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Ecosystem Services Evaluation of Karst New Urban Areas Based on Net Primary Productivity of Guanshanhu District, Guiyang, Guizhou Province, China

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Abstract

Net Primary Productivity (NPP) is the basis of the material and energy transport calculation in ecosystem studies. NPP directly reflects the production capacity of plant communities under natural conditions. Ecosystem services are hot topics in the field of ecology. Many studies calculate ecosystem service value based on NPP. Taking Guanshanhu District of Guiyang City, Guizhou Province as the research object, using TM, ETM$^+$, Gaofen2 and MOD17A3HGF.006 as data sources, this paper analyzed the change of ecosystem service value based on NPP in 2000, 2010 and 2020. The results showed that the area of forest ecosystem increased during 2000-2010 and decreased during 2010-2020. The artificial surface grew rapidly from 1146.82 hm^2 to 7544.29 hm^2 during 2000-2020. The farmland ecosystem decreased from 13308.29 hm^2 to 6342.33 hm^2 during 2000-2020. With the dynamic changes in ecosystem spatial distribution and component structure, the total NPP in 2000, 2010 and 2020 was 12.58×10^4 t, 11.90×10^4 t and 11.78×10^4 t, respectively, showing a decreasing trend. The total value of natural and semi-natural ecosystems services based on NPP showed an increasing trend, which was ¥ 6.938×10^8 in 2000, ¥ 8.052×10^8 in 2010 and ¥ 10.306×10^8 in 2020 respectively. The ecosystem contributed the most to the ecological service value in 2000 was farmland, but in 2010 and 2020, it was the forest ecosystem. The ecological service value of grassland and wetland was relatively small, while the ratio of the wetland ecological service value displayed a decreasing trend. In the future, it is necessary to establish a strict pretrial system for land use, so as to effectively protect the natural and semi-natural ecosys-

tems and fulfill the growing ecological demands of residents.

Keywords

Karst, Net Primary Productivity (NPP), Ecological Service Physical Quantity, Ecological Service Value, Guanshanhu District

1. Introduction

Vegetation net primary productivity (NPP) refers to the increments in biomass per unit of land surface and time, calculated as the difference between the energy fixed by plant photosynthesis and their respiration [1] [2]. As the core concept in studies of ecosystem material and energy transportation, NPP directly reflects the production capacity of plant communities under natural conditions. The production capacity of ecosystems is directly related to the ability of maintaining the dynamic balance of CO_2 and O_2 and nutrient cycling [3] [4]. Ecosystem refers to any geographic area that includes all of the organisms and nonliving parts of their physical environment. Ecosystem is divided into natural ecosystem, semi-natural ecosystem and artificial ecosystem based on the amount of human interference. Agricultural ecosystem can be regarded as semi-natural ecosystem [5]. Ecosystem services are the products and services obtained directly or indirectly by human through the functions of the ecosystem, which is crucial to the survival of mankind while being difficult to duplicate [6]. The evaluation of ecosystem service is to quantitatively study the value of various ecosystem services, and to calculate the monetary value of natural factors [7] [8]. NPP can effectively represent the ecosystem services of carbon cycle regulation and nutrient transportation, which is conducive to scientific management and rational utilization of natural resources, and applicable for the system of Environmental-Economic Accounting [9] [10].

To enhance the productivity and services of ecosystems in new urban area of Karst, mountains are the fundamental guarantee to ensure that the urban ecosystem can give full play to its social, economic and ecological benefits. This article, on the basis of MOD17A3HGF, using RS and GIS technology, and with the help of field sampling data, studied the spatial distribution and dynamic changes of ecosystems and their NPP from 2000 to 2020 in the new urban area of Guanshanhu District, Guiyang City, Guizhou Province, Southwest China. Based on NPP, the natural and semi-natural ecosystem's ecological service value of carbon cycle regulation and nutrient transportation are evaluated. Location and quantitative evaluation of the long time series ecosystem services based on NPP is the novelty of the study, which clearly reflect the future development trend of the ecosystem, and to rationally protect, develop and utilize biological resources, which is of great significance for creating a stable and high-yield ecosystem in karst urban new areas.

2. Materials and Methods

2.1. Study Area

Guanshanhu District is located in the central karst area of Qianzhong mountain, northwest of Guiyang, Guizhou Province, China. There are three towns under the jurisdiction of Guanshanhu District: Baihuahu Town, Jinhua Town, Zhuchang Town, and are divided into nine community service centers (**Figure 1**). As a pioneer area of ecological civilization in Guiyang city, Guanshanhu District shoulders the historical mission of building ecological civilization demonstration area in the future development.

2.2. Materials and Pre-Processing

The remote sensing interpretation data of different ecosystem types in Guanshanhu District is mainly obtained from the national geographic information monitoring cloud platform (http://www.dsac.cn/DataProduct/Index/1002), which includes: Landsat TM, ETM+, Gaofen2 and other multivariate medium and high-resolution remote sensing images (**Figure 2**).

NPP data are the MOD17A3HGF data products provided by NASA (https://lpdaac.usgs.gov/) of the United States. This data comes from the sum of MOD17A2HGF data of all eight-day net photosynthesis (PSN) products in a given year. The spatial resolution is 500 m, and the temporal resolution is 1 a [11] [12].

2.3. Methodological Approach

1) Remote sensing image interpretation method. According to the spectral characteristics and texture characteristics of the image, combining with the

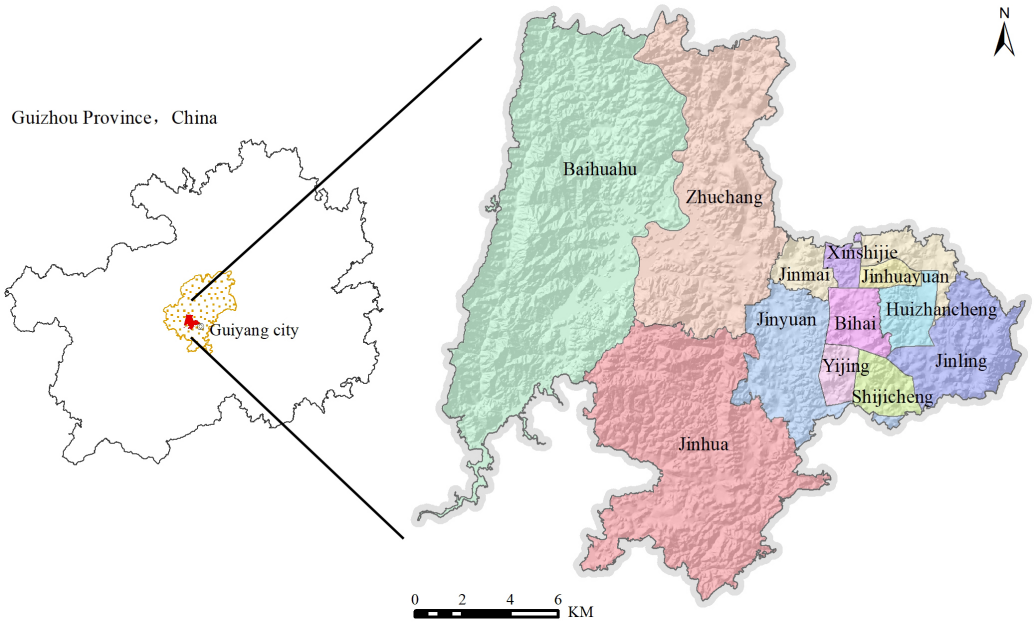

Figure 1. Position and general situation of Guanshanhu district.

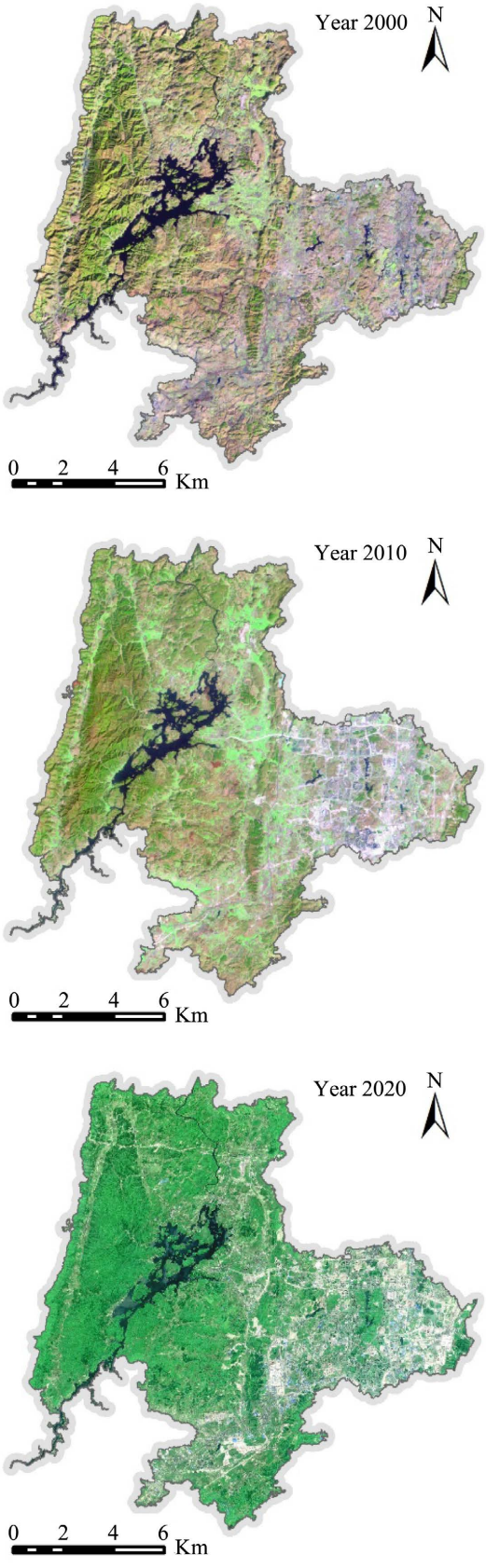

Figure 2. Remote sensing images of Guanshanhu district.

existing land cover/land use information and field survey sample data, the interpretation signs and sample database are established. The eCognition object-oriented image automatic classification technology is used to assist human-computer interaction interpretation, and the spatial distribution map of ecosystem types is extracted. The confusion matrix is established by random verification samples, and the accuracy of image classification is evaluated [13] [14].

2) Estimation method of ecological services physical quantities. It is a very important function of the ecosystem to synthesize organic matter by solar energy, which supports the whole life system and is the food basis for all consumers and restorers. The amount of organic matter production in the ecosystem can be calculated by NPP. The content of carbon in plant dry matter accounts for about 45%, that is, organic matter production = NPP ÷ 45%. Ecosystems exchange CO_2 and O_2 with the atmosphere through photosynthesis and respiration, absorb CO_2 in the atmosphere and release O_2, which plays an important role in maintaining the dynamic balance of CO_2 and O_2 in the atmosphere. According to the photosynthetic equation:

$$6CO_2\left(264\text{ g}\right)+6H_2O\left(108\text{ g}\right)\rightarrow C_6H_{12}O_6\left(108\text{ g}\right)+6O_2\left(193\text{ g}\right)\rightarrow \text{Polysaccharide}\left(162\text{ g}\right)$$

The production of 162 g dry matter can absorb 264 g CO_2, in other words, 1 g dry matter needs 1.62 g CO_2 and releases 1.20 g O_2. 1 g Carbon(C) fixed in the ecosystem can accumulate 0.025426 g Nitrogen(N), 0.00201 g Phosphorus(P) and 0.01012 g Potassium(K), thus the nutrient accumulation in the ecosystem can be calculated [15] [16].

3) Ecological service value method. The value of organic matter production service is calculated by energy substitution method, that is, the fixed Carbon in the ecosystem is converted into the standard coal weight of equal energy, and the value of organic matter production is indirectly estimated by the standard coal price. The calorific value of carbon is 0.036 MJ/g, and the calorific value of standard coal is 0.02927 MJ/g. Standard coal price is calculated by market price. Carbon fixation value = carbon fixation volume * unit carbon price, carbon fixation price is calculated according to Swedish carbon tax. Oxygen release value = oxygen release volume * unit oxygen price, oxygen release price is calculated according to market price. Nutrient accumulation value is the average price of fertilizer multiplied by the amount of pure fertilizer of nutrient N, P, K. In order to facilitate the comparison of the ecological service value in 2000, 2010 and 2020, the comparable price is used in the specific pricing process, and the comparable price is reduced by the price index.

3. Results

3.1. Dynamic Changes of Ecosystem Spatial Pattern and Structure

According to the spectral characteristics and texture characteristics of the image combining with field survey sample data, the spatial distribution map of ecosystem types is extracted by eCognition object-oriented image automatic classification technology and human-computer interaction interpretation, and the spatial

distribution map of ecosystem types is extracted. The overall accuracy of image classification in 2000, 2010 and 2020 was 88.86%, 89.28% and 92.79%, respectively. The spatial distribution pattern and dynamic changes of ecosystem in Guanshanhu District are shown in Figure 3.

According to the attribute statistics in Figure 3, the dynamic changes of ecosystem structure in Guanshanhu District are shown in Table 1.

The area of forest and grassland ecosystem in Guanshanhu District increased from 14876.12 hm^2 in 2000 to 17205.08 hm^2 in 2010, with a net increase of 2328.96 hm^2, and the increase ratio was 7.59%. With the acceleration of urban expansion, the area of forest-grass ecosystem continued to decrease, reaching 13937.54 hm^2 in 2020, showing a net decrease of 1634.36 hm^2 compared with 2010. The construction of new urban areas caused the artificial surface to grow rapidly, and the area grew from 1146.82 hm^2 in 2000, accounting for 3.74% of total area of the district, to 7544.29 hm^2 in 2020, accounting for 24.58%. The development of new urban areas occupies a relatively lower elevation of farmland. The area of farmland ecosystem had decreased from 13308.29 hm^2 in 2000 to 6342.33 hm^2 in 2020, from accounting for 43.36% to 20.66%, showing a net decrease of 22.70%. The area of wetland ecosystem has generally increased from 2000 to 2020. There is no significant change in the main rivers and large reservoirs.

3.2. NPP Dynamic Changes of Ecosystems

Based on MOD17A3HGF.006 dataset, the MODIS MOD17A3HGF NPP data of Guanshanhu District are generated by batch splicing, projection conversion and clipping using MRT tool and Python language code. NPP Dynamic Changes in 2000, 2010 and 2020 are shown in Figure 4.

Based on Figure 3 and Figure 4, the mean NPP of each natural and semi-natural ecosystem of per unit area was extracted by the ArcGIS spatial analysis. Total NPP was calculated from per unit area NPP multiplied by ecosystem area. The changes of the natural and semi-natural ecosystems NPP in year 2000, 2010 and 2020 are shown in Table 2 and Figure 5.

Table 1. Dynamic changes of ecosystem structure in Guanshanhu district.

Ecosystem types	Year2000		Year 2010		Year 2020	
	Area/hm^2	Ratio/%	Area/hm^2	Ratio/%	Area/hm^2	Ratio/%
Forest	10892.74	35.49	15571.90	50.73	13937.54	45.41
Grassland	3983.38	12.98	1633.18	5.32	1240.14	4.04
Farmland	13308.29	43.36	8087.76	26.35	6342.33	20.66
Wetland	1363.77	4.44	1298.64	4.23	1630.70	5.31
Artificial surface	1146.82	3.74	4103.52	13.37	7544.29	24.58
Total	30695.00	100.00	30695.00	100.00	30695.00	100.00

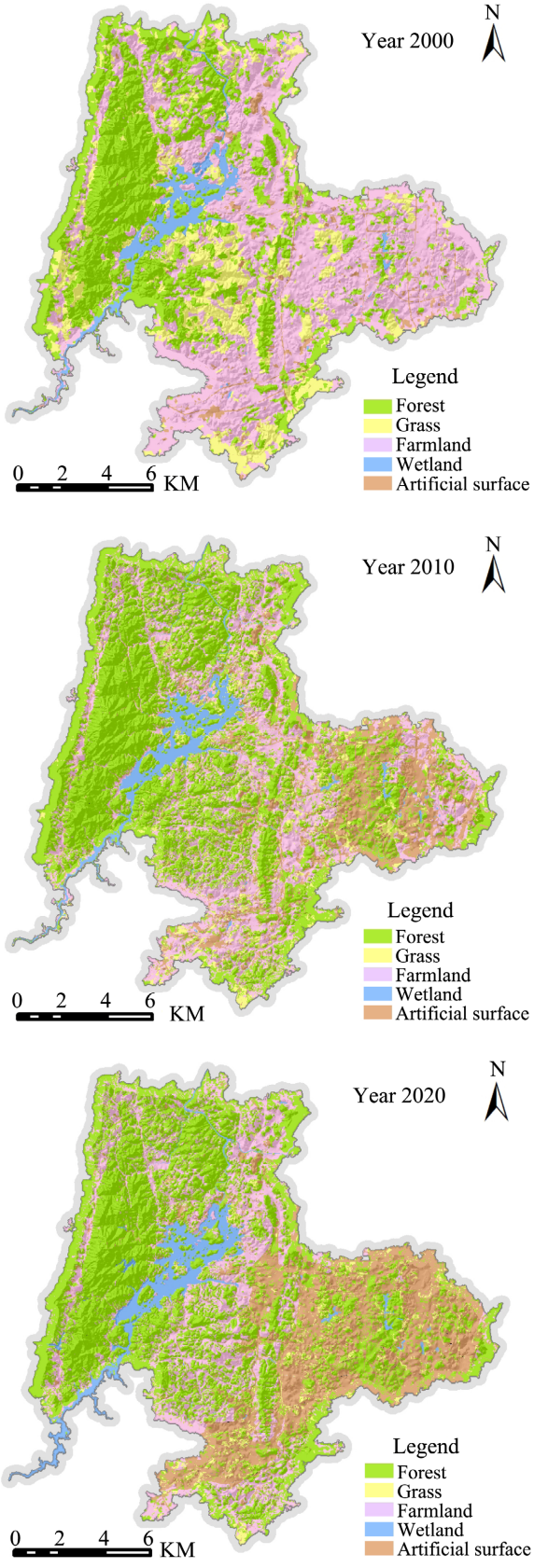

Figure 3. Dynamic changes of ecosystem spatial pattern in Guanshanhu district.

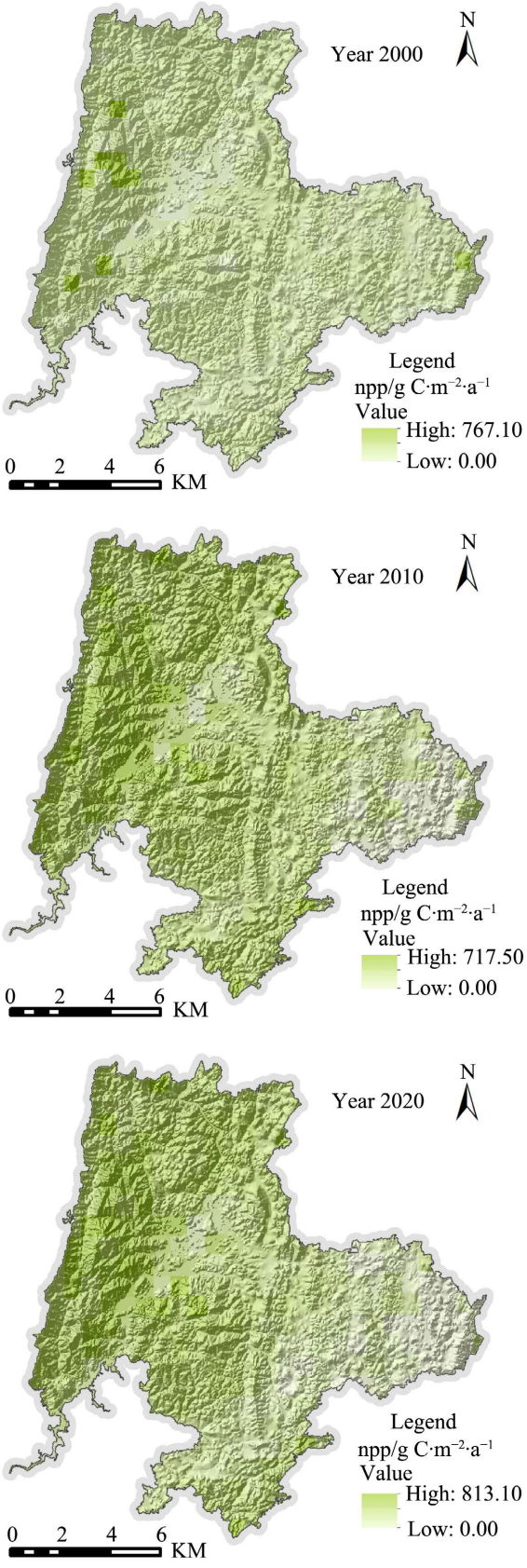

Figure 4. Distribution map of NPP Dynamic changes of Guanshanhu district.

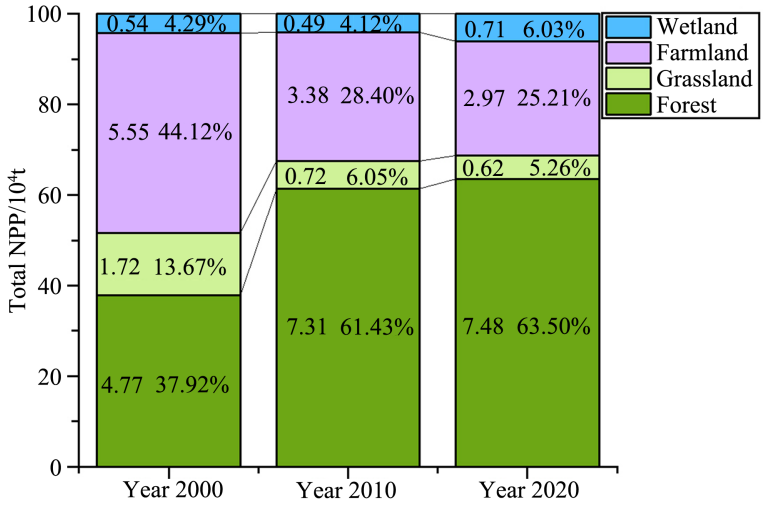

Figure 5. Total NPP changes of Guanshanhu district.

Table 2. Changes of ecosystems NPP in Guanshanhu district.

Ecosystem types	Year2000		Year 2010		Year 2020	
	NPP per unit area/g C·m^{-2}·a^{-1}	Total NPP/10^{4}t	NPP per unit area/g C·m^{-2}·a^{-1}	Total NPP/10^{4}t	NPP per unit area/g C·m^{-2}·a^{-1}	Total NPP/10^{4}t
Forest	438.13	4.77	469.68	7.31	536.38	7.48
Grassland	431.17	1.72	440.13	0.72	498.95	0.62
Farmland	416.99	5.55	418.32	3.38	468.42	2.97
Wetland	396.95	0.54	375.61	0.49	435.16	0.71
Total		12.58		11.90		11.78

The NPP per unit area of Guanshanhu District showed an increasing trend, and the NPP per unit area of forest was the highest, which was 438.13 g C·m^{-2}·a^{-1}, 469.68 g C·m^{-2}·a^{-1} and 536.38 g C·m^{-2}·a^{-1} in 2000, 2010 and 2020, respectively. The second was grassland, which was 431.17 g C·m^{-2}·a^{-1}, 440.13 g C·m^{-2}·a^{-1} and 498.95 g C·m^{-2}·a^{-1}, respectively. Total NPP in 2000, 2010 and 2020 was 12.58 × 10^4 t, 11.90 × 10^4 t and 11.78 × 10^4 t, respectively, showing a decreasing trend. The total NPP of forest land was the highest, which were 4.77 × 10^4 t, 7.31 × 10^4 t and 7.48 × 10^4 t in 2000, 2010 and 2020, and the ratios were 37.92%, 61.43% and 63.50%, respectively. Farmland was 4.77 × 10^4 t, 7.31 × 10^4 t and 7.48 × 10^4 t, and the ratios were 37.92%, 61.43% and 63.50%, respectively.

3.3. Physical Quantity of Ecological Service Based on NPP

According to the above estimation method of ecological service material quantity, the organic matter production, carbon fixation, O_2 release and nutrient accumulation were calculated. The changes of ecological service physical quantity based on NPP of Guanshanhu District are shown in Table 3.

Table 3. Changes of ecological service physical quantity based on NPP in Guanshanhu district.

Ecosystem types	Year 2000			Year 2010			Year 2020		
	Organic matter/ 10^4t	Carbon fixation/ 10^4t	Oxygen release/ 10^4t	Organic matter/ 10^4t	Carbon fixation/ 10^4t	Oxygen releaser/ 10^4t	Organic matter/ 10^4t	Carbon fixation/ 10^4t	Oxygen releaser/ 10^4t
Forest	10.61	17.18	12.73	16.25	26.33	19.50	16.61	26.91	19.94
Grassland	3.82	6.18	4.58	1.60	2.59	1.92	1.38	2.23	1.65
Farmland	12.33	19.98	14.80	7.52	12.18	9.02	6.60	10.70	7.92
Wetland	1.20	1.95	1.44	1.08	1.76	1.30	1.58	2.55	1.89
Total	27.96	45.29	33.55	26.45	42.85	31.74	26.17	42.39	31.40
Ecosystem types	Year 2000 Nutrient accumulation/t			Year 2000 Nutrient accumulation/t			Year 2000 Nutrient accumulation/t		
	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Forest	1213.45	95.93	482.98	1859.61	147.01	740.16	1900.82	150.27	756.56
Grassland	436.69	34.52	173.81	182.76	14.45	72.74	157.33	12.44	62.62
Farmland	1411.01	111.54	561.61	860.23	68.00	342.39	755.37	59.71	300.65
Wetland	137.64	10.88	54.78	124.02	9.80	49.36	180.43	14.26	71.81
Total	3198.80	252.87	1273.18	3026.63	239.26	1204.65	2993.94	236.68	1191.64

The total amount of ecological services physical quantity based on NPP showed a decreasing trend in Guanshanhu District. The largest ecological service physical quantity in 2000 was farmland ecological system and the largest physical quantity in 2010 and 2020 both were forest ecological system. The ecological service physical quantity of forest showed an increasing trend, but the increasing trend was slow down, such as the organic matter production in 2000, 2010 and 2020 were 10.61×10^4 t, 16.25×10^4 t and 16.61×10^4 t, respectively. The ecological service physical quantity of farmland showed a significant decreasing trend, and the organic matter production in 2000, 2010 and 2020 were 12.33×10^4 t, 7.52×10^4 t and 6.60×10^4 t, respectively. The ecological service physical quantity of grassland and wetland was relatively small.

3.4. Ecosystems Service Value Based on NPP

According to the above ecological service value method, the ecosystem services value based on NPP in Guanshanhu District were calculated. The standard coal price used the market average price, which was 996.36 ¥·t^{-1} in year 2000. In 2020, Sweden's carbon tax value was 137 \$·t^{-1}, and the RMB exchange rate was 6.90, and then the Carbon tax was 944.94 ¥·t^{-1}. Oxygen market price was 1400.00 ¥·t^{-1}. The average price of chemical fertilizer of diammonium phosphate is 2360.00 ¥·t^{-1}, potassium chloride is 2300.00 ¥·t^{-1}. In order to facilitate the comparison of the ecological service value in 2000, 2010 and 2020, the comparable price is used in the specific pricing process, and the comparable price is reduced by the con-

sumer price index. The carbon tax values in 2000 and 2010 were 599.75 ¥·t^{-1} and 721.67 ¥·t^{-1}. Oxygen market price was 888.10 ¥·t^{-1} and 1082.68 ¥·t^{-1} in 2000 and 2010. The prices of diammonium phosphate were 1825.09 ¥·t^{-1} and 1497.08 ¥·t^{-1} in 2000 and 2010, respectively. The prices of potassium chloride were 1778.69 ¥·t^{-1} and 1459.02 ¥·t^{-1} in 2000 and 2010. The changes of ecological service value based on NPP and their percentage composition in Guanshanhu District are shown in Table 4 and Figure 6.

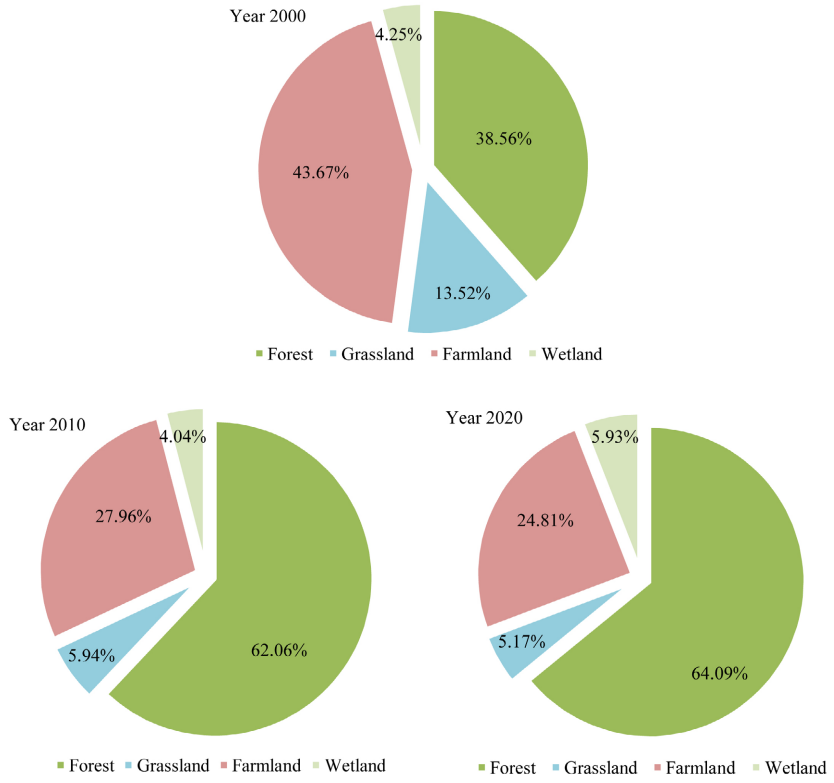

Figure 6. Percentage composition changes of ecological service value based on NPP.

Table 4. Changes of ecological service value based on NPP in Guanshanhu district.

Ecosystem types	Year2000 Ecosystems service value/10^8¥				Year 2010 Ecosystems service value/10^8¥				Year 2020 Ecosystems service value/10^8¥			
	Organic matter production	Carbon fixation & oxygen release	Nutrient accumulation	Total value	Organic matter production	Carbon fixation & oxygen release	Nutrient accumulation	Total value	Organic matter production	Carbon fixation & oxygen release	Nutrient accumulation	Total value
Forest	0.371	2.160	0.144	2.675	0.693	4.036	0.269	4.998	0.916	5.334	0.355	6.605
Grassland	0.109	0.777	0.052	0.938	0.055	0.397	0.026	0.478	0.062	0.442	0.029	0.533
Farmland	0.351	2.512	0.167	3.030	0.261	1.867	0.124	2.252	0.296	2.120	0.141	2.557
Wetland	0.034	0.245	0.016	0.295	0.038	0.269	0.018	0.325	0.071	0.506	0.034	0.611
Total	0.865	5.694	0.379	6.938	1.047	6.568	0.437	8.052	1.344	8.402	0.560	10.306

With the changes of ecosystem structure and quality in Guanshanhu District, the total ecosystem services value based on NPP showed an increasing trend, and the total values in 2000, 2010, and 2020 were ¥ 6.938×10^8, ¥ 8.052×10^8 and ¥ 10.306×10^8, respectively. The largest ecological service value in 2000 was farmland ecological system, but in 2010 and 2020 both were forest ecological system. The ecological service value based on NPP of forest showed an increasing trend, which were ¥ 3.030×10^8, ¥ 2.252×10^8 and ¥ 6.605×10^8 in 2000, 2010 and 2020, and the ratio of the forest ecological service value grew from 38.56% to 64.09% during year 2000 to 2020. The ratio of the farmland ecological service value decreased from 43.67% to 24.81% during year 2000 to 2020. The ecological service value of grassland and wetland was relatively small, and the ratio of the wetland ecological service value showed a decreasing trend.

4. Discussion and Conclusions

4.1. Discussion

NPP directly reflects the production capacity of plant communities under natural conditions, and the productivity of ecosystems is directly related to the ability of maintaining the dynamic balance of CO_2 and O_2 and nutrient cycling. With the establishment of Guanshanhu District in 2012 and the acceleration of urban expansion, the construction of new urban areas caused the artificial surface to grow rapidly. On the other hand, based on the deep reflection of the 1998 flood disaster in the Yangtze River Basin, the Natural Forest Protection Program (NFPP) and the Conversion of Cropland to Forest Project (CCFP) were carried out around 2000, and the Comprehensive Control Project of Rocky Desertification (CCPRD) in karst area was launched in 2007. Thus, the forest and grass ecosystems have been well protected for a long time in the development of karst new urban areas. Due to the bidirectional growth and decline of ecological engineering and the acceleration of urban expansion, the natural and semi-natural ecosystems had changed greatly in the past 20 years. The NPP per unit area showed an increasing trend, but still lower than the annual average NPP in Guiyang [17]. The natural production capacity of ecosystems was relatively low, and it was necessary to strengthen ecological protection and improve ecosystem quality. The value of natural and semi-natural ecosystems services value based on NPP showed a steady growth trend because of the improving quality of ecosystem by implementing of various ecological engineering programs. And the total values in 2000, 2010, 2020 were ¥ 6.938×10^8, ¥ 8.052×10^8 and ¥ 10.306×10^8, respectively. In the development of karst new urban areas, great importance should be attached to the protection of the natural and semi-natural ecosystems.

4.2. Conclusions

This paper analyzes the change of ecosystem service value based on NPP in 2000, 2010 and 2020. The location and quantitative evaluation of the ecosystem services is the peculiarity of the study. The result shows that:

1) With the urban expansion, ecosystem spatial pattern and structure, the area of forest ecosystem increased during 2000-2010 and decreased during 2010-2020. The artificial surface grew rapidly from 1146.82 hm^2 to 7544.29 hm^2 from 2000 to 2020. The farmland ecosystem continued to decrease from 13308.29 hm^2 in 2000 to 6342.33 hm^2 in 2020.

2) With the dynamic changes of ecosystem spatial pattern and structure, the NPP per unit area showed an increasing trend, and the total NPP in 2000, 2010 and 2020 was 12.58×10^4 t, 11.90×10^4 t and 11.78×10^4 t respectively, also showing a decreasing trend. The total amount of ecological services physical quantity based on NPP showed a decreasing trend in Guanshanhu District. The ecological service physical quantity of forest showed an increasing trend, but the increasing trend was slow down. The ecological service physical quantity of farmland showed a significant decreasing trend. The ecological service physical quantity of grassland and wetland was relatively small.

3) The comparable price is used in the specific pricing process, and the comparable price is reduced by the consumer price index. The total value of the natural and semi-natural ecosystems services value based on NPP showed an increasing trend, and the total values in 2000, 2010, 2020 were ¥ 6.938×10^8, ¥ 8.052×10^8 and ¥ 10.306×10^8, respectively. The largest ecological service value in 2000 was farmland ecological system, but in 2010 and 2020 both were forest ecological system. The ecological service value of grassland and wetland was relatively small, and the ratio of the wetland ecological service value showed a decreasing trend.

In the future, it is necessary to establish a strict pretrial system for the land use, so as to effectively protect the natural and semi-natural ecosystems and meet the growing ecological needs of residents.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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