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Ecological Value Analysis Based on Land Use Change in Liuhe District of Nanjing, China (2009, 2019)

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Abstract: The ecological value refers to the valuation of ecosystem service function, which includes the value of market functions (i.e., economic value) and the shadow value of non-market functions (i.e., natural value). Given that different land-use patterns result in varied service values, this study investigated recent urban and rural spatial changes in the Liuhe district of Nanjing, China, over a 10-year period, especially driven by the state-level new area strategy. Using Landsat TM data with a 30-m resolution, spatial datasets of land use in 2009 and 2019 were obtained by image interpretation. Costanza's natural value estimation method was applied to calculate the profits and losses of ecological value caused by land-use change. From 2009 to 2019, the expansion of construction space (residential/service land, industrial/mining land, and transportation/other land) led to a decrease of 3.3% in the natural value of the whole district. According to the strong sustainable development principle of "natural value cannot be reduced", the Liuhe district is deemed to be in a weak state of sustainable development. Considering the ecological value of non-construction space (water area, woodland, wetland, grassland, and cultivated land), the "uneconomical" phenomenon was investigated under the logic of "economic civilization" in urban and rural spatial expansion. The ratio of ecological value between non-construction and construction spaces increased from 1: 5 to 1: 3, indicating that the comprehensive benefits of construction space are no longer prominent. Accordingly, it is necessary to limit the occupation of non-construction space such as water area by the extensive expansion of urban and rural construction land.

Keywords: **state-level new area; land-use change; ecological profit and loss; Liuhe district; Nanjing city**

Data Avialable Statement:

The dataset supporting this paper was published and public available at: Wang, B., Liu, D. Y. Dataset of land use and its ecological value assessment in Liuhe district of Nanjing city (2009, 2019) [DB/OL/J]. Global Change Data Repository, 2020. DOI:10.3974/geodb.2020.05.17.V1.

1 Introduction

Through its long period of industrial civilization, both the quality of the ecological environment and the efficiency of resource utilization have declined in some regions of China,

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[2] Wang, B., Liu, D. Y. Dataset of land use and its ecological value assessment in Liuhe district of Nanjing City (2009, 2019) [DB/OL/J]. Global Change Data Repository, 2020. DOI: 10.3974/geodb.2020.05.17.V1.

rendering a disharmonious relationship between man and nature. The prime reason for this situation is that most of the contribution that eco-environmental system services make to human welfare is purely public welfare, without directly increasing human welfare in the form of a monetary economy. In many cases, people are not even aware of the existence of eco-environmental system services[1–3].

It should be recognized that the estimation of ecological value, especially the natural value, is a problematic issue worldwide. Since the concept of ecosystem service function was first proposed by the “Study of Critical Environmental Problems” in 1970[4–5], many ecologists, economists, and policy makers have carried out a staggering mountain of research work. In 1997, Costanza *et al*. [1] published the infamous article, “The value of the world’s ecosystem services and nature capital” in *Nature*, which had great repercussions felt globally. Costanza *et al*.[1] divided the global ecosystems into 16 categories, such as woodland, grassland, and cultivated land, while their service functions were divided into 17 categories, such as gas regulation, climate regulation, water regulation, and soil formation. Subsequently, the value of global ecosystem service functions was estimated, showing that that the average annual value of the global biosphere ‘industry’ was 33 trillion US dollars, equivalent to 1.8 times gross national product (GNP) of the same period. Later, Zong *et al*.[6] (2002) analyzed the value structure of regional ecosystem service functions in Lingwu city of Ningxia, China, thereby extending Costanza *et al*.’s work from the simple estimation of natural value to the comprehensive estimation of natural value and economic value. It was pointed out that an increase or decrease in the natural value ought to serve as the core index to measure whether a town or a region can realize sustainable development, which in so doing must meet the requirements of the strong sustainable development principle of “natural value cannot be reduced”[7–8]. In follow-up research—essentially following Costanza’s theoretical framework but combining it with the actual situation in China—the ecological value coefficient of various ecosystems has been revised[9–11], while the changes in ecological value caused by land-use changes have been extensively explored[12–18].

On June 27, 2015, the State Council officially approved the establishment of Jiangbei new area in Nanjing city, Jiangsu province. Located north of the Yangtze River, Jiangbei includes parts of Liuhe district and Pukou district, with a planning area of 788 km^2[19]. Meanwhile, Jiangbei and its surrounding rural areas are coordinated as a whole, encompassing a total area of 2,451 km^2 (Figure 1). Jiangbei is being positioned not only as an independent innovation pilot area, a new urbanization demonstration area, and a modern industrial agglomeration area in the Yangtze River Delta, but also as a pivotal platform for the cooperation and opening up of the Yangtze River Economic Belt (together referred to as “three zones and one platform”). Liuhe district, as an integrated development area within the planning and coordination scopes of Jiangbei, has always been the leading functional area of eco-tourism and agricultural development in Nanjing. At least 80% of its territory is cultivated land, water area, and woodland, and the proportion of these three land-use types in 2019 totaled 83.54%[22].In recent years, the pace of urban construction has accelerated in Jiangbei under the guidance of the state-level new area strategy. The subcentral city of Liuhe and the new town of Longpao have since become urban areas with highly dense populations and developed economic and industrial activity next to the central city of Jiangbei within the scope of the new area, which has driven reductions in the availability of non-construction land. Therefore, the establishment of ecological values and their accounting, together with the coordination of ecological protection and urban construction, are keys to achieving a high-quality development of Liuhe district.

Given that different land-use patterns result in varied service values, this study investigated the profits and losses of ecological value in the Liuhe district of Nanjing over the past 10 years, especially driven by the state-level new area strategy. Spatial datasets of land use were obtained via image interpretation based on Landsat TM data. Ecological values of different ecosystems were comprehensively assessed based on international natural value estimation methods[1–3] combined with domestic comprehensive capital estimation methods. Considering the ecological value of non-construction space (water area, woodland, wetland, grassland, and cultivated land), the ratio of ecological value between non-construction and construction spaces has increased over time from 1: 5 to 1: 3. Hence, we advise that further occupation by urban and rural construction land of remaining non-construction space such as water area should be restricted.

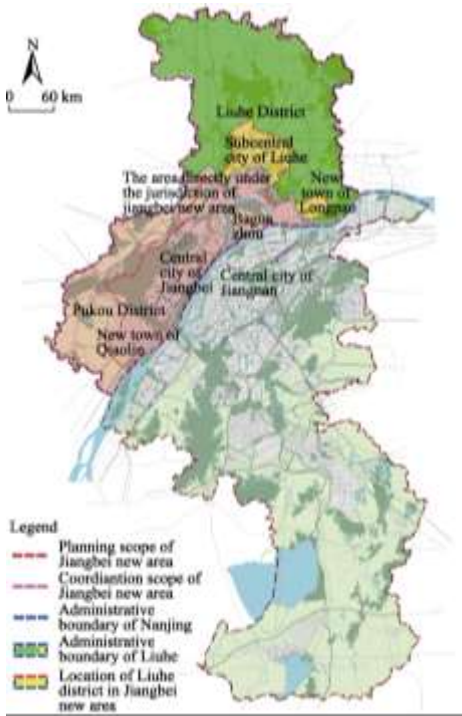

Figure 1 Location of Liuhe district and state-level Jiangbei new area in Jiangsu province, China

2 Metadata of the Dataset

The metadata of the dataset[22] are listed in Table 1.

Table 1 Metadata summary of the dataset

Items	Description
Dataset full name	Dataset of land use and its ecological value assessment in Liuhe district of Nanjing city (2009, 2019)
Dataset short name	Land Use Ecological Value Assessment in Liuhe
Authors	Wang, B. AAZ-3013-2020, Nanjing Academy of Urban Planning & Design Co., Ltd, 279813263@qq.com Liu, D. Y. AAZ-2671-2020, State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, dyliu@issas.ac.cn
Geographical region	Liuhe district of Nanjing city, Jiangsu province, China
Data age	2009, 2019 Time resolution 10 years
Spatial resolution	30 m Data format .adf, .xlsx
Data size	2.47 MB (940 KB after compression） Data files 36 documents
Foundation	National Natural Science Foundation of China (41977049)
Computing environment	ArcGIS
Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (data products), and publications (in this case, in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be freely downloaded via the Internet; (2) End users are encouraged to use ***Data***, subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data***, subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license, and; (4) If ***Data*** are used to compile new datasets, the 'ten percent principal' should be followed, such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be noted in suitable places in the new dataset[23]
Communication and searchable system	DOI, DCI, CSCD, WDS/ISC, GEOSS, China GEOSS, Crossref

3 Research Area and Data Development Methods

3.1 Research Area

Liuhe district has distinct natural resources and cultural characteristics. Situated between the Yangtze River and Chuhe River, its northern hills are undulating. Going from north, natural mountains and rivers give way to a geological garden area and subcentral city in the middle, with a wetland polder area and new town in the south. Its northern part is one of the two garden areas in Nanjing, constituting both an ecological protection and suburban urban-rural integration development area. In the central and southern area, the part west of the ring expressway is a highly urbanized metropolitan area built within a 40-km radius of Xinjiekou, while the part east of the ring expressway is home to a riverside ecological protection and suburban urban-rural integration development area (Figure 2). The new version of the master plan puts forward the overall pattern of "northern-southern gardens, central metropolis, riverside development, and urban-rural integration"[20]. The Chuhe River basin, wherein Liuhe district is located, has been an vital place for human settlement in prehistoric and ancient times. Liuhe is also the main producing area of Yuhua stone, which is a national treasure given by nature and uniquely found in China. It is also the birthplace of the Jiangsu folk song 'Jasmine'.

3.2 Data Development Methods

3.2.1 Land-use Quantity and Its Distributional Changes

(1) Analyzing land-use quantity and its distributional changes

The quantity of land resources available determines its degree of scarcity. First, their changes in quantity can be gauged by the total areas of different land-use types. Through analyzing the total change undergone for one or more land-use types, we can grasp the general trend of land-use changes over time and space. Second, such changes could be conveyed also in terms of per capita change of differing land-use types, which can more directly reflect quantitative changes in land use.

According to the "Classification of land use status"[24] and considering the characteristics of Liuhe district, we divided the land-use types providing ecosystem service functions into eight categories: cultivated land, woodland, wetland, grassland, water area, residential/ service land, industrial/ mining land, and transportation/other land. Based on Landsat TM images from 2009 and 2019, the data on land-use change in Liuhe district over a 10-year period were obtained, by using ArcGIS v10.5 (ArcGIS, ESRI Inc., Redlands, CA, USA) to calibrate coordinates, cut grids, and identify the pertinent attribute data. To compare the changes in the spatial distribution of land use, both the statistical yearbook of Liuhe district[25] and Nanjing's annual report of urban planning [26]were queried to extract supervision data of land-use classifica-

Figure 2 Spatial structure planning of Nanjing[20]

tion and other comparative reference data.

(2) Analyzing changes in land-use structure

Given the tight correlation between economic structure, land-use structure, and ecosystem service function, investigating the structure-function relationship can better fulfill the role of land use as a macroeconomic means.

The land-use dynamic index (LUDI) expresses the change in the area of a certain land-use type per unit time; that is, the change rate of this given land-use type in area. It is calculated this way:

$$\mathrm{LUDI} = \frac{U_a - U_b}{U_a} \cdot \frac{1}{T} \cdot 100\% \tag{1}$$

where U_a and U_b represent the area (km^2) of a certain land-use type at time *a* and *b*, respectively, and *T* is the length of the study period, from time *a* to time *b*. When *T* is in years, LUDI represents the annual change rate of this land-use type in area.

3.2.2 Ecosystem Service Classification System

Here, the value of regional ecosystem service functions was divided into two components (natural value and economic value) with a total of 24 items based on the theoretical framework of Costanza *et al.* [1] and informed by localized estimation experience of Zong *et al.* [6], coupled to the actual situation in Liuhe district. The natural value comprised 12 items, gas regulation, climate regulation, interference regulation, water regulation, water supply, erosion prevention, soil formation and nutrient cycling, environmental protection, waste treatment, pollination, biological pest control, and habitat (shelter). The economic value also comprised 12 items, agricultural value, forestry value, animal husbandry value, aquatic product value, industrial value, construction industry value, transportation and storage value, wholesale and retail value, accommodation and catering value, financial industry value, real estate industry value, and tourism and other service industry value.

3.2.3 Ecological Value Estimation Methods

According to the current statistical caliber, this study considered the economic value while paying special attention to the natural value of ecosystem service functions. To do this, important non-market regulation and purification functions plus habitat and life support functions were taken into account by a specific estimation method, for which “the natural value cannot be reduced” is the principle of strong sustainable development of urban and rural areas[7–8]. Based on land-use data and ecological value accounting theory, the ecological value per unit area (Yuan ·hm^{-2} ·a^{-1}) was estimated; then, the ecological value was calculated for 2009 and 2019 based on the total areas of various ecosystem types present in the region in each year[1–3].

(1) Estimating natural value

Natural value is mainly provided by cultivated land, woodland, wetland, grassland, and water area. The natural value coefficient of 12 ecological service functions[1–3] was used to derive the natural value of ecosystem service function per unit area, after corrections. To ensure the consistency between natural value and economic value estimations, 1997 was taken as the benchmark year. The 1997–2019 data were obtained from the “Nanjing Statistical Yearbook” [27] to calculate the consumer price index of Nanjing in 2019, which was 144.2 (it was 100 in 1997). Based on this, the global universal value coefficient of Costanza *et al.* in 1997 could then be converted into the value coefficient of Nanjing region in 2019.

(2) Estimating economic-social value

Economic value mainly refers to the economic production function of ecosystems, that is, those marketized products or utility as provided by different ecosystems. Traditional statistical methods mainly infer economic value from GNP. To avoid repeated calculations, this study classified the economic value of a give ecosystem according to its corresponding land-use type. In this way, agricultural value belonged to cultivated land, and likewise forestry value to woodland, animal husbandry value to grassland and cultivated land, aquatic product value to water area and wetland, industrial value and part of construction industry value to industrial and mining land, and transportation and storage value to transportation and other land. Similarly, for the values of wholesale and retail industry, accommodation and catering industry, financial industry, real estate industry, tourism and other service industries, and part of the value of construction industry, they all belonged to residential and service land. The economic-social value of ecosystem service function per unit area (10 thousand Yuan ·hm^{-2} ·a^{-1}) was then calculated as follows:

$$V_i = G_i / S_i \quad (2)$$

where V_i is the economic-social value per unit area of industry i (10 thousand Yuan ·hm^{-2} ·A^{-1}), G_i is the gross domestic product (GDP: 10 thousand Yuan), and S_i is the area of industry i (hm^2).

4 Results and Validation

4.1 Dataset Products

The dataset includes spatial data and table data. The spatial data include land use data in 2009 and 2019. The spatial resolution is 30 m. The table data include: (1) area and proportion of different land-use types in 2009 and 2019; (2) LUDI from 2009 and 2019; (3) natural value of ecosystem service functions per unit area in 2019; (4) economic value of ecosystem service functions per unit area in 2019; (5) ecological value of different ecosystem types in 2009 and 2019. The dataset is archived in ArcGIS Grid (.adf) and .xlsx data format, which consists of 36 data files with data size of 2.47 MB (compressed to 931 KB in one file).

4.2 Data Results

4.2.1 Spatial Changes of Land Use in Liuhe district

(1) Quantitative changes of land use

From 2009 to 2019, the residential/service land, industrial/mining land, transportation/other land, woodland, and grassland all increased in total area, while the water area, wetland, and cultivated land each decreased (Figure 3). The per capita land area* decreased from 0.21 hm^2 in 2009 to 0.18 hm^2. In particular, the cultivated land area for human survival has been reduced by 20%, from 0.10 hm^2 to 0.08 hm^2, while the per capita residential/service land remained stable, at 0.018 hm^2. Therefore, it will soon approach the 0.053 hm^2 warning threshold of the Food and Agriculture Organization of the United Nations that would threaten the food supply capacity.

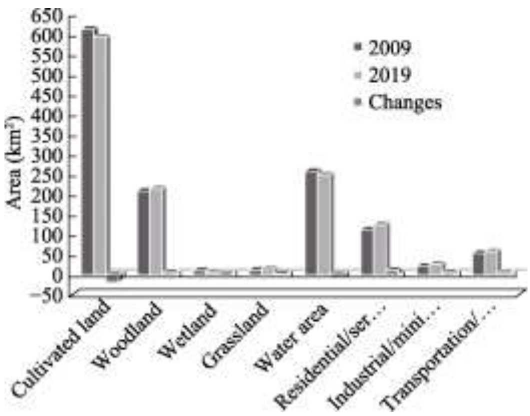

Figure 3 Changes of land-use area in Liuhe district of Nanjing from 2009 to 2019

(2) Distributional changes of land use

After conducting the spatial overlap analysis, it was evident that the expansion of urban construction space was mainly concentrated in the subcentral city Liuhe. The expansion of living space and spread of economic development zone go together. Influenced by ecologi-

*According to the “statistical yearbook of Liuhe district” and the “statistics of floating population by the Public Security Bureau”, the permanent residents of Liuhe District in 2009 and 2019 numbered 616,000 and 704,500, respectively.

cal restoration strategy, the woodland and grassland increased in the northern and central-northern areas (Figure 4–6).

(3) Structural change of land use

From 2009 to 2019, the cultivated land showed the largest range of change, followed by that of water area. The proportion of these two land-use types out of total land use declined from 67.33% in 2009 to 65.12%, with an absolute decrease of 2.21 percentage points. Corresponding to that decrease, the residential/service land, industrial/ mining land, and transportation/other land together increased by 1.76% over the past decade (Figure 7).

According to the LUDI of various land-use types, the annual change rates of industrial/mining land (–0.026) and wetland (0.02) spanning the 10 years were the greatest, followed by grassland (–0.018), residential/service land (–0.011), transportation/other land (–0.009), and least for water area (0.004), woodland (–0.003), and cultivated land (0.003). The primary reason for the pronounced annual change rate of industrial/mineral land is that the manufacturing industry- bearing function has been strengthened. There are three major reasons for the moderate increases found in residential/service land, and transportation/other land. First, the central urban area of Nanjing has formed a closed loop of coordinated development, which is beneficial for Liuhe to undertake the functional spillover. Second，the construction of Liuhe subcentral city as an “anti-magnetic” center has sped up. Third, the Jinniuhu plate has achieved a qualitative leap. In contrast, the growth of woodland and grassland is mainly due to the restoration of northern garden areas in Nanjing.

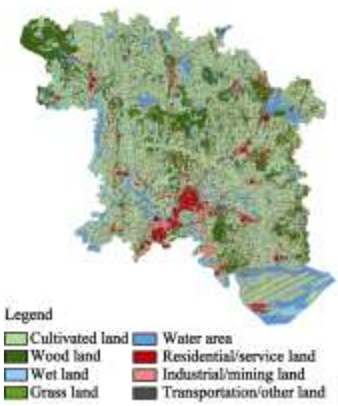

Figure 4 Land use status of Liuhe district in 2009

Figure 5 Land use status of Liuhe District in 2019

Figure 6 Spatial changes of Liuhe district construction from 2009 to 2019

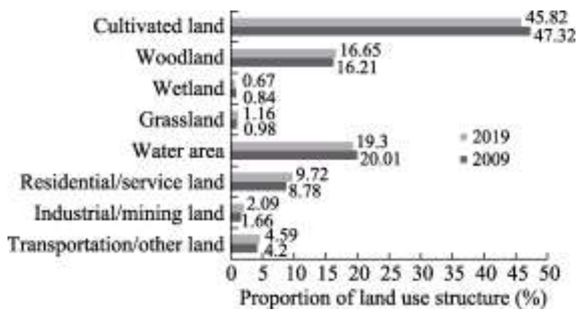

Figure 7 Changes of land-use structure in Liuhe district of Nanjing from 2009 to 2019

4.2.2 Ecological Value Profits and Losses in Liuhe district

(1) Natural value and economic value

The natural value of ecosystem service function per unit area is presented in Table 2. Evidently, the total natural value of wetland was the highest. Considering the economic value of ecosystem service function per unit area, that of industrial/mining land was the largest;

the economic values of wetland, water area, and woodland were all relatively low (Table 3).

Table 2 Natural value of ecosystem service function per unit area in Liuhe district of Nanjing in 2019 (10 thousand Yuan·hm^{-2}·a^{-1})

Ecosystem types	Gas regulation	Climate regulation	Disturbance regulation	Water regulation	Water supply	Erosion control	Soil formation	Nutrient cycling	Waste treatment	Pollination	Biological control	Habitat/shelter	Total value
Woodland	–	0.17	0.003	0.003	0.004	0.12	0.013	0.44	0.12	–	0.003	0.28	1.156
Grassland	0.01	–	–	0.004	–	0.05	0.001	–	0.12	0.03	0.03	0.26	0.505
Wetland	0.16	–	5.44	0.03	4.56	–	–	–	5.01	–	–	0.38	15.58
Water area	–	–	–	6.52	2.54	–	–	–	0.81	–	–	0.26	10.13
Cultivated land	–	–	–	–	–	–	–	–	–	0.02	0.03	–	0.05

Notes: ① Data were derived from Costanza *et al*.[1–3]. In 1997, the official exchange rate of US dollar to the RMB was 1: 8.3. ② Costanza *et a*l. did not assign value to the function of habitat (shelter) when calculating the ecological value of woodland, grassland, or water area. Here, the mean value of wetland and estuary was used to revise the natural value coefficient of habitat (shelter) of woodland, grassland, and water area. ③ In 2000, the average per unit area values[9] of woodland and cultivated land were 18,789 and 13,054 Yuan·hm^{-2}, respectively; the consumer price index of Nanjing was 98.6 (100 in 1997), whose conversion into per unit area values of woodland and cultivated land in 1997 were 19,056 and 13,240 Yuan·hm^{-2}. In 2019, the per unit area values of woodland and cultivated land were 27,479 and 19,093 Yuan·hm^{-2}. When calculating the ecological service value later, the revised data shall be used.

Table 3 Economic value of ecosystem service function per unit area in Liuhe district of Nanjing in 2019 (10 thousand Yuan·hm^{-2}·a^{-1})

Ecosystem types	Cultivated land	Woodland	Wetland	Grassland	Water area	Residential/service land	Industrial/mining land	Transportation/other land
Economic value	8.25	1.92	4.28	6.5	4.28	199.13	559.44	6.05

(2) Profits and losses of ecological value

The ecological values of different ecosystem types (Table 4) were obtained based on the ecological value per unit area of each ecosystem type, combined with the total area. By analyzing the results of ecological value accounting, the profits and losses of ecological value from 2009 to 2019 were derived.

Table 4 Ecological values of different ecosystems in Liuhe district of Nanjing (100 million Yuan·a^{-1})

Ecosystem types		Year	Cultivated land	Wood land	Wetland	Grassland	Water area	Residential/service land	Industrial/mining land	Transportation/other land	Total value
Ecological value		2009	62.29	9.81	2.17	0.89	37.35	226.59	120.22	3.29	462.61
		2019	60.32	10.07	1.73	1.06	36.03	250.74	151.78	3.59	515.32
	Natural value	2009	11.71	5.78	1.70	0.06	26.26	—	—	—	45.51
		2019	11.34	5.93	1.36	0.08	25.33	—	—	—	44.04
	Economic value	2009	50.58	4.03	0.47	0.83	11.09	226.59	120.22	3.29	417.10
		2019	48.98	4.14	0.37	0.98	10.70	250.74	151.78	3.59	471.28

(i) The total natural value of various ecosystems decreased from 4.551 billion Yuan in 2009 to 4.404 billion Yuan in 2019, with a decrease of 147 million Yuan. The increasing occupation of surrounding cultivated land, water area, and wetland by urban and rural construction land, continuously drove down the natural value of these three ecosystems on yearly basis. In contrast, thanks to the increase in woodland area, its natural value rose from 578 million to 593 million Yuan. However, the natural value still decreased by 3.3%. According to the principle of "natural value cannot be reduced", it's in a weak sustainable development state. Therefore, to ensure the extant area of woodland is not reduced, the occupation of the surrounding cultivated land and water area by urban and rural construction land should be mitigated as far as possible.

(ii) The total economic value of various ecosystems increased from 41.710 billion Yuan in 2009 to 47.128 billion Yuan in 2019, amounting to a net increase of 5.418 billion Yuan. This increase mainly arose from increased urban and rural construction land areas. The economic value of residential/service land increased from 22.659 billion to 25.074 billion Yuan, as did the economic value of industrial/mining land (from 12.022 billion to 15.178 billion Yuan). The economic values of cultivated land, water area, and wetland all gradually fell due to considerable displacement of these ecosystems by urban and rural construction land.

(iii) The total ecological value of various ecosystems increased from 46.261 billion Yuan in 2009 to 51.532 billion Yuan in 2019, representing a net increase of 5.271 billion Yuan. Of this, natural value and economic value accounted for 9.84% and 90.16% (in 2009) and 8.55% and 91.45% (in 2019), respectively. The proportion of natural value has continuously shrunk, a trend which suggests that the expansion of urban and rural construction land is unavoidably accompanied by the loss of natural value (e.g., cultivated land and water area).

(iv) In 2009, the total natural value of various ecosystems (4.551 billion Yuan) accounted for 10.91% of their total economic value (41.710 billion Yuan). In 2019, the total natural value (4.404 billion Yuan) accounted for 9.34% of their total economic value (47.128 billion Yuan). In the past decade, the ratio of natural value to economic value has decreased from one-ninth to one-tenth, demonstrating that the expansion of urban and rural construction land has impaired the service function of ecosystems. Therefore, in the process of economic accounting, we should not only consider the growth of economic value, but also the parallel loss of natural value, so as to reflect the rate of economic growth more truthfully.

(v) Considering different types of ecosystems, non-construction space (water area, woodland, wetland, cultivated land, and grassland) plays vital role in sustaining life support systems. The natural value of wetland per unit area is the largest, followed by water area, woodland, cultivated land, and grassland. Still, when considering economic values, those of construction space (residential/service land, industrial/mining land, and transportation/other land) are dozens of times greater than those of woodland and water area. Therefore, in the development of urban and rural construction land, the potential value of woodland and water area is overlooked, resulting in a loss of natural value. When comprehensively assessing the relationship between the economic value and natural value of each ecosystem, the economic value of non-construction space in 2009 accounted for 19.1% of the economic value of construction space; this ratio fell to 16.1% in 2019. However, considering both the natural value and economic value, the ecological value of non-construction space accounted for 32.2% of the ecological value of construction space in 2009, but less so (26.9%) in 2019. Therefore, concerning the non-market valuation of ecosystems, the ratio of ecological value between non-construction and construction spaces has risen from 1: 5 to 1: 3. Hence, the comprehensive benefits of urban and rural construction land are no longer prominent. Accordingly, it is necessary to limit the occupation of non-construction space including cultivated land, woodland, and water area by further extensive expansion of urban and rural construction land.

4.3 Date Validation

Taking Lingwu of Ningxia as an example, Zong et al. (2002) [6] extended the simple estimation of natural value by Costanza et al. [1] and derived a comprehensive estimation of natural value and economic value. Here, we verified our results by comparing them with the data from Lingwu. From 1990 to 1997, due to industrial development in Lingwu, especially five types of small enterprises (including chemistry and metallurgy), the loss of natural value became increasingly prominent, with an annual decrease of 4% on average. In terms of the ecological value, its rate of increase lagged behind that of GDP in Lingwu. From 2009 to 2019, driven principally by the state-level new area strategy, the city-industry integration of Liuhe subcentral city accelerated, resulting in a concomitant greater loss of natural value marked by an average annual decrease of 3.4%. The growth rate of ecological value was also lower than that of GDP. It should be pointed out that because of different regions and time periods, especially the distinct stages of regional urbanization, the comprehensive estimation of ecological value is partially influenced by the estimation of economic-social value; hence, certain differences are perhaps inevitable between the present and previous studies.

5 Discussion and Conclusion

Considering that differing land-use patterns result in varied service values, this study explored the urban and rural spatial changes in Liuhe district in the last 10 years, especially driven by the state-level new area strategy. The profits and losses of ecological value caused by land-use changes were analyzed by refining the service functions as far as possible based on Costanza's and other value accounting methods. The findings could provide timely support for measuring regional sustainable development.

The results indicate that the expansion of construction space has led to 3.3% reduction in the natural value, rendering the whole district in a weak sustainable development state. Considering the ecological value of non-construction space, this study analyzed the "uneconomical" phenomenon under the logic of "economic civilization" in urban and rural spatial expansion. As the ratio of ecological value between non-construction space (represented by five ecosystems) and construction space (represented by three ecosystems) has increased from 1:5 (simple estimation of economic value) to 1:3, the comprehensive benefits of construction space are no longer prominent in the study area.

The accounting of ecological value for each type of ecosystem includes both natural value and economic value. Specifically, the natural value is the potential value of the ecosystem, which cannot be marketized. Through our estimations, we find that under the influence of traditional values, economic indicators are rather incomplete. If economic indicators are solely relied upon for decision-making, it would lead to a waste of resources and the destruction of ecological environment.

Further, the significance of this study lies in reviewing the "economic civilization" logic of urban and rural spatial expansion，and unveiling the "uneconomical" aspects hidden within "economic civilization". Under a revamped logic centered on "ecological civilization" in the new era, land space development that maximizes ecological value while maximizing comprehensive benefits should be carried out in a carefully planned, step-by-step manner.

Due to the diversity and complexity of ecosystem service functions, it is challenging to achieve comprehensive and accurate assessments of ecological value. Nevertheless, it is a laudable and correct process to estimate the minimum value of ecological service function by referring to leading research practices in China and elsewhere. This study, however, did not consider the disastrous losses caused by emergencies in natural, economic, and social processes, nor the impacts of various bottlenecks, threshold effects, and abrupt events on valuations.

Author Contributions

Wang, B. developed the frame of the dataset. Wang, B. and Liu, D. Y. designed dataset processing. Wang, B. designed the models and algorithm. Liu, D. Y. performed the data verification. Wang, B. wrote the data paper.

References

[1] Costanza, R., d'Arge, R., de Groot, R., *et al*. The value of the world's ecosystem services and nature capital [J]. *Nature*, 1997, 387: 253–260.

[2] Costanza, R., d'Arge, R., de Groot, R., *et al*. The value of ecosystem services: putting the issues in perspective [J]. *Ecological Economics*, 1998, 25(1): 67–72.

[3] Costanza, R., d'Arge, R., de Groot, R., *et al*. Tao, D. L. Translate. The value of the world's ecosystem services and nature capital [J]. *Chinese Journal of Ecology*, 1998, 18(2): 70–78.

[4] Turner, K. Economics and wetland management [J]. *Ambio*, 1991, 20(2): 59–63.

[5] Kellert, S. R. Assessing wildlife and environmental values in cost-benefit analysis [J]. *Joural of Environmental Management*, 1984, 18: 4.

[6] Zong, Y. G., Zhou, S. Y., Wen L., *et al*. Assessment with eco-economic valuation of sustainable development of a regional ecosystem: a case study of Lingwu city, Ningxia province [J]. *Acta Ecologica Sinica*, 2002, 22(10): 1573–1580.

[7] Pearce, D. W, Warford, J. J. World without end Economics, And Sustainable Development [M]. Oxford: Oxford University Press, 1993.

[8] Pearce, D. W., Atkinson, G. D. Capital theory and the measurement of sustainable development: an indicator of "weak" sustainability [J]. *Ecological Economics*, 1993, 8(2): 103–108.

[9] He, H., Pan, Y. Z., Zhu, W. Q., *et al*. Measurement of terrestrial ecosystem service value in China [J]. *Chinese Journal of Applied Ecology*, 2005, 16(6): 1122–1127.

[10] Xie, G. D., Zhang, C. X., Zhang, L. M., *et al*. Improvement of the evaluation method for ecosystem service value based on per unit area [J]. *Journal of Natural Resources*, 2015, 30(8): 1245–1246.

[11] Wu, Q., Peng, Y. Y., Ma, H. Y., *et al*. Research on the value of forest ecosystem services and compensation in a Pinus massoniana forest [J]. *Acta Ecologica Sinica*, 2019, 39(1): 117–130.

[12] Peng, W. F., Zhou, J. M., Yang, C. J., *et al*. Research on ecosystem service values based on land use change in Sichuan province [J]. *Resources and Environment in the Yangtze Basin*, 2014, 23(7): 1053–1062.

[13] Bai, Z. L., Bao, A, M, Chang, C., *et al*. Impacts of land use change on ecosystem services value in the Ebinur lake basin [J]. *Bulletin of Soil and Water Conservation*, 2013, 33(1): 167–173, 177.

[14] Liu, Y. Q., Liao, L. W., Long, H. L., *et al*. Effects of land use transitions on ecosystem services value: A case study of Hunan province [J]. *Geographical Research*, 2015, 34(4): 691–700.

[15] Gao, Y. M., Sun, H. L. Ecological service value of the Ili River valley based on land use cover classification [J]. *Ecological Science*, 2017, 36(1): 193–200.

[16] Meng, X. B., Cao, G. L., An, W. H., *et al*. Study on ecosystem services of Xixian new area based on land use planning [J]. *Ecological Science*, 2017, 36(3): 142–148.

[17] Zhao, Z. G., Yu, D., Han, C. Y., *et al*. Study on the spatial and temporal changes in ecosystem services in Poyang lake ecological economic zone from 2008 to 2016 [J]. *Resources and Environment in the Yangtze Basin*, 2017, 26(2): 198–208.

[18] Hu, C. X., Guo, X. D., Lian, G., *et al*. Effects of land use change on ecosystem service value in rapid urbanization areas in Yangtze river delta—a case study of Jiaxing city [J]. *Resources and Environment in the Yangtze Basin*, 2017, 26(3): 333–340.

[19] The State Council. Reply of the State Council on approving the establishment of Jiangbei new area in Nanjing city [Z]. 2015.

[20] Nanjing Municipal Bureau of planning and natural resources, Nanjing Academy of Urban Planning & Design Co., Ltd, *et a*l. The master plan of Nanjing city (2018–2035) (draft) publicity [Z]. 2018.

[21] Liuhe branch of Nanjing Municipal Bureau of planning and natural resources, Nanjing Academy of Urban Planning & Design Co., Ltd. The development outline of Liuhe district in Nanjing city master plan (2018–2035) [Z]. 2018.

[22] Wang, B., Liu, D. Y. Dataset of land use and its ecological value assessment in Liuhe district of Nanjing City (2009, 2019) [DB/OL/J]. Global Change Data Repository, 2020. DOI: 10.3974/geodb.2020.05.17.V1.

[23] GCdataPR Editorial Office. GCdataPR Data Sharing Policy [OL]. DOI: 10.3974/dp.policy.2014.05 (Updated 2017).

[24] National standards of the people's Republic of China. Classification of land use status (GB/T 21010–2017) [S]. 2017.

[25] Liuhe District Bureau of Statistics in Nanjing. Liuhe Statistical Yearbook 2010; Liuhe Statistical Yearbook 2020 [Z]. 2010, 2020.

[26] Nanjing Municipal Bureau of planning and natural resources. Nanjing's annual report of urban planning 2009, Nanjing's annual report of urban planning 2019 [Z]. 2009, 2019.

[27] Nanjing Bureau of Statistics. Nanjing Statistical Yearbook 1998; Nanjing Statistical Yearbook 2020 [Z]. 1998, 2020.