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Impacts of land-use change on ecosystem service value in Changsha, China

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Abstract: Changsha, a typical city in central China, was selected as the study area to assess the variations of ecosystem service value on the basis of land-use change. The analysis not only included the whole city but also the urban district where the landscape changed more rapidly in the center of the city. Two LANDSAT TM data sets in 1986 and 2000 and land use data of five urban districts from 1995 to 2005 were used to estimate the changes in the size of six land use categories. Meanwhile, previously published value coefficients were used to detect the changes in the value of ecosystem services delivered by each land category. The result shows that the total value of ecosystem services in Changsha declines from $1 009.28 million per year in 1986 to $938.11 million per year in 2000. This decline is largely attributable to the increase of construction land, and the conversion from woodland and water body to cropland to keep the crop production. In the five districts, there is $6.19 million decline in ecosystem service value between 1995 and 2005. Yuelu District has the highest unit ecosystem service value while Yuhua District has the lowest one. This may be attributed to the greater conversion from cropland and grassland to woodland and water body with the increase of construction land in Yuelu District. It is suggested that the increase rate of construction land should be controlled rigorously and the area of woodland and water body should be increased or at least retained in the study area.

Key words: land-use change; urban expansion; city scale; district scale; central China; Changsha

1 Introduction

Land Use and Land Cover Change (LUCC) is a core joint project of the International Geosphere Biosphere Programme (IGBP) and International Human Dimensions Program on Global Environmental Change (IHDP). It has been focused on, because of its interactions with climate, ecosystem processes, biogeochemical cycles, biodiversity and human activities in recent decades [1−2]. Ecosystem services represent the benefits that living organisms derive from ecosystem functions to maintain the Earth's life support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet [3]. The economic valuation of ecosystem services has been a hot topic in ecological economic research. Numerous studies have been conducted to estimate the ecosystem service value (ESV) [4−11]. Although many researches have been undertaken on the assessment of ecosystem service value, less work has addressed to the application of results of the evaluation. Changes in land use may significantly impact ecosystem processes and services, especially in the urban areas, where the land use is changed significantly [12−15].

There are some researches on the changes of ecosystem service value in response to land use/land cover change. KREUTER et al [16] reported the change in the ecosystem service value in San Antonio area, Texas, USA. ZHAO et al [17] investigated the ecosystem service value assessment of the land use change on Chongming Island, China. VIGLIZZO and FRANK [18] analyzed the land use options for Del Plata Basin in South America based on the ecosystem service provision. CAI et al [19] studied the variation of ecosystem service values of Kunshan, China, and considered the relation between ecosystem service value and GDP. China has experienced rapid development over last two decades. Together with the economic development, the land use is

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changed significantly [20], and the population growth impacts the urban areas increasingly. In China, researches on the impacts of land-use change on ESV have been reported of some cities in Eastern China, such as Shenzhen [21], Chongming Island [17], and of province scale, such as Jilin Province [22]. However, less work has been addressed on big cities in central China which correctly depict the general situation of urbanization and consequential landscape change in China. Scientific recommendations for policy were needed to guide the land use and protect the ecological environment in these cities.

In this study, Changsha, a typical city in central China, was chosen as the study area. Changsha is the capital of Hunan Province, and its rapid economic development and population growth have significantly influenced the land use. Geographic Information System (GIS) techniques were used to determine land use changes of the entire city from 1986 to 2000, and particular data of the five urban districts from 1995 to 2005 were used for the detailed analysis. Mathematical simulations were applied to estimate the economic value of ecosystem services provided by each biome as a proxy for each land use category. This study included two scales to analyze, city level and district level. The city level scale indicated the whole city, including five districts, three counties and one city administered by Changsha, and the district scale just referred the five districts in the center of Changsha. The five urban districts have been significantly affected by the policy of Changsha-Zhuzhou-Xiangtan integration. Thus, the urban expansion in this area was more noticeable, aggravating the ecological and environmental problems in some ways [23]. The three primary objectives of the study are: 1) to detect the changes of land use within the entire city between 1986 and 2000, and five urban districts from 1995 to 2005, 2) to evaluate and analyze the ecosystem service value, and 3) to discuss the appropriate spatial scale of analysis for the study of variations in ecosystem service value in response to land-use change in urban areas.

2 Experimental

2.1 Study area

Changsha (111°53′−114°15′E, 27°51′−28°40′N) is situated in the northeast of Hunan Province, China, with an area around 1.18 million hm^2 (Fig.1). It is composed of five districts (Furong District, Yuhua District, Kaifu District, Tianxin District and Yuelu District, total 5 5634 hm^2), three counties (Changsha County, Wangcheng County and Ningxiang County) and one city (Liuyang City). Changsha lies on the transition belt of Central Hunan Foothill to Dongting Lake Plain, and the terrain is inclined from south to north with complex geologic structure. A majority of the soil in the area is red soil, accounting for more than 70% of the total land area of the city. Subtropical monsoon humid climate determines its precipitation, which is about 1 483.6 mm/a with most occurring from April to July. Xiangjiang River runs through the city from south to north.

As the capital of Hunan Province, Changsha is the center of administration, economy, culture and transportation. With the implementation of rising strategy in central region of China, Changsha has experienced rapid urbanization process. Its development characteristics and land use change provide good representatives of the central cities in China, since most of them have experienced the same political and economic reforms. Especially, on the background of Changsha-Zhuzhou-Xiangtan urban agglomeration integration, as the center of the three cities, urban sprawl

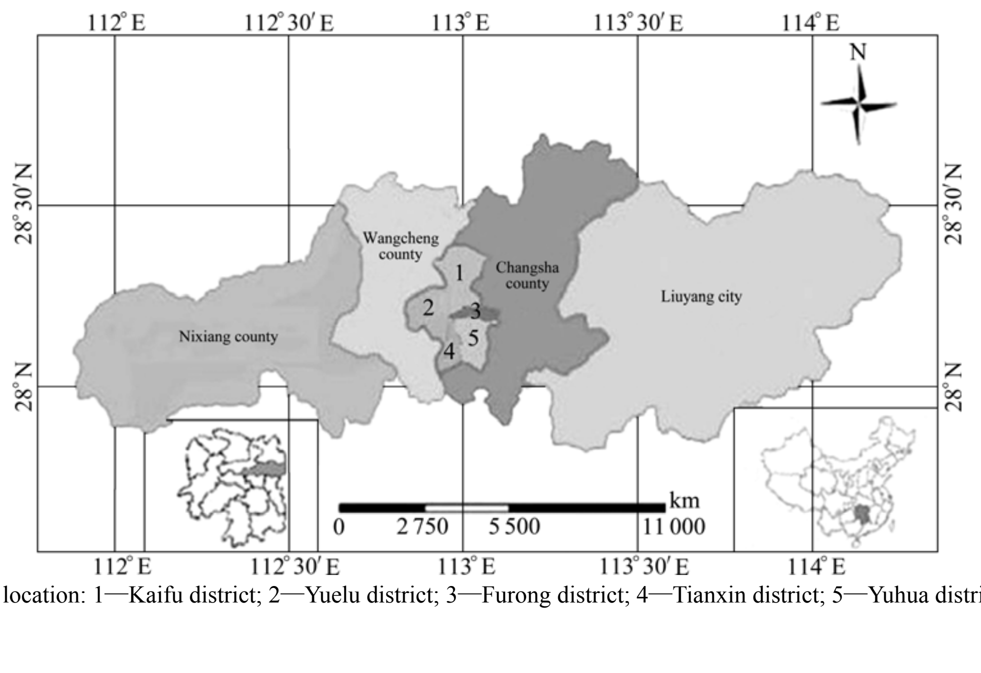

Fig.1 Study site location: 1—Kaifu district; 2—Yuelu district; 3—Furong district; 4—Tianxin district; 5—Yuhua district

in Changsha is significant. There would be great reference significance to other central cities in China by researching the variations in ecosystem service value in response to land-use change in Changsha.

2.2 Data sources

The data used to estimate changes in the size of various ecosystems of the entire city were extracted from two cloud-free LANDSAT Thematic Mapper (TM) images obtained on November 1st, 1986 and April 30th, 2000. The data of the land use change of five urban districts between 1995 and 2005 were obtained from Changsha Bureau of Land Resources.

The two scenes of LANDSAT TM images were interpreted with ERDAS Imagine 8.5 to get the information of land use by supervised classification. After the supervised classification of the two data sets were completed, according to China Land Use/Land Cover Classification System and some ground-truth studies, each image was grouped into six land use categories, including woodland, cropland, grassland, water body, construction land and unused land (Table 1). Based on National 1:250 000 Basic Terrain Database, ERDAS Imagines were used to adjust geometric correction of the two TM images, and the vector files were obtained, then the areas were calculated by ARCGIS 8.1.

2.3 Methods of analysis

2.3.1 Relative change rate of land use

For the land use changes of five urban districts, the relative change rate was considered, which can reflect the differences of the land use change among different districts:

$$R=\frac{|K_{\mathrm{b}}-K_{\mathrm{a}}|/K_{\mathrm{a}}}{|C_{\mathrm{b}}-C_{\mathrm{a}}|/C_{\mathrm{a}}} \tag{1}$$

where R is the relative change rate of land use; K is the area of one land use category in a certain district; C is the area of this land use category in the total districts; ‘a’ and ‘b’ represent the initial and end of the study periods, respectively. If R is greater than 1, changes of a certain land use category in this district are greater than the total area, and it is the hot area of this category change, and vice versa.

2.3.2 Assignment of ecosystem service value

Among the studies of estimating the value of ecosystem services, results from COSTANZA et al [3] are the most notable. They presented a model for placing an economic value on different biomes and the services. Based on their model, the economic values of 17 ecosystem services for 16 biomes were estimated, and most of the values are outside the market. Although some methodological troubles and uncertainties have been found, they do represent the most comprehensive set of first-approximations available for quantifying the change in the value of services provided by a wide array of ecosystems [16], and such data are the best information available for our purpose.

Ecosystem service value was assigned based on the most representative biome as a proxy for each land use category, as listed in Table 1. The following equation was used to calculate the ecosystem service value [3]:

$$E=\sum_k (Ak\cdot V_k) \tag{2}$$

where E is the estimated ecosystem service value; A_k is the area; V_k is the value coefficient for land use category k.

In order to detect how the land-use change influences the ecosystem service value, gain and loss of ESV analyses were considered:

$$G_{mn}=(V_n-V_m)\times A_{mn} \tag{3}$$

where G_{mn} is the gain and loss of ESV after initial land use category m is converted to category n at the end of study periods, V_m and V_n present the value coefficients for land use category m and n, respectively, and A_{mn} is the change area from land use category m to n.

Science biomes used as proxies for the land use categories are not perfect matches in every case, there are uncertainties of the value coefficients. Sensitivity analyses were conducted to test the change in total ecosystem service value per unit change in a value coefficient. In each analysis, the coefficient of sensitivity (S) was calculated as [16]

Table 1 Biome equivalents of six land-use categories in Changsha, and corresponding ecosystem service value coefficients (VC)

Land use category	Composition	Equivalent biome	Ecosystem service value coefficient/($\$\cdot hm^{-2}\cdot a^{-1}$)
Woodland	Forest land, open forest land and shrub land	Forest	969
Cropland	Paddy field, glebe field and vegetable field	Cropland	92
Grassland	Moderate coverage grassland and high coverage grassland	Grass/rangelands	232
Water body	Rivers, land reservoirs fishery and lakes	Lakes/rivers	8 498
Construction land	Residential, commercial and transportation	Urban	0
Unused land	Mostly bare soil	Desert	0

$$S = \frac{(E_j - E_i)/E_i}{(V_{jk} - V_{ik})/V_{ik}} \tag{4}$$

where S is the coefficient of sensitivity; E is the estimated ecosystem service value; V is the value coefficient; i and j represent the initial and adjusted values, respectively; k represents the land use category. The relatively low coefficient of sensitivity reflects the area and/or the value coefficients associated with these land use categories are relatively small, and this ecosystem value estimate is reasonably robust [16−17].

3 Results and discussion

3.1 Changes of land use

3.1.1 Land-use change at city scale

By comparing the two classification maps, the conversion matrix of land-use change of Changsha city from 1986 to 2000 was got. According to the result from Table 2, the woodland category dominated within the entire city with the proportion of 72.03% in 1986 and 65.20% in 2000. Area of construction land, cropland, water body and unused land increased, while woodland and grassland decreased. The most affected category was construction land, which broadened in area from 9497 hm^2 in 1986 to 29 877 hm^2 in 2000. The change rate reached 214.59% and the effective annual rate was 8.53%. The grassland category, decreased from 26 525 hm^2 in 1986 to 5 691 hm^2 in 2000, with a change rate of −78.54% and an estimated annual rate of −10.41%.

The increase of construction land was mostly converted from woodland and cropland. This was caused by the urban sprawl and concentration of housing as the population also increased significantly during 14 years. One part of cropland changed to construction land while large part was changed from woodland, which may be associated with the clearing of woodland for crop production. So, the cropland category was increased with an estimated annual rate of 1.80%. The grassland was

Table 2 Estimated area of each land-use category in Changsha, and conversion matrix of land-use change from 1986 to 2000

1986	2000						1986 total/hm^2 (Proportion/%)
	Woodland	Cropland	Grassland	Water body	Construction land	Unused land	
Woodland/hm^2	685 643	146 953	4 185	4 275	8 305	4 275	853 637 (72.03)
T/%		17.21	0.49	0.50	0.97	0.50	
F/%		41.79	84.61	23.33	27.80	61.77	
Cropland/hm^2	60 038	195 477	288	5 261	12 466	520	274 050 (23.12)
T/%	21.91		0.11	1.92	4.55	0.19	
F/%	7.77		5.06	28.71	41.72	7.51	
Grassland/hm^2	23 429	2 034	973	57	33	0	26 525 (2.24)
T/%	88.33	7.67		0.21	0.12	0	
F/%	3.03	0.58		0.31	0.11	0	
Water body/hm^2	2 025	6 558	35	7627	816	680	17 741 (1.50)
T/%	11.41	36.97	0.20		4.60	3.83	
F/%	0.26	1.87	0.62		2.73	9.83	
Construction land(ha)	963	57	1	316	8151	9	9 497 (0.80)
T/%	10.14	0.60	0.01	3.33		0.09	
F/%	0.12	0.02	0.02	1.72		0.13	
Unused land/hm^2	575	549	210	788	105	1 437	3 664 (0.31)
T/%	15.69	14.98	5.73	21.51	2.87		
F/%	0.07	0.16	3.69	4.30	0.35		
2000 total/hm^2 (Proportion/%)	772 673 (65.20)	351 627 (29.67)	5 691 (0.48)	18 324 (1.55)	29 877 (2.52)	6 921 (0.58)	1 185 113
Change rate/%	−9.48	28.31	−78.54	3.92	214.59	88.89	—
Annual change rate/%	−0.71	1.80	−10.41	0.23	8.53	4.63	—

T—Proportion of certain land-use category converting to other categories; F—Proportion of certain land use category converting from other categories. For example, there are 146 953 hm^2 converted form woodland to cropland, so T=(146 953/853 637)×100%≈17.21%, meaning 17.21% of woodland area in 1986 is changed to cropland; F=(146 953/351 627)×100%≈41.79%, meaning area converted from woodland occupies about 41.79% of cropland area in 2000 mostly converted to woodland. The small increase of water body was mainly due to the conversion from cropland and woodland. More than 60% of unused land was converted to other five categories; meanwhile, 4 275 hm^2 woodland was changed to unused land mainly because of the soil and water loss after slashing woods, so bare soil almost increased by 4.63% per year. Although there were other land use categories converted to woodland, it was too small to offset the decrease of it, and woodland was decreased by 0.71% per year.

3.1.2 Land-use change at district scale

The construction land category dominated almost all the districts in 1995 and 2005 (Fig.2). The woodland category mostly distributed in Yuelu District and Kaifu District, a little in Furong District and Tianxin District, especially Furong District only 0.39% in 1995 and 0.65% in 2005. The changes in the five districts of the six land use categories are presented in Table 3. Woodland, cropland, water body and unused land were decreased. The loss of cropland reached 3 302.29 hm^2, with the annual change rate of −2.33%. Grassland and construction land were increased, and the latter was increased by 5 518.76 hm^2 in ten years. Influenced by the initial area, the grassland category had the highest change rate of 310.15%, and the construction land category was increased by 28.62% approximately between 1995 and 2005.

In the five urban districts, the increase of construction land category mostly came from cropland. Significantly, unlike the whole city, these districts have not enough woodland to offset the cropland, so a large decrease of cropland and woodland appeared. The unused land was decreased by about 0.88% per year during ten years, and most of it was converted to construction land.

The relative change rates of land use categories in each district were calculated using Eq.(1), as shown in Table 4. According to the results, the hot change areas of cropland distributed in Furong, Yuhua, Yuelu and Tianxin districts, and the variation range in Kaifu District was lower than the total area. The reason is that the government has implemented some policies of cropland protection in this district. Relative change rates of construction land in Yuhua and Yuelu districts were greater than 1, which indicated that construction land category in Yuhua District and Yuelu District was changed greatly. The government of Changsha City moved to Yuelu District in 2001, and according to the master plan of Changsha, Yuelu District will be built into the university town and the high-tech industrial development zones. These all accelerated the urban construction. As the join part of Changsha-Zhuzhou-Xiangtan area, the variation of construction land category in Yuhua District was greatly influenced by the

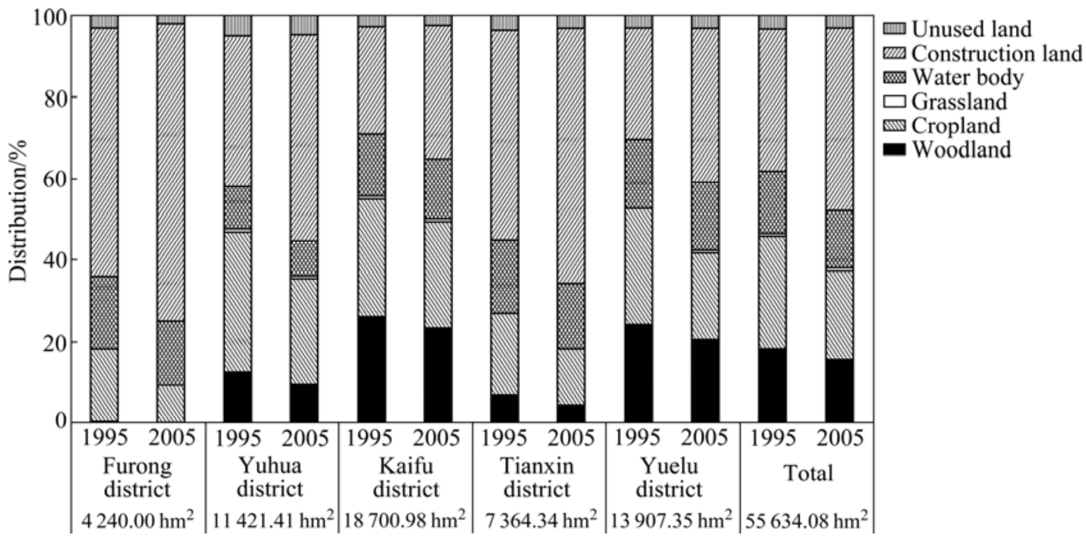

Fig.2 Size and contribution of six land use categories in each district

Table 3 Area of each land use category in five districts and changes in land use from 1995 to 2005

Land use category	Area in 1995/hm^2	Area in 2005/hm^2	Changed area/hm^2	Changing rate/%	Annual changing rate/%
Woodland	10 115.52	8 578.61	−1 536.91	−15.19	−1.63
Cropland	15 696.50	12 394.21	−3 302.29	−21.04	−2.33
Grassland	1.97	8.08	6.11	310.15	15.16
Water body	8 544.48	8 027.35	−517.13	−6.05	−0.62
Construction land	19 282.18	24 800.94	5 518.76	28.62	2.55
Unused land	1 993.43	1 824.89	−168.54	−8.45	−0.88

integration of the three cities. With the quickening of the economic integration process, the construction speed of Yuhua District became more and more rapid. The relative change rate of woodland in Furong District was about 4.489, much greater than other districts.

Land-use change in urban areas is governed by complex factors, such as policy, economic development and population growth. Especially, socio-economic policy strongly affects urban expansion. Since the policy of Changsha-Zhuzhou-Xiangtan integration has been implemented from 1990s, Changsha is strongly influenced by it, especially the five urban districts. Changsha-Zhuzhou-Xiangtan urban agglomeration plays an important role in central China. It improves the economic integration, which has attracted extensive attention from Pearl River Delta area and Hong Kong. By the end of 2005, these three cities have integrated on electric power, transportation, finance and environmental protection. Just because of this, landscape in the five urban districts was changed rapidly, and as the join part of the three cities, land-use changes in Yuhua District became more noticeable.

3.2 Estimation of changes in ecosystem services

3.2.1 ESV of whole city

Based on the ecosystem service value coefficients reported by COSTANZA et al [3] and areas of land use categories, ecosystem services values were obtained by Eq.(2). The total ecosystem service value of Changsha was about $1 009.28 million in 1986 and $938.11 million in 2000. There was $71.17 million net decline in ecosystem service value from 1986 to 2000. Woodland category contributed almost about 80% to the total ESV because of its large value coefficient and large area (about 81.95% in 1986 and 78.81% in 2000). Since water body has the highest value coefficient, although the proportion of its area was smaller than that of the cropland, its ESV was much higher. The ESV of woodland was $150.76 million in 1986 and $155.72 million in 2000, while that of cropland was $25.21 million and $32.34 million in 1986 and 2000, respectively. Grassland generated little (about 0.61% in 1986 and 0.14% in 2000) services value because of its small area.

Construction land and unused land were assigned no ecosystem service value. This may underestimate their actual ecological values derived from plants in residential etc. However, we can detect how the urban sprawl influenced the ecosystem service value more obviously. Using the conversion matrix of land-use change from 1986 to 2000 and Eq.(3), the gain and loss of ESV were calculated (Table 5). Converting to construction land caused about $16.12 million loss of ESV, and converting from woodland and water body to cropland lost almost $184.24 million. So, the main reasons of the decrease of ESV in Changsha are the increase of construction land, and the conversion from woodland and water body to cropland to keep the crop production. The increase of ESV (about $124.17 million) caused by cropland, grassland, construction land and unused land converting to ‘more’ value category than itself could not offset the decrease of ESV (about $195.34 million) caused by the variations of woodland and water body. So, woodland and water body are the

Table 4 Relative change rates of six land use categories in each district

District	Woodland	Cropland	Grassland	Water body	Construction land	Unused land
Furong	4.489 0	2.501 8	—	1.690 6	0.691 7	4.612 6
Yuhua	1.581 0	1.165 7	1.731 4	2.496 4	1.283 5	1.068 0
Kaifu	0.718 0	0.432 2	0.184 6	0.568 4	0.815 8	0.476 4
Tianxin	2.314 1	1.501 2	—	1.972 1	0.768 3	1.271 3
Yuelu	0.991 8	1.149 9	—	0.008 4	1.367 2	0.298 7

Table 5 Composition and changes of ecosystem service value in Changsha from 1986 to 2000 ($10^6$$)

Land-use category	Woodland	Cropland	Grassland	Water body	Construction land	Unused land	Total
Woodland	0	−128.88	−3.08	32.19	−8.05	−4.14	−111.96
Cropland	52.65	0	0.04	44.22	−1.15	−0.05	95.71
Grassland	17.27	−0.28	0	0.47	0.01	0	17.47
Water body	−15.25	−55.13	−0.29	0	−6.93	−5.78	−83.38
Construction land	0.93	0.005	0.00	2.69	0	0	3.63
Unused land	0.56	0.05	0.05	6.70	0	0	7.36
Total	56.16	−184.24	−3.61	86.27	−16.12	−9.97	−71.17

keys to maintain ecosystem service value in the study area.

3.2.2 ESV of five districts

The ecosystem service values of five urban districts in Changsha were calculated, as listed in Table 6. Different from the whole city, it was the water body category not the woodland that contributed most in the urban areas. This is because Xiangjiang River runs through the urban area, and the value coefficient of water body is the highest. There was about $6.19 million net decline in ecosystem services value between 1995 and 2005 in the five districts. ESV of the land use categories decreased, except the grassland. The loss of ESV caused by water body was the most, which reached $4.39 million, more than 70% of the total loss. The increase of ESV of grassland was only about $1 417, and it was too small to offset the decrease of ESV.

ESV of all five districts was decreased. Yuhua District was decreased most rapidly, with the annual change rate of −1.78%, and Tianxin took the second place, Yuelu was the slowest. From the above analyses of land use conversions, variations of each land use category in Kaifu District were at lower level, so the loss of ESV in this district was not large, with an estimated annual change rate of only −0.48%. The unit ESV was calculated for comparison, as there were different total ESV of each district because of their different areas. Yuelu District had the highest ecosystem service value per unit both in 1995 and 2005 because of its large woodland area. It is noteworthy that although construction land changed greatly in both Yuhua District and Yuelu District, the change rate of Yuhua was much higher than Yuelu District. This may be explained by the fact that there was a greater conversion from cropland and grassland to woodland and water body which were ecologically ‘more’ valuable when they were converted to construction land in Yuelu District. If we pay attention to adjusting the land use structure, the decrease of ecosystem services value can be mitigated.

3.3 Ecosystem service sensitivity analyses

By using Eq.(4), the effects of 50% adjustment in value coefficient to estimated total ecosystem service values were calculated (Table 7). The coefficient of sensitivity was less than 1.00 in all cases, indicating that the total ecosystem values estimated in the study were relatively inelastic with respect to the ecosystem service coefficients. For the whole city, the coefficient of sensitivity for cropland, grassland and water body was near 0, while that for woodland was relatively higher, 0.80−0.82, may be due to its large area in the whole city and relatively high value coefficient. For the five districts,

Table 6 Composition and changes of ecosystem service value in five urban districts from 1995 to 2005 ($10^5$$)

Land-use categories	Furong		Yuhua		Kaifu		Tianxin		Yuelu		Total	
	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005	1995	2005
Woodland	0.16	0.27	13.79	10.48	46.93	41.81	4.84	3.14	32.30	27.43	98.02	83.13
Cropland	0.69	0.33	3.67	2.77	5.06	4.60	1.35	0.93	3.67	2.78	14.44	11.40
Grassland	0.00	0.00	0.002	0.01	0.003	0.001	0.00	0.00	0.00	0.007	0.005	0.02
Water body	63.52	57.02	102.31	86.86	246.00	237.54	114.18	100.56	200.09	200.19	726.11	682.16
Total	64.37	57.62	119.77	100.11	297.99	283.95	120.38	104.62	236.06	230.42	838.57	776.71
Change of ESV	−6.75		−19.66		−14.04		−15.76		−5.64		−61.86	
Annual change rate/%	−1.10		−1.78		−0.48		−1.39		−0.24		−0.76	
Unit ESV	0.015	0.013	0.010	0.009	0.016	0.015	0.016	0.014	0.017	0.017	0.017	0.015

Construction land and unused land are assumed to have ecosystem service value of zero, so they are not listed

Table 7 Percentage change in estimated total ecosystem service value and coefficient of sensitivity resulting from adjustment of ecosystem valuation coefficients

Land-use category	Whole city				Five districts			
	1986		2000		1995		2005	
	Change rate/%	CS	Change rate/%	CS	Change rate/%	CS	Change rate/%	CS
Woodland VC±50%	±40.98	0.82	±39.91	0.80	±5.84	0.12	±5.35	0.11
Cropland VC±50%	±1.25	0.01	±1.72	0.03	±0.86	0.02	±0.73	0.01
Grassland VC±50%	±0.30	0.00	±0.07	0.00	±0.00	0.00	±0.00	0.00
Water body VC±50%	±7.47	0.04	±8.30	0.17	±43.29	0.87	±43.91	0.88

CS—Coefficient of sensitivity

because of the large area of water body and its highest value coefficient, the coefficient of sensitivity was much higher than other three categories, ranging from 0.87 to 0.88. The coefficient of sensitivity close to 0 reflected that the ecosystem value estimation was reasonably robust, while the coefficient of sensitivity close to 1.00 for an assumed ecosystem service suggested that the assumed value coefficient for the ecosystem service should be treated with caution. The results emphasized that the value coefficient of woodland at the city scale and that of water body at the district scale should be treated more carefully.

The results from the two scale analyses are different, indicating that the spatial scale may affect the outcome of this kind of study. The appropriate spatial scale is important and should be taken into account in the estimation of ecosystem service value in city areas where there are more spatial pattern fragments. For the research with city as the study area, the broader scale analysis may reflect the overall trend of the variations in ecosystem service value in response to land-use change, and the smaller scale analysis could be more helpful to concrete policy recommendations as the administrative power is relatively concentrated in these areas. Suggestions are put forward that for this kind of study in urbanization areas, with reliable and available land use data, practical significance of policy making should be taken into account in appropriate scale selection.

The investigation provides a case study of changes in ecosystem service value in cities in central China. The other analogous cities could select the appropriate spatial scale to analyze land-use change on ecosystem service value according to their actual situations. With the increasing pressure on land in urban areas, it is important to find the balance of economic benefit and ecological benefit in land use. The consideration of ecosystem service value in the design of sustainable land use strategies in China is still not a priority for policymakers. In order to mitigate the decline of ecosystem service value in Changsha, the government can focus on the economic benefits and the values of ecosystem services as well in land use planning. It is imperative to control the increase rate of construction land category strictly and make great effect to retain and increase the areas of woodland and water body which provide a greater level of ecosystem services. For the five districts, it is important to adjust the land use structure when the construction land has increased rapidly, especially in the Yuhua District. To achieve this, more detailed studies of how to find the optimal balance between economy and ecology in land use policy should be done.

4 Conclusions

1) The total annual ecosystem service value in Changsha declined from \$1 009.28 million in 1986 to \$938.11 million in 2000. This decline is largely attributable to the increase of construction land and the conversion from woodland and water body to cropland. Construction land occupied the cropland, and woodland and water body were converted to cropland to keep the crop production.

2) In the five urban districts, there was \$6.19 million decline in ecosystem service value between 1995 and 2005. Yuelu District had the highest unit ecosystem service value because of its large area of woodland, with an annual change rate of −0.24%; while Yuhua District had the lowest unit ecosystem service value and the annual decline rate reached −1.78%. This may be attributed mainly to the fact that with the increase of construction land in Yuelu District, there was a greater conversion from cropland and grassland to woodland and water body.

3) If there was a concomitant increase in size of other land use types which provided a greater level of ecosystem services, the downtrend of ecosystem service value in cities may be mitigated, just like the Yuelu District in this study.

References

[1] LOPEZ E, BOCCO G, MENDOZA M, DUHAU E. Predicting land-cover and land-use change in the urban fringe: A case in Morelia city, Mexico [J]. Landscape Urban Planning, 2001, 55(4): 271−285.

[2] ZHANG Wen-guang, HU Yuan-man, HU Jin-chu, CHANG Yu, ZHANG Jing, LIU Miao. Impacts of land-use change on mammal diversity in the upper reaches of Minjiang River, China: Implications for biodiversity conservation planning [J]. Landscape and Urban Planning, 2008, 85(3/4): 195−204.

[3] COSTANZA R, D'ARGE 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, BELT M. The value of the world's ecosystem services and natural capital [J]. Nature, 1997, 387(15): 253−260.

[4] TOBIAS D, MENDELSOHN R. Valuing ecotourism in a tropical rain-forest reserve [J]. Ambio, 1991, 20(2): 91−93.

[5] McNEELY J A. Economic incentives for conserving biodiversity: Lessons for Africa [J]. Ambio, 1993, 2/3(22): 144−150.

[6] CHOPRA K. The value of non-timber forest products: An estimation for tropical deciduous forests in India [J]. Economic Botany, 1993, 47(3): 251−257.

[7] CACHA M D M. Starting resource accounting in protected areas [M]// MUNASINGHE M, MCNEELY J. Protected Area Economics and Policy. Cambridge: IUCN, 1994: 151−157.

[8] MUNASINGHE M, MCNEELY J. Economic and policy issues in natural habitats and protected areas [M]// MUNASINGHE M, MCNEELY J. Protected Area Economics and Policy. Cambridge: IUCN, 1994: 15−49.

[9] GREN I M, GROTH K H, SYLVEN M. Economic values of Danube floodplains [J]. Journal of Environmental Management, 1995, 45(4): 333−345.

[10] GUO Zhong-wei, XIAO Xiang-ming, LI Dian-mo. An assessment of ecosystem services: Water flow regulation and hydroelectric power production [J]. Ecological Applications, 2000, 10(3): 925−936.

[11] CURTIS I A. Valuing ecosystem goods and services: A new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes [J]. Ecological Economics, 2004, 50(3/4): 163−194.

[12] PEARCE D, MORAN D. The economic value of biodiversity [M]. Cambridge: Earthscan Publications Ltd, 1994.

[13] GUO Zhong-wei, XIAO Xiang-ming, GAN Ya-ling, ZHANG Yue-jun. Ecosystem functions, services and their values: A case study in Xingshan County of China [J]. Ecological Economics, 2001, 38(1): 141−154.

[14] OUYANG Zhi-yun, WANG Ru-song, ZHAO Jing-zhu. Ecosystem services and their economic valuation [J]. Chinese Journal of Applied Ecology, 1999, 10(5): 635−640. (in Chinese)

[15] HEIN L, van KOPPEN K, de GROOT R S, van IERLAND E C. Spatial scales, stakeholders and the valuation of ecosystem services [J]. Ecological Economics, 2006, 57(2): 209−228.

[16] KREUTER, U P, HARRIS H G., MATLOCK M D, LACEY R E. Change in ecosystem service values in the San Antonio area, Texas [J]. Ecological Economics, 2001, 39(3): 333−346.

[17] ZHAO Bin, KREURTER U, Li Bo, MA Zhi-jun, CHEN Jia-kuan, NAKAGOSHI N. An ecosystem service value assessment of land-use change on Chongming Island, China [J]. Land Use Policy, 2004, 21(2): 139−148.

[18] VIGLIZZO E F, FRANK F C. Land-use options for Del Plata Basin in South America: Tradeoffs analysis based on ecosystem service provision [J]. Ecological Economics, 2006, 57(1): 140−151.

[19] CAI Bang-cheng, LU Gen-fa, SONG Li-juan, HUANG He-ping, HAN Shang-fu, CHEN Ke-liang. Variation of ecosystem services' value of Kunshan based on the land use change [J]. Acta Ecologica Sinica, 2006, 26(9): 3005−3010. (in Chinese)

[20] LIU Ji-yuan, ZHUANG Da-fang, LUO Di, XIAO Xiang-ming. Land-cover classification of China: Integrated analysis of AVHRR imagery and geo-physical data [J]. International Journal of Remote Sensing, 2003, 24(12): 2485−2500.

[21] LI Tian-hong, LI Wen-kai, QIAN Zheng-han. Variations in ecosystem service value in response to land use changes in Shenzhen [J]. Ecological Economics, 2010, 69(7): 1427−1435.

[22] LU Yuan-wang, WEI Liang-ying, MO Jian-fei. Land use change and its impact on values of ecosystem services in the West of Jilin Province [J]. Wuhan University Journal of Natural Sciences, 2006, 11(4): 1028−1034.

[23] JIANG De-song, JIANG Chong, ZHAO Ming-hua. Bio-engineering protection mechanism of city rock slope and its laboratory test [J]. Journal of Central South University: Science and Technology, 2008, 39(5): 1087−1093. (in Chinese)

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