AQUATIC ECOSYSTEM
HEALTH & MANAGEMENT

Dynamic evaluation on ecosystem service values of urban rivers and lakes: A case study of Nanchang City, China

Yaobin Liu
School of Economics and Management, Nanchang University, Nanchang 330031, China
liuyaobin2003@163.com

Urban rivers and lakes play a significant role in providing ecosystem services, such as water supply, purification, nutrient retention, recreation, aesthetics, and more. However, there is no widely-accepted methodology for how to dynamically evaluate the ecosystem service values of urban rivers and lakes. Using data from survey and remote sensing of Nanchang City, China, this article constructs a conceptual framework based on the Millennium Ecosystem Assessment to propose an integrated approach to evaluate the ecosystem service values of urban rivers and lakes. Furthermore, the article employs a GIS-based Markov chain model to predict the future probable distribution pattern of land use in Nanchang City, while it uses an artificial neural network model to simulate the potential changing of ecosystem service values. The Millennium Ecosystem Assessment-based dynamic evaluation shows that in the first period of 1989–1999, provisioning services are dominant, followed by regulating services, supporting services and cultural services, while during the second period of 1999–2008, regulating services rank firstly in the total change of ecosystem service values, followed by supporting services, cultural services and provisioning services. The artificial neural network-based simulation indicates that the total will slightly increase in line with a small undulation in regulating service values, whilst the most changes brought by the provisioning services will be stable. This study is intended to serve as a tool to be used in decision making for proper and informed urban aquatic ecosystem management.

Keywords: millennium ecosystem assessment-based evaluation, GIS-based Markov chain, artificial neural networks

Introduction

Urban development has frequently resulted in substantial impacts on the environment and urban planning has often overlooked the value of aquatic ecosystem functions. Consequently, urban rivers and lakes are often heavily degraded, and a situation that is not confined to a particular geographic region of the world, but common to all areas subject to urbanization (Morley and Karr, 2002). Initially, such waterways were managed as a resource for human benefit, including water supply, flood mitigation, disposal of wastewater and minimization of disease (Walsh, 2000; Paul and Meyer, 2001; Morley and Karr, 2002), but a combined impact, including an increase in impervious surfaces, channel modification, a disconnection of rivers and floodplains, and a high water demand and increase in contaminants, has degraded many urban rivers and lakes to the extent that some cease to provide the very resources or services for which the settlement developed (Groffman et al., 2003; Grimm et al., 2008). However, due to the lack of dynamic information available in the area when these studies were conducted, greater precision is still needed to understand the value of the benefits generated by this ecosystem. It is

Aquatic Ecosystem Health & Management, 17(2):161–170, 2014. ISSN: 1463-4988 print / 1539-4077 online
DOI: 10.1080/14634988.2014.907223

therefore necessary to obtain a more robust value for the urban rivers and lakes by improving the model by incorporating a dynamic integrated approach to evaluate the ecosystem service values (*ESV*).

In recent years, there is an increasing recognition of how to evaluate the ecosystem service values provided by freshwater ecosystems (Findlay and Taylor, 2006; MRC, 2010). One growing body of literature on the valuation of ecosystem services mainly focused on studies on the monetisation of services (Everard and Moggridge, 2012). While the value of this approach is still contested (Spangenberg and Settele, 2010), practitioners have found monetisation to be a useful means to factor ecosystems centrally into decision making processes. In the UK, the government Department for the Environment, Food and Rural Affairs published guidelines on ecosystem valuation and this has been used by the UK Environment Agency to evaluate ecosystem restoration schemes on the Wareham Harbour, River Tamar and Alborough Flats, River Glaven and a set of development options in the East of England (Everard, 2009, 2010; Glaves et al., 2009). However, full quantification and monetisation of ecosystem services is not always necessary. DEFRA (2007) proposes a simple weighting scheme for ecosystem service evaluation, based on the views of stakeholders or experts, which can prove useful in streamlining decision-making. Glaves et al. (2009) also abandoned monetised studies in favour of a weighted approach to identify favoured options for development in five sites across the region, recognising that reliance on readily monetised values alone would have perpetuated the exclusion of current externalities in decision-making. Nevertheless, a non-quantified but weighted approach was used to derive conclusions that have proved politically influential (Everard and Moggridge, 2012). Another pragmatic approach is that of "ecosystem services", which describes the multiple benefits that society derives from ecosystems (Daily, 1997). These were grouped by the UN Millennium Ecosystem Assessment (MEA, 2005; Norgaard, 2008; Yang et al., 2013) into four categories: "provisioning services", "regulatory services", "cultural services" and "supporting services". Amongst the most important examples of the regulating services described by the UN Millennium Ecosystem Assessment are those affecting water quality (Carpenter and Cottingham, 1997; Carpenter and William, 2004). The "ecosystem services" framework is being increasingly adopted in conservation and ecosystem management to demonstrate the wider benefits of functional ecosystems and justify ecosystem restoration (Eigenbrod et al., 2009; Hancock, 2010). Furthermore, with debate over reference conditions for river restoration and lake rehabilitation (Dufour and Piegay, 2009), the goals of evaluation are becoming increasingly focused towards societal benefits (Findlay and Taylor, 2006; Dufour and Piegay, 2009; Paetzold et al., 2010). However, implementation of this framework is still in its infancy and there is no widely-endorsed methodology for dynamic evaluating the ecosystem service values of urban rivers and lakes (Eden and Tunstall, 2006; Egoh et al., 2007).

The purpose of this article is to evaluate ecosystem services of urban rivers and lakes in Nanchang City, China and to show how a variety of methods, based on the Millennium Ecosystem Assessment (MEA) and two predictive techniques, can be integrated into urban aquatic ecosystem management. This present work considers an impact of urbanization on aquatic ecosystem and employs the ecosystem services framework for dynamic assessing urban rivers and lakes with to practitioner experience, in order to provide a reference of the application of this framework.

Materials and methods

Study area

Nanchang City (lat. 28° 09′–29° 11′N, long. 115° 27 ′–116° 35′ E, elevation 700 m above mean sea level), the capital of Jiangxi Province, lies in the southeast China (Appendix 1 in the supplementary information [SI]), covering a total area of 7,402 km^2 with a population of 4.5 million. Nanchang City has a subtropical monsoon climate with a mean annual temperature of about 17.58°C, annual rainfall of approximately 1700 mm, and a mean annual relative humidity about 77%. In Nanchang City, Vegetation cover is relatively high (38.2%) with a green space area of 7.5 m^2 per capita, and rapidly expanding urban forest area resulting from plantation establishment (Chen et al., 2010). Similar to other Chinese cities, Nanchang City has experienced rapid urbanization and economic development. Rapid urban sprawl have resulted in complex land use changes in the watersheds of urban rivers and lakes that are more obvious in Nanchang City than in other Chinese cities. This makes Nanchang City an appropriate case study for assessing the changes in ecosystem services.

As the soul of the city, the aquatic systems in Nanchang City can be summarized as “a river, two brooks and eight lakes.” ‘A river’ is the Gan River which flows through the Nanchang City, and most of the area of Nanchang lies on a vast plain irrigated by Gan River. The ‘two brooks’ are Fuhe River and Yudai River, and the ‘eight lakes’ are East Lake, South Lake, West Lake, North Lake, Qingshan Lake, Aixi Lake, Xiang Lake and Mei Lake. The rivers and lakes play an important role in providing habitats for native plant and animal species, in water purification and for protection against floods, as well as providing amenities such as aesthetics and recreational opportunities and so on. Despite the increased appreciation of urban rivers and lakes and government policies directed towards protecting them, loss of ecosystem services from urban rivers and lakes continues in Nanchang City. These losses during the period from 1989 to 2008 were estimated to be 10.13 km^2. Changes in agricultural policy have gone a long way toward reducing loss of natural areas in the watersheds of urban rivers and lakes to urban forest area. Other categories of threat have not been reduced as much. In fact, during the period of 1989 to 2008, the losses of the natural areas in the watersheds to urban construction outpaced the losses from agriculture. During this period, 62 percent of these losses were to urban development, while 24 percent of the losses were to agriculture.

Methods

The ecosystem services framework provides a means to quantify benefits to society, encouraging better integration of ecosystem services into urban planning and other decision-making processes (Egoh et al., 2007). It can also enable assessment of the impacts of marginal changes, such as management or development interventions. This is a particularly useful approach in urban ecosystems, such as urban rivers and lakes. The article first develops a MEA-based evaluation framework and a series of valuation methods to evaluate *ESV* of urban rivers and lakes in Nanchang City. Then, a GIS-based Markov chain is adapt to investigate the change in land use of urban rivers and lakes so as to grasp the natural of the existing ecosystem services and applied it to dynamic evaluate the values provided by urban aquatic ecosystems. Last, a valid approach using a back propagation (BP) model of artificial neural networks is constituted as an alternative to traditional statistical methods, for modelling the potential changing of the ecosystem service values (Appendix 2 in the SI).

MEA-based evaluation on ecosystem service values

As the first step of making a dynamic evaluation, we initially adopted the MEA-based method to evaluate the ecosystem service values. A large number of ecosystem services have been identified, and various categorizing approaches have been developed in different studies with different purposes (Costanza et al., 1997; De Groot et al., 2002; Millennium Ecosystem Assessment, 2003, 2005; Farber et al., 2006; Wallace, 2007). In this study, we grouped ecosystem services into 4 categories including provisioning, regulating, supporting, and cultural services, which is established by Millennium Ecosystem Assessment (MEA, 2003, 2005). Appendix 3 provides a set of evaluating methods of the ecosystem services and functions for urban rivers and lakes in Nanchang City based on a review of the literature (Lu et al., 2001; Tong et al., 2007; Zander et al., 2010; Wang et al., 2010; Appendix 3 in the SI). Various valuation methods have been used to estimate the ecosystem service values. Shadow project method (Garrod and Willis, 1999), market value method (Roddewig and Rapke, 1993), travel cost method (Hoevenagel, 1994) and contingent valuation method (Sagoff, 1998) are applied in this study with corresponding models.

GIS-based MC evaluation on land use changes

Next we adopted the GIS-based MC evaluation to evaluate the land use changes. To obtain information on changing area of the urban rivers and lakes in Nanchang City, the dynamic information on land use during the 20-year period was calculated using the map algebra in ArcView GIS software version 3.3. According to the principles of map algebra, we can calculate three periods of land use type figure. Using this method we obtained a transition matrix that reflects the quantitative relationship amongst different land use types in the study area. The default Natural Breaks Classification method in ArcView was used to classify the image data into four classes including farmland, woodland, water body and construction land (Liu et al., 2012). Ground-truthing was performed in the field with a Global Positioning System (GPS) to help classify the images, with a scale of error much less than the minimum pixel size (30 m × 30 m) of the images.

To identify the probable future steady state, we performed a Markov chain model. The Markov chain can be described as a set of states $S = \{S_0,\ldots,S_r\}$. The process starts in one of these states and moves successively from one state to another, and each move is called a step. If the chain is currently in state S_i, then it moves to state S_j at the next step with a probability denoted by P_{ij}, and this probability does not depend on which states the chain was in before the current state. The probabilities P_{ij} are called transition probabilities. The process can remain in the state it is in, and this occurs with probability P_{ii}. An initial probability distribution, defined as $S(0)$, specifies the starting state. Usually, this is conducted by specifying a particular state as the starting state.

In a sequence of discrete time states, the probability of transitioning from state i in T_m to state j in T_{m+1} in a single step is $P_{ij} \cdot P_{ij}$ depends only on the state in T_m and $T_{m+1} \cdot P_{ij}$ is arranged in sequence to give the following transition probability matrix,

$$P = \begin{bmatrix} P_{00} & p_{01} & \cdots & P_{0m} \\ P_{10} & P_{11} & \cdots & P_{1m} \\ \cdots & \cdots & \cdots & \cdots \\ P_{m1} & P_{m2} & \cdots & P_{mm} \end{bmatrix} \tag{1}$$

where P_{ij} is the transition probability of wetland types from type i to j. There are three assumptions: first, the Markov chain is stochastic. The probability of transition from state i to j is as follows P_{ij} $(i, j = 1,\ldots,m)$. Second, Markov chains are usually assumed to be a first-order model so that the state of motion system in $T + 1$ depends only on that of T. Third, it is assumed that the transition probabilities do not change (Li and Cheng, 2006). In accordance with the Markov stochastic process theory, we can use the probability matrix in the initial state to calculate the state transition probabilities given from the initial state to the *nth* state and even a stable state. The formula of the *nth* state Markov transition probability was as follows,

$$P_{ij}^{(n)} = \sum_{k=0}^{m-1} P_{ik}^{(n-1)} P_{kj}^{(n-1)} \tag{2}$$

where m is the number of rows or columns of the transition probability matrix, and the *nth* transition probability matrix is equivalent to the *nth* power of the first transition probability matrix. According to the matrix of the initial $S(0)$ and the transition probability of the *nth* stage $P(n)$, we can calculate the land use distribution in Nanchang City in the future by using a computer simulation.

Artifical neural network-based prediction on potential trend of ecosystem service values

After the above evaluation, we finally employed an artifical neural network-based (ANN) model to predict the potential trend of ecosystem service values for the purpose of making some recommendations for the municipal planning and management. To make a better prediction of a potential trend of ecosystem service values in the study, a BP artificial neural network is introduced in this article because it offers more advantages over conventional modeling techniques, which include the ability to handle large amounts of noisy data from dynamic and nonlinear systems, especially where the underlying physical relationships are not fully understood (Tang et al., 2005). The BP network can be formulated as follows,

$$\begin{cases} a_{1i} = f_1(\sum_{j=1}^{r} w_{1ij} p_j + b_{1i})(i = 1, 2, \cdots, s_1) \\ a_{2k} = f_2(\sum_{i=1}^{s_1} w_{2ki} a_{1i} + b_{2k})(k = 1, 2, \cdots, s_2) \\ f_1 = \frac{1}{1+e^{-p}}, f_2 = wa_1 + b_2 \\ E(W, B) = \frac{1}{2} \sum_{K=1}^{S_2} (t_k - a_{2k})^2 \\ f(X^{(k+1)}) = \min f(X^{(k)} + \eta^{(k)} S(X^{(k)})) \\ X^{(k+1)} = X^{(k)} + \eta^{(k)} S(X^{(k)}) \end{cases} \tag{3}$$

where p_j, a_{1j} are input values on the input and hidden layer respectively; w_{1ij}, w_{2ki} are weights used to compute the hidden and output layers; b_{1i}, b_{2k} are threshold values on the input and hidden layer; t_k, a_{ak} are output value and predictive value; $E(W, B)$ is the vector of predictive errors; k is the training epoch; $\eta^{(k)}$ denotes the learning rate.

Results

Changes in land use

Appendix 4 shows the three maps produced about the changes in land use patterns in the watersheds of urban rivers and lakes after the orthophotos

Table 1. Transferring matrix (m^2) from the areas of urban rivers and lakes to other land use types.

Land use type	1989–1999	1999–2008	1989–2008
Farmland	1,373,972	5,335,465	6,709,437
Construction land	1,271,312	3,176,694	4,448,006
Woodland	2,420,417	1,509,344	3,929,761
Total	5,065,701	10,021,503	15,087,204

classification (Appendix 4 in the SI). They point out that evident changes in land use occurred over the last 20 years in the study area. From Appendix 4, it can be seen that in the two decades, there was a significant change in the occupied area of urban rivers and lakes in Nanchang City. In 1989 this area of urban rivers and lakes is about 64.64 km^2 but in 2008 the area is only approximately 54.51 km^2, indicating the area declined by 15.7% in the last 20 years.

Table 1 documents the changes in land use in the watersheds of urban rivers and lakes in Nanchang City from 1989 to 2008. We can conclude from Table 1 that most of the losses of natural areas in the watersheds of the urban rivers and lakes were the result of conversion into construction land, woodland and farmland. Although this was a combined result of urban sprawl, the policy of returning farmland to woodland and grassland, and grassland reclamation, there is a different transition magnitude in the two sub-periods of 1989–1999 and 1999–2008, respectively. In the first period (1989–1999), only small changes occurred in the areas of urban rivers and lakes denoting a higher stability. In fact, the persistence was even higher than 60% for the land use of the urban rivers and lakes. On the other hand, in the second period (1999–2008), a significant transition from the areas of urban rivers and lakes to other land use types occurred along with a rapid urbanization process in Nanchang City, when the urbanization level rose from 32% to 54%.

The GIS-based Markov model predicts future changes of urban land use in areas surrounding rivers and lakes. To test the precision of the Markov prediction model, the simulated and actual values of areas of urban rivers and lakes in 2008 are used to compare. The relative error of the simulation was about 0.98%, indicating that the difference between the simulation results and the actual areas of the urban rivers and lakes was very small, and both of which were in very good agreement. Therefore, it is feasible to use the transition matrix to establish a transition probability matrix of the Markov chain to predict the future changing areas of the urban rivers and lakes in Nanchang City. Appendix 5 reports the predicted results (Appendix 5 in the SI). The results indicated that the areas of urban rivers and lakes will be relatively stable after the city government implemented *Nanchang City Lake Protection Ordinance* in 2010.

Changes in ecosystem service values

The *ESV* for each ecosystem services including provisioning, regulating, supporting, and cultural services and the total value for the three study years (1989, 1999 and 2008) were calculated using the various valuation methods (Appendix 3) and the area of urban rivers and lakes (Appendices 4 and 5).

Many regulating, provisioning, supporting and cultural services are related to urban rivers and lakes. Some of the services that people benefit from most directly include the provision of drinking water, irrigation water, fish, and opportunities for recreation, and flood mitigation. Among these services, provisioning services directly relate to goods and services, including genetic resources, food, fiber and freshwater. The aquatic ecosystems of urban rivers and lakes in Nanchang City provide fish production including grass carp, silver carp, bighead carp, carp, bream and agriculture production. In the light of the average price of carp (5.8 Yuan/kg), the ecosystem service values of foodstuff supply were estimated in Table 2. From Table 2, it can be seen since 1999, the foodstuff production provided by the aquatic ecosystems has increased steadily, and in 2008 was 2.42 times that of 1989, which can result from a rapid technological advance in Nanchang City. Additionally, the calculated result in Table 2 by using the shadow project method shows that the ecosystem service values of the municipal water supply significantly increased in corresponding with a rapid urbanization process for the studied period. As a result, a substantial increase in urban

Table 2. The ecosystem service values of foodstuff supply and water supply.

	ESV of foodstuff supply		*ESV* of water supply	
Year	Total production (t)	Value (10^7 Yuan)	Total volume (10^4 m^3)	Value (10^4 Yuan)
1989	6435	3.73	25,974	51,948
1999	13,126	7.61	36,390	72,780
2008	15,583	9.04	35,588	71,176

population leaded to an increased demand in water supply.

Regulating services concerns with processes including the regulation of climate and water quality. The ecosystem service values provided by water purification and regulation of local micro-climate in Table 3 were calculated by using the shadow price method. From Table 3, it can be seem that during 1989–1999 the water purification function rapidly decreased firstly, and then substantially increased from 1999 to 2008 while climate regulation function steadily declined at the annual average changing rate of about 4.84%.

Urban rivers and lakes could provide various cultural services, such as recreation, aesthetic value, educational and scientific research value and so on. The residents of Nanchang City were found to be highly active in using urban rivers and lakes for recreation and amenity purposes. Over half of the respondents to a questionnaire survey stated visiting urban rivers and lakes more often than two to three times in per week. Relaxation, nature appreciation, educational and scientific research, and aesthetic enjoyment were ranked as the important reasons for using urban rivers and lakes. The ecosystem service values supplied by cultural service were estimated by applying travel cost method and shadow price method, and the result shows that the ecosystem service values are 2.94×10^7 Yuan in 1989, 3.00×10^7 Yuan in 1999 and 2.71×10^7 Yuan in 2008, respectively, indicating the value of cultural service from the urban rivers and lakes has been decreasing at the annual average changing rate of about −0.41%.

Supporting services can be defined as the services necessary for the production of other types of ecosystem services (MEA, 2003, 2005). Examples of supporting services include the production of atmospheric oxygen, soil formation, nutrient cycling, and ecosystem resilience. Amongst various supporting services, only biodiversity and CO_2 sequestration and O_2 release are considered within the scope of urban aquatic ecosystems in Nanchang City (Appendix 3). It is widely acknowledged that urban rivers and lakes play an important role in the biodiversity conservation and balance of carbon dioxide and oxygen in the urban atmosphere by sequestrating carbon dioxide and generating oxygen. To estimate the ecosystem service values from supporting services the contingent valuation method was applied, where in a questionnaire survey respondents were asked directly about their willingness-to pay for the provision of biodiversity conservation by urban rivers and lakes in Nanchang City. Meanwhile, the market value method was also employed to calculate the ecosystem service values. The result shows the ecological values provided by biodiversity conservation and CO_2 sequestration and O_2 release are 2.29×10^7 Yuan in 1989, 2.10×10^7 Yuan in 1999 and 1.68×10^7 Yuan in 2008, respectively, suggesting the function from supporting services for the urban rivers and lakes has steadily decreased.

Table 3. The ecosystem service values of water purification and climate regulation.

Year	Sewage (10^4 t)	Industrial wastewater (10^4 t)	Degradation value of the sewage (10^4 Yuan)	Treatment value of industrial wastewater (10^4 Yuan)	Values of water purification (10^4 Yuan)	Value of climate regulation (10^4 Yuan)
1989	9416	11,101.31	7532.81	16,651.52	24,184.30	263.08
1999	11,103	6491.86	8882.42	6737.79	15,620.19	243.51
2008	12,590	10,117.67	10,072.00	15,176.51	25,248.51	222.10

Table 4. Changes in the total *ESV* and its components.

Ecosystem services	Effect type	1989–1999 Changing values (10^7 Yuan)	1989–1999 Percentage in the total change (%)	1989–1999 Annual changing rate (%)	1999–2008 Changing values (10^7 Yuan)	1999–2008 Percentage in the total change (%)	1999–2008 Annual changing rate (%)
Provisioning services		25.7	44.2	0.04	0.55	0.66	0.00
	Foodstuff supply	3.88	104.02	0.07	1.43	18.79	0.02
	Municipal water supply	20.83	40.10	0.03	−1.60	−2.20	0.00
	Agriculture production	0.99	40.74	0.03	0.72	21.05	0.02
Regulating services		−8.58	−35.09	−0.04	9.59	60.43	0.05
	Water purification	−8.56	−35.40	−0.04	9.63	61.65	0.05
	Regulation of local micro-climate	−0.02	−7.41	−0.01	−0.04	−16.00	−0.02
Cultural services	0.06	2.04	0.00	−0.29	−9.67	−0.01	
	Recreation & entertainment	−0.16	−6.35	−0.01	−0.37	−15.68	−0.017
	Education & scientific research	0.22	52.38	0.041	0.08	12.5	0.011
Supporting services		−0.19	−8.27	−0.01	−0.42	−20.00	−0.02
	Biodiversity conservation	−0.09	−6.21	−0.01	−0.22	−16.18	−0.02
	CO_2 sequestration & O_2 release	−0.10	−11.90	−0.01	−0.2	−27.03	−0.03
Total value		16.99	19.35	0.02	9.43	9.00	0.01

The changes in the total *ESV* and its components were calculated and compared at the start and end of each of the 2 periods, and the result is shown in Table 4. From Table 4, it can be seem that in each year (1989, 1999 and 2008), the magnitude of kinds of ecosystem service values ranks as follows: municipal water supply > water purification > foodstuff supply > recreation & entertainment > agriculture production > biodiversity conservation > CO_2 sequestration and O_2 release > education and scientific research > regulation of local micro-climate. On the other hand, in the first period of 1989–1999 the ecosystem service values resulted from the provisioning services are the dominant component in the total *ESV*, followed by the regulating services, supporting services and cultural services while in the second period of 1999–2008 the values from the regulating services rank firstly in the total ESV, followed by the supporting services, cultural services and provisioning services. The results indicate along with an accelerated urbanization process in Nanchang City, more and more areas of urban rivers and lakes are occupied by urban development and green-land expansion. However, the total ecosystem service values have slightly increased because local residents have an increasingly needs so that they take effective measures to conserve and improve the ecosystem service functions.

Potential changes in ecosystem service values

The BP network cannot directly be applied for the original data set; otherwise, the errors will not meet the simulated requirements. Thus, the occupied areas of urban rivers and lakes (S_i), the annual volume of water consumption (Q_1), the volume of polluted water (Q_4), the power consumption volume of the air conditioners (Q_5), the increased visitor number (Q_t) and the number of stakeholders (V_w) as well as the total ESV and its components have to be normalized to a range of 0–1 before they are applied. The samples from 1989 to 2000 are employed to train BP network, and the samples during 2001–2008 are tested. The BP network only includes three neurons in the hidden layer, so less than six-step training on the errors. From the trained results, the average relative error between and actual values and simulated values is only 0.94%, sufficiently meeting accuracy evaluation demand.

The potential changes in the total ESV and its components provide by urban rivers and lakes in Nanchang City from 2009–2015 are predicted based on the propensity grid, which captures the likelihood of the observed past changes in the total ESV and its components including the provisioning service values (PSV), regulating service values (RSV), supporting service values (SSV) and cultural service values (CSV), respectively. The simulation results are shown in Appendix 6 in the SI. Because of nonlinear and high-order dynamics, the predicting results sometimes show counter-intuition outcomes. According to Appendix 6, the simulation results show that the most change brought by the provisioning services will be stable in its ecosystem service values. On the contrary, the prediction shows that the total ESV will slightly increase whilst there is only a small undulation in regulating service values. Obviously, the results indicate a rapid urbanization process in Nanchang City will do harm to the ecosystem service functions of urban rivers and lakes.

Discussion and conclusions

In this study, we have evaluated ecosystem services of land use surrounding urban rivers and lakes in Nanchang City, China by using a variety of methods from the Millennium Ecosystem Assessment (MEA) and other predictive techniques, and have shown how to better integrate ecosystem services valuation into urban aquatic ecosystem management. The dynamic evaluation we proposed in this article is constituted by the following three methods: the MEA-based evaluation, the GIS-based MC and ANN-based prediction. The MEA-based evaluation results show that in the first period of 1989–1999 the provisioning services is the dominant ESV, followed by regulating services, supporting services and cultural services while in the second period of 1999–2008 the regulating services ranks firstly in the total change of ESV, followed by supporting services, cultural services and provisioning services. The GIS-based MC evaluation and ANN-based prediction show that the total ESV will slightly increase in line with only a small undulation in regulating service values because the most changes brought by the provisioning services will be stable in its ecosystem service values. And also, the simulation results also demonstrate again that the urbanization process is conditioned on ecosystem service supporting.

Via our research we found that in the period of 1989 to 2008, most of the lost natural areas in the watersheds of the urban rivers and lakes in Nanchang City was converted into construction land, woodland and farmland. And 62% of these losses were used to urban development, while 24% of the losses were used to agriculture utilization. In 1989, the area of urban rivers and lakes is about 64.64 km^2 while in 2008 is only approximately 54.51 km^2, indicating the area has disappeared by 15.7% in the last 20 years. It was a combined result of urban sprawl, the policy of returning farmland to woodland and grassland, and grassland reclamation. Correspondingly, the calculated total ESV and its components show that there are significant differences in both the total ESV and its components in the past three periods and in the future, indicating the ecosystem services provided by urban rivers and lakes was influenced not only by a number of direct services (e.g. food, water and fuel) but also by some indirect (e.g. soil formation, flood regulation) services that underpin human wellbeing. It shows that the MEA-based conceptual framework used in evaluation on the ecosystem service values (*ESV*) of urban rivers and lakes deepens our understanding of the relationship and linkages between ecosystems and human well-being, including economic, social and cultural aspirations. Furthermore, the GIS-based MC evaluation and ANN-based prediction provide us a dynamic perspective for comparing the changes in the total *ESV* and its components.

There is an urgent need to study local ecosystem processes. This study is presented in an effort to measure ecosystem services by understanding the processes involved, and to better quantify the benefits brought to the local people, in this case through urban rivers and lakes. To achieve a full assessment of the ecosystem with the goal of identifying the ecosystem services that could benefit the community, it is necessary to identify the most important processes that determine the provision of service, the benefits, and measures to ensure that this service can actually impact human welfare.

One of the purposes of this article is to provide recommendations for the municipal planning and managers. Although this study focuses on a specific case in Nanchang City and the solutions may be local, sustainable water management is a global priority. Therefore, the ecosystem services analyses and data presented in this Nanchang City study will be useful to other large cities facing the challenges of urbanization and provision of ecosystem services. This study also shows how ecosystem services valuation can be used to support better decision-making for proper and informed water management. In the present work, the traditional procedure of economic valuation to establish *ESV* was used. Even though such calculations have considerable uncertainties and their values are therefore frequently debated in the academic literature, this article still provides a convenient way to obtain results that can be easily understood by decision-makers. In addition, as the results by the GIS-based MC evaluation and ANN-based prediction show, the management guidance provided by such analyses can be robust, even with considerable uncertainty in the potential values.

Funding

This work was supported by National Natural Science Foundation of China (No. 40961009; No. 41261037; No. 41210104055; No. 41110104005; No. 41310104007), the Program for New Century Excellent Talents in the University of China (No. NCET-12-0750), and the Natural Scientific Project of Jiangxi Provincial Government of China (No. KJLD13016; No. 20114BAB203025).

Supplemental material

Supplemental data for this article can be accessed on the publisher's website.

References

Carpenter, S. R. and Cottingham, K. L., 1997. Resilience and restoration of lakes. Conservation Ecology 1(1), 2.

Carpenter, S. R., William, A. B., 2004. Spatial complexity, resilience and policy diversity: fishing on lake-rich landscapes. Ecology and Society 9(1), 8. URL: http://www.ecologyandsociety.org/vol9/iss1/art8/print.pdf.

Chen, F. S., Fahey, T. J., Yu, M. Y. and Gan, L., 2010. Key nitrogen cycling processes in pine plantations along a short urban-rural gradient in Nanchang, China. Forest Ecology and Management 259(3), 477–486.

Costanza, R., dArge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P. and van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Daily, G., 1997. *Nature's services: societal dependance on natural ecosystems*. Island, Washington DC.

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.

DEFRA, 2007. An introductory guide to valuing ecosystem services. Department for Environment, Food and Rural Affairs, London. Available online: http://www.defra.gov.uk/wildlife-countryside/pdf/natural-environ/ eco-valuing.pdf.

Dufour, S. and Piegay, H., 2009. From the myth of a lost paradise to targeted river restoration: forget natural references and focus on human benefits. River Research and Applications 25(5),568–581.

Eden S. and Tunstall, S., 2006. Ecological versus social restoration? How urban river restoration challenges but also fails to challenge the science- policy nexus in the United Kingdom. Environment and Planning C: Government and Policy 24(5), 661–680.

Egoh, B., Rouget, M. and Reyers, B., 2007. Integrating ecosystem services into conservation assessments: a review. Ecological Economics 63(4), 714–721.

Eigenbrod, F., Anderson, B. J., Armsworth, P. R., Heinemeyer, A., Jackson, S. F., Parnell, M., Thomas, C. D., Gaston, K. J., 2009. Ecosystem service benefits of contrasting conservation strategies in a human-dominated region. Proceedings Royal of Society B, Biological Sciences 276(1669), 2903–2911.

Everard, M., 2009. Ecosystem services case studies. Science Report SCHO0409BPVM-E-E. Environment Agency, Bristol. (http://publications.environment-agency.gov.uk/pdf/SCHO0409BPVM-E-E.pdf)

Everard, M., 2010. Ecosystem services assessment of sea trout restoration work on the River Glaven, North Norfolk. Environment Agency Evidence report SCHO0110BRTZ-E-P. Environment Agency, Bristol. (http://publications.environment-agency.gov.uk/pdf/SCHO0110BRTZ-e-e.pdf)

Everard, M. and Moggridge, H. L., 2012. Rediscovering the value of urban rivers. Urban Ecosystem 15(3), 293–314.

Farber, S., Costanza, R., Childers, D. L., Erickson, J., Gross, K., Grove, M., Hopkinson, C. S., Kahn, J., Pincetl, S., Troy, A., Warren, P. and Wilson, M., 2006. Linking ecology and economics for ecosystem management. Bioscience 56(2), 121–133.

Findlay, S. J., Taylor, M. P., 2006. Why rehabilitate urban river systems? Area 38(3), 312–325.

Garrod, G. and Willis, K. G., 1999. Economic Valuation of the Environment: Methods and Case Studies. Edward Elgar Publishing Ltd., Cheltenham, UK.

Glaves, P., Egan, D., Harrison, K. and Robinson, R., 2009. Valuing ecosystem services in the East of England. East of England Environment Forum, East of England Regional Assembly and Government Office, East England.

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X. and Briggs, J. M., 2008. Global change and the ecology of cities. Science 319, 756–760.

Groffman, P. M., Bain, D. J., Band, L. E., Belt, K. T., Brush, G. S., Grove, J. M., Pouyat, R. V., Yesilonis, I. C. and Zipperer, W. C., 2003. Down by the riverside: urban riparian ecology. Frontiers in Ecology and the Environment1(6), 315–321.

Hancock, J., 2010. The case for an ecosystem service approach to decision-making: an overview. Bioscience Horizons 3(2), 188–196.

Hoevenagel, R., 1994. A comparison of economic valuation methods. In: Pethig, R. (Ed.), *Valuing the Environment: Methodological and Measurement Issues*. Kluwer Academic Publishers, Norwell, MA, 251–270.

Li, S. T. and Cheng, Y. C., 2006. A hidden Markov model-based forecasting model for fuzzy time series. WSEAS Transactions on Systems 5(8), 1919–1924.

Liu, Y., Li, J. C. and Zhang, H., 2012. An ecosystem service valuation of land use change in Taiyuan City, China. Ecological Modelling 225(2), 127–132.

Lu, C. X., Xie, G. D. and Cheng, S. K., 2001. Economic evaluation of river ecosystem service in recreation. Resources Science 23(5), 77–81.

Mekong River Commission for Sustainable Development (MRC), 2010. IWRM-based Basin Development Strategy for the Lower Mekong Basin, Fourth draft. November 29, 2010.

Millennium Ecosystem Assessment (MEA), 2003. Ecosystems and Human Well Being: a Framework for Assessment. Island Press, Washington, D.C.

Millennium Ecosystem Assessment (MEA), 2005. Ecosystems & human well-being: synthesis. Island, Washington, D.C.

Morley, S. A. and Karr, J. R., 2002. Assessing and restoring the health of urban streams in the Peuget Sound Basin. Conservation Biology 16(6), 1489–1509.

Norgaard, R. B., 2008. Finding hope in the millennium ecosystem assessment. Conservation Biology 22(4), 862–869.

Paetzold, A, Warren P. H. and Maltby, L. L., 2010. A framework for assessing ecological quality based on ecosystem services. Ecological Complexity 7(3), 273–281.

Paul, M. J. and Meyer, J. L., 2001. Streams in the urban landscape. Annual Review of Ecological Systems 32(3), 333–365.

Roddewig, R. and Rapke, G. R., 1993. Market value and public value: an exploratory essay. Appraisal Journal 61(1), 52–62.

Sagoff, M., 1998. Aggregation and deliberation in valuing environmental public goods: a look beyond contingent valuation. Ecological Economics 24(2), 213–230.

Spangenberg, J. H. and Settele, J., 2010. Precisely incorrect? Monetising the value of ecosystem services. Ecological Complexity7(3), 327–337.

Tang, Z., Engel, B. A., Pijanowski, B. C. and Lim, K. J., 2005. Forecasting land use change and its environmental impact at a watershed scale. Journal of Environmental Management 76(1), 35–45.

Tong, C. F., Feagin, R. A., Lua, J. J., Zhang, X. F., Zhua, X. J. Wang, W. and He, W. S., 2007. Ecosystem service values and restoration in the urban Sanyang wetland of Wenzhou, China. Ecological engineering 29(3), 249–258.

Wallace, K. J., 2007. Classification of ecosystem services: problems and solutions. Biological Conservation 139(3–4), 235–246.

Walsh, C. J., 2000. Urban impacts on the ecology of receiving waters: a framework for assessment, conservation and restoration. Hydrobiologia 431(2–3), 107–114.

Wang, G. H., Fang, Q. H., Zhang, L. P., Chen, W. Q., Chen, Z. M. and Hong, H. S., 2010. Valuing the effects of hydropower development on watershed ecosystem services: Case studies in the Jiulong River Watershed, Fujian Province, China. Estuarine, Coastal and Shelf Science 86(3), 363–368.

Yang, W., Dietz, T., Liu, W., Luo, J. Y., Liu, J. G. and Cebrian, J., 2013. Going beyond the Millennium Ecosystem Assessment: An index system of human dependence on ecosystem services. PLoS One 8(5), e64581.

Zander, K. K., Garnett, S. T. and Straton, A., 2010. Trade-offs between development, culture and conservation-Willingness to pay for tropical river management among urban Australians. Journal of Environmental Management 91(12), 2519–2528.