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Spatial Patterns and Intensity of Ecosystem Service Values in Beijing

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Ecosystem services (ES) are the benefits that humans receive from nature. The payments for ES provide financial incentives to urban managers to conserve natural ecosystems. The spatial pattern and intensity of ES values have become leading principles of urban planning. Although most ES evaluations of urban regions are at the city scale, urban land planning is typically made at the landscape level. The applications of remote sensing data provide a great opportunity for quantifying the ES in a finer analytical unit. In this study, we investigated the spatial patterns of ES in Beijing by calculating the economic value of each ES based on the landscape type. We compared the ES intensities observed in different administrative districts and land use types, and we obtained the following results: (1) The ES values in Beijing are distributed in a spatial pattern with low value at the center and high values in the surrounding area, with the highest value in Miyun District and the lowest value in Dongcheng District. The difference in ES intensity between above two districts is 4.087×10^4 yuan per hectare. (2) The ES type with higher value in Beijing are hydrology regulation and climate regulation services. (3) The land use type of forest is the main source of ES values, accounting for 67.2% of the total value. This study provides a spatial clarification of ES value in Beijing, which could supply a scientific reference to support urban optimization and resource allocation.

1. Introduction

Ecosystem services (ES) refer to the benefit that humans obtain directly or indirectly from ecosystems.(1) ES are resources and the environmental foundation for human survival and development.(2–4) Rapid urbanization is having adverse effects on biodiversity and ES in urban regions.(5,6) With the expected future climate change and the diversity of socioeconomic pathways, the ES of urban regions will face great challenges.(7) Therefore, it is meaningful to quantify the total value of current urban ES, which will contribute to specifying the protection priority of districts and the overall trends in ES.

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Ecosystems produce wide ranges of goods and services including provision, regulation, support, and cultural services.(8) Provision services are the basic ES directly provided by ecosystems (e.g., food, water, fibers, and timber). Regulation services are the benefits obtained from the regulation of ecosystem processes, including climate regulation, water regulation, and pest and disease control. Support services are indirect ES because they are necessary to maintain the provision, regulation, and cultural services. Typical support services include soil formation, nutrient cycling, and photosynthesis. Cultural services are the mental benefits that people obtain from ecosystems, such as aesthetic values, recreation, ecotourism, and cultural diversity.(9) In an urban ecosystem, support services are still the foundation and source of other services. Provision services account for a small proportion of ES, whereas regulation and cultural services account for a large proportion, both playing an important role in improving human wellbeing.(10,11) Urban ES are the bridge between urban systems and ecosystems. They affect the input of useful substances and energy into socioeconomic systems and the transformation of waste from socioeconomic systems to nature.(12)

The ES value is an economic measure of the benefits provided by an ecosystem to humans.(13) The ES value is increasingly focused on urban regions where human populations are densest.(14) The evaluation of the ES value is of great significance for ecological protection and economic development. Recently, research on the value of urban ES has primarily focused on multi-scenario projections and the exploration of related influencing factors, such as ecological risk,(15,16) urbanization intensity,(17) urban development strategy,(18) and landscape patterns.(19) Some studies have incorporated ES values into the planning and construction of urban ecological patterns.(20) The market value theory is the basis for conducting research on the ES value. There are three main market-based approaches to valuing ES: real market, alternative market, and hypothetical market approach. The value equivalent method is the most feasible approach with the greatest adaptability at various spatial scales. Correctly estimating and evaluating the value of ES are conducive to a correct understanding of the importance of ecosystems to human beings. However, most studies have been conducted at city or regional scale,(21–23) with fewer studies on quantifying ES values at the landscape scale inside cities. The assessment of ES values through remote sensing has increased substantially over the last few decades.(24) The new technologies and ES evaluation will be beneficial for integrating natural, technological, and socioeconomic systems to carry out the urban ecological infrastructure planning and to further improve human wellbeing.(25)

In this study, we calculated ES values in the Beijing metropolis, which is a rapidly urbanizing region. Data of landscape types were derived from a national geoinformation survey. This study aims to (1) quantify the ES values associated with different land use types and (2) compare the ES intensities observed in different administrative districts. This study will provide some useful guidelines for urban geospatial governance based on remote sensing applications in Beijing and similar cities.

2. Data and Methods

2.1 Study area

The total area of Beijing is 16410 km^2, with vegetation accounting for 79.6% of the total area (Fig. 1). The total area of cultivated land is 1374.92 km^2, accounting for 11% of the total area, garden land covers an area of 1562.44 km^2, and the area of grassland is about 886.83 km^2, about 7% of the total area. The distribution of green spaces in Beijing shows strong spatial heterogeneity. For example, forests are mainly distributed in northwestern suburbs, such as Huairou Distinct and Mentougou District. The cultivated land is mostly distributed in southwest suburbans, such as Daxing District. The garden land and grassland are more evenly distributed. Water is an important part of the ecosystem and has extremely high ES values. The abundant water resources and water reservoirs in Miyun District and other districts ensure the normal operation of the urban ecosystem.

2.2 Quantitative methods for the ES value

Four categories of ES were selected: provision, regulation, support, and cultural services. These ES types were further subdivided into 11 service functions: food production, raw material production, water supply, gas regulation, climate regulation, environmental purification, hydrology regulation, soil conservation, nutrient cycle maintenance, biodiversity, and aesthetic landscape. The quantification of ES values was based on the land use data in Beijing from the 2015 national geoinformation survey (https://www.bism.cn/zxfw/xzfw/wjxz/). The data used in this study were derived from *Beijing Statistical Yearbook 2015*, *China Price Yearbook 2015*, and *National Agricultural Product Cost and Benefit Data Compilation 2015*. The assessment adopted the service value per unit area of different terrestrial ecosystems in China based on the equivalent factor per unit area (Table 1).[13] The ES value per unit area in Beijing was calculated using these equivalent factors.

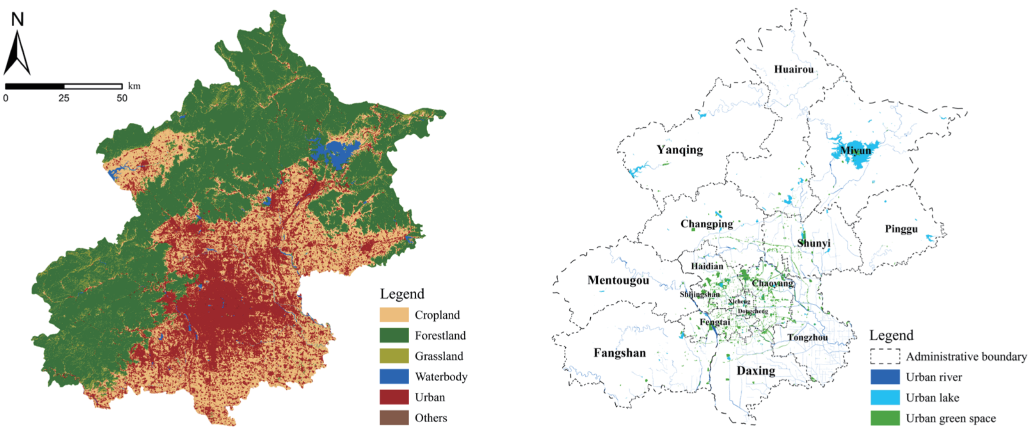

Fig. 1. (Color online) Distribution map of green space and water body types in Beijing.

Table 1
ES value equivalents per unit area.

Ecosystem classification		Provision services			Regulation services			
Primary classification	Secondary classification	Food production	Raw material production	Water supply	Gas regulation	Climate regulation	Environment purification	Hydrology regulation
Arable land	Dry land	0.85	0.40	0.02	0.67	0.36	0.10	0.27
	Paddy field	1.36	0.09	−2.63	1.11	0.57	0.17	2.72
	Coniferous	0.22	0.52	0.27	1.70	5.07	1.49	3.34
Woodland	Conifers	0.31	0.71	0.37	2.35	7.03	1.99	3.51
	Broadleaf	0.29	0.66	0.34	2.17	6.50	1.93	4.74
	Shrub	0.19	0.43	0.22	1.41	4.23	1.28	3.35
Grassland	Grassland	0.10	0.14	0.08	0.51	1.34	0.44	0.98
	Bushes	0.38	0.56	0.31	1.97	5.21	1.72	3.82
	Meadow	0.22	0.33	0.18	1.14	3.02	1.00	2.21
Wetland	Wetland	0.51	0.50	2.59	1.90	3.60	3.60	24.23
Water	Water system	0.80	0.23	8.29	0.77	2.29	5.55	102.24

Ecosystem classification		Support services			Cultural services
Primary classification	Secondary classification	Soil conservation	Nutrient cycle maintenance	Biodiversity	Aesthetic landscape
Arable land	Dry land	1.03	0.12	0.13	0.06
	Paddy field	0.01	0.19	0.21	0.09
	Coniferous	2.06	0.16	1.88	0.82
Woodland	Conifers	2.86	0.22	2.60	1.14
	Broadleaf	2.65	0.20	2.41	1.06
	Shrub	1.72	0.13	1.57	0.69
Grassland	Grassland	0.62	0.05	0.56	0.25
	Bushes	2.40	0.18	2.18	0.96
	Meadow	1.39	0.11	1.27	0.56
Wetland	Wetland	2.31	0.18	7.87	4.73
Water	Water system	0.93	0.07	2.55	1.89

Taking the net profit of food production per unit area of a farmland ecosystem as a standard equivalent factor of the ES value, we calculated the grain output of the farmland ecosystem on the basis of three major grain products, namely, rice, wheat, and corn. The equation is as follows.

$$D = \mathrm{S}_r \times F_r + S_w \times F_w + S_c \times F_c , \tag{1}$$

where D is the ES value of the standard equivalent factor (yuan/ha); S_r, S_w, and S_c are the ratios of sown areas of rice, wheat, and corn to the total sown crop area in Beijing; and F_r, F_w, and F_c are the average net profits per unit area of rice, wheat, and corn in that year (yuan/ha), respectively.

Using *National Agricultural Product Cost and Benefit Data Compilation 2015*, *Beijing Statistical Yearbook 2015*, and the above formulas, we found that the net profit of grain production per unit area of farmland ecosystem in Beijing was 1249.20 yuan/ha in 2014 and 839.29 yuan/ha in 2013. The average of 1044.24 yuan/ha for 2013 and 2014 was taken as the D value (the ES value of the standard equivalent factor) in our accounting.

Using the standard equivalent factor calculated above, the ES values per unit area were calculated as shown in Table 2.

Table 2
ES value per unit area (unit: yuan/ha).

Ecosystem classification		Provision services			Regulation services			
Primary classification	Secondary classification	Food production	Raw material production	Water supply	Gas regulation	Climate regulation	Environment purification	Hydrology regulation
Arable land	Dry land	887.60	417.70	20.88	699.64	375.93	104.42	281.94
	Paddy field	1420.17	93.98	−2746.35	1159.11	595.22	177.52	2840.33
Woodland	Coniferous	229.73	543.00	281.94	1775.21	5294.30	1555.92	3487.76
	Conifers	323.71	741.41	386.37	2453.96	7341.01	2078.04	3665.28
	Broadleaf	302.83	689.20	355.04	2266.00	6787.56	2015.38	4949.70
	Shrub	198.41	449.02	229.73	1472.38	4417.14	1336.63	3498.20
Grassland	Grassland	104.42	146.19	83.54	532.56	1399.28	459.47	1023.36
	Bushes	396.81	584.77	323.71	2057.15	5440.49	1796.09	3989.00
	Meadow	229.73	344.60	187.96	1190.43	3153.60	1044.24	2307.77
Wetland	Wetland	532.56	522.12	2704.58	1984.06	3759.26	3759.26	25301.94
Water	Water system	835.39	240.18	8656.75	804.06	2391.31	5795.53	106763.10

Ecosystem classification		Support services			Cultural services	Total value
Primary classification	Secondary classification	Soil conservation	Nutrient cycle maintenance	Biodiversity	Aesthetic landscape	Total
Arable land	Dry land	1075.57	125.31	135.75	62.65	4187.40
	Paddy field	10.44	198.41	219.29	93.98	4062.09
Woodland	Coniferous	2151.13	167.08	1963.17	856.28	18305.53
	Conifers	2986.53	229.73	2715.02	1190.43	24111.50
	Broadleaf	2767.24	208.85	2516.62	1106.89	23965.31
	Shrub	1796.09	135.75	1639.46	720.53	15893.33
Grassland	Grassland	647.43	52.21	584.77	261.06	5294.30
	Bushes	2506.18	187.96	2276.44	1002.47	20561.09
	Meadow	1451.49	114.87	1326.18	584.77	11935.66
Wetland	Wetland	2412.19	187.96	8218.17	4939.26	54321.36
Water	Water system	971.14	73.10	2662.81	1973.61	131166.99

3. Results

3.1 Spatial patterns of ES values in Beijing

The total ES value in Beijing is 664.256 billion yuan, with provision, regulation, support, and cultural services respectively accounting for 43.809, 457.353, 135.565, and 27.528 billion yuan (Table 3). Specifically, Miyun District has the highest total ES value of 119.569 billion yuan, followed by Huairou District with a total ES value of 99.583 billion yuan, then Yanqing Distinct, Fangshan Distinct, and Mentougou District with total ES values of 89.072, 78.227, and 62.804 billion yuan, respectively (Fig. 2).

From the perspective of ES types, the value of provision services is highest in Miyun District with a total value of 7.9584 billion yuan, with hydrology regulating services accounting for the largest proportion. Miyun District has the largest water conservancy project in north China, which is an important water source for the capital. Huairou District (6.1791 billion yuan) and Yanqing District (5.804 billion yuan) have the next highest values of provision services. Miyun District also has the highest value of regulation services with a total value of 86.0422 billion yuan, with Huairou District and Yanqing District providing regulation services of 67.1605 and

Table 3
ES values of administrative districts in Beijing (unit: 100 million yuan).

Urban district	Provision services			Regulation services			
	Food production	Raw material production	Water supply	Gas regulation	Climate regulation	Environment purification	Hydrology regulation
Dongcheng	0.05	0.09	0.20	0.30	0.90	0.36	2.52
Xicheng	0.08	0.11	0.43	0.35	1.04	0.54	5.39
Chaoyang	1.34	2.05	3.21	6.76	19.34	7.20	41.15
Fengtai	1.01	1.62	2.10	5.30	15.17	5.36	26.44
Shijingshan	0.30	0.57	0.54	1.88	5.56	1.78	6.52
Haidian	1.88	3.01	3.66	9.89	28.32	9.82	46.08
Mentougou	8.26	17.44	10.56	57.52	170.37	52.18	143.74
Fangshan	13.43	21.86	14.83	70.26	199.71	62.88	195.67
Dongzhou	6.80	7.13	10.12	21.49	55.53	21.35	128.94
Shunyi	7.75	8.52	8.13	25.61	66.27	23.07	103.96
Changping	7.72	13.52	10.54	44.33	127.27	40.97	137.91
Daxing	8.62	8.17	5.02	22.99	55.80	18.15	63.32
Huairou	15.19	27.77	18.84	90.18	261.76	80.96	238.70
Pinggu	7.67	11.12	9.22	35.86	99.02	32.73	118.10
Miyun	17.53	26.61	35.44	85.86	243.78	86.91	443.87
Yanqing	16.04	25.64	16.36	81.10	230.63	71.53	215.30
Total	113.66	175.22	149.21	559.68	1580.48	515.77	1917.60

Urban district	Support services			Cultural services	Total value
	Soil conservation	Nutrient cycle maintenance	Biodiversity	Aesthetic landscape	Total
Dongcheng	0.37	0.03	0.37	0.18	5.38
Xicheng	0.43	0.03	0.47	0.24	9.11
Chaoyang	8.24	0.64	7.85	3.66	101.44
Fengtai	6.49	0.50	6.04	2.78	72.80
Shijingshan	2.30	0.18	2.13	0.96	22.70
Haidian	12.08	0.94	11.23	5.14	132.05
Mentougou	70.16	5.33	64.15	28.33	628.04
Fangshan	86.34	6.73	76.51	34.03	782.26
Dongzhou	26.85	2.22	22.97	10.78	314.19
Shunyi	32.12	2.64	26.55	12.11	316.74
Changping	54.27	4.17	49.27	22.00	511.96
Daxing	29.43	2.51	21.86	9.82	245.69
Huairou	110.47	8.53	99.34	44.09	995.83
Pinggu	44.17	3.45	39.09	17.54	417.97
Miyun	105.39	8.21	97.28	44.80	1195.69
Yanqing	100.12	7.84	87.37	38.80	890.72
Total	689.22	53.95	612.48	275.28	6642.56

59.8561 billion yuan, respectively. Huairou District has the highest value of support services of 21.8342 billion, followed by Miyun District (21.0881 billion yuan) and Yanqing District (19.5323 billion yuan). Similarly, Miyun District provides 4.4801 billion yuan of cultural services, compared with 4.4091 and 3.8799 billion yuan for Huairou Distinct and Yanqing District, respectively.

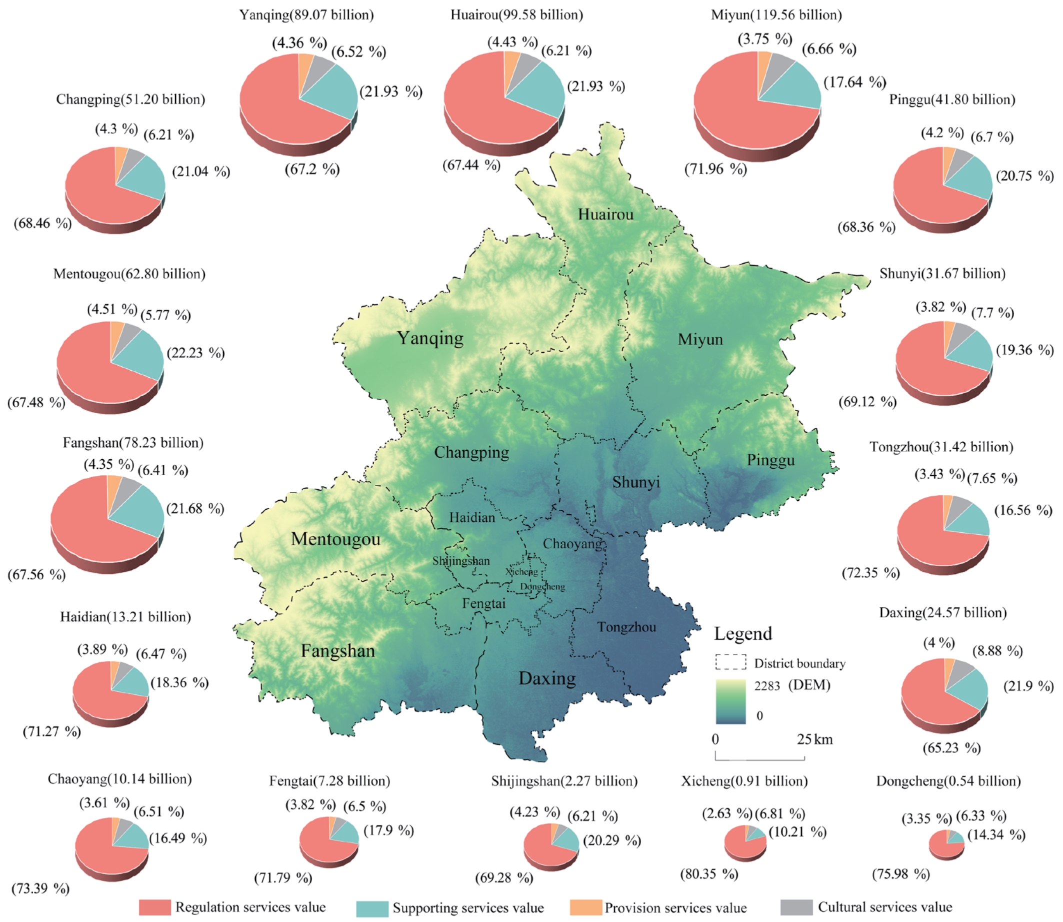

Fig. 2. (Color online) Total ES value of administrative districts of Beijing.

3.2 Intensity of ES values in Beijing

The intensity of ES values represents the potential of ES in different districts of Beijing (Table 4). Miyun District has the highest intensity of ES values with an average ES value of 537100 yuan/ha. The intensity of ES values is 469200 yuan/ha in Huairou District, followed by Yanqing District, Pinggu District, and Mentougou District with values of 446400, 440800, and 433600 yuan/ha, respectively (Fig. 3).

The highest intensity of provision services is 35700 yuan/ha in Miyun District, compared with 29500 and 29100 yuan/ha in Pinggu District and Huairou District, respectively. The highest intensities of regulation services are 386500, 316500, and 301300 yuan/ha in Miyun District, Huairou District, and Pinggu District, respectively. Support services have the highest intensity in Huairou District with a value of 102900 yuan/ha, with the value of 97900 and 96400 yuan/ha in Yanqing Distinct and Mentougou District, respectively. The intensity of cultural services is relatively high in Huairou Distinct (20800 yuan/ha), Miyun Distinct (20100 yuan/ha), and Mentougou Distinct (19600 yuan/ha).

Table 4
Average ES values per unit area of each district in Beijing (unit: 104 yuan/ha).

Urban district	Provision services			Regulation services			
	Food production	Raw material production	Water supply	Gas regulation	Climate regulation	Environment purification	Hydrology regulation
Dongcheng	0.13	0.22	0.48	0.73	2.16	0.86	6.00
Xicheng	0.16	0.21	0.86	0.69	2.06	1.06	10.66
Chaoyang	0.29	0.44	0.69	1.46	4.16	1.55	8.86
Fengtai	0.33	0.53	0.69	1.73	4.96	1.75	8.65
Shijingshan	0.35	0.68	0.64	2.23	6.59	2.11	7.73
Haidian	0.44	0.70	0.85	2.30	6.58	2.28	10.70
Mentougou	0.57	1.20	0.73	3.97	11.76	3.60	9.92
Fangshan	0.67	1.10	0.74	3.52	10.01	3.15	9.81
Dongzhou	0.75	0.79	1.12	2.37	6.13	2.36	14.24
Shunyi	0.77	0.84	0.81	2.54	6.56	2.28	10.29
Changping	0.57	1.01	0.78	3.30	9.48	3.05	10.27
Daxing	0.83	0.79	0.48	2.22	5.38	1.75	6.11
Huairou	0.72	1.31	0.89	4.25	12.33	3.81	11.25
Pinggu	0.81	1.17	0.97	3.78	10.44	3.45	12.46
Miyun	0.79	1.20	1.59	3.86	10.95	3.90	19.94
Yanqing	0.80	1.28	0.82	4.06	11.56	3.58	10.79

Urban district	Support services			Cultural services
	Soil conservation	Nutrient cycle maintenance	Biodiversity	Aesthetic landscape
Dongcheng	0.88	0.07	0.88	0.42
Xicheng	0.84	0.06	0.92	0.48
Chaoyang	1.77	0.14	1.69	0.79
Fengtai	2.12	0.16	1.98	0.91
Shijingshan	2.73	0.21	2.52	1.14
Haidian	2.80	0.22	2.61	1.19
Mentougou	4.84	0.37	4.43	1.96
Fangshan	4.33	0.34	3.83	1.71
Dongzhou	2.96	0.25	2.54	1.19
Shunyi	3.18	0.26	2.63	1.20
Changping	4.04	0.31	3.67	1.64
Daxing	2.84	0.24	2.11	0.95
Huairou	5.21	0.40	4.68	2.08
Pinggu	4.66	0.36	4.12	1.85
Miyun	4.73	0.37	4.37	2.01
Yanqing	5.02	0.39	4.38	1.94

3.3 ES values for land use types

The ES values are analyzed for different land use types (Table 5). Broad-leaved shrub forests provide the highest ES value in Beijing with an average of 153.206 billion yuan. Broad-leaved forests account for a total value of 131.875 billion yuan. The next highest ES values are 98.407 billion yuan for rivers, 67.128 billion yuan for orchards, and 58.150 billion yuan for mixed coniferous and broad-leaved forests, respectively. In total, Beijing's forest contributes the highest ES value, with a total value of 446.577 billion yuan. Water bodies have a total ES value of 100.042 billion yuan, gardens have a total value of 80.339 billion yuan, and grassland has a total value of 22.908 billion yuan (Fig. 4).

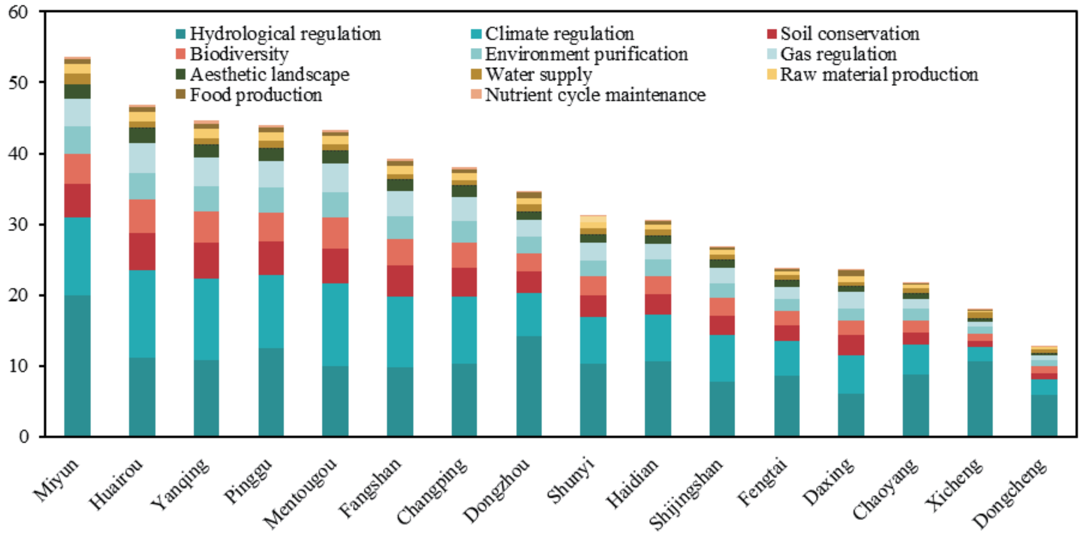

Fig. 3. (Color online) Intensities of ES values in different districts of Beijing (unit: 104 yuan/ha).

Table 5
ES values of various land types in Beijing (unit: 100 million yuan).

Primary class	Second class	Third class	Total area (ha)	ES value
Arable land	Dry land	Dry land	3414236.88	142.97
	Paddy field	Paddy field	23072.00	0.94
Woodland	Arbor	Broadleaf forest	5502751.56	1318.75
		Coniferous and broad-leaved forest	2411725.44	581.50
		Coniferous forest	2440639.63	446.77
	Bush	Broadleaf shrubs	9639641.88	1532.06
		Coniferous and broad-leaved shrubs	822653.06	130.75
		Coniferous forest	91994.44	14.62
	Mixed arbor and shrub forest	Mixed arbor and shrub forest	884543.63	213.28
	Sparse forest	Sparse forest	1706.63	0.31
	Green woodland	Green woodland	398922.19	63.40
	Young plantation	Young plantation	897144.81	164.23
	Sparse thickets	Sparse thickets	405.94	0.06
	Bamboo forest	Bamboo forest	555.94	0.03
Grassland	Natural grass	High coverage grass	1579812.31	188.56
		Medium coverage grass	152548.94	8.08
		Low coverage grass	58071.25	3.07
	Artificial grass	Slope protection shrub and grass	44424.88	9.13
		Green grass	205849.44	10.90
		Grassland	1466.31	0.08
		Other artificial grass	174909.31	9.26
Garden	Orchard	Herb orchard	558.81	0.11
		Tree bush orchard	3264808.75	671.28
		Fujimoto Orchard	63838.13	13.13
	Mulberry Garden	Mulberry Garden	7378.75	1.77
	Flowerbed	Flowerbed	17612.00	3.62
	Nursery	Nursery	546811.13	112.43
	Other fields	Other herb orchards	1171.13	0.24
		Other tree and shrub orchards	3119.69	0.64
		Other vine orchards	803.38	0.17
Water	Canals	River	750240.50	984.07
		Canal	12463.63	16.35

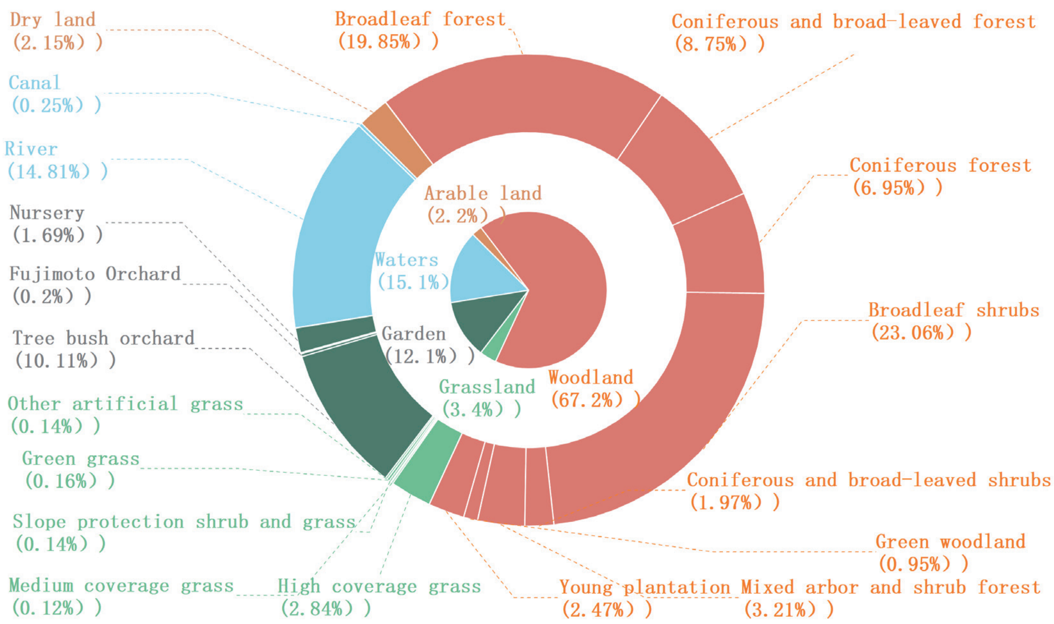

Fig. 4. (Color online) ES values for land use types in Beijing. The classes with a percentage below 0.1% are not shown.

4. Discussion

4.1 Implications for urban planning

This study shows that the total ES value varies greatly in different districts of Beijing. The intensities of ES values tend to increase from urban areas to suburban areas. This is mainly because the vegetation and water in the suburbs are well preserved, while the urban area is more greatly affected by anthropogenic activities, with low vegetation coverage and a large area of impervious surfaces in the core regions of Beijing. The results of this study are consistent with those of other studies in terms of ecosystem type.[26] The main ecological assets of Beijing's landscape are forests and water bodies, where the service types are dominated by regulation and support services. Our results have some research implications in urban planning and construction. First, we should pay attention to the potential ES values of forest land. Forest provides various ES values for urban residents, including climate regulation, water purification, and recreational activities. Such regions should be strictly protected. Second, the cultural services should be more strongly linked with urban residents: cultural services are currently mainly located outside the core city, and infrastructure should be improved to link the urban and rural regions. Finally, ecological compensation should be conducted between different districts during urban planning; Miyun District provides the highest ES value and thus should be compensated by other districts.

4.2 Limitations and improvements

This study provides the spatial patterns of ES values in Beijing. The results are important for urban planning to achieve sustainable city development. However, this study has some limitations, which should be addressed in the future. First, land use data were employed to calculate the ES values in one year. The update of land use data can provide new insights into ES values for urban ecological management. Second, the flow of ES among different districts may have important implications for urban planning. More data on the material transfer and trade between the core urban area of Beijing and the surrounding areas are required. Finally, the demand for ES, which has a strong leading effect on the future supply of ES, was not considered in this study. The demand for ES should be examined using more statistical and survey data to determine the preferences and requirements of citizens, enabling the government to deploy and integrate resources effectively.

5. Conclusions

We quantified the ES values of Beijing based on land use and socioeconomic statistical data. The results are conductive for clarifying the ecological status and resource potential of each district. We found that the ES value in Beijing was lower in urban areas and higher in suburbs. Miyun District has the highest ES value, whereas Dongcheng District has the lowest ES value, with a difference of 4.087×10^4 yuan/ha between them. In Beijing, the regulation service value is highest, while the support service value is lowest. Specifically, the hydrology regulation and climate regulation services have the highest values, with total values of 1917.6 and 158.048 billion yuan, respectively. Forest landscape is the main source of ES values, accounting for 67.2% of the total value. Cultivated land and grassland account for 3.4 and 2.2% of total ES value, respectively. The results will be useful for urban planners and policy makers to prioritize the regions for protecting natural ecosystem.

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