VALUATION OF WETLAND ECOSYSTEM SERVICES IN RAPIDLY URBANIZING REGION: A CASE STUDY OF THE NANJING JIANGBEI NEW AREA, CHINA

TANG, S.[1,2] – WANG, L. C.[1*] – WU, X. G.[1]

[1]*School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China*

[2]*Faculty of Humanities and Social Sciences, Jinling Institute of Technology, Nanjing 210038, China*

**Corresponding author*
e-mail: wang6312@263.net.cn; phone: +86-25-8359-3233

(Received 25th Mar 2019; accepted 2nd Jul 2019)

Abstract. Wetlands are considered as one of the most important ecosystems on the Earth. Rapidly urbanizing, being an intense way of human activities, has brought significant impact on the ecological functions of urban wetlands. This study focused on the urban wetland ecosystem in the Nanjing Jiangbei New Area, China, and presented a dynamic integrated approach to assess the monetized value of its services. A classification decision tree model was adopted to interpret the Landsat TM/ETM/OLI images to obtain the LUCC data of urban wetlands in different years. Then an integrated approach was employed to correct the equivalent values and their prices of various ecosystem services, dynamically evaluating the value of wetland ecosystem services. The results showed that the overall value of the wetland ecosystem services of the Jiangbei New Area was 893.99 million USD, 1365.63 million USD and 1016.46 million USD in 2002, 2009 and 2015, respectively. Among the service categories, the regulating service reaches the most and the provisioning service contributes the least to the total value. According to the analysis of annual valuation results, it was inevitable that the ecological conditions of wetlands in the rapidly urbanizing area would deteriorate and the capability to provide ecosystem services would degenerate. This research suggests that rapid urban development should adopt an ecosystem service oriented strategy to align sustainable utilization with conservation and to recognize the interaction between the wetland ecosystem services and the forces of urbanization.
Keywords: *LUCC, TCT, VTM, ecosystem services value, regulating services*

Introduction

As Millennium Ecosystem Assessment (MA) pointed, ecosystem services are the benefits people obtain from ecosystems. Every part of Earth produces a bundle of ecosystem services. These include provisioning services such as food and water; regulating services such as flood control; cultural services such as spiritual and recreational benefits; and supporting services, such as materials cycling (MA, 2003). All the services that the ecosystem provides maintain the conditions for life on Earth. Being known as the “kidney of the Earth”, the wetland ecosystem is one of the most valuable ecosystems. As a significant land-water interacted ecosystem, the wetland provides us a multitude of benefits, including supply of materials, water storage, environmental protection, flood control, soil maintenance, climate regulation and maintenance of biodiversity, etc.(Keddy, 2010; Sharma et al., 2015; LePage, 2011). It also provides essential materials and ecological benefits to support life and economic growth in urbans and cities (Azous and Horner, 2000; Sullivan et al., 2014; Parker et al., 2018). As previous studies have shown, land-use and land-cover change (LUCC) caused

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

by human activities have significant impact on the urban wetland ecosystem (Zorrilla-Miras et al., 2014; Šabić et al., 2018). Around the globe, disorganized land use and development have led to a decrease in the total area covered by wetlands (Gardner et al., 2015), and to problems such as debilitated wetland structures and soil erosion, with urbanization exacerbating the decrease of wetland resources (Ehrenfeld, 2000; Kentula et al., 2014; MA, 2005; Davidson, 2014; Sica et al., 2016).

The impacts of human activities on ecosystems have increased rapidly in the last few decades. While a part of these activities can be considered beneficial to human well-being, there is increasing evidence of adverse effects, especially in areas with a concentrated population such as cities and urbans. Protection and recovery of urban wetland resources entails increased awareness of the ecological value of wetlands among the public, for which it is necessary the assessment of the value that wetland ecosystem services provide (Zhang et al., 2017a).

The concept of ecosystem services has been drawing more and more attention in the global community since the 1990s. On the basis of previous research (Costanza et al., 1997; Daily, 1997; Costanza and Mageau, 1999; De Groot et al., 2002; Costanza et al., 2014), MA put forward a guiding solution classifying ecosystem services into four categories: provisioning services, regulating services, cultural services and supporting services, and performed an assessment about them (MA, 2003, 2005a, b). Research on the value of ecosystem services provides an efficient tool to compare them and estimate the effect of environmental policies (McPherson, 1997; Tyrväinen and Miettinen, 2000; Jim and Chen, 2009). In this case, the assessments of urban wetland ecosystem services could specify the substantial contribution of this intricate system to human well-being. Meanwhile, the value-related studies also provide the conditions for the further research and practice of decision-making about urban wetland resources management.

According to existing publications, China has lost nearly 33% of its wetlands from 1978 to 2008 (Niu et al., 2012). The total area of wetlands in 2014 was 3.4 million hectares smaller than in 2003, an 8.82% decrease, and wetlands used for urban construction increased nearly tenfold (Geng, 2014). In recent years there have been efforts by Chinese researchers to probe into the field of valuation of wetland ecosystem services, with mainly focused on the comprehensive valuation of urban wetland ecosystem services, the value of ecosystem services of specific urban wetlands or the value of specific services, among others (Li and Wei, 2015; Xue et al., 2015; Cao et al., 2017; Zhang et al., 2017b, 2014, 2015a; Yang and Liu, 2018).

An assessment of the ecosystems services and their relation to human well-being requires an integrated approach. This enables a decision process to determine which service or set of services is valued most highly and how to develop approaches to maintain services by managing the system sustainably (MA, 2003). Nevertheless, due to limitations in data and research methodologies, research on dynamic monitoring of urban wetlands is still scarce, while in-depth quantitative and comparative studies on the value of ecosystem services are not available, making it difficult to provide a basis for urban planning and management (Zhang et al., 2017a). Based on previous methodologies published by Constanza et al (1997, 2014), Xie and other Chinese researchers optimized a unit area and equivalent value-based system, which is called Value Transfer Method (VTM), to assess the monetized value of ecosystem services (Xie et al., 2001, 2008, 2010, 2015a, b). This optimization was done to increase the reliability of the results and to provide a basis for building an efficient valuation system of ecosystem services of urban wetlands.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

LUCC (land use/land cover change) analysis has already been recognized as an effective way to monitor changes in wetlands in a remote manner (Frohn et al., 2012). Through a discrimination method that combined the use of spectral information and supportive information, this study presents a comprehensive way that increases the precise level of land cover classification to improve accuracy of spatial information acquisition from the wetlands in research area. The study presented herein aims to develop an urban wetland ecosystem service valuation system based on the VTM combining modified equivalent values and LUCC data. It is an empirical study using the Nanjing Jiangbei New Area in the Jiangsu province in China as the study case.

Materials and methods

Research area

The Nanjing Jiangbei New Area in the Jiangsu province is located between 30°51′N and 32°27′N (latitude), 118°21′E and 119°03′E (longitude). It consists of three regions-Pukou District, Liuhe District and Baguazhou Sandbank, covering a total area of 2451 km^2, about 37% of the total of Nanjing (*Fig. 1*). With many rivers, polders and ponds, this area used to have abundant wetland resources which, however, were considerably reduced due to rapid urbanization and excessive reclamation. According to the “Overall Planning of Jiangbei New Area (2014-2030)”, the urbanization rate of this new area is expected to reach 90% in 2030, while it was 66.3% in 2014, which means that urbanization initiatives will be accelerated and thus impose larger threats to the wetlands within the area.

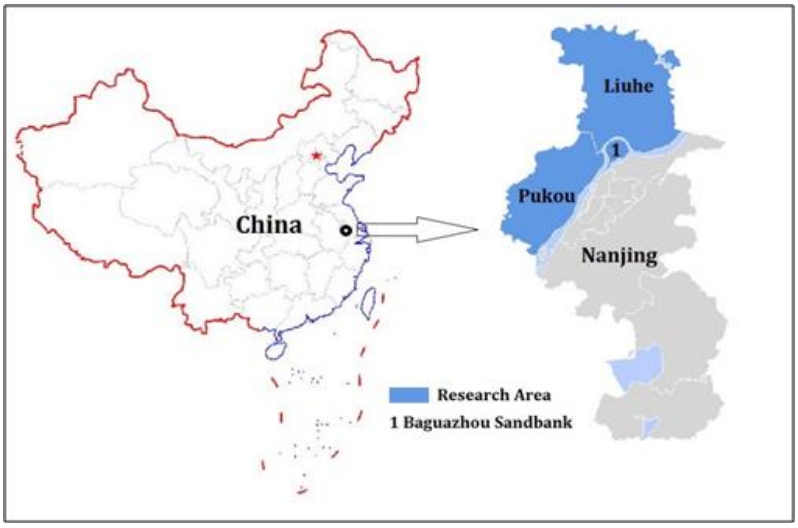

Figure 1. *The location of research area*

Remote sensing image processing

Data used in this study are remote sensing data collected in three periods during cloudless days in adjacent date (*Table 1*), including Landsat TM/ETM/OLI images captured in 2002, 2009 and 2015. The WGS-1984 coordinate system and the UTM projection are used to correct the images, and pre-processing steps including radiative correction, geometric correction and extraction of interested regions are taken before

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

utilization of the data. In light of the distribution of wetlands in the Jiangbei New Area and their main types, we took into consideration the features of valuation of remote images and put forward a system of classification of wetlands in the area (*Table 2*).

Table 1. *Remote sensing data source*

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	2015-09-02	120/38

Table 2. *Wetland classification system in research 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

Using spectral signatures, geometric features and environmental conditions of the main types of wetlands, our study followed the principle of “regional analysis followed by type recognition” and built a decision tree model of comprehensive indicators (*Fig. 2*).

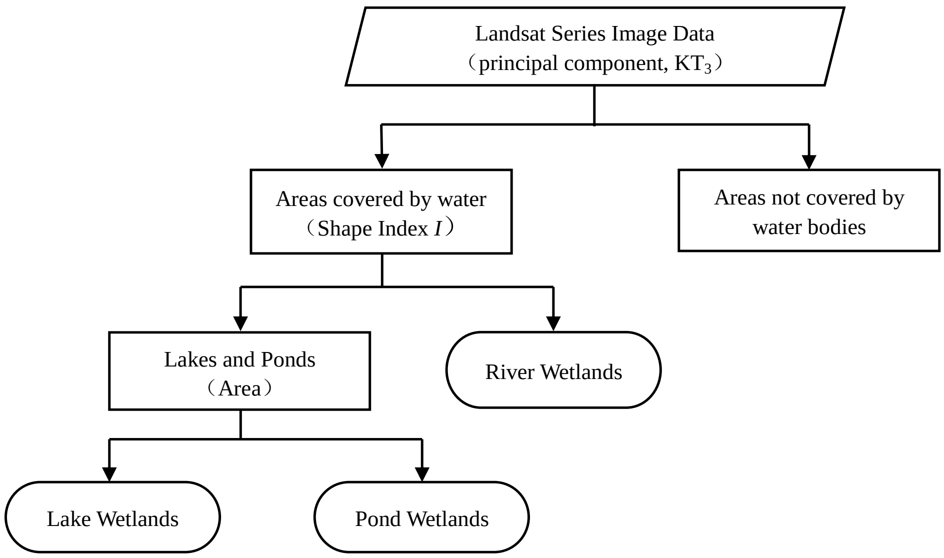

Figure 2. *Decision tree model for wetland information classification and extraction*

In the model, the Tasseled Cap transform (TCT), also known as Kauth–Thomas (K-T) transform, is performed to preprocess the images. The essence of TCT is similar to the principal component analysis by taking linear combinations of the original spectral

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

bands (Mostafiz and Chang, 2018). TCT is a widely used metric capable of capturing scene characteristics in related coordinate directions in a defined feature space and provides a mechanism for data volume reduction with minimal information loss and its spectral features can be directly associated with the important physical parameters of the land surface (Crist, 1985; Yarbrough et al., 2012). Consequently, the TCT conducting in TM imagery has been widely applied for ecological monitoring and other environmental studies, and its reliability and accuracy have been generally recognized (Zhang et al., 2002). In the studies of interpretation of land surface images, the TCT is usually employed to establish an automatic classification and recognition system (Thenkabail and Wu, 2012).

Valuation methods

Equivalent values

The MA definition follows Costanza and his colleagues in including both natural and human-modified ecosystems as sources of ecosystem services, and classify ecosystem services using categories of provisioning, regulating, cultural, and supporting services (MA, 2003). Among these services, 1) provisioning services refer to the products obtained from ecosystems, including food, fiber, wood, fresh water, etc.; 2) regulating services refer to the benefits obtained from the regulation of ecosystem processes, including gas regulation, climate regulation, soil erosion control, water purification and waste treatment, etc.; 3) cultural services are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences, etc., 4) supporting services refer to those that are necessary for the production of all other ecosystem services, including primary production, production of oxygen, soil formation and retention, materials cycling and provisioning of habitat, etc.

Based on the previous studies, a basic equivalent system for ecosystem service value accounting is proposed by Xie and other Chinese researchers, within a basic idea of VTM (Xie et al., 2001, 2008, 2010, 2015a, b). Since 2008, the method has been optimized and improved many times, and its research adaptability has been fully proved. With the equivalent value per unit area of the ecosystem services set as the basis in the study (Xie et al., 2010, 2015), we could calculate the monetized value per unit area according to the price of the average national crop production. The equivalent values per unit area of different ecosystem services in 2015 are presented (*Table 3*).

Correction of equivalent values of water supply and flood control

Adapting to the specific situation of the study area, *Equation 1* is used to amend the equivalent values of two sub-category services, water supply and flood control. Considering both services are related to the hydrological processes of wetland ecosystems, the amount of precipitation is employed as a reliable modifying factor to amend the equivalent values.

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

where R_i stands for the correction coefficient of equivalent values of water supply and flood control services in Region i, W_i refers to the annual precipitation in Region i, and $\overline{W}$ refers to the average annual precipitation in the whole nation.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

Table 3. *Equivalent values of different ecosystems*

Ecosystem services		**Provisioning services**		**Regulating services**				**Supporting services**			**CS**
Category	Subcategory	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

Correction of equivalent value of soil maintenance

The ratio between the soil maintenance amount per unit area in the study regions and nationwide average level is taken as the correction coefficient of the equivalent value of the soil maintenance service. The equation is presented as *Equation 2:*

$$S_i = E_i / \bar{E} \qquad \text{(Eq.2)}$$

where S_i stands for the correction coefficient of the equivalent value of soil maintenance in Region i, E_i refers to the soil maintenance amount per unit area in Region i, and $\bar{E}$ refers to the average amount of nationwide soil maintenance per unit area.

In most studies, the Universal Soil Loss Equation (USLE) is generally used to calculate the amount of soil erosion as it is a widely used mathematical model that describes soil erosion processes. The USLE was developed from erosion plot and rainfall simulator experiments. The USLE is composed of six factors to predict the long-term average annual soil loss in different situations. The equations take the simple product form as *Equations 3* and *4:*

$$SP_x = R_x \cdot K_x \cdot L \cdot S_x \cdot \qquad \text{(Eq.3)}$$

$$SA_x = R_x \cdot K_x \cdot L \cdot S_x \cdot C_x \cdot P_x \qquad \text{(Eq.4)}$$

where SP_x refers to the potential amount of average annual soil erosion, SA_x refers to the actual amount of average annual soil loss, while R_x, K_x, $L \cdot S_x$, C_x and P_x represent the rainfall erosivity factor, the soil erodibility factor, the land form factor, the land cover

http://www.aloki.hu • ISSN 1589 1623 (Print) • ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

and management factor and the land conservation measure factor, respectively. In addition, the potential amount of average annual soil erosion is a quantitative expression of the theoretical soil loss in the absence of vegetation and other management means.

According to *Equations 3* and *4*, we could obtain *Equation 5* to calculate average annual soil maintenance amount (SM_x):

$$SM_x = R_x \cdot K_x \cdot L \cdot S_x \cdot (1 - C_x \cdot P_x \quad \text{(Eq.5)}$$

Calculation of total values

The post-correction monetized value per unit area of each wetland ecosystem is calculated based on the equivalent values, the fundamental equivalent price and the correction coefficient. And the total value of ecosystem services is worked out based on the area of different types of wetlands in the research area. We first make calculations for different regions and then add them up to calculate the total value. The equation for this calculation is shown as *Equation 6:*

$$ESV = \sum A_{ki} \mathrm{m}_{ki} n_{ki} C \quad \text{(Eq.6)}$$

where ESV refers to the amount of ecosystem services value (USD/a), A_{ki} refers to the area (hm^2) of Type *k* wetland in Region *i*; m_{ki} is the equivalent value of Type *k* wetland in Region *i*; n_{ki} is the correction coefficient of the equivalent value of Type *k* wetland in Region *i*, and C refers to the fundamental equivalent price of ecosystem services per unit area (USD/(hm^2·a)).

Results

LUCC data

Landsat images were often used to extract LUCC data, and land surface water is often identified by TCT (Mcfeeters, 1996; Chandrasekar et al., 2010; Adam et al., 2014; Fu and Burgher, 2015; Friedl et al., 2018). Meanwhile, the significant effectiveness of TCT in classification and extraction of wetland image has also been proved (Jiang et al., 2015; Luo and Tao, 2017; Mostafiz and Chang, 2018). The TCT method enhances the spectral information content of Landsat data for different implications of the earth’s surface. Typically, there are three generally used dimensions in TCT, consisting by brightness (measure of soil), greenness (measure of vegetation), and wetness (measure of moisture) (Yarbrough et al., 2012; Adam et al., 2014; Fu and Burgher, 2015; Mostafiz and Chang, 2018). In this study, the water-covered areas were identified by the third principal component, KT_3 (wetness, mainly reflects the humidity information of ground objects), before extracting information of different types of wetlands according to the area and shape. Meanwhile, the area of paddy fields is taken as described from the yearbooks of Liuhe, Pukou and Baguazhou in different years. The results of the remote extraction and classification are shown below (*Figs. 3*, *4* and *5*), and the areas of different types of wetlands are presented (*Table 4*).

Following the results from the extraction and classification of remote images from 2015, we identified the sampling sites through an stochastic method based on the proportion that each of the three types of wetlands (rivers, lakes and ponds) takes up in the total area of wetlands. On that basis, we verified the accuracy of extraction results

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

through comparison between the land use map and site surveying data. As the results of accuracy tests by the confusion matrix show, the classification accuracy rate of rivers and lakes are high, reaching 97.33% and 94.21%, respectively; while the extraction accuracy of ponds is lower, standing at 82.31%. The overall classification accuracy of the extraction results is 86.50% and the overall Kappa coefficient is 0.8433.

Table 4. *Area of wetlands in different years*

Wetland types	Regions	2002		2009		2015	
		Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)	Area (hm^2)	Proportion (%)
Lake wetland	Pukou	408.38	0.45	500.22	0.55	256.95	0.28
	Liuhe	2145.69	1.44	2658.78	1.79	2546.28	1.71
	Baguazhou	38.61	0.69	29.05	0.52	22.41	0.40
	Jiangbei	2592.68	1.06	3188.05	1.30	2825.64	1.15
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	1566.58	0.64	2393.73	0.98	1330.53	0.54
Pond wetland	Pukou	3114.59	3.42	3836.79	4.22	1493.73	1.64
	Liuhe	2061.59	1.39	3585.87	2.41	2076.12	1.40
	Baguazhou	46.85	0.84	46.77	0.84	32.22	0.58
	Jiangbei	5223.02	2.13	7469.43	3.05	3602.07	1.47
Paddy field	Pukou	9562.00	10.51	8566.33	9.41	8426.67	9.26
	Liuhe	26677.00	17.96	27300.00	18.38	26100.00	17.58
	Baguazhou	2333.00	41.66	2333.00	41.66	2333.00	41.66
	Jiangbei	38572.00	15.74	38199.33	15.59	36859.67	15.04
Total area	Pukou	13359.50	14.68	13501.39	14.84	10400.01	11.43
	Liuhe	32106.62	21.62	35232.69	23.73	31760.73	21.39
	Baguazhou	2488.16	44.43	2516.46	44.94	2457.17	43.88
	Jiangbei	47954.27	19.57	51250.54	20.91	44617.91	18.20

According to the interpretation results and relevant statistical data (*Figs. 3*, *4*, and *5; Table 4*), during the three research periods, the total area of wetlands in Jiangbei New Area in 2002, 2009 and 2015 are 47954.27 hm^2, 51250.54 hm^2 and 44617.91 hm^2 respectively, accounting for 19.57%, 20.91% and 18.20% of the total land area respectively.

According to the dynamic change of the total wetland area in Jiangbei New Area, the total wetland area increased slowly during the period of 2002-2009 and decreased continuously during 2009-2015. On the basis of the long-term change from 2002 to 2015, the total wetland area decreased by 0.54% annually on average, showing a slowly decreasing trend on the whole. From 2002 to 2009, the area of other types of wetlands increased significantly except for paddy field wetlands, the most obvious increasing was shown as the average annual growth rate of river wetlands (7.54%) and pond wetlands (6.14%). From 2009 to 2015, by contrast, the area of all types of wetlands decreased relatively rapidly, and the average annual reduction rate of pond wetlands was the most significant (-8.63%).

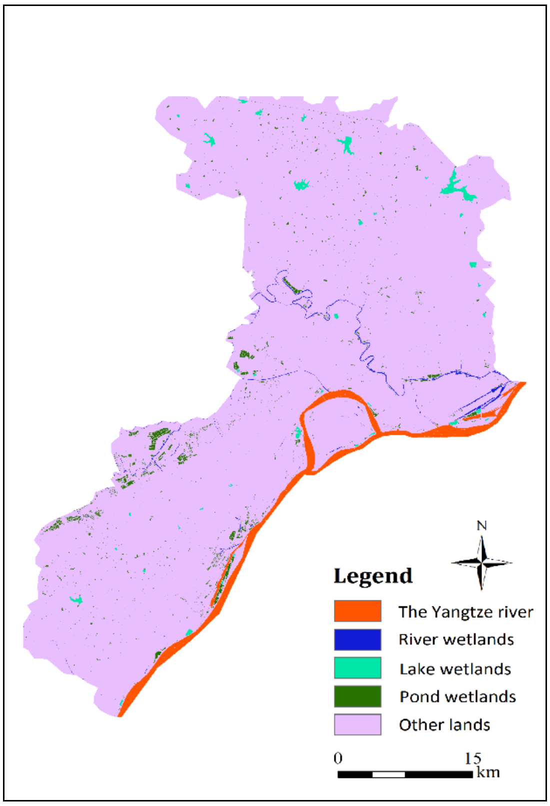

Figure 3. *Wetlands in the Jiangbei New Area (2002)*

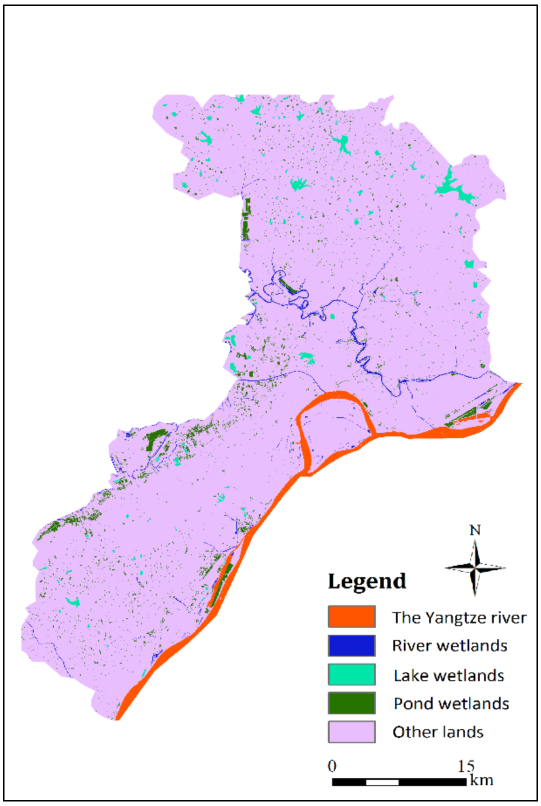

Figure 4. *Wetlands in the Jiangbei New Area (2009)*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

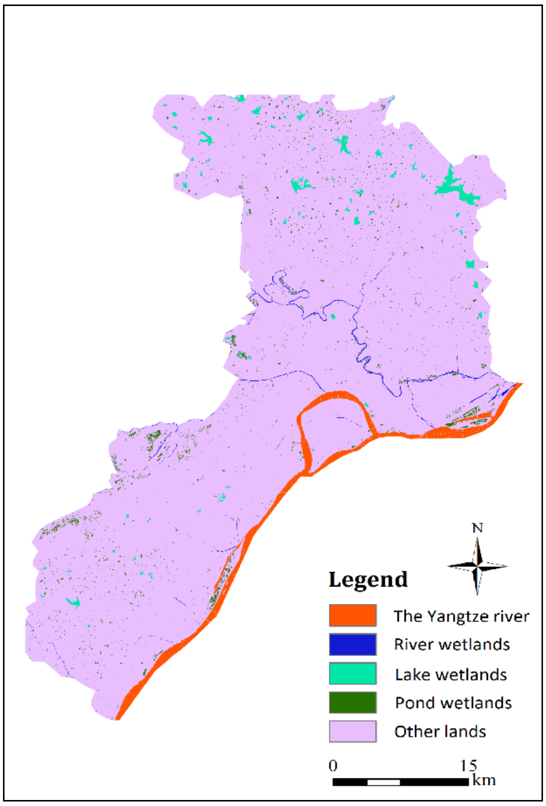

Figure 5. *Wetlands in the Jiangbei New Area (2015)*

Correction results

Fundamental equivalent price

Within the Value Transfer Method, the economic value of productivity per unit area of farmland is utilized as the basis of fundamental ecosystem service price calculating in unit area. Computation based on relevant data, the economic value of crops production per unit area in China in 2010 was 3406.5 RMB/hm^2 (Nie, 2011; Xie et al., 2015b; Zhang et al., 2016), converting to 503.21 USD/hm^2 according to the average exchange rate of RMB against US dollar in 2010 (6.7695). We obtained the corrected price of the standard equivalent by calculating the ratio between the value of crops production per unit area in Nanjing and the same value nationwide in 2010 (Nanjing Statistical Bureau, 2012), after which we then obtained a correction coefficient of 1.38. As a result, the economic value of the fundamental equivalent of ecosystem services per unit area in Nanjing was 4700.97 RMB/hm^2, converting to 694.43 USD/hm^2 according to the average exchange rate mentioned above.

Correction coefficients

Through the calculation of the ratio of annual precipitation in the Jiangbei New Area and the national average level, we obtained the correction coefficients for the equivalent values of the services of water supply and flood control (*Table 5*).

In 2010, the soil maintenance amount per unit area in China was 208.88 t hm^{-2} a^{-1} (Rao, 2015). The average soil erosion modulus (actual amount of average annual soil loss) in the Pukou District over several years was 2465 t km^{-2} a^{-1}, that in the Liuhe

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

District was 2357 t km^{-2} a^{-1} and 3546 t km^{-2} a^{-1} in the Baguazhou Sandbank, while the average *CP* value over those years in Nanjing was 0.0483 (Ma et al., 2011). Using *Equation 5* to calculate, we find that the average soil maintenance amount over those years in the Pukou is 485.70 t hm^{-2} a^{-1}, and that for the Liuhe and the Baguazhou Sandbank are 464.42 t hm^{-2} a^{-1} and 698.70 t hm^{-2} a^{-1}, respectively.

Table 5. *Correction coefficients of equivalent value of water supply and flood control services*

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
2015	648.8 mm	1508.1 mm	2.32	1300.4 mm	2.00	1535.8 mm	2.37

Using the ratio between the average Soil maintenance amount in each region and the national average level, we calculated the correction coefficients of the equivalent value of the Soil maintenance service in the Pukou District, the Liuhe District and the Baguazhou Sandbank, which are 2.33, 2.22 and 3.34, respectively.

Valuation results

Using the previously stated *Equation 6* for the calculations, the results for the valuation of wetland ecosystem services in 2002, 2009 and 2015 in the Jiangbei New Area in Nanjing are presented (*Tables 6, 7* and *8*). The ecosystem services of wetlands in this area reached its highest value in 2009 at 1365.63 million USD, and reached its lowest in 2002 at 893.99 million USD, with the 2015 value of1016.46 million USD in the middle.

To sum up, the value of ecosystem services of wetlands in the Jiangbei New Area presents a variable trend: it moved up sharply from 2002 to 2009, with an annual increase rate of 7.50%, but underwent a tangible drop from 2009 to 2015, with an annual decrease rate of 4.26% (*Fig. 6*).

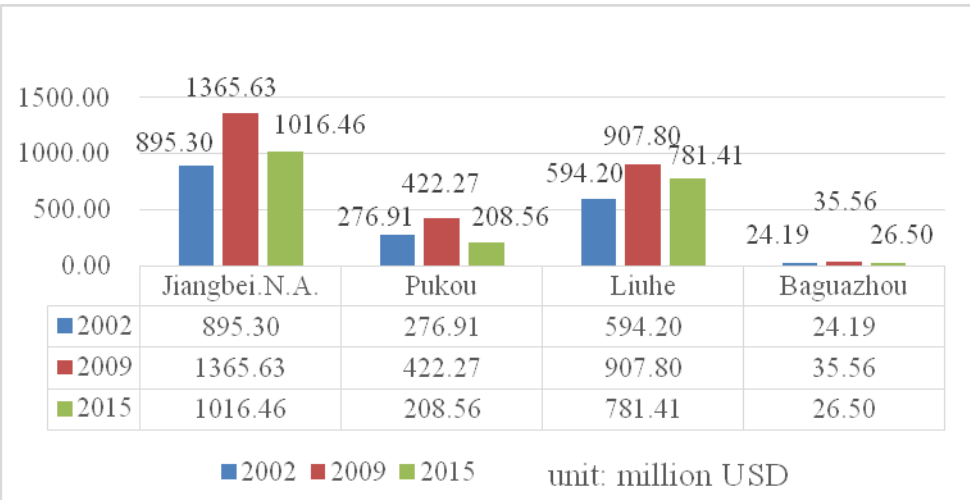

Figure 6. *Temporal change of wetland ecosystem services value in Jiangbei New Area*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

Table 6. *Valuation results of wetland ecosystem services in Jiangbei New Area, 2002*

Category		**Provisioning services**		**Regulating services**				**Supporting services**			**Cultural services**
Subcategory		MP	WS	GR	CR	WT	FC	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)		
		893.99 million USD, according to the average exchange rate of RMB against US dollar in 2010									

JNA: Jiangbei New Area; 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

Table 7. *Valuation results of wetland ecosystem services in Jiangbei New Area, 2009*

Category		**Provisioning services**		**Regulating services**				**Supporting services**			**Cultural services**
Subcategory		MP	WS	GR	CR	WT	FC	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

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

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)		
		1365.63 million USD, according to the average exchange rate of RMB against US dollar in 2010									

Table 8. *Valuation results of wetland ecosystem services in Jiangbei New Area, 2015*

Category		**Provisioning services**		**Regulating services**				**Supporting services**			**Cultural services**
Subcategory		MP	WS	GR	CR	WT	FC	SM	MC	BM	CS
Lake	Pukou	1.24	23.23	0.93	286.51	2.77	6.70	2.74	0.08	3.08	2.28
	Liuhe	12.33	198.46	9.22	2447.62	27.41	66.43	26.01	0.84	30.52	22.62
	Baguazhou	0.11	2.07	0.08	25.53	0.24	0.58	0.34	0.01	0.27	0.20
	JNA	13.68	223.76	10.23	2759.66	30.42	73.72	29.10	0.93	33.87	25.11
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	7.09	42.19	13.34	394.73	25.28	25.28	39.63	1.26	55.26	33.21
	Liuhe	9.86	50.56	18.54	472.96	35.14	35.14	52.67	1.76	76.81	46.16
	Baguazhou	0.15	0.93	0.29	8.70	0.55	0.55	1.23	0.03	1.19	0.72
	JNA	17.10	93.68	32.17	876.39	60.96	60.96	93.53	3.05	133.26	80.09
Paddy fields	Pukou	57.44	-241.71	43.97	249.98	22.58	6.73	0.97	7.53	8.32	3.57
	Liuhe	177.91	-645.38	136.19	667.46	69.94	20.86	2.87	23.31	25.77	11.04
	Baguazhou	15.90	-68.36	12.17	70.70	6.25	1.86	0.39	2.08	2.30	0.99
	JNA	251.25	-955.44	192.34	988.14	98.77	29.46	4.22	32.92	36.39	15.59
All	Pukou	66.85	-156.15	59.05	1179.50	53.02	44.53	45.73	8.95	69.33	41.04
	Liuhe	205.12	-315.43	167.71	4586.14	143.66	149.52	92.15	26.25	145.55	89.05
	Baguazhou	16.50	-58.94	12.79	184.14	7.79	4.81	3.03	2.14	4.60	2.52
	JNA	288.48	-530.52	239.55	5949.78	204.47	198.85	140.90	37.34	219.47	132.62
Total value		9244.62							(unit: million RMB)		
		1016.46 million USD, according to the average exchange rate of RMB against US dollar in 2010									

The category-related components of ecosystem services of wetlands in the Jiangbei New Area are presented (*Table 9*). Among the presented components, the regulating service plays a vital role, taking up about 90% of the total value and even up to 95.81% in 2015, while the provisioning service contributes the least to the ecosystem services, with the proportion being negative in 2002 and 2015, accounting for the major losses in the ecosystem services of urban wetlands.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

Table 9. *Category proportion of the wetland ecosystem services value*

Year	Provisioning services	Regulating services	Supporting services	Cultural services
2002	-1.30%	90.16%	8.35%	2.80%
2009	0.17%	89.96%	7.36%	2.51%
2015	-3.52%	95.81%	5.78%	1.93%

Discussion

The change and composition of value

The importance or “value” of ecosystems is viewed and expressed differently by different disciplines, cultural conceptions, philosophical views, and schools of thought (MA, 2003). The monetization of the value of ecosystem services is a more intuitively way to help people understanding the significance of ecosystem services to human well-being.

According to the valuation results, the value of ecosystem services of wetlands in the Jiangbei New Area reached 893.99 million USD, 1365.63 million USD and 1016.46 million USD in 2002, 2009 and 2015, respectively. In general, these results have the characteristics of temporal discretization, with notably changes in the values among different time periods, implicating a variable state of the wetland ecosystem. Among the three regions, Pukou shows the least stability with the sharpest and most obvious fluctuations over time. Consistent with findings of Zhang et al. (2015b), the change of wetland ecosystem service value is directly related to the change of land use pattern. Land use changes generally can be defined as a human-induced process that has great consequences for landscape and related ecosystems (Sawut et al., 2013).

Similar to the findings in Chaohu Lake Basin (Zhang et al., 2015b), the regulating service performances the core part of the ecosystem services of wetlands in study area. In this category, the flood control service has the highest value, which reflects the structural and functional stability of wetlands ecosystem is of vital importance for the ecological security in the Jiangbei New Area. Yet, the regulating services cannot be perceived or recognized directly by human observation. Located along the northern bank of the Yangtze River, the Jiangbei New Area is rich in precipitation and consists mainly of hilly lands; the landscapes and land covers have been largely damaged, leaving the area susceptible to inundation and waterlogging. Therefore, the regulating services, especially the flood control service, of the urban wetland ecosystem, deserves more attention as a key of the regional ecological security guarantee system.

The provisioning service contributes the least to the total value, with its contribution rate being negative in 2002 and 2015. This result is not consistent with the findings in Chaohu Lake Basin, Lakeside Wetland Park and other areas (Zhang et al., 2014, 2015b, 2017; Li and Gao, 2016). In previous research cases, the value calculation includes farmland, woodland and other types, so the provisioning service value is relatively high. Nevertheless, the land use type structure of our study area is different from that of lake basins, wetland parks or metropolis. Paddy fields and ponds wetland are the main components of production system in the study area. According to the calculation results, the value of the water supply service in 2015 was -78.37 million USD, mainly because the paddy fields take up the largest proportion in the total area of wetlands in the study area and these fields are largely water-consuming during the production process. Nonetheless, analysis of the hydrologic process of the paddy fields shows that these

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

fields are critical in water conservation (Xie et al., 2008) and, in particular, play an important role in underground water supply and water storage during floods; its function in water conservation has been included as a factor in the service type of flood control (Xie et al., 2015a, b). Therefore, respect to the direct benefits that humans receive from ecosystems, the water provisioning service of the paddy fields is obviously smaller compared to the water provisioning of other types of wetlands.

The impact of urbanization

Previous research has proved that regional massive urbanization had serious implications on the provision for ecosystem services, whether they be provisioning services or regulating services (Ai et al., 2015). Similarly, our research findings sufficiently proved that disorganized urbanization poses severe threats to the urban wetland ecosystem. A better understanding of the value of ecosystem services will facilitate protection and recovery of wetland resources in urban sprawl areas (Li et al., 2014). The rapidly urbanizing in Jiangbei New Are is acting as a violent form of human activity and causing obvious land use changes resulting in a great effect on the wetland ecosystem services.

According to this study, the area of wetlands in Pukou and the value of their ecological services witnessed a sharp drop between 2009 and 2015, because against the backdrop of fast urbanization driven by the planning of a new city center, wetlands were encroached and the original landscapes were destroyed, debilitating the ecosystem services. In the future, urban planners of Pukou should pay more attention to the ecological functions of urban wetlands, prevent the impertinently wetland occupying, protect and recover key wetlands and closely monitor wetland ecosystems in the city to build a stable ecosystem and support the development of the city center. Meanwhile, though there are no obvious losses in the value of ecosystem services of wetlands in Liuhe, protection and regional recovery of wetlands in this region should be given attention to maintain and improve the value of wetland ecosystem services. In particular, lake wetlands in the northern part of Liuhe and pond wetlands in the basin of the Chu River in the region’s center should be protected and properly utilized to avoid severe value losses caused by future rapid urbanization, as Pukou has experienced.

Conclusion

This study has presented a dynamic model system to assess the value of ecosystem services of urban wetlands. Following the principle of “regional analysis followed by type recognition”, our study developed a decision tree model for the automatic classification and extraction of remote images of urban wetlands. In addition, based on analysis of the spatial distribution and surrounding environment of urban wetlands, the model employed certain regulating factors to correct the fundamental price and the equivalent values, dynamically evaluating the value of wetland ecosystem services in different years in the research area. The study demonstrates that this approach is suitable for ecosystem services valuation in regional spatial scale and could accomplish a fast and convenient monitoring of the value of urban wetlands, supporting decision-making activities in urban management. Based on this study case, the application of VTM could be modified in other urban scale ecosystems.

The analysis empirically demonstrated that regional massive urbanization had serious implications on the provision for urban wetland ecosystem services. In the past period,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

the local government of the Jiangbei New Area applied special stress on the construction of infrastructure in localized regions to pursue a high level of quality to the economy and urban development, yet ignored the effective protection of the wetlands ecosystem there. It was inevitable that the ecological conditions of wetlands in the rapidly urbanizing area would deteriorate and the capability to provide ecosystem services would degenerate.

The valuation results would also provide a more appropriate reference to decision makers, and draw more attention to the importance of wetland systems in the field of urban ecological security, seeking the synchronized development of human well-being and the nature. Specifically, the valuation can help the regional policy maker (i.e., government, community) to aware the value of ecological resources and formulate or adjust policies accordingly to protect and restore ecosystem services in one particular area. The results suggest that rapid urban development should adopt an ecosystem service oriented strategy to align sustainable utilization with conservation and to recognize the interaction between the wetland ecosystem services and the forces of urbanization. The local administrators and planners should pay enough attention to analysis the value change in and maintain the capability of wetland ecosystem services in urban area. There is an urgent need for conducting the conservation and rehabilitation of urban wetland as key policies in the regional planning, while scientific appraisal can serve as the basis for policy formulation and valuation. Therefore, to evaluate urban wetland ecosystems correctly and frequently is of great significance.

Acknowledgements. This research was financially supported by the Jiangsu University Philosophy and Social Science Fund Project (key subject) (Grant N0. 2018SJZDI092) and the Jiangsu University Philosophy and Social Science Fund Project (Grant No. 2017SJB0487).

REFERENCES

[1] Adam, E., Mutanga, O., Odindi, J., Abdel-Rahman, E. M. (2014): Land-use/cover classification in a heterogeneous coastal landscape using RapidEye imagery: evaluating the performance of random forest and support vector machines classifiers. – International Journal of Remote Sensing 35(10): 3440-3458.

[2] Ai, J. Y., Sun, X., Feng, L., Li, Y. F., Zhu, X. D. (2015): Analyzing the spatial patterns and drivers of ecosystem services in rapidly urbanizing Taihu Lake Basin of China. – Frontiers of Earth Science 9(3): 531-544.

[3] Azous, A., Horner, R. R. (2000): Wetlands and Urbanization: Implications for the Future. – CRC Press Inc., Boca Raton.

[4] Cao, Y., Tang, C. D., Ma, Q., Xue, J. H. (2017): Reevaluation of the value of wetland ecosystem services in Chongming County, Shanghai. – Journal of Nanjing Forestry University (Natural Science Edition) 41(1): 28-34.

[5] Chandrasekar, K., Sesha Sai, M. V. R., Roy, P. S., Dwevedi, R. S. (2010): Land Surface Water Index (LSWI) response to rainfall and NDVI using the MODIS vegetation index product. – International Journal of Remote Sensing 31(15): 3987-4005.

[6] Costanza, R., Mageau, M. (1999): What is a healthy ecosystem? – Aquatic Ecology 33: 105-115.

[7] Costanza, R., d' Arge, R., de Groot, R. S., et al. (1997): The value of the world's ecosystem services and natural capital. – Nature 387: 253-260.

[8] Costanza, R., de Groot, R. S., Sutton, P., et al. (2014): Changes in the global value of ecosystem services. – Global Environmental Change 26: 152-158.

[9] Crist, E. P. (1985): A TM Tasseled Cap equivalent transformation for reflectance factor data. – Remote Sensing of Environment 17(3): 301-306.
[10] Daily, G. C. (1997): Nature's Services: Societal Dependence on Natural Eco-Systems. – Island Press, Washington, DC.
[11] Davidson, N. C. (2014): How much wetland has the world lost? Long-term and recent trends in global wetland area. – Marine and Freshwater Research 65(10): 936-941.
[12] De Groot, R. S., Wilson, M. A., Boumans, R. M. J. (2002): A typology for the classification, description and valuation of ecosystem functions, goods and services. – Ecological Economics 41(3): 393-408.
[13] Ehrenfeld, J. G. (2000): Evaluating wetlands within an urban context. – Urban Ecosystems 4(1): 69-85.
[14] Friedl, M. A., McIver, D. K., Hodges, J. C. F., Zhang, X. Y., Muchoney, D., Strahler, A. H., Woodcock, C. E., Gopal, S., Schneider, A., Cooper, A., et al. (2002): Global land cover mapping from MODIS: algorithms and early results. – Remote Sensing Environment 83: 287-302.
[15] Frohn, R. C., D'Amico, E., Lane, C., Autrey, B., Rhodus, J., Liu, H. (2012): Multi-temporal sub-pixel Landsat ETM+classification of isolated wetlands in Cuyahoga County, Ohio, USA. – Wetlands 32(2): 289-299.
[16] Fu, B., Burgher, I. (2015): Riparian vegetation NDVI dynamics and its relationship with climate, surface water and groundwater. – Journal of Arid Environment 113: 59-68.
[17] Gardner, R. C., Barchiesi, S., Beltrame, C., Finlayson, C. M., Galewski, T., Harrison, I., Paganini, M., Perennou, C., Pritchard, D. E., Rosenqvist, A., Walpole, M. (2015): State of the World's Wetlands and Their Services to People: A Compilation of Recent Analyses. – Ramsar Briefing Note No. 7. Ramsar Convention Secretariat, Gland, Switzerland.
[18] Geng, G. B. (2014): The situation of wetland protection in China is not optimistic. – Green China 3: 8-11.
[19] Jiang, H., Liu, C., Sun, X., et al. (2015): Remote sensing reversion of water depths and water management for the stopover site of Siberian cranes at Momoge, China. – Wetlands 35(2): 369-379.
[20] Jim, C. Y., Chen, W. Y. (2009): Ecosystem services and valuation of urban forests in China. – Cities 26: 187-194.
[21] Keddy, P. A. (2010): Wetland Ecology: Principles and Conservation. – Cambridge University Press, Cambridge.
[22] Kentula, M. E., Gwin, S. E., Pierson, S. M. (2004): Tracking changes in wetlands with urbanization: sixteen years of experience in Portland, Oregon, USA. – Wetlands 24(4): 734-743.
[23] LePage, B. A. (2011): Wetlands: A Multidisciplinary Perspective. – In: LePage, B. A. (ed.) Wetlands. Springer, Dordrecht.
[24] Li, H. B., Wei, N. N. (2015): Spatial transfer process of urban wetland ecosystem services—a case of estuarine wetlands Quanzhou Bay. – Wetland Science 13(1): 98-102.
[25] Li, T. Gao, X. (2016): Ecosystem services valuation of Lakeside Wetland Park beside Chaohu Lake in China. – Water 8: 301.
[26] Li, X. W., Li, M. D., Liang, C., Zhuge, H. J. (2014): On the current key issues in wetland restoration. – Journal of Natural Resources 29(7): 1257-1269.
[27] Luo, K. S., Tao, F. L. (2017): Method for wetland type extraction using remote sensing combing object-oriented and tasseled cap transformation – Transactions of the Chinese Society of Agricultural Engineering 33(3): 198-203.
[28] Ma, L., Bu, Z. H., Peng, G. L., et al. (2011): Temporal and spatial variation of soil and water loss and its control in Nanjing area from 2001 to 2008. – Acta Pedologica Sinica 48(4): 683-692.
[29] McFeeters, S. K. (1996): The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. – International Journal of Remote Sensing 17(7): 1425-1432.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

[30] McPherson, E. G., Nowak, D., Heisler, G., Rowntree, R. (1997): Quantifying urban forest structure, function, and value: the Chicago urban forest project. – Urban Ecosystem 1(1): 49-61.
[31] Millennium Ecosystem Assessment (MA) (2003): Ecosystems and Human Well-Being: A Framework for Assessment. – Island Press, Washington, DC.
[32] Millennium Ecosystem Assessment (MA) (2005a): Ecosystems and Human Well-being: Wetlands and Water Synthesis. – World Resources Institute, Washington, DC.
[33] Millennium Ecosystem Assessment (MA) (2005b): Ecosystems and Human Well-Being: Current State and Trends. – Island Press, Washington, DC.
[34] Mostafiz, C., Chang, N. B. (2018): Tasseled cap transformation for assessing hurricane landfall impact on a coastal watershed. – International Journal of Applied Earth Observation and Geoinformation 73: 736-745.
[35] Nanjing Statistical Bureau (2012): Nanjing Statistical Yearbook 2011. – Phoenix Publishing House, Nanjing.
[36] Nie, Z. B. (2011): China Foodstuff Yearbook 2011 – Economic Management Press, Beijing.
[37] Niu, Z. G., Zhang, H. Y., Wang, X. W., Yao, W. B., Zhou, D. M., Zhao, K. Y., Zhao, H., Li, N. N., Huang, H. B., Li, C. C., Yang, J., Liu, C. X., Liu, S., Wang, L., Li, Z., Yang, Z. Z., Qiao, F., Zheng, Y. M., Chen, Y. L., Sheng, Y. W., Gao, X. H., Zhu, W. H., Wang, W. Q., Wang, H., Weng, Y. L., Zhuang, D. F., Liu, J. Y., Luo, Z. C., Cheng, X., Guo, Z. Q., Gong, P. (2012): Mapping wetland changes in China between 1978 and 2008. – Chinese Science Bulletin 57(22): 2813-2823.
[38] Parker, K. A., Springall, B. T., Garshong, R. A., et al. (2018): Rapid increases in bat activity and diversity after wetland construction in an urban ecosystem. – Wetlands. https://doi.org/10.1007/s13157-018-1115-5.
[39] Rao, E. M. (2015): Soil Conservation Service Changes (2000-2010) and Its Influencing Factors of China's Ecosystem. – Chinese Academy of Science, Beijing.
[40] Šabić, D, Vujadinović, S., Stojković, S., Djurdjić, S. (2018): Urban development consequences on the wetland ecosystems transformations—case study: Pančevački Rit, Serbia. – Contemporary Problems of Ecology 11(2): 227-238.
[41] Sawut, M., Eziz, M., Tiyip, T. (2013): The effects of land-use change on ecosystem service value of desert oasis: a case study in Ugan Kuqa River Delta Oasis, China. – Canadian Journal of Soil Science 93(1): 99-108.
[42] Sharma, B., Rasul, G., Chettri, N. (2015): The economic value of wetland ecosystem services: evidence from the Koshi Tappu Wildlife Reserve, Nepal. – Ecosystem Service 12: 84-93.
[43] Sica, Y. V., Quintana, R. D., Radeloff, V. C., Cavier-Pizarro, G. I. (2016): Wetland loss due to land use change in the Lower Paraná River Delta, Argentina. – Science of the Total Environment 568: 967-978.
[44] Sullivan, P. L., Gaiser, E. E., Surratt, D., Rudnick, D. T., Davis, S. E., Sklar, F. H. (2014): Wetland ecosystem response to hydrologic restoration and management: The Everglades and its urban-agricultural boundary (FL, USA). – Wetlands 34(1): 1-8.
[45] Thenkabail, P. S., Wu, Z. T. (2012): An automated cropland classification algorithm (ACCA) for Tajikistan by combining Landsat, Modis, and secondary data. – Remote Sensing 4(10): 2890-2918.
[46] Tyrväinen, L., Miettinen, A. (2000): Property prices and urban forest amenities. – Journal of Environmental Economics and Management 39: 205-223.
[47] Xie, G. D., Lu, C. X., Cheng, S. K. (2001): Progress in evaluating the global ecosystem services. – Resources Science 23(6): 2-9.
[48] Xie, G. D., Zhen, L., Lu, C. X., Xiao, Y., Chen, C. (2008): Expert knowledge based valuation method of ecosystem services in China. – Journal of Natural Resources 23(5): 911-919.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927

[49] Xie, G. D., Zhen, L., Lu, C. X., Xiao, Y., Li, W. H. (2010): Applying value transfer method for eco-service valuation in China. – Journal of Resources and Ecology 1(1) 51-59.
[50] Xie, G. D., Zhang, C. X., Zhang, C. S., Xiao, Y., Lu, C. X. (2015a): The value of ecosystem services in China. – Resources Science 37(9): 1740-1746.
[51] Xie, G. D., Zhang, C. X., Zhang, L. M., Chen, W. H., Li, S. M. (2015b): Improvement of the evaluation method for ecosystem service value based on per unit are. – Journal of Natural Resources 8: 1243-1254.
[52] Xue, L. L., Yuan, X. Z., Wang, Y. H., He, B. L., Liu, F. B. (2015): Evaluation and analysis of the value of wetland ecosystem service in Chongqing. – Journal of Sichuan Forestry Science and Technology 36(5): 7-10.
[53] Yang, Q., Liu, G. Y. (2018): Wetland ecosystem services assessment based on emergy: a case of Pearl River delta urban agglomeration. – Acta Scientiae Circumstantiate 38(11): 4527-4538.
[54] Yarbrough, L. D., Easson, G., Kuszmaul, J. S. (2012): Proposed workflow for improved Kauth–Thomas transform derivations. – Remote Sensing of Environment 124(2): 810-818.
[55] Zhang, X. Y., Schaaf, C. B., Friedl, M. A., Strahler, A. H., Gao, F., Hodges, J. C. F. (2002): MODIS tasseled cap transformation and its utility. – IEEE International Geoscience and Remote Sensing Symposium 2: 1063-1065.
[56] Zhang, B., Shi, Y. T., Li, Q. X., Xie, G. D. (2017a): The key ecological services and their values of wetland ecosystems in Beijing. – Journal of Natural Resources 32(8): 1311-1324.
[57] Zhang, B., Shi, Y. T., Liu, J. H., Xu, J., Xie, G. D. (2017b): Economic values and dominant providers of key ecosystem services of wetlands in Beijing, China. – Ecological Indicators 77: 48-58.
[58] Zhang, X. H., Zhang, R., Wu, J., Zhang, Y. Z., Lin, L. L., Deng, S. H., Peng, H. (2016): An emergy evaluation of the sustainability of Chinese crop production system during 2000-2010. – Ecological Indicators 60: 622-633.
[59] Zhang, Y. R., Zhou, D. M., Niu, Z. G., Xu, F. J. (2014): Valuation of lake and marsh wetlands ecosystem services in China. – Chinese Journal of Geographical Sciences 24(3): 269-278.
[60] Zhang, Y. R., Zhou, D. M., Liu, M. (2015a): Ecosystem service valuation research of Chinese inland wetlands based on case study. – Acta Ecologica Sinica 35(13): 4279-4286.
[61] Zhang, Z., Gao, J. H., Gao, Y. N. (2015b): The influences of land use changes on the value of ecosystem services in Chaohu Lake Basin, China. – Environmental Earth Sciences 74(1): 385-395.
[62] Zorrilla-Miras, P., Palomo, I., Gómez-Bagghetun, E., Martín-López, B., Lomas, P. L., Montes, C. (2014): Effects of land-use change on wetland ecosystem services: a case study in the Doñana Marshes (SW Spain). – Landscape and Urban Planning 122: 160-174.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1705_1090910927