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Research Article

PRELIMINARY STUDY ON ECONOMIC VALUE OF GREEN INFRASTRUCTURE IN CHINA

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ABSTRACT

Green infrastructure is the combination of natural ecological infrastructure and half nature municipal green space, which improves the ecological environment and biodiversity conservation as well as provide new economic growth point. This study attempts to build a green infrastructure economic value evaluation index, estimate the economic value of China's green infrastructure from 2004 to 2015, explore its regional distribution, and further using the grey model to predict the Green infrastructure economic value of 2016, 2020 and 2025, in order to raise people's awareness of green infrastructure, provide reference to construction and improve the green infrastructure in urban planning.

INTRODUCTION

The development of modern city engulfs the natural space, destroys the natural system on which we live, the rapid economic development and the sharp decline of the ecological environment. The limitation of nature land and resources intensified the contradiction between urban construction and environmental protection. The 18th National Congress of the Communist Party of China put forward the call of ecological engineering construction. The 13th Five-Year Plan put the "eco-environmental quality" before "all aspects of the system", and put forward five development concepts of coordination, green, open and sharing. In 2014, the Ministry of Housing and Urban issued a sponge city construction guide, respond positively by the provinces and cities. Compared with the "gray infrastructure" composed of artificial facilities, the green infrastructure makes full use of natural resources such as forest, wetland and green road, which is one of the important ways to solve the city ecological environment problem. At the same time of improving the ecological environment and protect bio-diversity, contains a new economic growth point. Green infrastructure provides a predictable approach to development and growth that can effectively reconcile the conflictsof "development" and "protection" to promote sustainable development. In general, there is a process from ecological economics to economic ecology for region development. And economic infrastructure will benefit to raise awareness of the green infrastructure, implement the green development concept in urban construction, transform the urban development mode and promote the virtuous circle of the ecological environment and the economy.

LITERATURE REVIEW

Green infrastructure, representing region's natural life support system, is a multifunctional green space network that integrates social, economic and environmental resources in the community, promotes sustainable community development and maintains balance. It contains the concept of ecological infrastructure (EI), but broader than EI, not only includes ecological natural infrastructure concepts, but also low-carbon, green semi-natural and artificial infrastructures. As an "infrastructure", green infrastructure is an important part of the city infrastructure system with road, municipal, telecommunications and other gray infrastructure. Its connotation focused on the protection and restoration of human natural ecosystems to provide support and promote sustainable urban development. The green infrastructure is a combination of natural ecological infrastructure and semi-natural municipal green space, consisting of natural areas and open spaces. It follows the laws of natural development, integrates various ecological and environmental resources, provides a link to the process of biodiversity and natural purification, plays a fundamental role in the protection of the ecological environment network and promotion of the sustainable development of the city. Green infrastructure is a key element of "ecosystem services" (Nicole, 2013)[2], thus

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the value of ecosystem services is the first key of assessing the value of green infrastructure.

The concept of the ecosystem service function first appeared in the "*Human Impacts on the Global Environment*" published by UN University in 1970. Since then, Holder and Ehrlieh (1974) [3], Wesmtan (1977) [4] had studied global environmental service functions and natural service functions, and pointed out that biodiversity has a vital role in ecosystem services. However, there has been no progress in the study of its value assessment for a long time after the emergence of the ecosystem service concept. Until 1997, Costanzaand other 13 experts [5] published the most important paper up to now in Nature on the value of ecosystem services. Costanza[5] divided the global ecosystem into 16 types of land use according to the natural situation, divided the ecosystem service into 17 functions, and evaluated each function of each land use mode separately, provided the value of unit area of ecosystem services on a global scale. The research results not only attracted wide attention internationally, but also laid the foundation for scholars to study the value of ecosystem services. In 2000, the United Nations officially launched the Millennium Ecosystem Assessment (MA), which promoted the research and development of ecosystem services assessment around the world.

Most of the existing literature study green infrastructure are from the perspective of landscape planning, quantitative assessment of its economic value remains to be further developed. In the field of eco-economics, the study of the current ecosystem service evaluation has been greatly developed, but due to the ecosystem is a complex dynamic system, its value is diverse, and has a close relationship with the economic process. There is still remains uncertainty in the cognition of ecosystems, so the value of ecosystem services could only be roughly estimated. At present, it does not form a complete set of index system and evaluation theory, and there is no standard answer. This paper hopes to draw lessons from the value of ecosystem services, try to make a preliminary estimate of the economic value of green infrastructure in China.

Assessment of green infrastructure economic value in China

Evaluation model

Based on the market value method of Ouyang Zhiyun[6]and XieGaodi[7], the evaluation model of green infrastructure economic value is as follows:

$$GIV=\sum_{i=1}^{n}(A_i * VC_i) \quad (1)$$

In the formula (1): GIV represents the total economic value of the green infrastructure in the study area; i represents the different evaluation index; A_i indicates the area of the i-th evaluation index, VC_iindicates the ecosystem value of unit area of the i-th evaluation index.

The research data are derived from the "*China Statistical Yearbook*" and the "*China Statistical Yearbook of Water Resources*" from 2005 to 2016. According to the definition of green infrastructure and the availability of data, this paper divides Green Infrastructure Value (GIV) into two categories of first-class indicators of natural and semi-natural facilities, among which the natural facilities are mainly contain four indicators of natural forest, natural wetland, grassland and lake, and for semi-natural facilities, artificial forest, artificial wetland, reservoir and urban green space were selected. Refer to the assessment method of Costanza[5], XieGaodi[7], Wu Yong[8] *et al.*, after, according to the annual CPI price index changes in the consideration of the inflation factor, the national green infrastructure value from 2004 to 2015 are showed in Table 1.

The ecosystem services value of natural forests, natural wetlands, and water resources refers to the estimation value of global ecosystem services by Costanza (1997) [5], forest values $ 969 (hm^2 · y) $^{-1}$, wetland values $ 14785 (hm^2 · year) $^{-1}$, and then according to the US dollar exchange rate in 1994, the forest values 8351.52 yuan (hm^2 · y) $^{-1}$, wetland is127427.48 yuan (hm^2 · y) $^{-1}$. Because there is no direct data can be searched of the unit area ecological service value of artificial forest and artificial wetland, this paper countit as the half percent of natural forest and natural wetland unit value taking its semi-natural properties into account. Based on the data of the average natural ecosystem service value of the natural grassland estimated by XieGaodi *et al.* (2001) [9], the unit area ecosystem service price of grassland is $ 509.4 (hm^2 · y) $^{-1}$, 4217.37 yuan (hm^2 · y) $^{-1}$ according to the exchange rate in 1998.

Table 1 China's green infrastructure economic value of unit area from 2004 to 2015
Unit:thousand yuan·(hm^2·year)$^{-1}$

First-class indicators	**natural facilities**				**semi-natural facilities**			
Second-class indicators	**natural forest**	**natural wetland**	**grassland**	**lake**	**artificial forest**	**artificial wetland**	**reservoir**	**urban green space**
2004	11.23	171.36	4.39	98.49	5.62	85.68	5.81	6.19
2005	11.43	174.44	4.46	100.26	5.72	87.22	5.92	6.30
2006	11.60	177.06	4.53	101.77	5.80	88.53	6.00	6.39
2007	12.16	185.56	4.75	106.65	6.08	92.78	6.29	6.70
2008	12.88	196.50	5.03	112.95	6.44	98.25	6.66	7.10
2009	12.79	195.13	4.99	112.15	6.39	97.56	6.62	7.05
2010	13.21	201.57	5.16	115.86	6.61	100.78	6.84	7.28
2011	13.92	212.45	5.44	122.11	6.96	106.23	7.21	7.67
2012	14.29	217.98	5.58	125.29	7.14	108.99	7.39	7.87
2013	14.66	223.64	5.72	128.54	7.33	111.82	7.58	8.08
2014	14.95	228.12	5.84	131.12	7.48	114.06	7.74	8.24
2015	15.16	231.31	5.92	132.95	7.58	115.66	7.84	8.35

(Note: The starting year of natural forest, natural wetland, artificial forest and artificial wetland is 1994. The starting year of grassland data is 1998, green space starts from 1997 and the reservoir starts form 2000.)

The ecological value of reservoir is measured by Zhao Tongqian, Ouyang Zhiyun (2003) [10]. The ecological service value is 5532.9 yuan $(hm^2\cdot y)^{-1}$ by measuring the average comprehensive agricultural loss avoided by protecting

Table 2 The economic value of green infrastructure in major yeas of each province

Unit：billion yuan

Region	2004	2008	2010	2012	2015	Annual growth rate
China	100881.59	125974.81	135722.17	154734.42	176014.84	5.19%
Beijing	90.11	119.33	133.90	157.65	186.00	6.81%
Tianjin	297.84	382.26	419.34	491.19	594.63	6.49%
Hebei	2393.55	2522.96	2500.31	2621.58	2797.63	1.43%
Shanxi	1208.21	967.84	873.86	867.22	888.80	-2.75%
Neimenggu	12882.83	16416.46	17726.94	20142.86	22539.55	5.22%
Liaoning	2593.57	3030.11	3149.94	3466.31	3797.43	3.53%
Jilin	2945.59	3229.77	3247.50	3442.68	3586.28	1.81%
Heilongjiang	9727.62	11921.41	12626.15	14077.92	15422.25	4.28%
Shanghai	557.12	715.75	786.56	911.49	1105.92	6.43%
Jiangsu	3091.16	3886.27	4241.06	4992.73	6393.93	6.83%
Zhejiang	1932.51	2411.73	2584.62	2926.77	3295.12	4.97%
Anhui	1541.03	1948.72	2112.86	2429.84	2672.82	5.13%
Fujian	1496.83	1962.08	2176.58	2568.51	3043.60	6.66%
Jiangxi	2711.67	3021.72	3053.73	3249.04	3411.99	2.11%
Shandong	3319.14	3378.98	3320.57	3493.9	3862.33	1.39%
Henan	1467.44	1664.26	1702.88	1833.25	1970.54	2.72%
Hubei	2247.66	2807.09	3036.80	3498.17	4133.52	5.69%
Hunan	3008.24	3291.19	3310.64	3508.82	3684.57	1.86%
Guangdong	3141.15	3650.18	3795.14	4181.08	4673.17	3.68%
Guangxi	2295.83	2880.68	3043.36	3326.57	3615.59	4.22%
Hainan	655.18	751.09	771.11	836.14	891.43	2.84%
Chongqing	331.14	528.12	622.24	750.64	952.00	10.08%
Sichuan	3966.67	5268.73	5805.48	6724.73	7689.93	6.20%
Guizhou	687.36	983.68	1115.36	1313.15	1564.89	7.77%
Yunnan	2686.59	3456.49	3725.27	4199.87	4757.1	5.33%
Tibet	14152.29	17363.87	18418.79	20588.57	22624.53	4.36%
Shanxi	1383.04	1682.46	1768.84	1950.08	2135.49	4.03%
Gansu	3132.54	4113.99	4496.63	5138.22	5777.21	5.72%
Qinghai	8999.13	13152.36	15319.95	18880.87	22936.37	8.88%
Ningxia	608.34	633.50	624.66	657.19	698.90	1.27%
Xinjiang	5330.23	7831.72	9211.10	11507.39	14311.34	9.39%

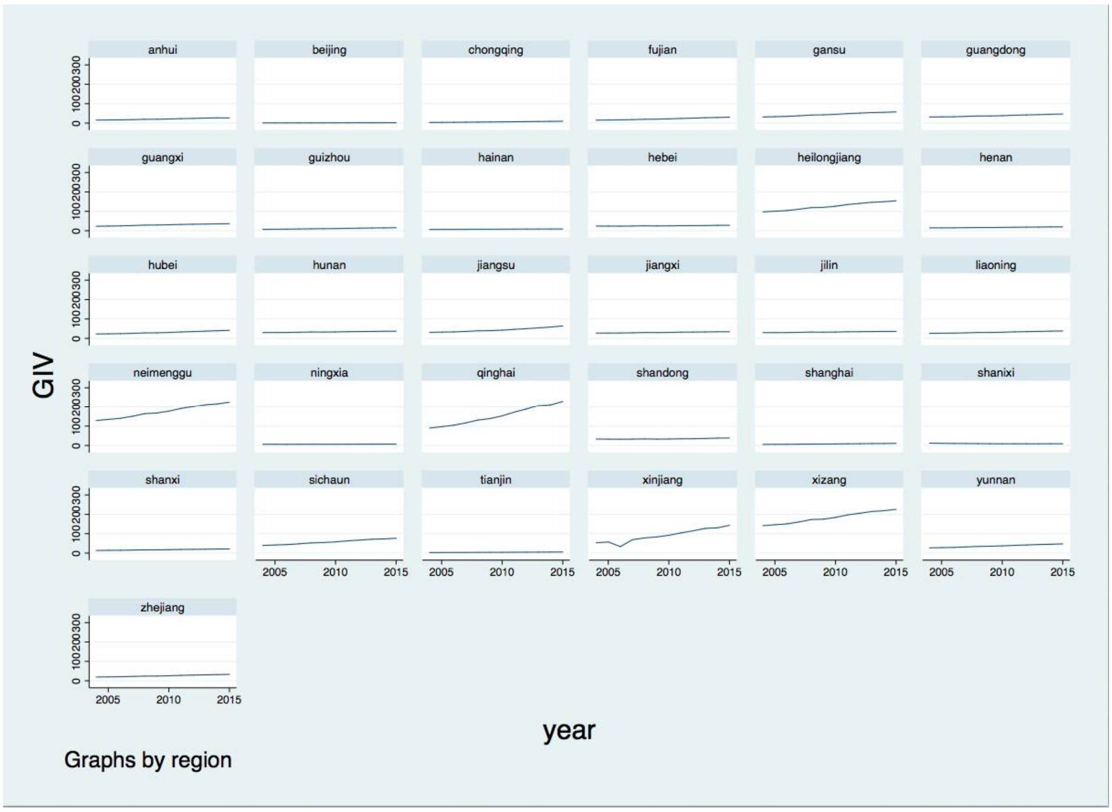


Figure 1 Changes in Economic Value of Green Infrastructure in Provinces from 2004 to 2015

cultivated land. We calculated waterlogging area to measure its function of arable land protection and flood storage. This study is based on a national scale while the economic value of the green space assessment conducted by Zhang Biao, XieGaodi, *et al* (2011,2012) [11-12] is focus on Beijing area. In the access to various types of literature, this paper selects the estimated data of 6,000 yuan (hm^2·y) $^{-1}$ by Wu Yong and Su Zhixian (2002) [8].

The Result and Analysis of Economic Value of Green Infrastructure in China

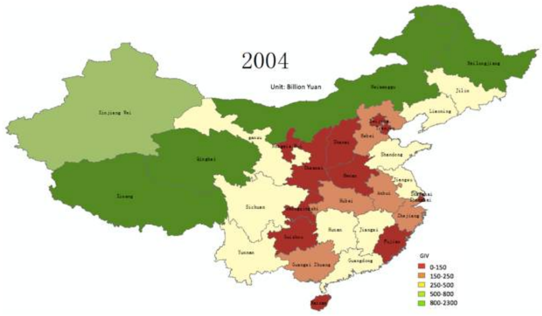
According to the formula (1), this study calculates the economic value of the green infrastructure of the provinces in China from 2004 to 2015. Table 2 shows the calculation results of major years. Figure 1 shows the changes in the provinces over the years.

The total value of the green infrastructure economy in China has increased year by year, from 1,080.4 billion yuan in 2004 to 175.91 billion yuan in 2015, with an average annual growth rate of 5.19%. In addition to the average annual growth rate of Shanxi is negative, the rest of the region are increasing year by year, of which Chongqing topped the list with 10.08%, Xinjiang ranked secondwith the growth rate of 9.39%. Among the 31 provinces, the top four of economic value are Tibet, Neimenggu, Heilongjiang and Qinghai, while the last four are Beijing, Tianjin, Chongqing and Shanghai. The gap between regions is large. In 2004, Tibet’s GIV reached 1415.2 billion yuan, which is 157 times more than the lowest Beijing (9 billion yuan), but by 2015, the gap between the two provinces has been reduced to 123 times. The green infrastructure value in the western region is the highest, andthe northeastern region is the lowest, but the gap between the eastern and western regions is widening. If considered the average GIV, the eastern region is the lowest, mainly because there are more provinces in the eastern region and only three in the northeastern region.

Refer to the system cluster resultsof GIV in China, the green infrastructure can be roughly divided into five categories, as shown in Table 3.

Table 3 Type division of Green infrastructure regional development

Type	Green infrastructure economic value (unit:billionyuan)
Scarce areas of Green infrastructure resources	0-1500
Relatively scarce areas of Green infrastructure resources	1501-2500
General rich area of Green infrastructure resources	2501-5000
Relatively rich area of Green infrastructure resources	5001-8000
Rich area of Green infrastructure resources	8001-23000



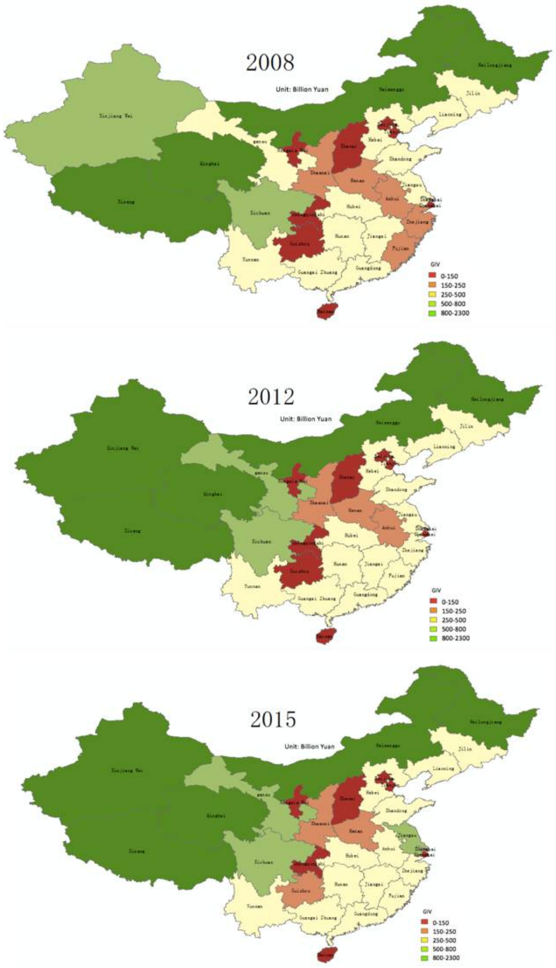


Figure 2 Distribution of Green Infrastructure Economic Value in China

It can be seen from Figure 2 that Qinghai, Tibet, Heilongjiang and Neimenggu are rich in green infrastructure resource, while the green infrastructure resources in Beijing, Tianjin, Shanxi, Ningxia, Chongqing, Shanghai and Hainanare very scarce. Since Xinjiang run from the second echelon into the first echelon in 2009, the first echelon is firmly occupied by these five provinces; Henan, Shaanxi and Guizhou run from the Scarce areas of GI resources to the Relatively scarce areasin 2006, 2007 and 2015 respectively; Hubei and Guangxi ranked from Relatively scarce areas to general rich areas in 2007; Gansu and Jiangsu rose to relatively rich areas in 2012 and 2013.

As pointed out by Anselin (1988) [13], "almost all spatial data have spatial dependence or spatial autocorrelation characteristics", the green infrastructure value of the study is of no exception. China's provincial green infrastructure economic value and regional economic development level also have typical geographical attributes. Based on its geographical attributes, this paper uses Moran's I to explore the spatial correlation of green infrastructure economic value distribution.

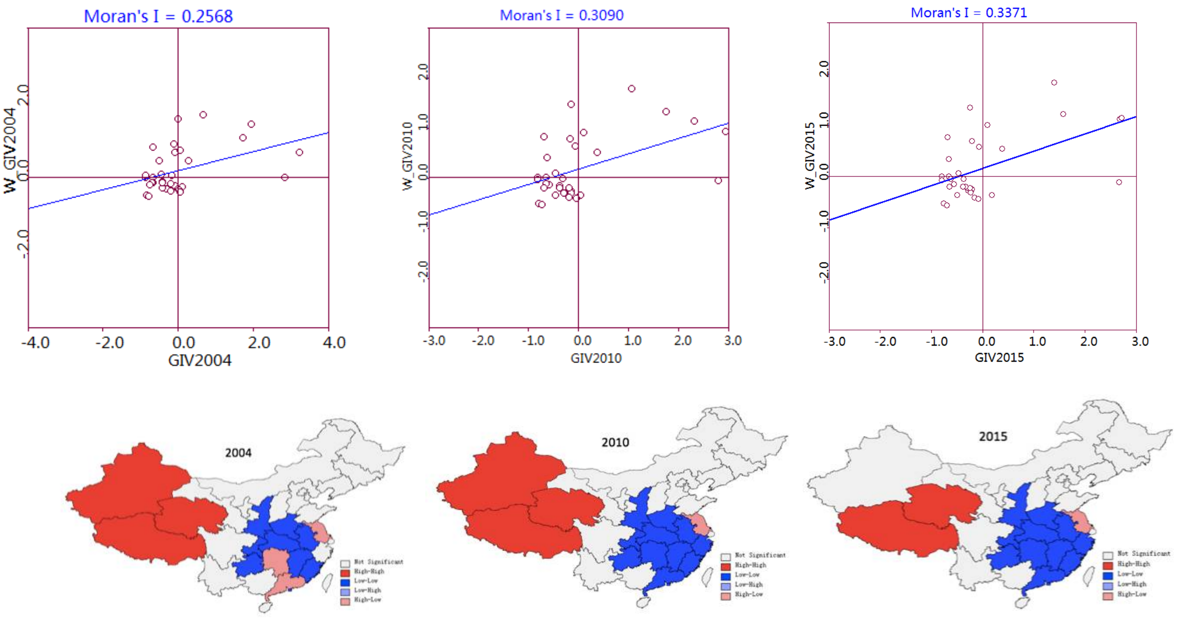


Figure 3 Moran Scatter Plot and LISA Agglomeration Chart of Green Infrastructure Economic Value in China of 2004,2010 and 2015

(Note: The spatial weight matrix "W" in the global spatial autocorrelation test is calculated according to the spatial geographic information of 31 provinces in China, with the rook contiguity of the "first order contiguity matrix" ,that is if regioni and j have a common vertex or common boundary, then notesW_{ij} = 1, otherwise,W_{ij}= 0.)

Furthermore, this paper predicts the economic value of China's green infrastructure in 2016, 2020 and 2025 according to the GM (1,1) model. The forecast results show that the economic value of green infrastructure in China is expected to be 1,884.7 billion yuan, 26880 billion yuan in 2020 and 405.14 trillion yuan in 2025. The accuracy test of the prediction model shows that mPhi = 0.0121 and Phi (12) = 0.0153 are less than 0.05 in the residual test. The probability of small residuals in the correlation test is p = 1> 0.95, the mean square error ratio C = 0.0383 <0.5, Probability and mean square error ratio belong to first level, so the model is qualified andcredible, which can be used to predict the economic value of China's green infrastructure.

CONCLUSIONS AND FURTHER DISCUSSION

This study tries to construct the economic value evaluation index of green infrastructure and measure the green infrastructure economic value in China from 2004 to 2015. The main conclusions are as follows:

The economic value of GI in China has steadily increased in the past 12 years, from 1,008,819 billion yuan in 2004 to 1760.1484 billion yuan in 2015, with an average annual growth rate of 5.19%. Chongqing's green infrastructure grows fastest, with an average annual growth rate of 10.08%. Shanxi has been declining in recent years at negative2.75%. The differences vary widely across China, but the gap is gradually narrowing. Qinghai, Tibet, Heilongjiang, Neimenggu ranked first in China with overwhelming advantages, with more than 800 billion yuan of the green infrastructure economic value, belongs to rich areasof green infrastructure resources; while the green infrastructure economic value of Beijing, Tianjin, Shanxi, Ningxia, Chongqing, Shanghai and Hainan are less than 100 billion yuan, belonging to scarce areas of green infrastructure resource. In 2004, Tibet, the highest value of green infrastructure area are 157 times more than the lowest Beijing, however, the gap narrowed to 123 times in 2015.

The distribution of the green infrastructure economic value has typical geographical features, with significant spatial autocorrelation, the western region belongs to the area where the green infrastructure is developing well, and the central and eastern regions (except Jiangsu and Guangdong) are the "low-low" gathering area of green infrastructure development.

At present, GI developed areas in Chinaareas not economically developed provinces. In general, there is always a process from ecological economy to economic ecology in the development of a region.The green infrastructure rich areas is supposed to think about how to turn resources into economic development momentum, while economic progress depends on the value of ecological services to be fully evaluated and reflected (XieGaodi, 2010) [1]. In this process, evaluation of the economic value of GI plays a key role. However, this study is only a preliminary attempt, the assessment results may be a relatively lower estimate of the green infrastructure economic value. Because on the one hand, the existing green infrastructure-related market is not perfect, it is difficult to accurately reflect the price through the real market behavior, this paper is a rough selection of large-scale regional ecosystem services to value the GI. In fact, the value of green infrastructure in different regions is quite different. For example, the economic value of wetlands in the Qinghai-Tibet Plateau and the eastern plains is obviously different. However, the study shows that the unit price is the same, thus cause inaccuracy in the estimation. On the other hand, the green infrastructure is an open system withdynamic development and organic link, so its assessment should be a continuous dynamic process, and this article is limited by data availability, only made a static evaluation.

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