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Spatial and Temporal Changes of Ecosystem Service Value in Airport Economic Zones in China

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Abstract: With the rapid development of the aviation industry, many negative effects on the local environment have been reported. This study examined the land use and land cover (LULC) and ecosystem service value (ESV) of airport economic zones (AEZs) in China and assessed the changes in LULC and ESV. The results indicate that LULC changed significantly from 1990 to 2015, characterized by the increase in construction land (increase rate, 68.53%) and water bodies (increase rate, 2.32%) and the decrease in cropland (decrease rate, 4.28%), forest (decrease rate, 0.73%), grassland (decrease rate, 4.64%) and unused land (decrease rate, 6.36%). The ESV of AEZs in 1990 and 2015 was RMB 3454 and 3483 million, respectively, with an overall ESV change of RMB 29 million. The ESV of AEZs is characterized by high value in the coastal area of China. From 1990 to 2015, AEZs with a high ESV were located in Inner Mongolia, while those with a high decrease in ESV were located in the southeastern coastal area. From 1990 to 2000, the AEZs with a high increase in ESV were located in Inner Mongolia and Qinghai and the AEZs with decreased ESV were mostly located in central and south China. However, from 2000 to 2010, AEZs with high and low increases in ESV were located in central China and the south coastal area of China, respectively. From 2010 to 2015, AEZs with a high decrease in ESV were located in southeast China.

Keywords: ecosystem services value; airport economic zones; China

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1. Introduction

Airport economic zones (AEZs), with a radius of about 30 km around an airport, are centers of urban and regional economic growth, which relies on the speed and flow of the economy of the airport [1,2]. In 1959, the Shannon free industrial zone and Shannon Town, early forms of AEZs, were established in Ireland to develop the export processing industry with foreign capital and raw materials [1,3]. With the development of the economy and the progress of the aviation industry, large modern airports all over the world, such as Kansai International Airport in Japan, Amsterdam Airport Schiphol in Amsterdam, Holland, Hong Kong International Airport, Taiwan Taoyuan International Airport, Memphis International Airport and Rhein-Main Airport, have launched plans for the construction of AEZs, making the airport and airport area organic parts of each other [3–5]. In 1993, the passenger throughput at Beijing Capital International Airport exceeded 10 million for the first time, which promoted the development of China's airport economy. In 2015, the National Development and Reform Commission and the Civil Aviation Administration jointly issued their opinions on the construction and development of airport economic demonstration zones; then, 14 national airport economic demonstration zones, namely, Zhengzhou, Beijing Daxing, Qingdao, Chongqing, Guangzhou, Shanghai, Chengdu, Changsha, Guiyang, Hangzhou, Ningbo, Xi'an, Beijing capital airport and Nanjing, were approved. By the end of 2019, 87 of China's 239 certified civil aviation airports had planned or built AEZs [6].

AEZs, where airports are regarded as key drivers of urban economic growth, have been developed into airport-led urban areas to attract investment, boost trade and create jobs [7]. The development of AEZs not only promotes the development of the regional economy, but also brings about a variety of adverse effects on ecological systems. First of all, the construction of AEZs is usually accompanied by a decrease in cultivated land, woodland, grassland and water bodies and an increase in built-up land. Changes in land use and land cover affect the regional ecological environment [8]. Vegetation, litter and soil in forest, grassland and farmland can intercept precipitation and store water, which can increase soil water content, regulate runoff, improve water quality by purification and improve the microclimate [9]. Moreover, vegetation plays an important role in the prevention and control of various types of soil erosion [9]. The reduction in ecological land is bound to weaken the above functions of an ecosystem. Secondly, the development of AEZs also affects the biodiversity of the region [10–13]. Because an airport is usually built in the suburbs, far away from the city center, the open and quiet environment of the airport and its surroundings provide suitable conditions and habitats for birds and other animals in which to eat, drink, live, breed, nest and rest overnight. The airport and its surrounding areas have tall trees, lush weeds, a variety of insects, underground animals, birds and mammals. The diverse environment creates a high degree of biodiversity in the region. However, in the process of the construction and development of AEZs, the occupation of cultivated land, the reduction in forest, grassland and water inevitably destroy the habitat of wild animals and plants. In addition, wildlife strikes with aircrafts are increasing in the world [14]. The number of wildlife strikes reported per year to the FAA increased steadily from about 1800 in 1990 to 16,000 in 2018 [15]. Due to the threat to the safety of aircraft posed by birds [16], airport management must reduce the number of birds threatening flight and minimize the occurrence of bird collision incidents. In this way, biodiversity is also damaged.

Land-use and land-cover change (LULCC), resulting from human activity, such as the construction of AEZs, involve a large number of terrestrial surface material cycles and life processes, such as biosphere–atmosphere interactions, biodiversity, biogeochemical cycles and sustainable use of resources [17–19]. There is myriad of literature studies highlighting the impact of LULCC. First, LULCC is considered the greatest threat to nature, having caused worldwide declines in the abundance, diversity and health of species and ecosystems [20]. Moreover, some studies revealed that the order of $PM_{2.5}$ concentration for the different land use and land cover types is construction lands > unused land > water > farmlands > grasslands > woodlands and, when high-grade land types are converted to low-grade types, the $PM_{2.5}$ concentration decreases; otherwise, the $PM_{2.5}$ increases [21]. In addition, LULCC contributes to the availability of water resources by changing the water balance in the area [22–24].

Ecosystem services (ESs), which are imperative for human well-being and the sustainable development of the economy and society, refer to life-support products and services obtained directly or indirectly through the structure, process and function of an ecosystem [25,26]. Paradoxically, urbanization processes constrain the types, distribution, quality and quantity of services that people obtain from nature, owing to decisions to plant or remove trees, pollute, or alter the hydrology of vegetated landscapes [27]. The quantification and estimation of ESs can identify the temporal and spatial changes in ESs and help us to study the impact of human activities on ESs. This helps to improve ecological awareness, strengthen the management of natural assets and improve resource allocation decisions when there is a contradiction between supply and demand [28,29].

A burgeoning pool of research has contributed to the evaluation of ecosystem services. Being more explicit about the value of ESs can help society make better decisions in which trade-offs exist [26]. Ecosystem service values (ESVs) can be aggregated to four levels, which are value transfer, unit value, statistical value transfer and spatially explicit functional modeling [26]. The 'value transfer' method assumes values constant over ecosystem types and transposes value estimates from one location to another, adjusting for differences in ecological and economic contexts [28,30]. The 'unit value' method adopts average values per unit area, aggregated over all evaluation studies for a particular ecosystem [26]. Costanza et al. [31] applied such global average 'unit values', which were updated by de Groot et al. [32], as part of an economics of ecosystems and biodiversity study. Xie et al. [33] produced a similar set of unit values for China, based on expert knowledge of a large group of Chinese researchers. The 'statistic value transfer' method allows for the building of a statistical model of spatial and other dependencies for the synthesis of 194 case studies capturing 839 monetary values of ESs [34]. The 'spatially explicit functional modeling' method builds spatially explicit statistical or dynamic systems models incorporating evaluation [35–39].

While there are a lot of studies analyzing the effects of landscape change on ecosystem services (ESs) [40–43], research about AEZs has tended to focus more on the industrial development mode, industrial spatial layout, structural optimization and land-use planning [2,7,44–50]; the effects of land-use and land-cover change (LULCC) in AEZs on ESVs and their implications for AEZs planning in China has received much less attention.

Therefore, the aims of this study are the following three: (1) examining the dynamic patterns of land-use and land-cover change (LULCC) in AEZs from 1990 to 2015 in China, (2) assessing the spatial and temporal patterns of ESV changes in different development phases of AEZs and (3) discussing some of the major implications for AEZ planning and construction in China.

2. Material and Methods

2.1. Data Source

The spatial distribution data of national civil transport airports used in this study were vectorized from Google Earth. First, according to the national civil transport information (http://www.caac.gov.cn/GYMH/MHGK/MYJC/ (accessed on 20 December 2019)) provided by the Civil Aviation Administration of China, the names of China's civil transport airports were obtained (data were obtained on 30 June 2019). Then, according to the name of the airport, the location of the airport was searched in Google Earth and further vectorized. Next, the vectorized data were exported to ArcGIS and a projection transformation of the obtained data of China's civil airports was carried out. Finally, combined with images from Google Earth, the spatial distribution of 154 domestic airports and 77 international airports were obtained, except for Haibei Qilian Airport, Ruoqiang Loulan Airport, Tumushuke Tangwangcheng Airport, Xinyang Minggang Airport, Fuyuan Dongji Airport and Sansha Yongxing Airport (Figure 1).

The 1 km spatial resolution land-cover data for China in 1990, 2000, 2010 and 2015 were provided by the Resource and Environment Science and Data Center (https://www.resdc.cn/ (accessed on 30 December 2019)), Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences. These data were obtained through manual visual interpretation of Landsat TM/ETM satellite images from 1990, 2000, 2010 and 2015. The land-use and land-cover dataset was classified into six first-level categories: cropland, forest, grassland, water bodies, construction land and unused land. The comprehensive evaluation accuracy of the first level of land use was greater than 93% and that of the second level was greater than 90% [50,51].

2.2. Definition of the Research Scope

The evolution of airport economic zones (AEZs) can be divided into four stages (Figure 2). In the stage of the first generation of airport economic zones (airport area, AA), the airport is a transportation facility in the traditional sense, which only carries passengers and goods. The airport is small in scale and mainly focuses on aviation operations, including an airport runway, terminal building, air cargo, a supporting airport airline office base, an airport transit overnight hotel, catering and other necessary functions.

In this stage, the role of urbanization is greater than the influence of the airport and the enterprises located around the airport are mostly industries without air orientation. In the second stage (airport industrial area, AIA), through the improvement of the airport's air transport capacity, the agglomeration of the airport and the influence of radiation on the surrounding area are constantly strengthened. At this time, enterprises with time value orientation and flexible production mode spontaneously arise within 5–10 km of the airport. In this stage, the industrial layout of the airport significantly improved, including aviation manufacturing, high-tech manufacturing and commercial office industries. In the third stage (airport metropolitan area, AMA), the modern service industry, represented by finance, exhibition, research and development, logistics and information, promotes the development of the aviation manufacturing industry, reduces production costs, improves efficiency and provides a good service environment for enterprises. The aviation industry chain shows the trend of cluster development and promotes the formation of an advanced self-economic cycle mode in the airport economic zone. The airport economic zone also gradually expands to have a 10–15 km radius around the airport. In the fourth stage (airport town cluster, ATC), with the enhancement of the radiating capacity of the hub airport and the economy of the hinterland where the hub airport is located, the radiating range of the airport economic zone extends to a 15–30 km radius around the airport. Compared with the AMA, an ATC has stronger spatial radiation capacity and plays a greater role in promoting regional economic integration [1].

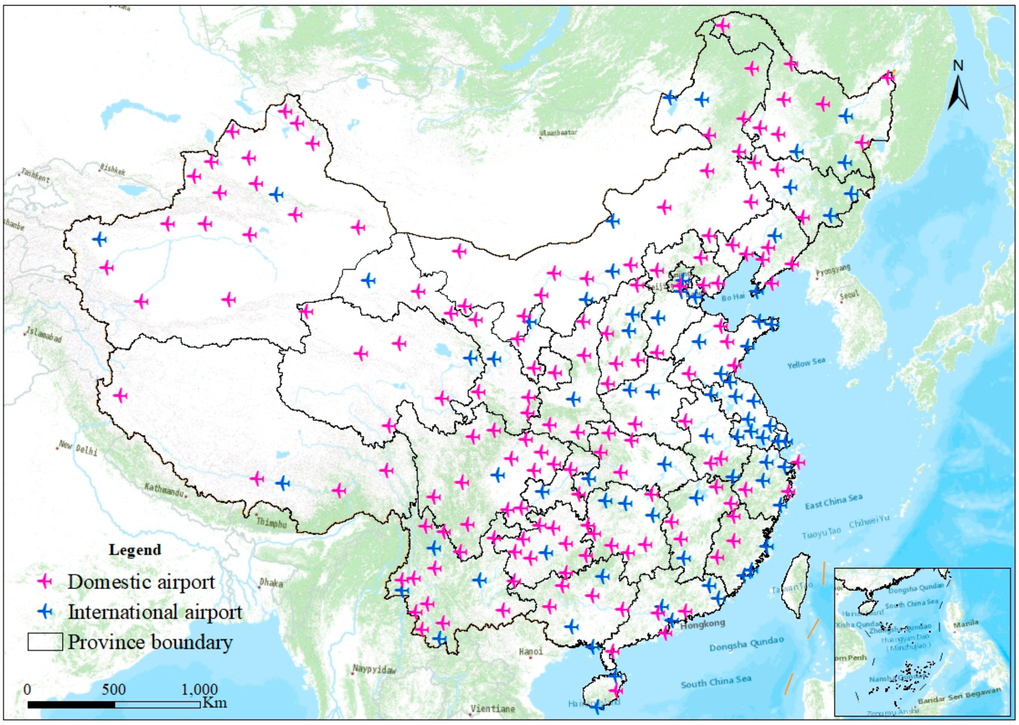

Figure 1. Spatial distribution of civilian airports in China.

Considering the development of China's economy and the acceleration of the construction of AEZs, we believe that, in addition to the AEZs that have already been built, it is possible to form AEZs near other airports. Therefore, in this study, we analyze the ecosystem services value (ESV) of AEZs in China's 231 civil transport airports at different stages of development (Figure 2). Taking the airport as the center, we built 5 km, 10 km, 15 km and 30 km multi-ring buffer zones, respectively, to obtain the AAs, AIAs, AMAs and ATCs.

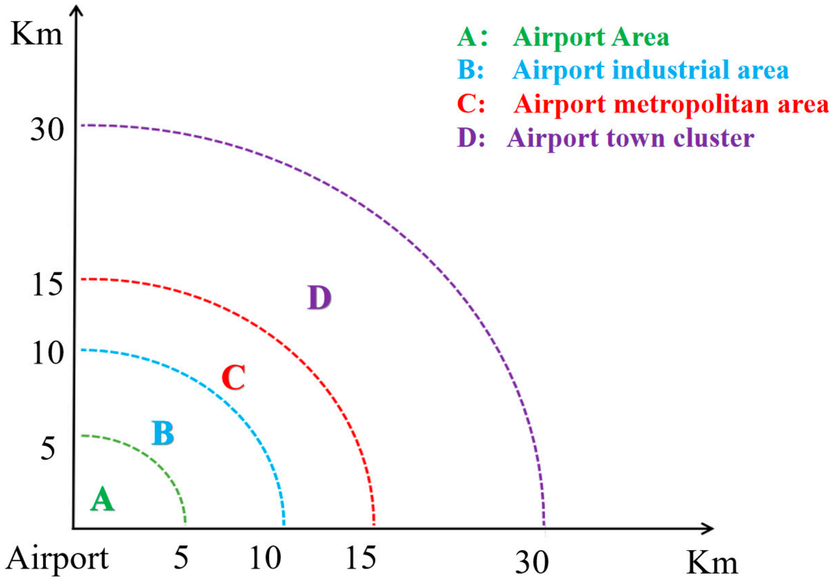

Figure 2. Different development stages of airport economic zones (AEZs).

2.3. Ecosystem Services Value (ESV) Assessment

Applying the method of millennium ecosystem assessment (MA), in this paper, we divided ecosystem services (ESs) into provisioning services, regulating services, supporting services and cultural services; then, we further subdivided them into 11 services, which were food production, material production, water resources supply, gas regulation, climate regulation, environmental purification, hydrological regulation, soil conservation, maintenance of nutrient cycle, biodiversity and aesthetic landscape (Table 1). The definition of these ES functions was detailed in references [25,33,35].

Table 1. Ecosystem services value (ESV) of different land-use and land-cover (LULC) types per unit area (RMB per km^2).

LULC	FP	MP	WRS	GS	CR	EP	HR	SC	MNC	Bio	AL
11	136	9	263	111	57	17	272	1	19	21	9
12	85	40	2	67	36	10	27	103	12	13	6
21	25	58	30	191	571	167	374	232	18	212	93
22	19	43	22	141	423	128	335	172	13	157	69
23	25	58	30	191	571	167	374	232	18	212	93
24	25	58	30	191	571	167	374	232	18	212	93
31	23	34	19	121	319	105	234	147	11	134	59
32	23	34	19	121	319	105	234	147	11	134	59
33	23	34	19	121	319	105	234	147	11	134	59
41	80	23	829	77	229	555	10,224	93	7	255	189
42	80	23	829	77	229	555	10,224	93	7	255	189
43	80	23	829	77	229	555	10,224	93	7	255	189
44	0	0	216	18	54	16	713	0	0	1	9
45	51	50	259	190	360	360	2423	231	18	787	473
46	51	50	259	190	360	360	2423	231	18	787	473
51	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0
61	1	3	2	11	10	31	21	13	1	12	5
62	1	3	2	11	10	31	21	13	1	12	5
63	0	0	0	2	0	10	3	2	0	2	1
64	51	50	259	190	360	360	2423	231	18	787	473
65	0	0	0	2	0	10	3	2	0	2	1

Table 1. *Cont.*

LULC	FP	MP	WRS	GS	CR	EP	HR	SC	MNC	Bio	AL
66	0	0	0	2	0	10	3	2	0	2	1
67	1	3	2	11	10	31	21	13	1	12	5

Note: LULC, land use and land cover; 11, paddy field; 12, dry land; 21, woodland; 22, shrubwood; 23, sparse woods; 24, other woodlands; 31, high coverage grassland; 32, medium coverage grassland; 33, low coverage grassland; 41, canal; 42, lake; 43, reservoirs and ponds; 44, permanent glacier and snow; 45, beach; 46, shallows; 51, urban land; 52, rural residential area; 53, other construction land; 61, sand; 62, gobi; 63, saline alkali land; 64, swamp land; 65, bare land; 66, bare rock; 67, other unused land. FP, food production; MP, material production; water resources supply, WRS; Ggas regulation, GS; CR, climate regulation; EP, environmental purification; HR, hydrological regulation; SC, soil conservation; MNC, maintenance of nutrient cycle; Bio, biodiversity; AL, aesthetic landscape.

In this study, the table of equivalent factors of secondary ecosystem services in China proposed by Xie et al. [35] was employed and was based on the recognition level of the equivalent factors of ESs in the 2010s. As described, food production, material production, gas regulation, climate regulation, environmental purification, nutrient cycling maintenance, biodiversity and aesthetic landscape function of the ecosystem are positively correlated with biomass on the whole [35]. Water supply and hydrological regulation are related to precipitation change and soil conservation is closely related to precipitation, topographic slope, soil properties and vegetation density [35]. Therefore, the regulatory factors of NPP, precipitation and soil conservation regulation are determined. Based on the ESV basis, the improved ESV equivalent was obtained based on the following formula:

$$F_{ni} = \begin{cases} P_i \times F_1 \\ R_i \times F_2 \\ S_i \times F_3 \end{cases} \quad (1)$$

$$P_i = B_i / \overline{B} \quad (2)$$

$$R_i = W_i / \overline{W} \quad (3)$$

$$S_i = E_i / \overline{E} \quad (4)$$

$$VC_i = F_{ni} \times D \quad (5)$$

where F_{ni} refers to the equivalent factor of unit area value of the n type of ecological service function of an ecosystem in area i in the 2010s. F_1 refers to the equivalent factor of ESV of food production, material production, gas regulation, climate regulation, environmental purification, nutrient cycling, biodiversity maintenance and aesthetic landscape; F_2 is the equivalent factor of ESV of water resource supply or hydrological regulation service function; F_3 is the equivalent factor of ESV of soil conservation services; P_{ij}, R_{ij} and S_{ij} are the NPP regulator in the 2010s, precipitation regulator in the 2010s and soil conservation regulator in the 2010s, respectively; B_i is NPP of the ecosystem in the 2010s in area i and $\overline{B}$ is the average NPP of the ecosystem in the 2010s over the whole of China; W_i and $\overline{W}$ are average precipitation per unit area in the 2010s in area i and in the whole of China, separately; E_i and E are per unit area simulation amount of soil maintenance in area i and in the whole of China in the 2010s; D is the value of the equivalent factor, which, in the 2010s, was RMB 3406.5 (when USD 1 equaled to RMB 6.8262 in 2010) per hectare.

The factors F_1, F_2 and F_3 were obtained from literature [33]. Based on the ecosystem service value evaluation system proposed by Constanza [28], Xie [33] conducted a questionnaire survey on 700 professionals with ecological background in China in 2002 and 2006 and obtained a new ecosystem service evaluation system. The questionnaire selected 6 types of ecosystems and 9 service functions. The respondents to the questionnaire were chosen among people with an ecological education background to ensure their understanding and recognition of the respondents (services and products), including sufficient understanding of the quality, quantity, availability and effectiveness of substitutes and the possibility of change. Questionnaires were distributed by mail and by face-to-face interview.

The questionnaire also provided Constanza's ecological service price list as a reference and told the interviewees that Constanza's ecological service price list did not necessarily fully comply with China's ecosystem service status. The respondents were required to judge and choose according to the relative utility of different ecosystem services.

Due to the different classification systems, the second-class land-use types in this study probably do not correspond to those in the literature [35]; therefore, in this study, the solution is to calculate the average value of the second classes under the first class corresponding to the types in this paper.

$$\mathrm{ESV} = \sum (A_i \times VC_i) \tag{6}$$

where ESV denotes the total value of ecosystem services, and A_i and VC_i represent the area and value coefficient (Table 1) for LULC type 'i', respectively.

2.4. Spatial Clustering Analysis on the Ecosystem Services Value (ESV) Change

A hot spot analysis was used to explore the cluster patterns of the ESV change in AEZs in China. In the hot spot analysis, the Getis-Ord *Gi** for each element in the dataset was calculated; then, through the Z score and p value, the location of high-value or low-value clustering in space could be identified [52–54]. The Getis-Ord *Gi** was calculated as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} W_{ij} x_j}{\sum_{j=1}^{n} x_j} \tag{7}$$

For convenience of explanation and comparison, a standardized value was calculated as follows:

$$\mathrm{Z}(G_i^*) = \frac{\sum_{j=1}^{n} W_{ij} x_j - \overline{\mathrm{X}} \left(\sum_{j=1}^{n} \mathrm{W_{ij}} \right)}{\sqrt{\frac{S^2}{n-1} \left(n \sum_{j=1}^{n} W_{ij}^2 - \left(\sum_{j=1}^{n} W_{ij} \right)^2 \right)}} \tag{8}$$

where X_j is the change value of ESV of AEZ_j, W_{ij} is the spatial weight, $\overline{X}$ is the mean value of X_j, n is the total number of AEZs and S^2 is the variance. A significantly positive $\mathrm{Z}(G_i^*)$ indicates that the ESV change near area i is greater than the mean value (hot spot). In contrast, a significantly negative $\mathrm{Z}(G_i^*)$ means the ESV change around area i is lower than the mean value (cold spot).

3. Results

3.1. Land-Use and Land-Cover Change (LULCC) in Airport Economic Zones (AEZs)

In order to analyze the internal structural variability of land use and land cover (LULC) in AEZs, a spatial overlay analysis was carried out based on the four interpreted land-use maps. Four maps of LULC over the period from 1990 to 2015 in AEZs were obtained (Figure 3).

The LULC have changed significantly over the whole period from 1990 to 2015 in AEZs, which was characterized by the increase in the construction land and water bodies and the decrease in cropland, forest, grassland and unused land (Table 2). From the perspective of the changes in the construction land, the area expanded very quickly, from 32,579 km^2 in 1990 to 54,904 km^2 in 2015, with an increase of 22,325 km^2 and an increase rate of 68.53% (Table 2). On the contrary, during the period from 1990 to 2015, the cropland and grassland decreased from 252,975 km^2 to 242,155 km^2 and from 136,939 km^2 to 130,590 km^2, with decrease rates of 4.28% and 4.64%, respectively (Table 2). During this period, forest and unused land decreased by 0.73% and 6.36%, from 173,231 km^2 and 58,929 km^2 in 1990 to 242,155 km^2 and 55,181 km^2, respectively. Small changes occurred in water bodies, which increased by 2.32% (Table 2).

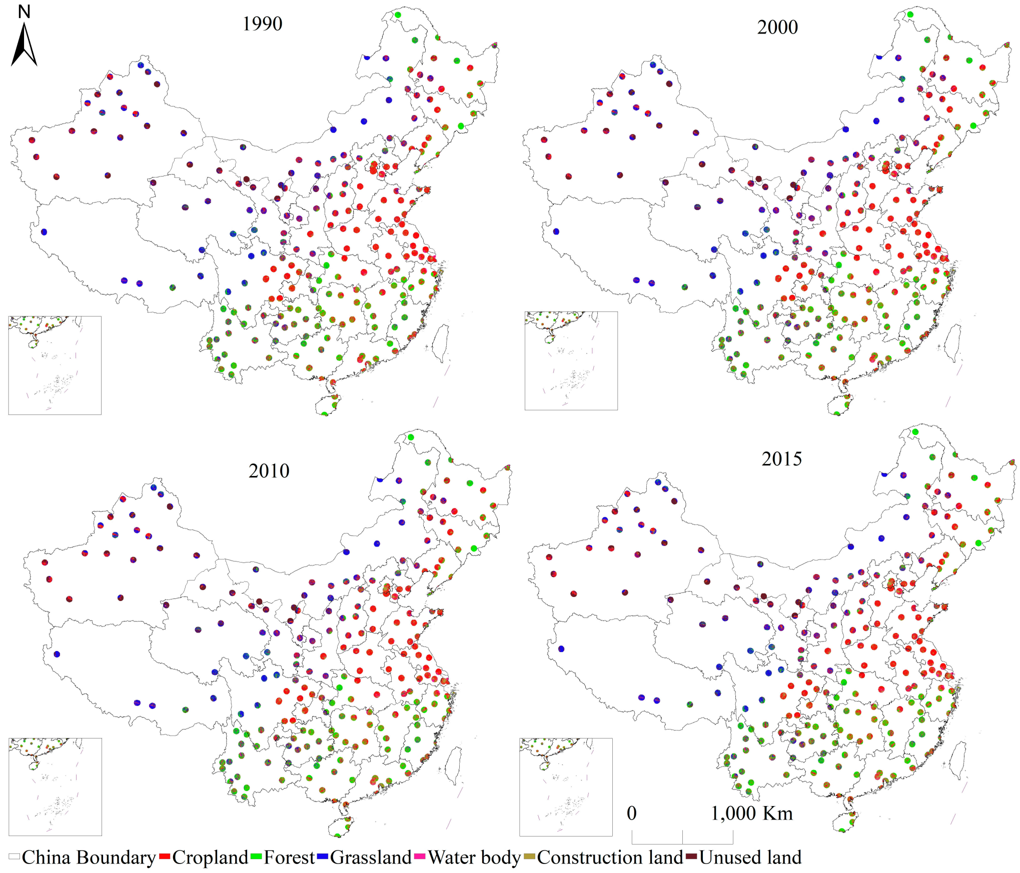

Figure 3. Spatial patterns of LULC in AEZs in 1990, 2000, 2010 and 2015.

Table 2. LULC and LULCC from 1990 to 2015 (unit, Km^2; green color for positive change and red color for negative change).

Year	Cropland	Forest	Grassland	Water Body	Construction Land	Unused Land
1990	252,975	173,231	136,939	23,152	32,579	58,929
2000	251,361	172,944	134,826	23,513	38,032	57,273
2010	245,333	172,991	132,307	23,714	47,585	56,294
2015	242,155	171,963	130,590	23,689	54,904	55,181
2015–1990	−10,820	−1268	−6349	537	22,325	−3748
2000–1990	−1614	−287	−2113	361	5453	−1656
2010–2000	−6028	47	−2519	201	9553	−979
2015–2010	−3178	−1028	−1717	−25	7319	−1113

In order to explore the internal conversion between different LULC types, which took place between the compared periods from 1990 to 2015, we regarded the change (increase or decrease) in LULC types in the study year 2015 relative to the previous year 1990 as a result of several "decrease or increase" conversions. Then, a LULC change matrix was obtained (Table 3). The expansion of the construction land was caused mainly by the cropland and water bodies, which shrank by 30,635 km^2 and 2251 km^2, respectively (Table 3). The extension of water bodies was influenced by the decrease of 6594 km^2 in cropland (Table 3).

3.2. Changes in Ecosystem Services Value (ESV) in Airport Economic Zones (AEZs)

According to the method of ESV assessment, we estimated the ESV of different AEZs and detected the changes (Table 4). As we can see, the total ESVs of AAs, AIAs, AMAs and ATCs in 1990 were RMB 34, 68, 126 and 3226 million, respectively; in 2000, the total ESVs in AAs, AIAs, AMAs and ATCs were RMB 33, 79, 125 and 3245 million, correspondingly; in 2010, the total ESVs in AAs, AIAs, AMAs and ATCs were RMB 32, 78, 124 and 3268 million; the total ESVs in AAs, AIAs, AMAs and ATCs of 2015 were RMB 31, 77, 123 and 3252 million (Table 4).

Table 3. Change matrixes of each compared LULC types from 1990 to 2015 (Km^2).

		LULC Type in 2015					
		Cropland	**Forest**	**Grassland**	**Water Body**	**Construction Land**	**Unused Land**
LULC Type in 1990	**Cropland**	164,040	28,487	17,817	6594	30,635	2022
	Forest	28,081	119,123	16,947	1578	3710	826
	Grassland	22,199	17,507	84,233	1414	2850	6608
	Water Body	5660	1488	1177	11,356	2251	613
	Construction Land	14,694	1496	1115	1048	13,485	281
	Unused Land	4115	923	7199	785	1042	43,963

Table 4. ESV of AEZs (in million RMB; FP, food production; MP, material production; water resources supply, WRS; gas regulation, GS; CR, climate regulation; EP, environmental purification; HR, hydrological regulation; SC, soil conservation; MNC, maintenance of nutrient cycle; Bio, biodiversity; AL, aesthetic landscape; PS, provisioning services; RS, regulating services; SS, supporting services; CS, cultural services).

	Provisioning Services			Regulating Services				Supporting Services			Cultural Services	
1990	*FP*	*MP*	*WRS*	*GS*	*CR*	*EP*	*HR*	*SC*	*MNC*	*Bio*	*Al*	**Sum**
AA	2	1	2	3	5	2	13	3	0	2	1	34
AIA	3	2	5	5	9	4	27	5	1	5	2	68
AMA	5	3	7	10	21	8	45	11	1	10	5	126
ATC	25	17	33	53	117	44	2317	60	6	530	25	3226
	Provisioning Services			Regulating Services				Supporting Services			Cultural Services	
2000	*FP*	*MP*	*WRS*	*GS*	*CR*	*EP*	*HR*	*SC*	*MNC*	*Bio*	*Al*	**Sum**
AA	2	1	2	3	5	2	13	3	0	2	1	33
AIA	3	2	5	6	12	5	29	7	1	6	3	79
AMA	5	3	7	10	21	8	45	11	1	10	5	125
ATC	24	17	33	53	117	44	2343	59	6	525	25	3245
	Provisioning Services			Regulating Services				Supporting Services			Cultural Services	
2010	*FP*	*MP*	*WRS*	*GS*	*CR*	*EP*	*HR*	*SC*	*MNC*	*Bio*	*Al*	**Sum**
AA	2	1	2	3	5	2	12	3	0	2	1	32
AIA	3	2	4	6	12	5	29	7	1	6	3	78
AMA	5	3	7	10	21	8	45	11	1	9	5	124
ATC	24	17	32	52	116	44	2371	59	6	522	25	3268
	Provisioning Services			Regulating Services				Supporting Services			Cultural Services	
2015	*FP*	*MP*	*WRS*	*GS*	*CR*	*EP*	*HR*	*SC*	*MNC*	*Bio*	*Al*	**Sum**
AA	2	1	2	2	5	2	12	3	0	2	1	31
AIA	3	2	4	6	12	5	29	7	1	6	3	77
AMA	5	3	7	10	20	8	45	11	1	9	4	123
ATC	24	16	32	52	115	44	2360	59	6	520	25	3252
	Provisioning Services			Regulating Services				Supporting Services			Cultural Services	
2015–1990	*FP*	*MP*	*WRS*	*GS*	*CR*	*EP*	*HR*	*SC*	*MNC*	*Bio*	*Al*	**Sum**
AA	−0.17	−0.06	−0.28	−0.25	−0.39	−0.16	−0.79	−0.19	−0.03	−0.23	−0.11	−2.65
AIA	−0.09	0.28	−0.15	0.84	3.04	0.85	1.92	1.17	0.07	0.99	0.42	9.34
AMA	−0.30	−0.10	−0.36	−0.41	−0.59	−0.17	0.29	−0.31	−0.06	−0.32	−0.15	−2.49
ATC	−0.76	−0.27	−0.74	−1.22	−1.97	−0.41	43.35	−0.92	−0.16	−10.04	−0.45	26.41

In the four periods, the regulating services value contributed the most to the total ESV of AAs, AIAs, AMAs and ATCs, while cultural services and provisioning services offered the least (Table 4). During the period of 1990–2015, the total ESV of AAs and AMAs decreased from RMB 34 and 126 million, to RMB 31 and 123 million, with decrease rates of 7.78% and 1.98%, respectively. While the total ESV of AIAs and ATCs increased from RMB 68 and 3226 million, to RMB 77 and 3252 million, with increase rates of 13.74% and 0.82%, respectively (Table 4). In AAs, all kinds of ESV reduced from 1990 to 2015. In AIAs, the value of climate regulation and hydrological regulation increased more. Moreover, the value of hydrological regulation increased most both in AMAs and ATCs in this period, while the values of climate regulation and biodiversity decreased the most in AMAs and ATCs, respectively (Table 4).

From the spatial patterns of ESV from 1990 to 2015, we can see that the ESV of AEZs was characterized by a high value in the coastal area of China and a low value in the north (Figure 4), which is related to the geographical regional differences in China.

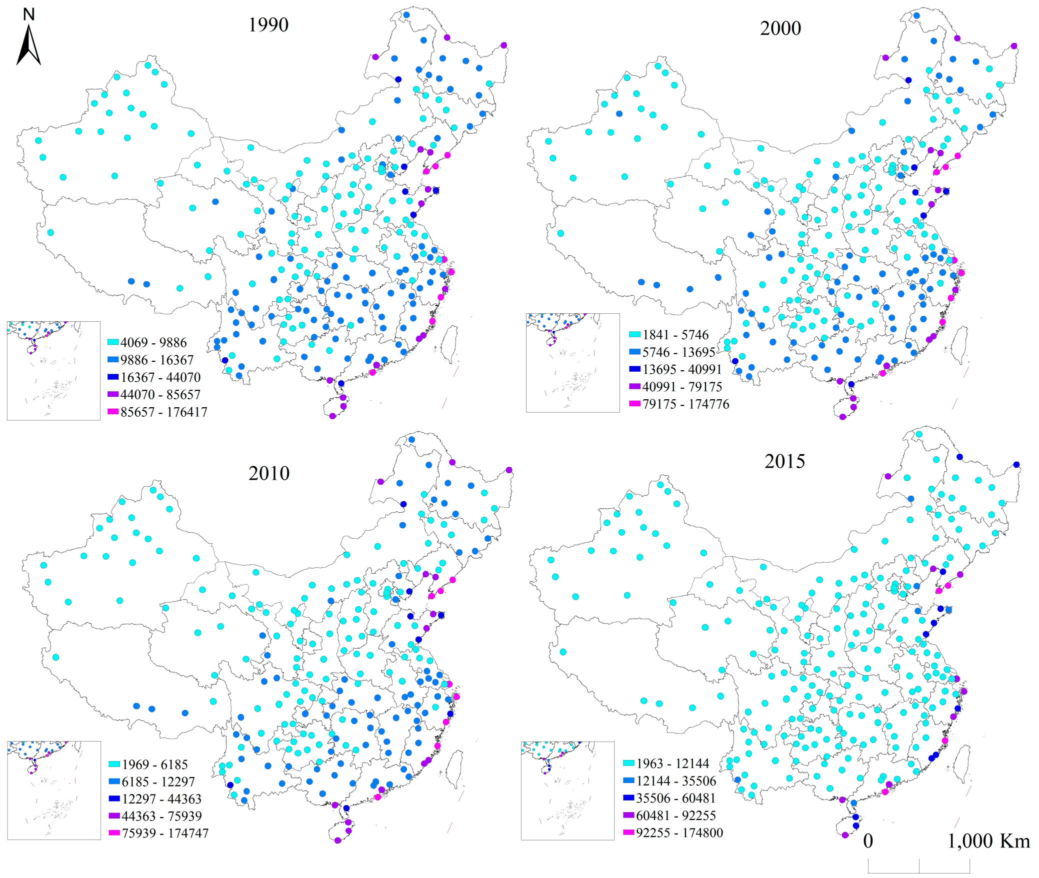

Figure 4. Spatial patterns of ESV from 1990 to 2015 (RMB 1000).

In order to further analyze the spatial heterogeneity of the ESV changes between 1990 and 2015 in AEZs, we analyzed the difference among the ESVs of 231 AEZs (Figure 5). In general, from 1990 to 2015, the ESV of AEZs that increased were mostly located in Inner Mongolia, while the ESV of AEZs that decreased were mostly located in southeast coastal area. From 1990 to 2000, the AEZs with a high increase in ESV were located in Inner Mongolia and Qinghai and the AEZs whose ESV decreased were mostly located in central and south China. However, from 2000 to 2010, AEZs with high and low increases in ESV were located in central China and the south coastal area of China, respectively. From 2010 to 2015, AEZs with a high decrease in ESV were located in southeast China (Figure 5).

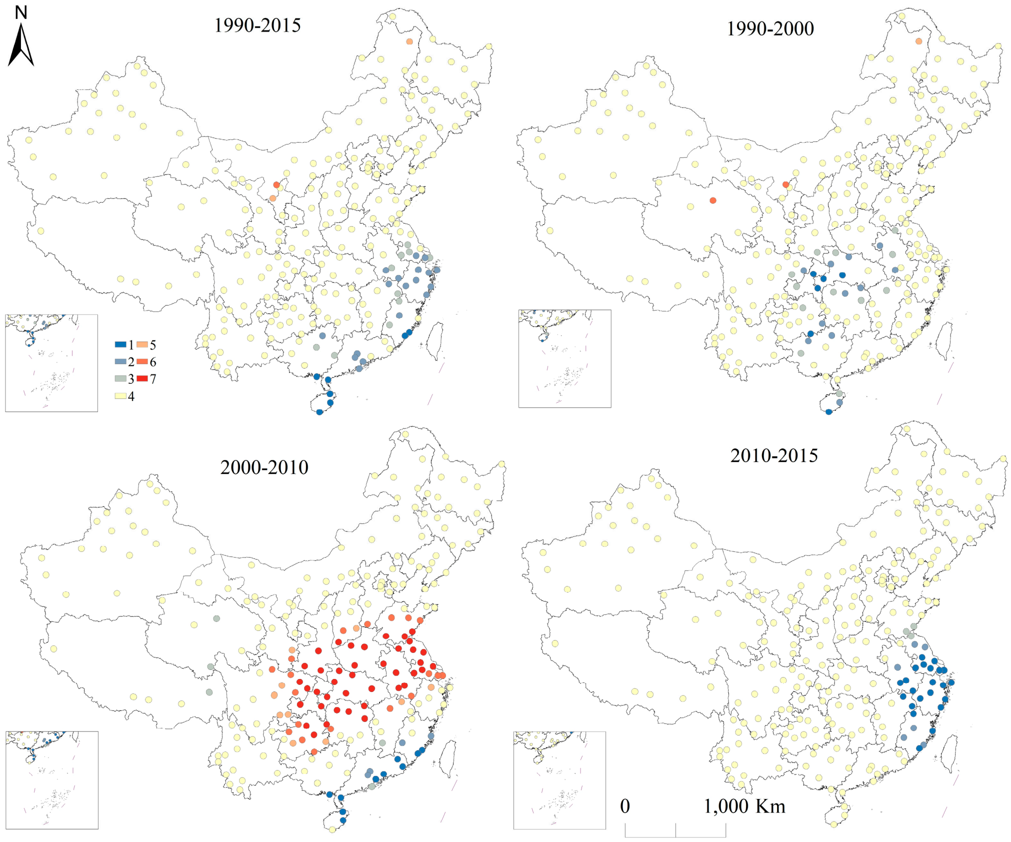

Figure 5. High–low-value aggregation of AEZs' ESV change from 1990 to 2015 (1, cold spot with 99% confidence; 2, cold spot with 95% confidence; 3, cold spot with 90% confidence; 4, not significant; 5, hot spot with 90% confidence; 6, hot spot with 95% confidence; 7, hot spot with 99% confidence).

4. Discussion

4.1. Changing Patterns of Land Use and Land Cover (LULC) and Their Corresponding Effect on Ecosystem Services Value (ESV)

Relying on the development of airports, the airport economy is the most effective way to quickly allocate global high-quality resources [55]. Since 1993, China's airport economy has begun to develop. At present, it is in a stage of rapid development and will become the main source of economic growth in the future [56]. With the development of airport economic zones (AEZs), land-use and land-cover change (LULCC) follows, which is bound to pose great challenges for ecosystems to provide ecosystem services (ES) [57–59]. Notably, the cropland, grassland and forest degradation was quite severe in the AEZs as a result of the considerable substitutes of construction land (Table 2), suggesting the poor management of AEZ planning and construction. A substantial reduction in the cropland, grassland and forest have a significant effect on the ESV.

With the functions of agricultural product supply, carbon sink, soil conservation, nutrient circulation and water regulation, cropland plays an irreplaceable role in the ecosystem [60,61]. The supply of agricultural products is the most important contribution of the farmland ecosystem to human welfare [61]. Vegetation, such as grassland, forest and crops, is important, as it provides a variety of ecosystem functions [61]. Plant communities in vegetation not only provide net primary production materials through photosynthesis and provide necessary materials and energy for consumers and decomposers, but also provide the surface with a certain cover and the roots consolidate the soil, so that the soil can be protected from water erosion [61–63]. In addition, grassland and forest have dense roots under the soil surface and leave a large amount of organic matter. Under the action of soil microorganisms, these substances can promote the formation of aggregate structures, so as to improve the soil and enhance fertility. At the same time, due to the cementation of soil humus and calcium, vegetation can improve the corrosion resistance of soil to a certain extent [63]. Vegetation, which is capable of absorbing carbon dioxide in the atmosphere through photosynthesis, plays an important role in regulating atmospheric components [62,64]; however, once vegetation is damaged, the carbon stored would return to the atmosphere, which would increase carbon dioxide emissions and exacerbate the greenhouse effect and global warming. Due to their function of intercepting precipitation and high permeability and water retention, vegetation is of great significance for water conservation [63,65]. There are abundant biological germplasm resources, which play an important role in the succession of natural communities, the development of natural populations and the evolution of species [66]. In addition, the recreation, landscape scenic beauty and cultural services of grassland, farmland and forest ecosystems provide human beings with places for leisure and entertainment, so as to eliminate fatigue and delight their body and mind [67–69].

4.2. Spatio-Temporal Patterns of Airport Economic Zones' (AEZs) Ecosystem Services Value (ESV) Changes

From 1900 to 2015, the ESV of AEZs generally proved to be high in the south coastal area of China and low in the north, which is closely related to the ecological background of the south and north. Besides that, variations in AEZs' ESV changes were observed under the circumstances of China's regional characteristics of land-use and land-cover change (LULCC). The areas with a greater decline in the ESV of AEZs were concentrated in the middle-eastern, south and coastal areas of China. These areas are densely populated and present a strong intensity of production and living activities, which has a great impact on the ecological environment. Although the ecological background in the central and northern regions is poor, the ecological environment has been greatly improved under the influence of a series of ecological projects.

From 1990 to 2015, China's cultivated land decreased in the south and increased in the north and the cultivated land's center gradually moved from northeast to northwest. Before 2000, the newly increased cultivated land was mainly concentrated in the northeast, north China and northwest agroforestry ecotone and the reduced cultivated land was mainly occupied by the industrial and mining land of urban residents on the southeast coast. After 2000, the new cultivated land was mainly concentrated in the northwest. The expansion of industrial and mining land for urban residents and the project of returning farmland to forest and grassland in the ecologically fragile areas of the central and western regions occupied a large amount of cultivated land [70,71].

The rapid expansion of urban and rural construction land in China is mainly concentrated in the Huang Huai Hai Plain, the Yangtze River Delta, the Pearl River Delta and the Sichuan Basin, which are flat, economically developed and densely populated [51,70].

From 1990 to 2000, the deforestation of forest land in key forest areas such as northeast China and the occupation of forest land by the expansion of agricultural areas reduced the area of forest land [70]. Since 2000, due to the implementation of six key forestry projects, especially the project of returning farmland to forest, the area of forest land in China's Loess Plateau and southern hilly areas increased [51,70].

From 1990 to 2000, the grassland in Northeast, North and Northwest China was reclaimed as cultivated land and the grassland area in the south was reduced by artificial afforestation [70]. From 2000 to 2010, the grassland in Northwest China was reclaimed as cultivated land and the grassland in the south was transformed into forest land [70]. From 2010 to 2015, forest and grass land in the central region increased, regional contraction decreased and regional expansion decreased in the east and west [51].

4.3. Construction of Ecological Security Pattern for Economic Zones (AEZs) in South and North China

The areas with reduced ecosystem services value (ESV) of AEZs are mainly located in southern regions with a better ecological situation. Therefore, the construction of AEZs in the southern region should focus on strengthening the protection of the environment in the future and we should carry out conservation and restoration on the basis of the existing ecological resources.

For the northern regions with a relatively fragile environment, we should vigorously maintain the ecological security pattern in the AEZs, commit to environmental improvement and coordinate land use and ecological protection. Moreover, we should accelerate the construction of an ecological security system with an ecological park corridor and a river ecological corridor as the skeleton, an airport road and trunk road ecological axis as the focus and other important ecological function areas as the support, as well as building urban ecological security spaces with this "corridor" as the main body.

4.4. Integrating Advantageous Regional Ecological Resources and Construction of Ecological Security Patterns

The integration of existing ecological resources is the key to the construction of an ecological security pattern of airport economic zones (AEZs). For example, wide shelterbelts and ecological protection corridors on both sides of the main canal and main rivers within AEZs could be set. Following the principle of giving priority to water-quality protection, forest parks, water-system landscapes and green corridors along the coast are constructed in accordance with river and main canal management regulations, so as to create a landscape belt integrating ecological protection and leisure tourism. In addition, combined with the development of regional creative agriculture and high-efficiency ecological agriculture, the seasonal changes in plants can be used to enrich the landscape of the airport and its surrounding areas.

It should be noted that, in the process of ecological environment construction of AEZs, the existing landscape resources and ecological assets of the city should be fully utilized and minimal intervention in nature should be achieved through natural ecological design techniques, so as to seek the unification of ecological and economic benefits.

4.5. Highlighting the Protection and Restoration of Existing Ecological Resources

The protection and restoration of the existing ecological resources is the first step to building ecological economic zones (AZEs). There are abundant ecological resources in some AEZs, such as the Muma Mountain in Chengdu AEZ, Longshan and Baishiling in the Zhuhai AEZ, Yellow River, Xiaoqing River, Lotus Pond, Baiyu Lake and Queshan Reservoir in the Jinan AEZ, agricultural ecological park in Pudong, Shanghai, Yongding River System in Daxing, Beijing, etc. In the construction of AEZs, we should strengthen the protection of water resources and strengthen the comprehensive improvement of the water environment. For example, constructing a water conservation forest upstream of a reservoir not only has a strong water conservation function, but can also prevent soil erosion. In addition, a large number of human interference factors and some construction activities have caused serious damage to the primary vegetation of mountain parks, which greatly weakens the function of soil and water conservation and causes great damage to the mountain ecology, so it is urgent to carry out ecological restoration. For example, microbial technology can be used to improve the ecological environment of mountain vegetation. Two kinds of bacteria, antipollution bacteria and nutrition bacteria, can be inoculated into the microbial community of mountain vegetation. Through the implantation of these two kinds of bacteria, the activity of the microbial community will be restored, the growth of vegetation will be improved and the benign cycle of ecological environment of mountain vegetation will be promoted [71].

5. Conclusions

This study analyzes the land-use and land-cover change (LULCC) within airport economic zones (AEZs) from 1990 to 2015 and assesses the changes in the ecosystem service value (ESV) by using remote sensing (RS) and geographic information system (GIS) technology, based on the latest research paper by Xie et al. [35] on the China's ESV. This is the first study of its kind for AEZs, providing values for AEZ planning for the present and future.

With distinguished features of the expansion of construction land and water bodies, land use and land cover (LULC) varied greatly from 1990 to 2015. The expansion of construction land mainly comes from cropland and water bodies, with 30,635 km^2 and 2251 km^2 having been converted to construction land, respectively. In addition, cropland also contributed much to the expansion of water bodies.

A higher ESV of AEZs was observed in the coastal area of China. Over the whole period, a higher increase in the ESV of AEZs was noted in Inner Mongolia, while the ESV of AEZs decreased mostly in the southeast coastal area. The AEZs with a high increase and decrease in ESV were distributed in different parts of China in each studied period.

AEZs are comprehensive development systems that include the subsystems of economy, society, culture and environment. Ecological AEZ planning should adhere to the principle of ecological priority and properly handle the relationship between AEZ construction and ecological protection by strengthening the protection of rivers, wetlands and so on. Overall, more attention should be paid to the building of China's AEZs as ecological areas where there is harmony between people and nature.

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