuhe	1222.34	0.82	1688.04	1.14	1038.33	0.70
	Baguazhou	69.70	1.24	107.64	1.92	69.54	1.24
	Jiangbei N.A.	1566.58	0.64	2393.73	0.98	1330.53	0.54
Pond Wetland	Pukou	3114.59	3.42	3836.79	4.22	2568.24	2.81
	Liuhe	2061.59	1.39	3585.87	2.41	2466.33	1.66
	Baguazhou	46.85	0.84	46.77	0.84	33.22	0.59
	Jiangbei N.A.	5223.02	2.13	7469.43	3.05	5067.79	2.06
Paddy Field	Pukou	9562.00	10.51	8566.33	9.41	8431.22	9.23
	Liuhe	26677.00	17.96	27300.00	18.38	26333.00	17.73
	Baguazhou	2333.00	41.66	2333.00	41.66	2333.00	41.66
	Jiangbei N.A.	38572.00	15.74	38199.33	15.59	37097.22	15.11
Total Area	Pukou	13359.50	14.68	13501.39	14.84	11597.35	12.70
	Liuhe	32106.62	21.62	35232.69	23.73	32440.03	21.84
	Baguazhou	2488.16	44.43	2516.46	44.94	2458.78	43.91
	Jiangbei N.A.	47954.27	19.57	51250.54	20.91	46496.16	18.94

This study takes the results of remote sensing image classification in 2017 as samples. According to the proportion of various wetland areas, the sample points are generated by random method, and the accuracy test is carried out by comparing with land use map and on-site survey. The results of the confusion matrix accuracy test show that the classification accuracy of the three wetlands such as rivers, lakes and ponds is 94.31%, 92.13% and 80.07%, respectively; the overall classification accuracy of the extraction results is 85.72%, and the overall Kappa coefficient is 0.828, which indicates that the general result is satisfactory for further research.

According to the dynamic change of wetland in Jiangbei New Area, the total area increased slowly during the period of 2002-2009 and decreased continuously during 2009-2017. From the spatial distribution of lakes, rivers and ponds, the results of interpretation show a relatively uniform distribution pattern. Lake wetlands are mainly distributed in the north of Liuhe, while river wetlands are relatively concentrated in Chuhe river and its main tributaries. In addition, there are some small rivers and artificial water channels in the southwest riverside area. The distribution of pond and pit wetlands presents a spatial pattern described as "generally dispersed with accumulation in certain areas". In the river plain areas, mainly distributed in east, south, north and southwest of Jiangbei New Area, there are relatively concentrated distribution of ponds, cisterns and river marshes and other small areas of wetlands.

Compared with 2002, wetland area in the study area increased by 3296 hm^2 in 2009. Among them, the area of lake wetland, river wetland and pond wetland increased 596 hm^2, 827 hm^2 and 2246 hm^2, respectively, while the area of paddy field wetland decreased 373 hm^2. The main reasons are as follows. Firstly, from 2002 to 2009, the urbanization rate of Jiangbei New Area was basically stable. The urbanization rates of Liuhe and Pukou remained at 47% and 61% respectively. There was no large-scale encroachment on wetlands due to urban construction. Secondly, from 2005 to 2008, Jiangbei New Area implemented more effective ecological protection measures centralized the control of lake occupation in the north. The river dredging, ecological slope protection and other restoration projects in Chuhe River Basin in the central part are implemented simultaneously, effectively increasing the area of lakes and river wetlands. Thirdly, from 2006 to 2009, ecological conservation projects such as river dredging and conversion of farmland to fishery were carried out on key riverside wetlands such as Green Water Bay and Longpao. The area of pond wetlands in riverside areas was rapidly restored during the projects. Fourthly, the 2009 remote sensing image shows the notable sensitivity to the third component (humidity), which may be related to the region just experienced a precipitation before the image was taken.

Compared with 2009, the wetland area in the study area decreased by 4755 hm^2 in 2017. Among them, the area of river wetland, pond wetland and paddy field wetland decreased by 1063 hm^2, 2402 hm^2 and 1102 hm^2, respectively. The reason is mainly related to the rapid urbanization. In 2015, Jiangbei New Area was formally established, and the orientation of regional development changed to industrial and population agglomeration. By 2017, the urbanization rates of Liuhe and Pukou had exceeded 60% and 70% respectively, which increased rapidly compared with 2009. With the increase of population, the area of urban construction land, such as residential and commercial land, has expanded rapidly. Wetlands in Chuhe River Basin, central Pukou and along the Yangtze River have been occupied seriously. The disappearance of small watershed in urban construction area directly leads to the rapid reduction of wetland area in rivers, while the non-agricultural nature of land use is the main reason for the reduction of wetland area in pits and ponds and paddy fields.

2.3. Evaluation

(1) Value equivalent

Based on the economic value of the national average grain output, the value transfer method (VTM) is used to calculate the unit area value of different types of ecosystem services. This study uses the research results of 2015 (Xie et al., 2015a, 2015b), and the service value equivalent per unit area of each type of ecosystem is shown in Table 4.

(2) Coefficient correction of value equivalent

1) Value equivalent correction of water source supply and flood and waterlogging regulation and storage services

Use (Eq. 1) to correct the value equivalent of water source supply and flood and waterlogging regulation and storage services.

$$R_i = W_i / \overline{W} \tag{1}$$

where: R_i refers to the correction coefficient of equivalent value of water supply and flood and waterlogging regulation and storage services in the i–th area, W_i refers to the average annual precipitation per unit area in the i–th area and $\overline{W}$ refers to the average annual precipitation per unit area in China.

2) Value equivalent correction of soil conservation services

The ratio of the soil conservation amount per unit area of the study area to national soil conservation amount per unit area is used as the correction coefficient of value equivalent of the soil conservation services. (Eq. 2) shows the calculation method as follow:

$$S_i = E_i / \overline{E} \tag{2}$$

Table 4. Fundamental value equivalents of ecosystem services per unit area (2015)

Ecosystem Services		***Provisioning services***	***Regulating services***					***Supporting services***		***CS****	
Category	***Sub-category***	***MP****	***WS****	***GR****	***CR****	***WT****	***FC****	***SM****	***MC****	***BM****	***CS****
Cropland	Dry field	1.25	0.02	0.67	0.36	0.10	0.27	1.03	0.12	0.13	0.06
	Paddy fields	1.45	-2.63	1.11	0.57	0.17	2.72	0.01	0.19	0.21	0.09
Forest	Coniferous	0.74	0.27	1.70	5.07	1.49	3.34	2.06	0.16	1.88	0.82
	Mixed	1.02	0.37	2.35	7.03	1.99	3.51	2.86	0.22	2.60	1.14
	Broad leaved	0.95	0.34	2.17	6.50	1.93	4.74	2.65	0.20	2.41	1.06
	Shrub	0.62	0.22	1.41	4.23	1.28	3.35	1.72	0.13	1.57	0.69
Grassland	Prairie	0.24	0.08	0.51	1.34	0.44	0.98	0.62	0.05	0.56	0.25
	Bush	0.94	0.31	1.97	5.21	1.72	3.82	2.40	0.18	2.18	0.96
	Meadow	0.55	0.18	1.14	3.02	1.00	2.21	1.39	0.11	1.27	0.56
Marshland	Marshland	1.01	2.59	1.90	3.60	3.60	24.23	2.31	0.18	7.87	4.73
Wilderness	Desert	0.04	0.02	0.11	0.10	0.31	0.21	0.13	0.01	0.12	0.05
	Bare land	0.00	0.00	0.02	0.00	0.10	0.03	0.02	0.00	0.02	0.01
Water Area	River/Lake	1.03	8.29	0.77	2.29	5.55	102.24	0.93	0.07	2.55	1.89
	Glacier Snow	0.00	2.16	0.18	0.54	0.16	7.13	0.00	0.00	0.01	0.09

**MP: Materials Production; WS: Water Supply; GR: Gas Regulation*
CR: Climate Regulation; WT: Waste Treatment; FC: Flood Control
SC: Soil Maintenance; MC: Materials Cycling; BM: Biodiversity maintenance; CS: Cultural Services

where: S_i refers to the correction coefficient of soil conservation value equivalent in the *i*–th area, E_i refers to the soil conservation amount per unit area in the *i*–th area and $\overline{E}$ refers to national average soil conservation amount per unit area.

In the study, the general soil loss equation is generally used to calculate the amount of soil erosion (Eqs. 3-4).

$$Potential\ soil\ erosion = R_x \cdot K_x \cdot LS_x \quad (3)$$

$$Actual\ soil\ erosion = R_x \cdot K_x \cdot LS_x \cdot C_x \cdot P_x \quad (4)$$

where: R_x, K_x, LS_x, C_x *and* P_x refer to rainfall erosivity factor, soil erodibility factor, topographic factor, land cover and management factor and soil conservation measure factor respectively of the *x*-th land.

Soil conservation amount is the difference between potential soil erosion and actual soil erosion. It is concluded that soil erosion pattern and *CP* value should be obtained in order to obtain soil conservation data per unit area in the study area. On the premise that the actual soil erosion and *CP* value are known in the study area, the following results can be obtained. From equations (3-4) it may be expressed as (Eq. 5):

$$Soil\ conservation\ amount = R_x \cdot K_x \cdot LS_x \cdot (1 - C_x \cdot P_x) \quad (5)$$

(3) Value accounting

According to the monetary equivalent value, value equivalent and correction coefficient, the revised unit area value is obtained, and the total value of ecosystem services is calculated according to the spatial area of each type of wetlands in the study area. The current evaluation adopts the method of first calculating the total value by regions and then summing up the total value. The equation is expressed as (Eq. 6):

$$ESV = \sum A_{ki}\, m_{ki}\, n_{ki}\, C \quad (6)$$

where: *ESV* is the value for ecosystem services (RMB/a); A_{ki} is the distribution area of the *k*-th wetland in the *i*-th area (hm^2); m_{ki} is the equivalent value of the *k*-th wetland in the *i*-th area; n_{ki} is the correction coefficient of the equivalent value of the *k*-th wetland in the *i*-th area; *C* is the value for standard equivalent ecosystem services (RMB/ ($hm^2 \cdot a$)).

2.4. Spatial mapping

(1) Ecosystem Services Change Index (ESCI)

ESCI is suitable for analyzing the temporal change of the value of a specific ecosystem services, and quantitatively describing the gain or loss of the value by calculating the temporal change rate of the value of a specific ecosystem services. The equation for calculating the ESCI is expressed as (Eq. 7):

$$ESCI_x = (ES_{ax} - ES_{bx}) / ES_{bx} \quad (7)$$

where: $ESCI_x$ represents the value change index of an ecosystem services with a function, ES_{ax} represents the value of ecological services in the latter state and ES_{bx} represents the value of ecological services in the former state.

ESCI=0 indicates that there is no change in the value of the ecosystem services between the two periods, i.e. no gain or loss; $ESCI < 0$ indicates that the value of the ecosystem services has been lost in the contrast period; and $ESCI > 0$ indicates that the value of the ecosystem services has increased during the contrast period.

(2) Ecosystem Services Status Index (ESSI)

ESSI is suitable for quantitative analysis of the temporal variation of the value of one or all ecosystem services, and provides a tool to evaluate the accumulation of the value of all ecosystem services. Compared with ESCI, ESSI cannot describe the change direction of the value of an ecosystem services, but can calculate and evaluate the value of two or more ecosystem services as a whole, because the accumulation of ecosystem services value is a dimensionless process in the region. ESSI is calculated with the (Eq. 8) as below:

$$ESSI_x = \sum ESCI_x / n \quad (8)$$

where: $ESSI_x$ represents the ecosystem services status index and n represents the cumulatively calculated quantity of ecosystem services.

(3) ESSI change

Although ESCI itself cannot analyze the accumulation change in the value of ecosystem services, it can be used to quantitatively express all or part of the changes in the value of ecosystem services in the same region, which is helpful to identify the change trend of regional ecosystem structure and function as a whole, with the (Eq. 9) as follows:

$$ESCI_{ESSIx} = (ESSI_{ax} - ESSI_{bx}) / ESSI_{bx} \quad (9)$$

where: $ESCI_{ESSIx}$ represents the index of changes in the value of a particular ecosystem services (e.g. supply services, regulatory services, etc.), $ESSI_{ax}$ represents the index of the state of the ecosystem services for the latter period, and $ESSI_{bx}$ represents the index of the state of the ecosystem services for the former period.

(4) Spatial mapping rules

1) With ArcGIS as the mapping platform, according to the grid establishment rules, the research district is divided into several 1km×1km grid data area (fishnet). The scope of spatial mapping does not include Baguazhou due to its lower value and inapparent change. In the research, many factors should be taken into account in the establishment of grid standards. Zhao (2016) selected a 2.5km×2.5km spatial grid to calculate the value of ecosystem services in Nanchang. Li (2014) selected and established a 2km×2km spatial grid for data calculation to analysis the ecosystem services value in Guanzhong-Tianshui Economic Zone. Furthermore, Jia et al. (2014), Li et al. (2016), Qiao et al. (2018) and Song (2018) have chosen to establish a 1km×1km spatial grid for data calculation. Gu (2017) shows that the factors influencing the trade-off and synergy of regional ecosystems are mainly related to DEM, NDVI, annual rainfall and the proportion of land use types such as waters and woodlands within 1km×1km. Meanwhile, according to the guidance of InVEST, a common model for ecosystem services research, the maximum impact distance of ecological threats of landscape types such as ponds, paddy fields, rivers, lakes and reservoirs are between 0.5 km and 2km. In the light of the parameters used in the model, the grid partition of 1km*1km could effectively reflect the ecological services function of various types of wetlands. Considering the above reasons, the relatively common method of building 1km×1km space grid was conducted.

2) The value of various ecosystem services of each grid is calculated with the spatial distribution data of various types of wetlands (lake wetlands, river wetlands, pit and pond wetlands) interpreted by remote sensing images, in combination with the equivalent factor calculation method of ecosystem services value.

3) With the ecosystem services value of each grid as the basic data source, the ESCI, ESSI and ESSI change values of the grid are calculated, and the grid color assignment is used to realize the spatial visualization of the calculation results.

3. Research results

3.1. Equivalent value and coefficient correction results

(1) Equivalent value correction

Based on the ratio of grain yield per unit area of farmland in Nanjing to that in China, the economic value of benchmark equivalent is revised (Nanjing Statistical Bureau, 2012), and the economic value of benchmark equivalent of ecosystem services per unit area in the study area is calculated to be RMB 4,700.97 /hm^2.

(2) Value equivalent correction coefficient

By calculating the regional precipitation and the national average precipitation in the same year, the correction coefficient of the value equivalent of water supply and flood and waterlogging regulation and storage services is obtained (Table 5).

In 2010, the soil conservation amount per unit area in China was 208.88t hm^{-2} a^{-1} (Rao, 2015), the average annual soil erosion modulus in Pukou District was 2,465t km^{-2} a^{-1}, that of Liuhe District was 2,357t km^{-2} a^{-1}, that of Baguazhou was 3,546t km^{-2} a^{-1} and The average annual *CP* value in Nanjing is 0.0483 (Ma et al., 2011). According to the calculation, the average annual soil conservation amount of Pukou District is 510.35 t hm^{-2} a^{-1}, that of Liuhe District is 487.99 t hm^{-2} a^{-1}, and that of Baguazhou is 734.16 t hm^{-2} a^{-1}. According to the ratio of annual soil conservation amount in each region to the national average, the correction coefficient of equivalent value of soil conservation services in Pukou, Liuhe and Baguazhou is 2.44, 2.34 and 3.51, respectively.

3.2. Evaluation results

After calculation, the value of wetland ecosystem services in Jiangbei New Area was RMB 6,060.77 million, RMB 9,244.62 million and RMB 7709.68 million respectively in 2002, 2009 and 2017 (Table 6 to Table 8). The value of wetland ecosystem services in Jiangbei New Area is unstable in general, rising rapidly from 2002 to 2009, with an average annual growth rate of 7.50 %, and showing a notably decline from 2009 to 2017 with an annual decrease of 2.29 %.

3.3. Spatial mapping results

According to the evaluation results (Table 6 to Table 8), flood and waterlogging regulation and storage, material production, atmospheric regulation and soil conservation are the core of wetland ecosystem services in the study area, accounting for 84.51%, 3.86%, 3.30% and 2.35% of the total value in 2017, respectively, with the cumulative proportion of 94.02%.

Therefore, the study selects the four secondary services and calculates their ESCI values for 2009-2017 respectively. The mapping results are shown in Fig. 4 to Fig. 7.

Table 5. Correction coefficient of equivalent value of water supply and flood and waterlogging regulation and storage service in the study area

Year	*Average Annual Precipitation in China*	*Annual Precipitation & Correction Coefficients in Pukon*		*Annual Precipitation & Correction Coefficients in Liuhe*		*Annual Precipitation & Correction Coefficients in Baguazhou*	
2002	660 mm	1083.6 mm	1.64	980.2 mm	1.49	1105.7 mm	1.68
2009	591.1 mm	1174.2 mm	1.99	1055.1 mm	1.78	1368.9 mm	2.32
2017	641.3mm	1488.6mm	2.32	1275.4mm	1.99	1498.7 mm	2.34

Table 6. Evaluation results of wetland ecosystem services value in Jiangbei New Area, 2002

Category		*Provisioning Services*		*Regulating Services*				*Supporting Services*			*Cultural Services*
Sub-Category		*MP**	*WS**	*GR**	*FC**	*CR**	*WT**	*SM**	*MC**	*BM**	*CS**
Lake	Pukou	1.98	26.10	1.48	321.89	4.40	10.65	4.36	0.13	4.90	3.63
	Liuhe	10.39	124.59	7.77	1536.60	23.10	55.98	21.92	0.71	25.72	19.06
	Baguazhou	0.19	2.53	0.14	31.18	0.42	1.01	0.59	0.01	0.46	0.34
	JNA	12.55	153.22	9.38	1889.67	27.91	67.64	26.87	0.85	31.08	23.04
River	Pukou	1.33	17.55	0.99	216.40	2.96	7.16	2.93	0.09	3.29	2.44
	Liuhe	5.92	70.98	4.42	875.36	13.16	31.89	12.48	0.40	14.65	10.86
	Baguazhou	0.34	4.56	0.25	56.28	0.75	1.82	1.07	0.02	0.84	0.62
	JNA	7.59	93.09	5.67	1148.04	16.86	40.87	16.49	0.52	18.78	13.92
Pond	Pukou	14.79	62.19	27.82	581.82	52.71	52.71	82.64	2.64	115.23	69.25
	Liuhe	9.79	37.40	18.41	349.89	34.89	34.89	52.30	1.74	76.27	45.84
	Baguazhou	0.22	0.96	0.42	8.96	0.79	0.79	1.79	0.04	1.73	1.04
	JNA	24.80	100.55	46.65	940.67	88.39	88.39	136.73	4.42	193.23	116.14
Paddy Fields	Pukou	65.18	-193.88	49.90	200.52	25.62	7.64	1.10	8.54	9.44	4.05
	Liuhe	181.84	-491.44	139.20	508.25	71.48	21.32	2.93	23.83	26.34	11.29
	Baguazhou	15.90	-48.46	12.17	50.12	6.25	1.86	0.39	2.08	2.30	0.99
	JNA	262.92	-733.77	201.27	758.89	103.36	30.83	4.41	34.45	38.08	16.32
All	Pukou	83.27	-88.04	80.19	1320.62	85.68	78.17	91.03	11.40	132.86	79.37
	Liuhe	207.94	-258.46	169.81	3270.11	142.63	144.08	89.63	26.68	142.98	87.05
	Baguazhou	16.65	-40.41	12.98	146.54	8.21	5.48	3.84	2.16	5.33	2.99
	JNA	307.86	-386.92	262.98	4737.26	236.52	227.73	184.50	40.24	281.17	169.41
Total Value		6060.77							(unit: million RMB)		

JNA: Jiangbei New Area; MP: Materials Production; WS: Water Supply; GR: Gas Regulation; FC: Flood Control; CR: Climate Regulation; WT: Waste Treatment; SC: Soil Maintenance; MC: Materials Cycling; BM: Biodiversity maintenance; CS: Cultural Services

Table 7. Evaluation results of wetland ecosystem services value in Jiangbei New Area, 2009

Category		*Provisioning Services*		*Regulating Services*				*Supporting Services*			*Cultural Services*
Sub-Category		*MP**	*WS**	*GR**	*FC**	*CR**	*WT**	*SM**	*MC**	*BM**	*CS**
Lake	Pukou	2.42	38.79	1.81	478.43	5.38	13.05	5.34	0.16	6.00	4.44
	Liuhe	12.87	184.44	9.62	2274.63	28.62	69.37	27.16	0.87	31.87	23.62
	Baguazhou	0.14	2.63	0.11	32.39	0.31	0.76	0.45	0.01	0.35	0.26
	JNA	15.44	225.86	11.54	2785.46	34.32	83.18	32.95	1.05	38.22	28.33
River	Pukou	2.90	46.38	2.16	572.00	6.44	15.60	6.39	0.20	7.17	5.31
	Liuhe	8.17	117.10	6.11	1444.15	18.17	44.04	17.24	0.56	20.24	15.00
	Baguazhou	0.52	9.73	0.39	120.02	1.16	2.81	1.65	0.04	1.29	0.96
	JNA	11.59	173.21	8.66	2136.17	25.77	62.45	25.28	0.79	28.69	21.27
Pond	Pukou	18.22	92.96	34.27	869.69	64.93	64.93	101.80	3.25	141.95	85.31
	Liuhe	17.03	77.71	32.03	727.04	60.69	60.69	90.97	3.03	132.67	79.73
	Baguazhou	0.22	1.32	0.42	12.36	0.79	0.79	1.79	0.04	1.73	1.04
	JNA	35.46	172.00	66.72	1609.08	126.41	126.41	194.56	6.32	276.34	166.09
Paddy Fields	Pukou	58.39	-210.76	44.70	217.97	22.95	6.85	0.98	7.65	8.46	3.62
	Liuhe	186.09	-600.79	142.45	621.35	73.15	21.82	3.00	24.38	26.95	11.55
	Baguazhou	15.90	-66.92	12.17	69.21	6.25	1.86	0.39	2.08	2.30	0.99
	JNA	260.38	-878.47	199.33	908.54	102.36	30.53	4.37	34.12	37.71	16.16
All	Pukou	81.93	-32.63	82.94	2138.10	99.71	100.43	114.52	11.26	163.57	98.70

	Liuhe	224.16	-221.55	190.22	5067.16	180.63	195.91	138.37	28.85	211.72	129.90
	Baguazhou	16.79	-53.24	13.09	233.98	8.51	6.22	4.27	2.17	5.67	3.24
	JNA	322.87	-307.41	286.25	7439.25	288.86	302.57	257.16	42.28	380.97	231.84
Total Value		9244.62						(unit: million RMB)			

Table 8. Evaluation results of wetland ecosystem services value in Jiangbei New Area, 2017

Category		***Provisioning Services***		***Regulating Services***				***Supporting Services***			***Cultural Services***
Sub-Category		***MP****	***WS****	***GR****	***FC****	***CR****	***WT****	***SM****	***MC****	***BM****	***CS****
Lake	Pukou	1.82	33.93	1.36	418.40	4.04	9.79	4.01	0.12	4.50	3.33
	Liuhe	12.60	202.83	9.42	2501.54	28.02	67.90	26.58	0.86	31.20	23.12
	Baguazhou	0.11	2.13	0.08	26.22	0.25	0.60	0.35	0.01	0.28	0.20
	JNA	14.53	238.89	10.86	2946.16	32.30	78.29	30.94	0.99	35.97	26.66
River	Pukou	1.08	20.13	0.81	248.28	2.40	5.81	2.38	0.07	2.67	1.98
	Liuhe	5.03	80.93	3.76	998.10	11.18	27.09	10.61	0.34	12.45	9.23
	Baguazhou	0.34	6.42	0.25	79.21	0.75	1.81	1.07	0.02	0.83	0.62
	JNA	6.44	107.48	4.82	1325.59	14.32	34.71	14.05	0.44	15.95	11.82
Pond	Pukou	12.19	72.55	22.94	678.68	43.46	43.46	68.14	2.17	95.02	57.11
	Liuhe	11.71	60.06	22.03	561.85	41.74	41.74	62.57	2.09	91.25	54.84
	Baguazhou	0.16	0.96	0.30	8.97	0.56	0.56	1.27	0.03	1.23	0.74
	JNA	24.06	133.56	45.26	1249.50	85.76	85.76	131.98	4.29	187.49	112.69
Paddy Fields	Pukou	57.47	-241.84	43.99	250.11	22.59	6.74	0.97	7.53	8.32	3.57
	Liuhe	179.50	-651.14	137.41	673.42	70.56	21.04	2.89	23.52	26.00	11.14
	Baguazhou	15.90	-68.36	12.17	70.70	6.25	1.86	0.39	2.08	2.30	0.99
	JNA	252.87	-961.34	193.58	994.23	99.40	29.65	4.25	33.13	36.62	15.70
All	Pukou	72.56	-115.23	69.10	1595.47	72.49	65.80	75.50	9.90	110.51	65.99
	Liuhe	208.83	-307.32	172.61	4734.91	151.49	157.77	102.65	26.81	160.88	98.33
	Baguazhou	16.51	-58.85	12.81	185.10	7.81	4.84	3.08	2.14	4.64	2.55
	JNA	297.90	-481.40	254.52	6515.49	231.79	228.41	181.22	38.85	276.03	166.86
Total Value		7709.68						(unit: million RMB)			

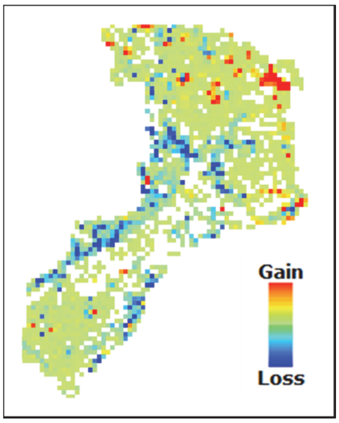


Fig. 4. Changes in value of flood regulation and storage services 2009-2017

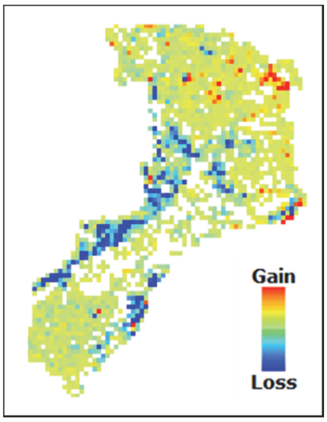


Fig. 5. Changes in the value of material production services 2009-2017

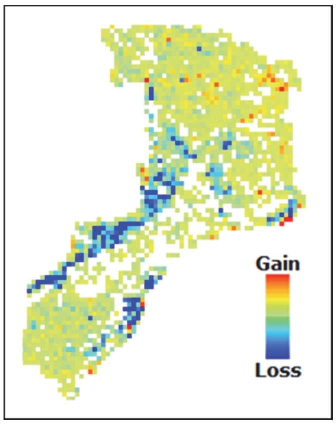


Fig. 6. Changes in the value of atmospheric regulation services 2009-2017

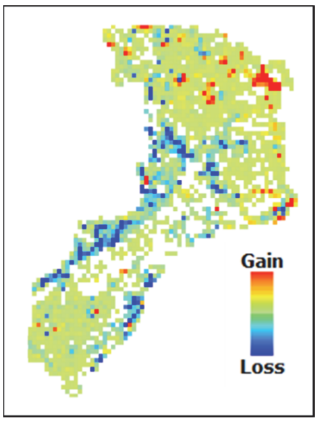


Fig. 7. Changes in value of soil conservation services 2009-2017

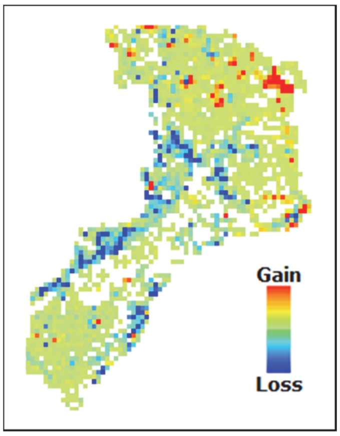


Fig. 8. Changes in total value of ecosystem services 2009-2017

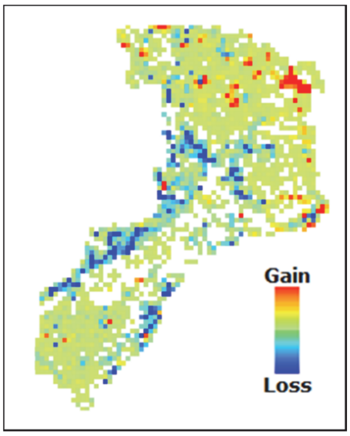


Fig. 9. Changes in the value status of supply services 2009-2017

(2) ESSI mapping of ecosystem services

For the total value of wetland ecosystem services in the study area, and ESSI for three primary services such as supply services (including material production and water source supply), regulation services (including gas regulation, climate regulation, purification of the environment and flood regulation and storage) and support services (soil conservation, material recycling and biodiversity maintenance) and its changes. The mapping results are shown in Fig. 8 to Fig. 11.

4. Findings and discussion

4.1. Evaluation of the value of wetland ecosystem services

The value of wetland ecosystem services in Jiangbei New Area was RMB 6,060.77 million, RMB 9,244.62 million and RMB 7,709.68 million respectively in 2002, 2009 and 2017, which show obvious fluctuation, and regulation services was the core value, among which flood and waterlogging regulation and storage services value accounted for the highest, i.e., 78.16%, 80.47% and 84.51% in three years, respectively.

Obviously, wetland flood control function is the key to urban ecological security. Wetland resources can protect Jiangbei New Area from being or less affected by flood disasters. With the increase of annual precipitation, its flood storage value is more obvious.

The proportion of wetland ecosystem's support services and cultural services has a downward trend, which is consistent with previous studies and is directly related to the wetland distribution fragmentation and wetland habitat degradation caused by urbanization. Soil conservation and biodiversity maintenance are the main components of the value of wetlands' support services. Although the value of pit & pond wetlands in soil conservation and biodiversity maintenance is higher than that of lakes and rivers, remote sensing data show that the area of pit & pond wetlands in the study area is gradually decreasing and seriously fragmented in recent years, which directly limits the ecological function of pit & pond wetlands.

Cultural services value is an important part of wetland ecosystem service. It should be noted that the basic value equivalent conducted are worked out combining with the questionnaire analysis of more than 200 experts (Xie et al., 2015a, 2015b).

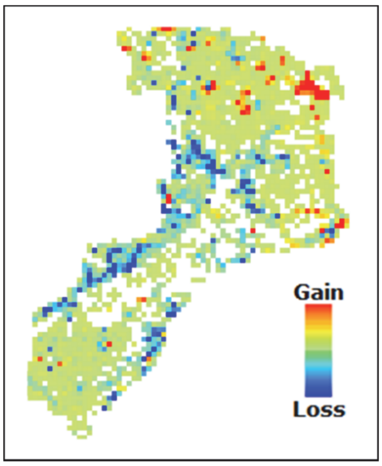


Fig. 10. Changes in the value status of regulation services 2009-2017

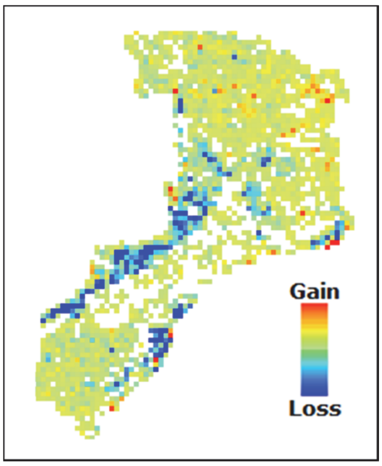


Fig. 11. Changes in the value status of support services 2009-2017

In this study framework, the value of cultural services has not been further classified, and the corresponding value equivalent is mainly given by integrating expert opinions. Although using a single cultural services equivalent makes the valuation more convenient, the results of cultural services value calculation will be insufficient. Even so, the calculation results of the cultural services value show that the cultural services is an important part of urban wetland ecosystem services, as well as delivers direct benefit to urban residents, so the further use of wetland resources should be more rationally and the effect of wetland cultural services must be enhanced.

4.2. Changes in the value of wetland ecosystem services

From the results of spatial mapping, it can be seen that the value of wetland ecosystem services in most regions presents a small gain (Fig. 8), which is related to the higher precipitation in 2017. Surface water is the basis of maintaining the basic ecological process of wetlands. Significant value-added areas are concentrated in the north of Liuhe, where has more lakes and reservoirs, is far away from the city center and less affected by human activities, so the lake wetland ecological function is stable.

The areas with obvious loss of value are concentrated in the north of Pukou and the Chuhe River Basin in the west and middle of Liuhe River (Fig. 8), with a roughly "T"-shaped distribution. This area is the alluvial plain of Chuhe River, with developed water system and abundant wetland resources. In the process of rapid urbanization, due to the influence of central town layout and chemical park construction, population and industry agglomeration significantly disturb wetland resources in the region, its ecological function has been significantly reduced and its ecosystem services value has been significantly lost in 2009-2017. Combining the analysis of Fig. 4 to Fig. 7, the wetland ecosystem in this area only partially maintains the basic function of flood regulation and storage, material production, atmospheric regulation, soil conservation and other functions are obviously lost, and among others, soil conservation function loss is the most serious, which is directly related to the rapid decrease of wetland resources, especially the area of pit & pond wetlands.

Comparing with the mapping of the changes in the value of major secondary services (Figs. 4-7), the changes in the value of the major secondary services maintain a synergistic relationship. Among them, the synergy of changes in the value of material production and flood regulation and storage, atmospheric regulation and soil conservation is relatively high, which is basically similar to previous research findings (Acreman et al., 2011; Cohen-Shacham et al., 2011) and can be used as a clue for the research on synergy/trade-off among ecosystem services.

From the comparison of the value change figures of supply, regulation and support services (Figs. 9-11), we can see that the value change relationship is relatively complex. Based on the raster data, the Person test is used to test the value change of supply, regulation and support services during 2009-2017. The correlation coefficient between supply and regulation services is 0.833 ($p < 0.01$), that between support and supply services is 0.427 ($p < 0.05$), and the correlation between regulation and support services fails to pass the significance test, so the correlation between support services and other primary services is not significant.

The research findings of the value changes and their correlations are based on space grid of 1km. When mapping ecosystem services value, spatial grid of 275m could be used to reflect the changes of specific ecological landscape in detail. And given the sufficient spatial data, 25m×25m pixel could be applied. However, at present, small-scale grid research is mainly applied to the study of spatial and temporal variation and compare of a particular ecosystem services value. The further research and empirical tests of an approach to express the overlapping changes of ecosystem service value through small scale grid are needed.

5. Conclusions

Unreasonable rapid urbanization will seriously threaten the urban wetland ecosystem, and scientific understanding of its ecosystem services value is conducive to the protection and restoration of wetland resources in urbanization construction areas. The study realizes the automatic classification and extraction of urban wetland remote sensing image based on decision tree classification model. Through the modification of basic equivalent value and value equivalent coefficient, this study builds the evaluation system based on value conversion method, and realizes the dynamic evaluation of the value of wetland ecosystem services in Jiangbei New Area. At the same time, this study introduces the overlay analysis of ESCI and ESSI to quantitatively express the value change of evaluation data of wetland ecosystem services from 2009 to 2017 in the study area with the spatial raster data interpreted using remote sensing images, and realizes the visualization of value change of wetland ecosystem services based on ArcGIS platform and remote sensing image interpretation of spatial raster data.

The results show that the research methods used in this study can better realize the dynamic monitoring of wetland ecosystem in urban spatial scale, with easy-to-operate and reliable evaluation of the value, good visualization effect of value change, and easy comparative analysis, so it can effectively support the decision-making of urban ecological resources management.

In the future, how to take into account the specific composition of the cultural services value of and use more reasonable socio-economic factors for comprehensive evaluation while implementing dynamic evaluation is worthy of further research. It is also worth discussing the way to realize the visual analysis of the overlapping changes of multi-type ecosystem services value in smaller scale grids.

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