Characteristic analysis of ecosystem service value of water system in Taiyuan urban district based on LUCC

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Abstract: Changes in the land use and ecosystem service value of the 600 m buffer zone of Jinyang Lake and the 1000 m riparian zone of the Fenhe River in the Taiyuan urban district in China, were studied using satellite image data collected in June 2006 and June 2013. According to the ecosystem services assessment system based on expert knowledge, the ecosystem service value (ESV) per unit area was determined for various land-use types and the value of the water system and its buffer regions in the Taiyuan urban district were determined. And then the relationship between LUCC (Land Use/Cover Change) and ESV was discussed. Moreover, the accuracy and validity of the results was analyzed. The results showed that: (1) the areas of green vegetation and water bodies of Jinyang Lake and its buffer region decreased by 24.96% and 3.22%, respectively, between June 2006 and June 2013, whereas the areas of farmland and built-up land increased by 15.81% and 12.37%, respectively. At Jinyang Lake, the degree of dynamic change for green vegetation, water bodies, farmland, built-up land, and unused land was −0.13, −0.02, 0.17, 0.09, and −0.05, respectively. In the Fenhe River's buffer region, the areas of green vegetation, farmland and unused land decreased by 1.36%, 6.36% and 0.3%, respectively, but those of built-up land and water bodies increased by 1.41% and 6.61%, respectively. Their degree of dynamic change was −0.03, −0.02, −0.04, 0.01 and 0.32, respectively; (2) In 2006, the landscape fragmentation indices (LFI) of Jinyang Lake buffer of 0-200 m zone were greater than 2, but those of 200-600 m buffer zone were less than 0.3, the water-body index not included. However, in 2013, the landscape fragmentation indices of green vegetation and water bodies of 0-600 m buffer zone were both high, meaning that the land-use pattern had improved. The fragmentation index of green vegetation of the 0-200 m buffer increased from 0.1 (the minimum for the year) to 1.7 (the maximum for the year) during the seven years of this study along the Fenhe River. The fragmentation index of built-up land increased from 0.007 to 0.01 in the 200-500 m buffer and from 0.007 to 0.06 in the 500–1000 m buffer. (3) The total ecosystem service value of Jinyang Lake and its buffer region decreased by 22.673%, whereas during the same period, that of the Fenhe River and its buffer region increased by 41.345%. The total ecosystem service value of the water bodies and their buffer regions in the Taiyuan urban area increased by 13.725% overall. (4) The change rate of the ecosystem service value of the 0-600 m buffer region decreased by 1.579% at Jinyang Lake, while that of the 0-1000 m buffer region increased 5.079% at the Fenhe River over the seven years.

Keywords: remote sensing, water system, land use, LUCC, ecosystem service value, urban

DOI: 10.3965/j.ijabe.20160901.2021

Citation: Liu P, Zheng X Q, Chen J F, Zhang Q, Li J L, Wu B. Characteristic analysis of ecosystem service value of water system in Taiyuan urban district based on LUCC. Int J Agric & Biol Eng, 2016; 9(1): 153－165.

1 Introduction

With the economic development of society and the gradually accelerating urbanization, urban water has been emphasized as one of the most important factors in urban development. Human activities, such as stabilizing river banks and constructing artificial lakes, are transforming

Received date: 2015-07-31 **Accepted date:** 2015-11-24

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urban water bodies and their natural evolution. Hence, the appearance of artificial water bodies has become inevitable[1,2]. Long-term land use has greatly changed the landscape pattern and has influenced the ecological environment to some extent. In the field of ecosystem services, Holder et al[3-5] were among the early researchers. Daily[6] contributed to the conception, classification and methods of ecosystem service function. And much has been achieved regarding ecosystem service value[7-10]. In particular, the total value of global ecosystem services has been assessed by Costanza, Arge, Groot et al.[11]. And many have since based their research on this study. The evaluation methods of ecologic value can be categorized into three different types[5]. The first is an actual market evaluation method, which mainly contains market methods and expenditure methods[12-14]. The second is an alternative market valuation method, mainly including a replacement cost technique, an opportunity cost approach, a recovery and preventive approach, a shadow project approach and a travel cost method[15,16]. The third is a simulation market evaluation method. The conditional value method and the contingent valuation method are both representatives of this type of method[17,18]. In practical assessment, several methods are often used simultaneously to evaluate the values of different ecosystem services. The various methods and data sources used result in large differences in the valuations[19]. The rapid development of Earth observation technology and the advent of high-resolution commercial satellites have provided new technical means for the study of water bodies[20,21] and land use[22,23]. Use of multi-temporal remote-sensing image data to study land cover and environmental conditions has become a hot topic[24-26]. Moreover, LUCC and the ecosystem service value of urban areas have gradually attracted more attention[2,27,28]. Palomo et al.[29] research shows that a park and its buffer areas provide a diverse range of ecosystem services that benefit the surrounding lands. With the rapid development of urbanization, land use change of areas surrounding water systems has intensified. The LUCC dynamic evolution of the urban water systems and their extended areas has affected ecosystem services. Water is a key factor in the evaluation process of ecosystem service value. It is difficult to implement long-term protection planning of an urban environment if the relationship between LUCC and ecosystem services of the water system and its surrounding lands, as well as the environmental response of the broader surrounding area cannot all be carefully considered[29,30].

In recent research the assessment scale for ecosystem service value can be seen to be decreasing gradually[5], with research data focusing mainly on services provided by a single ecosystem[31]. Therefore, there is a need to study the methods and indexes used at the different scales and in different ecosystems. To date, research estimating ecosystem service value has often considered large areas or special areas such as forests, wetlands, or cities. Thus a study concerning urban water bodies and their surrounding zones, which are subject to artificial intervention, forms an important innovation. This paper analyzes the characteristics of LUCC of the water bodies and their surrounding zones in Taiyuan, China, as they have been affected by the urban environment and production systems (agriculturalization, industrialization/ urbanization, etc). The analysis is based on the MapGIS platform, using remote-sensing technology. The ecosystem service value of the urban water bodies and their buffer regions is estimated using an amended parameter. The results may offer a basis for decision-making in urban ecological environmental planning and protection.

1 Study area and data sources

1.1 Study area

Taiyuan is the capital city of Shanxi Province. The city is located at longitude 111°30'-113°09'E and latitude 37°27'-38°25'N. It is situated in the northern part of the Taiyuan basin, surrounded by mountains to the west, north, and east, while its central and southern area is formed by a spacious river valley basin. The Taiyuan urban district covers an area of 1460 km^2, and the average altitude is about 800 m[2]. The study area belongs to the warm semi-arid continental monsoon climate, with four clearly distinguishable seasons. The weather is dry and windy in spring, wet in summer, mild in autumn, and relatively snow-free in winter. The annual rainfall is 456 mm, 70% of which occurs in July, August, and September.

The Fenhe River and Jinyang Lake are the main water bodies in the Taiyuan urban district. In recent years, with urbanization and efforts towards city beautification, the urban ecological environment has been changed greatly. The Fenhe River is the second largest tributary of the Yellow River, is 70 km in length, and flows from the northwest to the southeast. Taiyuan Fenhe Park is a waterfront park, which is part of a hydraulic engineering and greening project. Its construction began in 1998 and was completed in 2013. The park's total length and width are 26 000 m and 500 m, respectively. The included artificial compound channel is divided into two channels by a middle wall. The clear water channel on the east side is 220 m wide, and the muddy water channel on the west side is 80 m wide. These are used, respectively, to transport reservoir irrigation water and to discharge upstream floods. With its combination of water and green space, Fenhe Park has developed multiple thematic landscapes covering about 1300 hm^2. It is currently the largest public green leisure space in Taiyuan.

Jinyang Lake is located in the southwestern part of the urban district of Taiyuan City, 3000 m from the center of town. Jinyang Lake, situated at an altitude of 780 m, with a water area of 466 hm^2, an average water depth of 5 m, and a storage capacity of 24 000 000 m^3, is the largest artificial lake in northern China. It was created by diverting the west main stream of the Fenhe River. The water has a high enough temperature to never freeze, which makes it suitable for farming. In the mid-1990s, the water was seriously polluted because of excessive aquaculture, and Jinyang Lake's surrounding ecological environment was degraded by human activity. For example, heavily polluting enterprises were concentrated on the western shore of Jinyang Lake, and real estate development intensified as well. The emphasis on ecological construction in Taiyuan in recent years has led to improvement in the ecological environmental of Jinyang Lake.

1.2 Data sources

Land-use data were obtained from Landsat TM on June 27, 2006, and from Landsat OLI on June 24, 2013. The study area was delineated according to boundary vector data of the Chinese administration, based on the MapGIS 10 platform, using RS and GIS technology. Two images with little to no cloud covering the study area were downloaded from a geographic information cloud Web site.

As expected in late June, in the pre-flood period of the summer, the vegetation was luxuriant and precipitation and inflow were both low. Therefore, the image data used fully reflected the conditions of vegetation cover and water. The land-use patterns were representative.

2 Methods

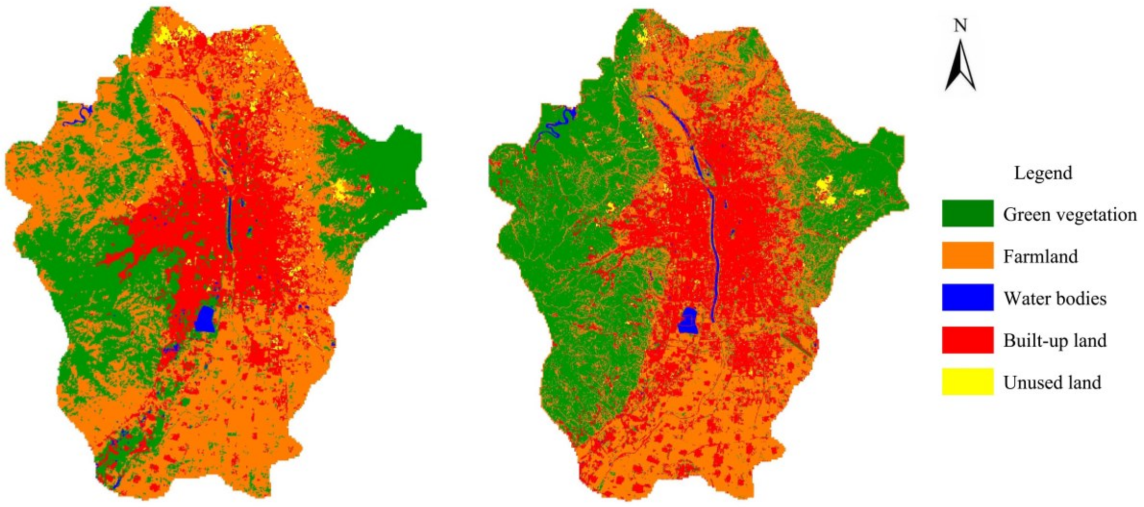
2.1 Remote-sensing image classification

After computing the normalized difference vegetation index (NDVI), compounding the wave bands, interpreting the composite image manually, and selecting the area of interest, the land-use classification was performed using the maximum likelihood method for the 2006 TM image. For 2013, by choosing the OLI images of wave bands 6, 5, and 4 as the RGB combination, fusing the composite image with the 15 m resolution panchromatic image, and selecting the fusion algorithm based on wavelet transform fusion, a fused image was created (Figure 1).

2.2 Buffer setting

Taking into account the actual water distribution as well as the layout of the urban landscape, different riparian buffers were decided upon in the Taiyuan urban district, using the buffer analysis function based on the MapGIS 10 platform. The gauge of the buffer region is in accordance with the urban water planning regulations concerning specification of China.

The layout of the littoral zones along both the east and west side of the Fenhe River is symmetric. From the river bank, first the park's green land is encountered, then the riverside expressway and finally the urban construction. The width of the park's green land and of the expressway is 100 m and 50 m, respectively. Along the sides and center of the expressway as well as in the transition region between the expressway and the urban construction large areas have been afforested. As a result, the main landscape type in the 0-200 m buffer region of the Fenhe River is green land.



a. 2006 b. 2013

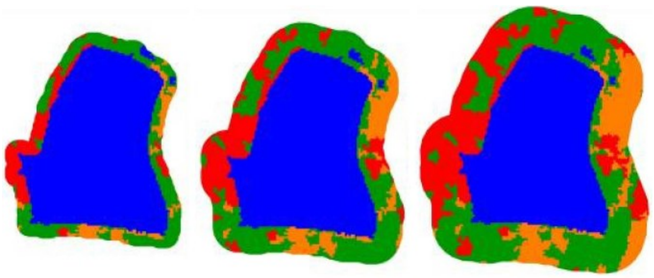
Figure 1 Land-use patterns in Taiyuan City in 2006 and 2013

According to existing research, to control sediment and soil erosion it is preferable that the width of a riparian vegetation zone is greater than 80-100 m. And 20-200 m is the width of a riparian buffer zone stipulated by U.S. governmental organizations[32,33]. The larger the width of a buffer zone, the more the benefit will be to the protection of the ecological environment. Thus the first buffer region selected is the 0-200 m area, the maximum range in America. The urban road nearest to the riverside expressway is about 500 m away from the river bank. There are many riverside residences, and the land use type is mainly construction. Therefore, this 200-500 m area is selected as second buffer region. The ‘temptation distance’ of an urban water system to people is 1000-2000 m, amounting to 15-30 minutes walking distance[34]. However, there are so many urban buildings and roads in the zone 1000-2000 m from river bank, and its land use type is the same to that of the region 500-1000 m from the water system. Considering the scale of the three buffer zones, the largest range of the buffer region was set based on the ‘temptation distance’ from which people would be tempted to visit the urban water system. Therefore, the third buffer region is selected on the basis of the minimum ‘temptation distance’ value of 1000 m and set at 500-1000 m.

Jinyang Lake is an artificial lake used for industrial applications. Based on this characteristic as well as the situation of the surrounding ecological environment, there is a great difference between Jinyang Lake and the Fenhe River. On the one hand, there are many problems concerning the decreasing traditional industry, the depressed economy and the deteriorating ecology. On the other hand, rapid development of real estate and the presentation of regional development planning will bring new opportunities. Because of the lush vegetation situated around the lake shore, the first buffer region for the lake is set as 0-200 m, which is identical to the Fenhe River’s first buffer region. The shortest distance between the shorelines of Jinyang Lake and the Fenhe river is 1600 m. In order to avoid overlap between their buffer zones, the maximum buffer boundary for Jinyang Lake is set at 600 m. From 200 m outwards both old industrial factories and new residences can be found. The occurring land degradation and deteriorating trend regarding the ecological environment are disquieting. To analyze the environment surrounding this industrial artificial lake in detail, three buffer zones have been determined, as for the Fenhe river, however in this case the second and third buffer region are chosen to be of equal width. Therefore the second buffer region is set at 200-400 m, and the third buffer region at 400-600 m.

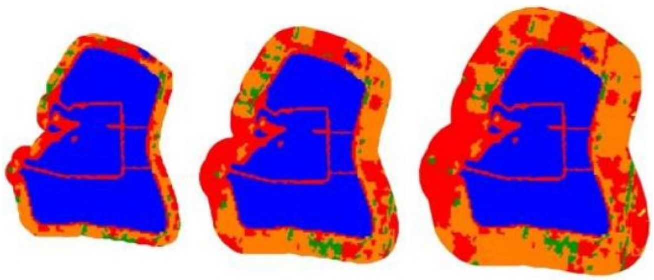
The buffer zones of the Jinyang Lake did not change between 2006 and 2013 as the water’s edge of this artificial lake stayed almost unchanged. The Jinyang

Lake buffer regions of 0-200 m, 0-400 m, and 0-600 m, and the land use of these areas in 2006 and 2013 are shown in Figures 2 and 3, respectively. At the Fenhe River Park, the implementation of the southern and northern extension projects was in progress during the period studied (2006 to 2013). Though the three Fenhe River buffer regions extending from the water's edge were set at 0-200m, 0-500 m, and 0-1000 m, to analyze the changes of the total ecosystem service value along the Fenhe River in the urban area over the seven years, the original buffer boundaries of 2013 were also used for 2006, as the water area had changed greatly. The land use for the Fenhe River buffers in 2006 and 2013 are shown in Figures 4 and 5, respectively.



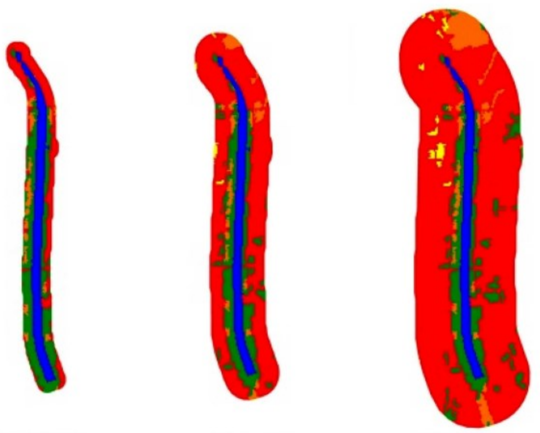
a. 0-200 m b. 0-400 m c. 0-600 m

Figure 2 Land-use of Jinyang Lake and its buffer regions in 2006



a. 0-200 m b. 0-400 m c. 0-600 m

Figure 3 Land-use of Jinyang Lake and its buffer regions in 2013



a. 0-200 m b. 0-500 m c. 0-1000 m

Figure 4 Land-use of the Fenhe River and its buffer regions in 2006

a. 0-200 m b. 0-500 m c. 0-1000 m

Figure 5 . Land-use of the Fenhe River and its buffer regions in 2013

2.3 Methods

2.3.1 LUCC

The land-use patterns in the buffer zones (0-200 m, 200-400 m, and 400-600 m of Jinyang Lake and 0-200 m, 200-500 m, and 500-1000 m of the Fenhe River) were determined using a GIS statistics function. The landscape pattern evolution of the various buffer zones was analyzed using a landscape ecological method. The total class area (CA), number of patches (NP), percentage of landscape (PLAND), perimeter area fractal dimension (PAFRAC), and landscape fragmentation index (LFI) were calculated statistically. Landscape change and human impact on different water bodies were studied by analyzing the index data, and the changes over time in the ecosystem service value of land use associated with urban water bodies were investigated.

2.3.2 Ecosystem service value

On the basis of Costanza's[7] research of global ecosystem service value and natural capital, Xie et al.[35] formulated a scale of ecosystem service value per unit area for China's ecosystems. Wang[2] calculated the ecosystem service value and total value of different types of land use for individual ecosystems. In this paper, using land-use data for Taiyuan, this scale was converted into an ecosystem service value per unit area for different land-use types. The ecosystem service value for green vegetation per unit area was considered to be equal to the average value for forest and garden land, as shown in Table 1. The formula used is:

$$ESV = \sum_{k=1}^{n} VC_k \times A_k \quad (1)$$

where, *ESV* is the total ecosystem service value (*yuan*); *k* is a sequence number indicating a specific land-use type; A_k is the area of land-use type *k*; and VC_k is the corresponding ecosystem service value per unit area (Yuan/hm^2·year).

Table 1 Ecosystem service value per unit area for various land-use types in Taiyuan.

Units: Yuan/hm^2·yr

	Farm land	Green vegetation	Water bodies	Unused land
Gas Regulation	1750	9887.5	0	0
Climate Regulation	3115	7875	1610	535.5
Conservation of Water Resources	2100	9100	71330	23845.5
Soil Development and Protection	5110	11943.75	35	59.5
Waste Disposal	5740	4585	63630	21234.5
Bio-diversity Conservation	2485	9511.25	8715	3699.5
Food Production	3500	525	350	140
Raw Material	350	6868.75	35	10.5
Cultural Recreation	35	3395	15190	5085.5
Total	24185	63691.25	160895	54610.5

2.3.3 Sensitivity analysis

The concept of elasticity (commonly used in economics) may be applied to determine the degree of dependence of the ecosystem service value change on the value coefficient[30]. Therefore, the coefficient of sensitivity (*CS*) of the value coefficient needs to be calculated. In order to measure the ecosystem service value's change, the value coefficients of the various land use types should each be adjusted by 50%. If *CS*<1, *ESV* lacks flexibility compared with *VC*; if *CS*>1, *ESV* is flexible compared with *VC*. The greater the value of *CS* is, the more critical the accuracy of the *VC* of the ecosystem services is[30]. The formula is as follows:

$$CS = \left| \frac{(ESV_j - ESV_i) / ESV_i}{(VC_{jk} - VC_{ik}) / VC_{ik}} \right| \quad (2)$$

where, *ESV*, *VC* and *k* are as in formula (1), while *i* and *j* are the initial and the adjusted ecosystem service value, respectively.

3 Results and discussion

3.1 LUCC of Jinyang Lake and its buffer regions

The Landscape patch characteristics of Jinyang Lake's buffer regions in 2006 and 2013 are presented in Table 2. In 2006, the PLAND values of green vegetation in the 0-200 m, 200-400 m, and 400-600 m buffer zones were 56.5%, 51.1%, and 36.4%, respectively. The PLAND values of farmland were 15.9%, 20.1%, and 26.6%, respectively. The PLAND values of built-up land were 25.9%, 28.7%, and 36.8%, respectively. All the LFI values in the 0-200 m buffer zone were between 2.2 and 3.7. Meanwhile, in the 200-600 m buffer zone, the value of water-body was 8, and the values of all other categories were less than 0.3. Moreover, the PLAND values of green vegetation showed a clear decreasing trend in 2006, declining by 20% between the first (0-200 m) and the third (400-600 m) buffer zone, while the PLAND values of farmland and built-up land showed an increasing trend here, growing by 10.7% and 1.9%, respectively.

From 2006 to 2013, the PLAND values of green vegetation in the 0-200 m, 200-400 m, and 400-600 m buffer zones decreased by 49.5%, 45.2%, and 33.6%, respectively. But the PLAND values of farmland increased by 22.5%, 31.3%, and 19.5%, respectively. And the PLAND values of built-up land increased 27.2%, 13.2%, and 14.1%, respectively. In 2013, all the LFI values of green vegetation were greater than 1.4 in the 0-600 m buffer zone, and the water-body LFI values in the 200-400 m and 400-600 m buffer zones were 0.8 and 1.2, respectively. Moreover, in 2013, the PLAND values of green vegetation in the three buffer zones, from the water's edge and first buffer zone to the third buffer zone, were 7%, 6.3%, and 2.8%, respectively, showing a decreasing trend. But the PLAND values of farmland in those buffer zones were 38.4%, 51.4%, and 46.1%, respectively, showing a stable trend after an initial increase. And the PLAND values of built-up land of those buffer zones were 53.1%, 41.9%, and 50.9%, respectively.

Table 3 shows LUCC of Jinyang Lake and its 0-600 m buffer region from 2006 to 2013. The proportions of water-body and green vegetation decreased by 3.22% and 24.96%, respectively. However, the proportions of farmland and built-up land increased by 15.81% and 12.37%, with the values of land-use dynamic degree of 0.17 and 0.09, respectively. The results indicated that a large number of green vegetation had been converted to farmland and built-up land in the buffer zones of Jinyang Lake during the past seven years. And the total increase in farmland and built-up land was almost equivalent to the reduction in green vegetation from 2006 to 2013. Moreover, human activities had strongly influenced green vegetation and water bodies. Actually, the change in landscape patterns of Jinyang Lake and its buffer zone was just a reallocation among these three land-use patterns.

Table 2 Landscape patch characteristics of Jinyang Lake's buffer regions in 2006 and 2013

Year	Buffer	Landscape pattern	CA/hm^2	NP/ea	PLAND	PAFRAC	Landscape fragmentation
2006	0-200 m	Green vegetation	117.9	290	0.565	1.35	2.5
		Farmland	33.1	123	0.159	1.34	3.7
		Water bodies	3.6	10	0.017	1.18	2.8
		Built-up land	53.9	121	0.259	1.32	2.2
	200-400 m	Green vegetation	113.0	21	0.511	1.23	0.2
		Farmland	44.5	14	0.201	1.23	0.3
		Water bodies	0.2	2	0.001	1.12	8.0
		Built-up land	63.4	15	0.287	1.25	0.2
	400-600 m	Green vegetation	89.2	25	0.364	1.25	0.3
		Farmland	65.2	14	0.266	1.21	0.2
		Built-up land	90.3	17	0.368	1.23	0.2
		Unused land	0.6	2	0.002	1.18	0.3
2013	0-200 m	Green vegetation	16.2	22	0.07	1.32	1.4
		Farmland	88.7	18	0.384	1.30	0.2
		Water bodies	3.5	3	0.015	1.12	0.8
		Built-up land	122.9	30	0.531	1.34	0.2
	200-400 m	Green vegetation	13.7	21	0.063	1.32	1.5
		Farmland	111.7	22	0.514	1.28	0.2
		Water bodies	0.9	1	0.004	1.10	1.2
		Built-up land	91.1	24	0.419	1.26	0.3
	400-600 m	Green vegetation	6.6	13	0.028	1.28	2.0
		Farmland	110.3	26	0.461	1.26	0.2
		Built-up land	121.7	25	0.509	1.25	0.2
		Unused land	0.4	2	0.002	1.16	0.3

Table 3 LUCC of Jinyang Lake and its 0-600 m buffer region in 2006 and 2013

Landscape pattern	2006		2013		Variable quantity		Dynamic degree
	Area/hm^2	Percentage/%	Area/hm^2	Percentage/%	Area/hm^2	Percentage/%	
Green vegetation	320.1	28.30	36.5	3.34	−283.60	−24.96	−0.13
Farmland	142.8	12.63	310.7	28.44	167.9	15.81	0.17
Water bodies	459.8	40.66	409.0	37.44	−50.8	−3.22	−0.02
Built-up land	207.6	18.36	335.7	30.73	128.1	12.37	0.09
Unused land	0.6	0.05	0.4	0.04	−0.2	−0.01	−0.05

3.2 LUCC of the Fenhe River and its buffer regions

The landscape patch characteristics of the Fenhe River's buffer regions in 2006 and 2013 are presented in Table 4. In 2006, the PLAND values of green vegetation in the 0-200 m, 200-500 m, and 500-1000 m buffer zones were 50.0%, 5.9%, and 4.2%, respectively. The PLAND values of farmland were 9.8%, 4.5%, and 6.5%, respectively. The water-body LFI value in the 0-200 m buffer zone was 7. All the other LFI values in the three buffer zones were less than 2. Moreover, green vegetation was the main land use type in the 0-200 m buffer zone, while almost 90% of the land in the 200-1000 m buffer zone consisted of built-up land.

From 2006 to 2013, the PLAND change values of green vegetation in the 0-200 m, 200-500 m, and 500-1000 m buffer zones were −40%, −0.9%, and 1.4%, respectively. The PLAND change values of farmland in the buffer zones were 36.7%, 36.3%, and 31.7%, respectively. The PLAND change values of built-up land in the buffer zones were 3%, −35.5%, −33.3%, respectively. And the PLAND change values of water bodies in the buffer zones were 0.2%, 0.2%, 0.5%, respectively. In 2013, the water-body LFI value in the 0-200 m buffer zone was 10. All the other LFI values in the three buffer zones were almost less than 3. Moreover, the 500-1000 m buffer zone had a larger green vegetation area than the 0-200 m buffer zone. Meanwhile, built-up land and farmland became the main land-use types in the 200-1000 m buffer zone in 2013.

Table 5 shows LUCC of the Fenhe River and its 0-1000 m buffer region from 2006 to 2013. The proportions of water-body and built-up land increased by 6.61% and 1.41%, respectively. However, the proportions of green vegetation, farmland, and unused land decreased by 1.36%, 6.36%, and 0.3%, respectively. The increasing trend of water bodies and the decreasing trend of farmland are extremely obvious. The land-use dynamic degrees of green vegetation, farmland, water bodies, built-up land, and unused land were −0.03, −0.02, 0.32, 0.01, and −0.04, respectively. This occurred because during these seven years, the Fenhe River project extension was implemented, and urban planning and construction continued at a stable rate in the Fenhe River buffers.

Table 4 Landscape patch characteristics of the Fenhe River's buffer regions in 2006 and 2013

Year	Buffer	Landscape pattern	CA/hm^2	NP/ea	PLAND	PAFRAC	Landscape fragmentation
2006	0-200 m	Green vegetation	150.5	15	0.500	1.29	0.1
		Farmland	29.4	21	0.098	1.29	0.7
		Water bodies	0.4	2	0.001	1.12	7.0
		Built-up land	120.9	22	0.401	1.28	0.2
	200-500 m	Green vegetation	29.0	35	0.059	1.34	1.2
		Farmland	21.9	16	0.045	1.23	0.7
		Built-up land	433.3	3	0.887	1.23	0.007
		Unused land	4.4	6	0.009	1.20	1.4
	500-1000 m	Green vegetation	39.4	21	0.042	1.30	0.5
		Farmland	60.9	8	0.065	1.17	0.1
		Built-up land	822.1	6	0.877	1.21	0.007
		Unused land	14.9	12	0.016	1.25	0.8
2013	0-200 m	Green vegetation	120.9	207	0.100	1.44	1.7
		Farmland	562.3	176	0.465	1.40	0.3
		Water bodies	3.7	35	0.003	1.38	10.0
		Built-up land	522.3	226	0.431	1.42	0.4
		Unused land	0.7	5	0.001	1.22	0.7
	200-500 m	Green vegetation	88.1	186	0.050	1.42	2.1
		Farmland	723.4	231	0.408	1.36	3.2
		Water bodies	3.5	7	0.002	1.22	2.0
		Built-up land	943.9	111	0.532	1.33	0.1
		Unused land	14.7	26	0.008	1.30	1.8
	500-1000 m	Green vegetation	169.4	197	0.056	1.41	1.2
		Farmland	1167.0	177	0.382	1.35	0.2
		Water bodies	14.9	12	0.005	1.23	0.8
		Built-up land	1661.9	106	0.544	1.31	0.06
		Unused land	38.7	57	0.013	1.35	1.5

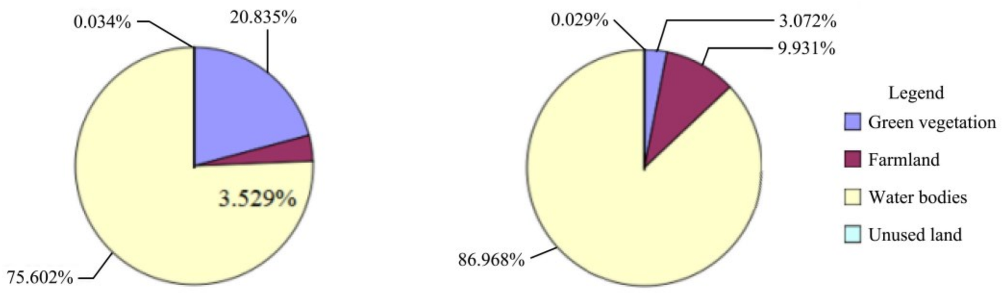
Table 5 LUCC of the Fenhe River and its 0–1000 m buffer region in 2006 and 2013

Landscape pattern	2006		2013		Variable quantity		Dynamic degree
	$Area/hm^2$	Percentage/%	$Area/hm^2$	Percentage/%	$Area/hm^2$	Percentage/%	
Green vegetation	468.3	7.08	378.4	5.73	−89.9	−1.36	−0.03
Farmland	2873.1	43.47	2452.7	37.11	−420.4	−6.36	−0.02
Water bodies	159.1	2.41	596.0	9.02	436.9	6.61	0.32
Built−up land	3034.8	45.92	3128.1	47.33	93.3	1.41	0.01
Unused land	74.0	1.12	54.1	0.82	−19.9	−0.3	−0.04

3.3 Structure of the total value of water system and its buffer regions

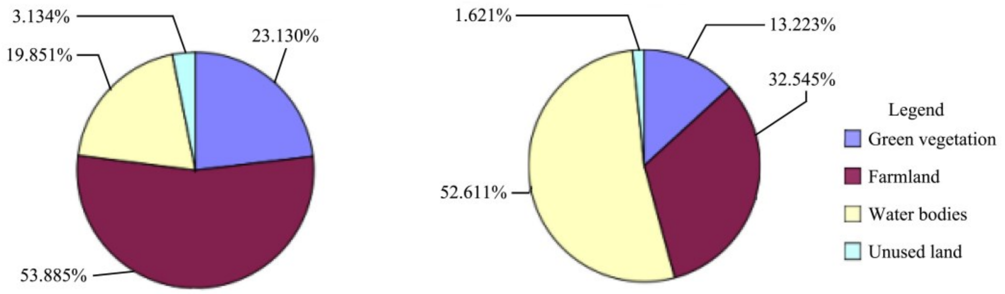
To perform the calculations, the land-use area (Table 3 for Jinyang Lake and Table 5 for Fenhe River) and the ecosystem service value per unit area (Table 1) were substituted into Equation (1). Then the ecosystem service values of all land-use types of water system and the buffer zones (0-600 m and 0-1000 m) in 2006 and

2013 were calculated (Table 6). The proportions of ecosystem service value of all land use types of water system and its buffer zones in 2006 and 2013 are shown in Figures 6 and 7. The change values of ecosystem services of water system and the buffer zones from 2006 to 2013 are presented in Figure 8. The change rates of ecosystem service value of water system and the buffer zones from 2006 to 2013 are presented in Figure 9.



a. 2006 b. 2013

Figure 6 ESV proportions of all land-use types of Jinyang Lake and its 0-600 m buffer zone in 2006 and 2013



a. 2006 b. 2013

Figure 7 ESV proportions of all land-use types of the Fenhe River and its 0-1000 m buffer zone in 2006 and 2013

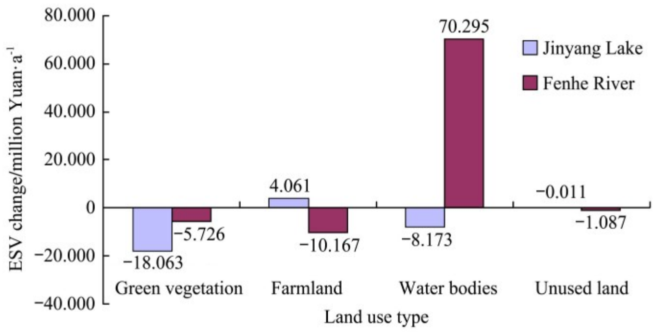


Figure 8 Change values of ecosystem services of water system and the buffer regions from 2006 to 2013

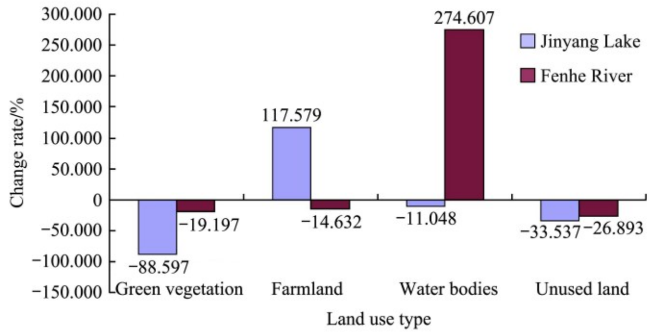


Figure 9 Change rates of ecosystem service value of water system and the buffer regions from 2006 to 2013

From Table 6, Figures 6 and 7: (1) From 2006 to 2013, the change rate of the total ecosystem service value of green vegetation and water bodies of Jinyang Lake and its 0-600 m buffer region decreased by 88.597% and 11.048%, respectively. Whereas the change rate of the total ecosystem service value of farmland increased by 117.579%. The total ecosystem service value of Jinyang Lake and its 0-600 m buffer region decreased by 22.187 million Yuan and the annual change rate was −22.673% from 2006 to 2013. The main reason was that the areas of green vegetation and water bodies decreased by 24.96% and 3.22%, respectively, from 2006 to 2013. In conclusion, the great decrease of green vegetation area resulted in the change of the total ecosystem service value of Jinyang Lake and its buffer regions during the past seven years. (2) From 2006 to 2013, the change rate of the total ecosystem service value of green vegetation and farmland of the Fenhe River and its 0-1000 m buffer region decreased by 19.197% and 14.632%, respectively. However, the change rate of the total ecosystem service value of water bodies increased by 274.607%. This resulted in the total ecosystem service value of the Fenhe River and its 0-1000 m buffer region increased by 53.315 million *yuan* and the annual change rate was 5.906% from 2006 to 2013. (3) On the whole, the total value of water system and its buffer regions increased by 31.129 million Yuan with an annual change rate of 1.961% from 2006 to 2013 in Taiyuan. The increase of ecosystem service value of water bodies of the Fenhe River accounted for an important part of the total ecosystem service value of water system in the whole district.

Table 6 Ecosystem service value of all land-use types of water system and the buffer regions (0-600 m of Jinyang Lake and 0-1000 m of the Fenhe River) in 2006 and 2013

	Land use type	2006		2013		2006-2013		
		ESV/ $\times 10^6$ Yuan·a^{-1}	Change rate/ %	*ESV*/ $\times 10^6$ Yuan·a^{-1}	Change rate/ %	*ESV*/ $\times 10^6$ Yuan·a^{-1}	Change rate/ %	Change rate per year/%
Jinyang Lake	Green vegetation	20.3876	20.835	2.3247	3.072	-18.063	-88.597	-12.657
	Farmland	3.4536	3.529	7.5143	9.931	4.061	117.579	16.797
	Water bodies	73.9795	75.602	65.8061	86.968	-8.173	-11.048	-1.578
	Unused land	0.0328	0.034	0.0218	0.029	-0.011	-33.537	-4.791
	Total	97.8535	100	75.6669	100	-22.187	-22.673	-3.239
Fenhe River	Green vegetation	29.8266	23.130	24.1008	13.223	-5.726	-19.197	-2.742
	Farmland	69.4859	53.885	59.3185	32.545	-10.167	-14.632	-2.090
	Water bodies	25.5984	19.851	95.8934	52.611	70.295	274.607	39.230
	Unused land	4.0412	3.134	2.9544	1.621	-1.087	-26.893	-3.842
	Total	128.9521	100	182.2672	100	53.315	41.345	5.906
The total of Taiyuan		226.8056	100	257.9341	100	31.129	13.725	1.961

From Figures 8 and 9: The change value of ecosystem service of water system was unbalanced from 2006 to 2013 in Taiyuan. The ecosystem service values of all land use types of the Fenhe River and its buffer region showed decreasing trends during the past years, the value of water bodies of the Fenhe River not included. But the maximum change value of ecosystem service of the Fenhe River and its buffer region was 70.295 million Yuan and its change rate was 274.607%. However, the ecosystem service values of all land use types of the Jinyang Lake and its buffer region showed decreasing trends during the past years, the value of farmland not included. And the change value of farmland of Jinyang Lake was greatly less than that of water bodies of the Fenhe River. In addition, the ecosystem service value of green vegetation of Jinyang Lake decreased by nearly 90%.

In conclusion, the total value of ecosystem service of water system of Taiyuan increased by 13.725% from 2006 to 2013. It was due to the LUCC of Jinyang Lake, the Fenhe River, and their buffer zones.

3.4 Ecosystem service value in the buffer regions of water system

The proportions of ESV in the buffer regions of Jinyang Lake and the Fenhe River from 2006 to 2013 are presented in Table 7. In 2006, the total proportion of ecosystem service value in the 0-600 m buffer region of Jinyang Lake was 25.023%. It was almost twice as large as that in the 0-1000 m buffer region of the Fenhe River. However, in 2013, the total proportion of ecosystem service value in the buffer zone of Jinyang Lake decreased to 13.968% and that of the Fenhe River increased to 49.339%. In addition, the proportions of ecosystem service value in the buffer regions of Jinyang Lake and the Fenhe River, from the water's edge and first buffer zone to the third buffer zone, both showed downward trends in 2006. In 2013, the proportions of ecosystem service value in the three buffer regions of Jinyang Lake were all close to 4% while those in the three buffer regions of the Fenhe River were all greater than 12%. In a word, the proportions in the buffer regions of the Fenhe River increased by 5.079% per year whereas the proportions in the buffer regions of Jinyang Lake decreased by 1.579% per year. It was known that the ecological environments of the buffer regions of Jinyang Lake and the Fenhe River had been changed greatly and that resulted in the quite different consequences. Therefore, the ecosystem service value will decrease in all probability if the land use types are changed in order to make short-term economic gains in urban district.

Table 7 Proportions of ESV in the buffer regions of Jinyang Lake and the Fenhe River from 2006 to 2013

Water	Buffer region	2006	2013	2006-2013	
		Rate/%	Rate/%	Change/%	Change rate per year/%
Jinyang Lake	0-200 m	9.084	4.943	−4.141	−0.592
	200-400 m	8.488	4.915	−3.573	−0.510
	400-600 m	7.451	4.110	−3.341	−0.477
	Total	25.023	13.968	−11.055	−1.579
The Fenhe River	0-200 m	8.035	12.033	3.998	0.571
	200-500 m	2.029	13.427	11.398	1.628
	500-1000 m	3.719	23.879	20.160	2.880
	Total	13.783	49.339	35.556	5.079

3.5 Coefficients of sensitivity

According to Equation (2) the ecosystem service value coefficient (*VC*) was regulated up and down by 50%, respectively, and then the coefficients of sensitivity could be calculated (Table 8). It can be seen that all of the coefficients of sensitivity of all land use types of water system and its buffer regions were smaller than 1 in the district. In addition, the value trend of water bodies > green vegetation > farmland > unused land was shown. Therefore the ecosystem service value (*ESV*) lacks of flexibility compared with *VC* meanwhile the results of this research are accurate and credible[30].

Table 8 Coefficients of sensitivity of ecosystem service value

Year	Green vegetation +50% −50%	Farmland +50% −50%	Water bodies +50% −50%	Unused land +50% −50%
2006	0.221	0.322	0.439	0.018
2013	0.102	0.259	0.627	0.012

4 Conclusions

Firstly, with the sharp decrease in green vegetation area, which was transformed to built-up land, the total ecosystem service value decreased by 22.673% in the Jinyang Lake buffer from 2006 to 2013. On account of the construction of the Fenhe Park, the total ecosystem service value increased by 41.345% although the ecosystem service values of the other three land-use types all decreased from 2006 to 2013. Implementation of the Fenhe Park project made a great contribution to the city's ecosystem, so that the total ecosystem service value of the water system and its buffer regions in Taiyuan urban district increased by 13.725% overall. In addition, the coefficients of sensitivity for all land use types in the water system and its buffer regions were less than 1. The results of this study are therefore credible. Secondly, the results showed that the LUCC of the Fenhe River and its buffer regions benefited the urban ecological environment but the ecological degradation had occurred in the buffer regions of Jinyang Lake in 2013. Different policy guidelines and program implementations brought about different changes in the ecosystem services within the same city. Finally, as urbanization accelerates and short-term economic benefits are pursued, more green vegetation, farmland, and unused land will be transformed to urban land in urban districts. Then the urban ecological health will be affected. However, the construction of associated water engineering works and public green space can lead to an improvement in the ecological environment. To promote regional sustainable development, the land in the buffer region of water system should be well planned and utilized. Water system may make a greater contribution to the ecosystem service of urban districts. This study indicates the need for a broader river system management strategy.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (No. 41572239, 41502243, 51409184), the Specialized Research Fund for the Doctoral Program of Higher Education (No. 20131402110008), the Chinese Natural Science Foundation of Shanxi Province (No. 2015021169), the Science Fund for Young Scholars of Taiyuan University of Technology (No. 2014TD052), and the Government Financial Grants Project (ZNGZ2015-036). We thank the editors of the journal and the reviewers for their useful comments and suggestions for improvements. We especially thank Prof. Wu Penglin for his assistance in improving the manuscript.

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