ANALYZING THE LANDSCAPE PATTERN AND ECOSYSTEM SERVICE VALUE OF ECO-INDUSTRIAL DEMONSTRATION PARKS: A CASE STUDY OF ZHENGZHOU ECONOMIC TECHNOLOGICAL DEVELOPMENT ZONE, CHINA

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Abstract. The establishment of an eco-industrial demonstration park is based on the principles of sustainable development and aims to achieve social progress and economic growth before ultimately evolving into a fully developed industrial ecosystem. This study explores the relationship between the ecological environment and socioeconomic development in Zhengzhou Economic Development Zone (area of 158.7 km^2), China. By analyzing the landscape patterns and changes in ecosystem service values over the periods of 2010, 2015, and 2019, results revealed a remarkable shift in land use in this area from 2010 to 2019. Particularly noteworthy was the remarkable growth in forest lands, which expanded from 0.98 km^2 in 2010 to 23.42 km^2 in 2019, whereas cultivated and bare lands decreased by 47.55% and 73.81%, respectively. The value of ecosystem services experienced a continuous increase and reached 13.3009 billion yuan in 2019. This study also examined the coordination degree of socioeconomic development and ecological environment coupling and found considerable progress from 2010 to 2019. The coupling degree values of 0.129, 0.809, and 0.960 for the aforementioned years indicated a remarkable improvement in synergistic and integrated development between the socioeconomic system and the ecosystem in this area. The landscape patterns in this area underwent noteworthy transformations.
Keywords: *landscape patterns, landscape patches, land use, collaborative development, coupling analysis*

Introduction

Compared with traditional industrial parks, eco-industrial demonstration parks have emerged as a pioneering solution to sustainable urbanization and industrialization. While conventional industrial parks have undeniably driven economic growth, their rapid expansion has led to the encroachment of farmland and natural ecological areas. This unchecked growth has severely damaged natural resources and burdened the regional ecological environment with uncontrolled industrial pollution emissions, posing critical challenges (Zhao and Zhang, 2003). By contrast, eco-industrial demonstration parks place emphasis on living in harmony with the environment. They regard the land system as fundamental support, and their industrial landscapes are shaped to mimic the balance in natural ecosystems (Jia et al., 2021). By optimizing resource utilization and minimizing waste emissions, these parks create an interconnected ecological network that utilizes common sources and material information. They have diverse urban functions, such as

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enhancing efficiency and sustainability, aside from industrial production. Since the 1990s, eco-industrial demonstration parks have been gaining global recognition and reshaping the paradigm of industrial park development. China has also embraced this transformative approach and initiated pilot eco-industrial demonstration park constructions in the late 1990s. China took a step forward when it established the Guigang Eco-Industrial (Sugar) Demonstration Zone in 2001. By the end of 2020, China had 65 national eco-industrial demonstration parks. Scholars worldwide have investigated the effects of eco-industrial demonstration parks on landscapes and ecosystem services. Jerzy Solon analyzed landscape pattern changes in the Warsaw metropolitan area and highlighted the influence of urbanization on cultural landscapes and ecosystems (Solon, 2009). Chen Zhicong utilized remote sensing data to study the evolution of wetlands in Nansihu Lake and provided a scientific basis for the comprehensive management of Nansihu Nature Ecological Reserve (Chen et al., 2016). Jin et al. (2021) investigated gridding landscape patterns and quantitatively evaluated ecosystem service values and ecological risks. Zhao Shikuan et al. conducted a tradeoff–synergy analysis by using Chongqing Municipality as a case study; their work contributes to the understanding of ecosystem service value measurement (Zhao et al., 2021). Studies have consistently demonstrated the positive effects of eco-industrial demonstration parks on human life, cultural development, economic prosperity, and ecological well-being in and around these regions (Zhang et al., 2015; Chen, 2012). However, existing research focused on economic development, resource utilization, pollution control, and park management and did not conduct in-depth examinations of landscape patterns and ecosystem service values in eco-industrial demonstration parks.

By analyzing the landscape patterns and changes in ecosystem service value after the establishment of the eco-industrial demonstration park in Zhengzhou Economic Development Zone, this study explores the relationship between the ecological environment and socioeconomic development during park construction. This research serves as a core guide and offers insights into the sustainable development of eco-industrial demonstration parks. We aim to provide a strategy that optimizes the ecological integrity and industrial layout of these parks, thus enhancing their appeal to investors. Our approach seeks to improve the overall strength and value of neighboring areas. Through these efforts, we aim to achieve harmonious balance between economic progress and environmental conservation in eco-industrial demonstration parks and their neighboring regions. This study provides a scientific guidance for the construction of landscape pattern and the enhancement of ecosystem service value for the future development of the Ecological Industrial Park.

Materials and methods

Study area

Zhengzhou Economic Development Zone, established in April 1993 and approved by the State Council in February 2000, is the first state-level economic development zone (with an area of 158.7 km^2) in Henan Province, China. This zone is located in the southwestern fringes of the North China Plain and shares its boundaries with the remnants of Songshan Mountain. This area has a diverse topography, with the elevated terrain in the southwest gradually sloping down to the northeast. Its ground elevation ranges from 85.2 m to 117.1 m, and the slopes vary from 2‰ to 69‰ (*Fig. 1*). Situated in the alluvial region of the Yellow River, the zone predominantly comprises of flat

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landscapes, including sandy wastelands and slender fields. Its climate is characterized by a northern temperate continental monsoon pattern with four distinct seasons. The average annual precipitation is approximately 632 mm. The zone is supported by three major industries: the automobile and parts industry, equipment manufacturing, and modern logistics. In 2020, the area enjoyed 233 days of favorable weather conditions, making it the second most climate-friendly zone in the city. Its environmental quality exhibits a positive trajectory, with PM10, PM2.5, and NO_2 concentrations of 91 μg/m^3, 50 μg/m^3, and 36 μg/m^3, the PM10 and PM2.5 are greater than the national secondary standards of 70 μg/m^3 and 35 μg/m^3, and NO_2 is less than the national secondary standard of 50 μg/m^3. It is a good performance for industrial parks. Respectively, all of which continue to show a consistent decline. The rivers in the developed zone have a stable water quality rating of Grade III. The southern region contains Butterfly Lake and Butterfly Lake Wetland Park and covers an expansive shrub ground area that exceeds 300,000 m^2. Remote sensing imagery for 2010, 2015, 2019 is shown in *Figure 2*.

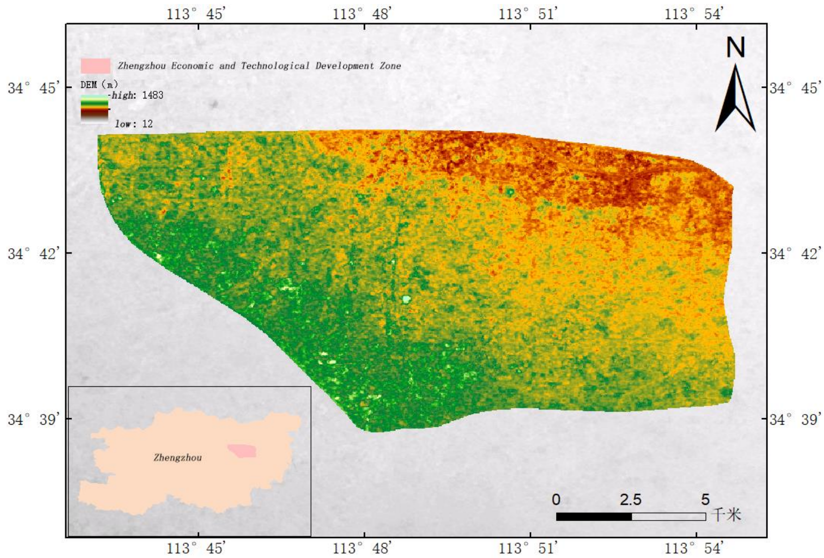

Figure 1. *Map of the location elevation of Zhengzhou Economic Development Zone*

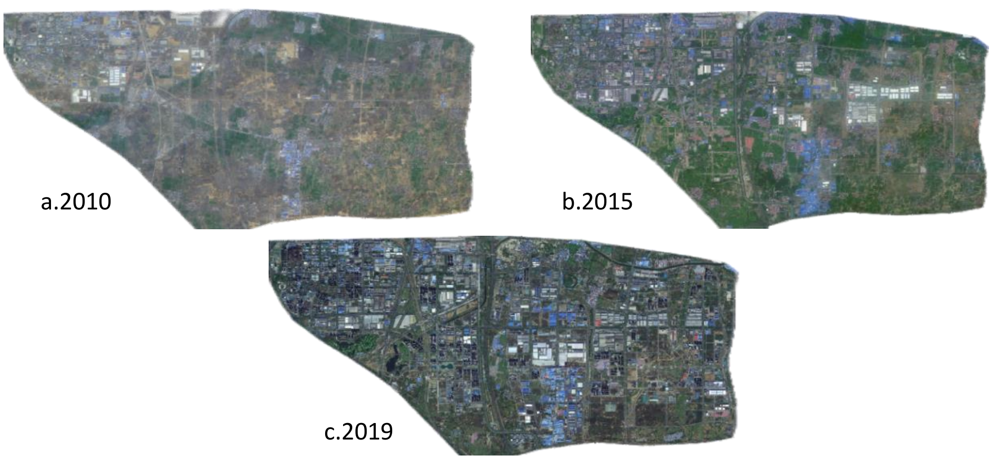

Figure 2. *Remote sensing imagery of Zhengzhou Economic Development Zone*

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Data type and source

The basic data used in this study included altitude and high-resolution remote sensing image. Altitude data were collected from the Geospatial Data Cloud (http://www.gscloud.cn), with a spatial resolution of 30 m. High-resolution Remote sensing data in 2010, 2015 and 2019 were from Zj-view (https://www.zj-view.com), with a spatial resolution of 0.8 m.

Evaluation methods

Evaluation of ecosystem service value measurement

In this study, the equivalent table of ecosystem service value per unit area of Chinese ecosystems (2007) developed by Xie et al. (2015). was used as the foundational framework. The correction process for Zhengzhou City was as follows. Data obtained from the Zhengzhou City Bureau of Statistics revealed that the average grain production (wheat and corn) in Zhengzhou City between 1994 and 2019 was 4293.98 kg/hm^2/a. The purchase price of grain in Zhengzhou City in 2019 was 2.36 yuan/kg. In the absence of human intervention, the existing unit ecosystem service value is 1/7 of the economic value derived from food production provided on a unit area of farmland (Wei et al., 2017). The value of natural grain production in Zhengzhou City was calculated to be 1447.68 yuan/hm^2/a. Using these data as a foundational reference, we adjusted the ecosystem value equivalent of ecosystem services for Zhengzhou Economic Development Zone. The calculations for the changes in the ecosystem service value of the Zhengzhou Economic Development Zone from 2010 to 2019 were analyzed. The method proposed by Costanza et al. (1997) is applied to calculate the value of ecosystem services, and the formula was as follows:

$$ESV = \sum A_i \times K_i \quad \text{(Eq.1)}$$

$$ESV_f = \sum \left(A_{fi} \times K_{fi}\right) \quad \text{(Eq.2)}$$

In *Equation 1*, ESV represents the ecosystem service value; A_i is the area of the i-th land use type; K_i is the ESV coefficient of the i-th land use type. In *Equation 2*, ESV_f represents the value of individual ecosystem services; K_{fi} is the single ecosystem service value of land use type i per unit area.

Coupling coordination analysis

The selected social and economic development indicators of Zhengzhou Economic Development Zone, the landscape index, and the ecosystem service value derived from ecological environment assessments were used to establish a response indicator system (Wu, 2018). A coupled coordination degree model was applied to analyze the relationship between socioeconomic development in Zhengzhou Economic Development Zone and the ecological environment. The coupled coordination degree model was constructed as follows:

$$D = \sqrt{C \times T}, T = \alpha u_1 + \beta u_2 \quad \text{(Eq.3)}$$

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where D represents the coupling coordination degree between the socioeconomic system and the ecosystem and T represents the comprehensive evaluation index of socioeconomic development and the ecological environment. The coefficients α and β are yet to be determined. α and β were assigned a value of 0.5 because of the inherent disparities in the mutual promotion of socioeconomic development and the ecological environment (Wang and Yu, 2012). The coupled coordination degree of the two subsystems was classified and ranked (Ding, 2013), as shown in *Table 1,* to provide a direct representation of the coupling degree of the coordinated development of the socioeconomic system and ecosystem.

Table 1. *Coupling coordination evaluation level criteria*

Degree of coupling coordination	Level	Degree of coupling coordination	Level
0–0.19	Severe disorder	0.6–0.69	Mild coordination
0.2–0.39	Moderate disorder	0.7–0.79	Moderate coordination
0.4–0.49	Mild disorder	0.8–0.89	Good coordination
0.5–0.59	Barely coordinated	0.9–1.00	Moderate coordination

Results and analysis

Assessment of the landscape pattern index for the economic development zone

This study analyzed the land resource characteristics in the study area through extensive fieldwork. High-resolution satellite imagery was utilized to assess the land use dynamics in Zhengzhou Economic Development Zone (Yi et al., 2008). In the initial phase (2010), Advanced Land Observing Satellite data with a resolution of 2.5 m were chosen for analysis. Gaofen II imagery from 2015 and 2019 with an improved resolution of 0.8 m was employed from May to July (Deng, 2015) to ensure optimal image quality. The images were preprocessed using ENVI5.3 for radiometric calibration, atmospheric correction, ortho-correction, cropping, and mosaicking. The processed images were subjected to object-oriented classification using eCognition image processing software (Zhang et al., 2007; Meyer and Neto, 2008) in accordance with the national land use classification system. Five categories, namely, waters, forest land, cultivated land, bare land, and impervious surface, were identified (Qian et al., 2015; Yi, 2022; Bi and Gao, 2012). A sample area was established through field trips. The comparison of the classified images with ground truth data yielded high accuracy scores of 0.91, 0.86, and 0.86 for the years 2010, 2015, and 2019, respectively. ArcGIS 10.3 software was employed to generate land use classification maps of Zhengzhou Economic Development Zone for the three periods (2010, 2015, and 2019). Fragstats10.4 software was used to calculate landscape pattern indices for Zhengzhou Economic Development Zone across the three periods. The results are shown in *Figures 3, 4*, and *5*.

Characterization of land use change

Analysis of area changes in land use types

The transformation of land use types in Zhengzhou Economic Development Zone between 2010 and 2019 (*Fig. 6*) revealed remarkable shifts in the landscape of the region. In 2010, the dominant land use types ranked from the largest to the smallest area were

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bare land, cultivated land, impervious surface, forest land, and waters. In 2015, the main types of land use from largest to smallest were bare land, impervious surface, cultivated land, forest land, and waters. In 2019, the major land use types ranked from the largest to the smallest area were impervious surface, forest land, cultivated land, bare land, and waters. The impervious surface area expanded considerably to 74.01 km^2, showing an increase of 87.48% relative to 2010. The area of cultivated land and bare land has continued to decline significantly throughout the decade. Cultivated land decreased by about 19.05 km^2, and bare land decreased by 47.60 km^2 over the same period. Forest land has increased by 22.44 km^2 and the area covered by waters increased by 89.02%.

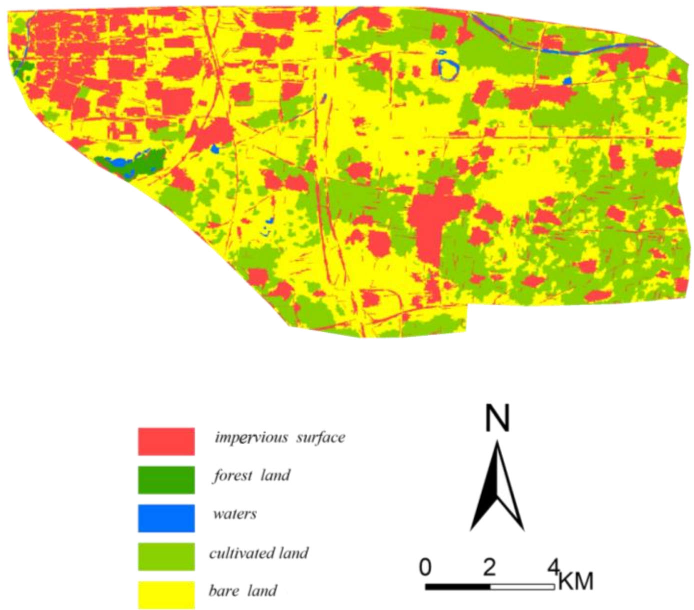

Figure 3. *Map of Zhengzhou Economic Development Zone land use classification in 2010*

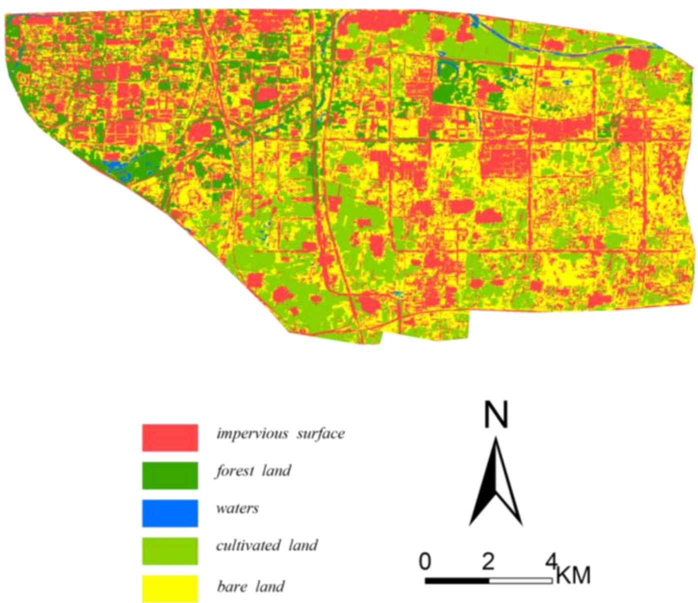

Figure 4. *Map of Zhengzhou Economic Development Zone land use classification in 2015*

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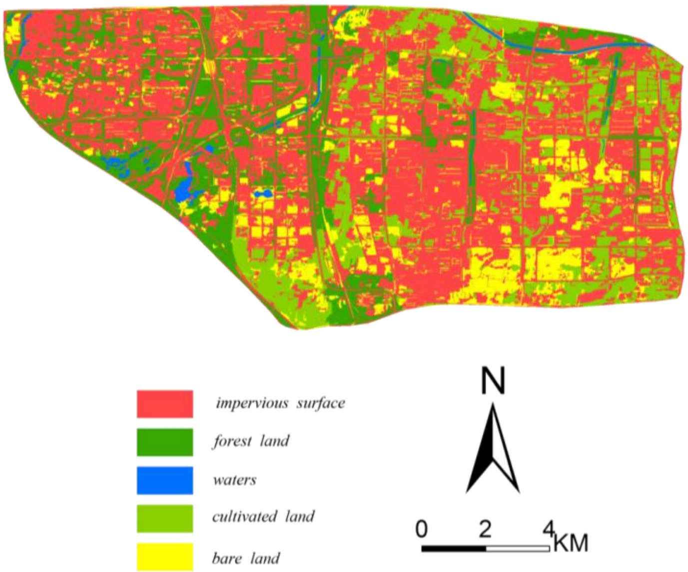

Figure 5. *Map of Zhengzhou Economic Development Zone land use classification in 2019*

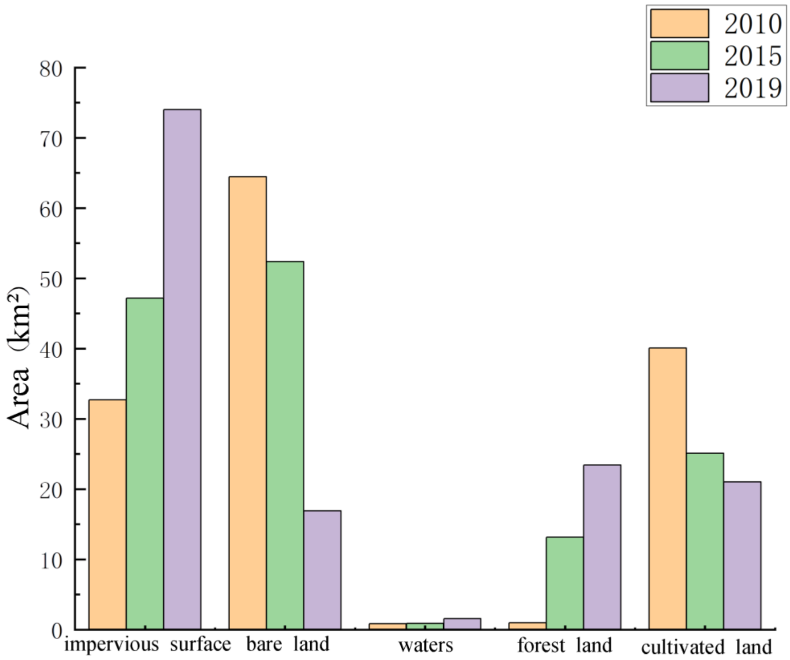

Figure 6. *Chart of land type area changes from 2010 to 2019*

Analysis of changes in land use dynamics

The speed and intensity of land use changes in Zhengzhou Economic Development Zone in different periods were analyzed, and the trend of evolving patterns was obtained, as shown in *Table 2*. Among the land use types, forest land and impervious surface exhibited the most striking transformation from 2010 to 2019; their growth rates were 253.92% and 14.02%, respectively. The rapid expansion of the forest land can be attributed to the implementation of eco-friendly urban garden policies by park. Bare land and cultivated land experienced moderate changes and had reduction rates of −8.20% and

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−5.28%, respectively. This moderate decline aligns with the sustainable development characteristics of eco-industrial demonstration parks. During 2010–2015, forest land experienced rapid expansion, whereas the other land use types exhibited relatively balanced growth rates. Among them, bare land and cultivated land have negative growth. During 2015–2019, forest land presented decelerated growth, the growth rate of impervious surface has increased, and bare land and cultivated land entered a phase of negative growth, which intensified their decline.

Table 2. *Changes in the landscape types of the different land use types*

Landscape type	**Change（%）**		
	2010–2015	**2015–2019**	**2010–2019**
Impervious surfaces	8.86	14.20	14.02
Bare land	−3.76	−16.94	−8.20
Waters	1.64	18.68	9.89
Forest land	247.99	19.50	253.92
Cultivated land	−7.47	−4.07	−5.28

Landscape pattern index analysis

Landscape type pattern index analysis

The analysis of the landscape pattern indices at the landscape type level is shown in *Table 3*. The proportion of landscape types (PLAND) in the region was explored. In 2010, the predominant landscape types ranked from high to low PLAND values were cultivated land, impervious surfaces, forest land, waters, and bare land. In 2015, the predominant landscape types ranked from high to low PLAND values were forest land, impervious surfaces, cultivated land, bare land, and waters. A shift occurred in 2019, with forest land ranking first, followed by impervious surfaces, bare land, cultivated land, and waters. The maximum patch index (LPI) is generally used to determine the dominant landscape patch in a region (Wang, 2021). In 2010, the LPI values of impervious surfaces, waters, and forest land were much smaller than those for cultivated land, indicating that cultivated land was dominant in Zhengzhou Economic Development Zone. In 2019, the LPI values of forest land exceeded those of the other landscape land types, This trend shows the continued emphasis on environmental conservation, especially woodland ecology of the zone.

The LSI of Zhengzhou Economic Development Zone reflects the complexity of the overall landscape in the region. It is a fundamental indicator that describes the spatial pattern of the landscape (Kong et al., 2020). Compared with 2010, The LSI values of all landscape types in the eco-industrial demonstration park increased. This upward trajectory indicates a growing diversity in landscape traits and enhanced connectivity among patches in the eco-industrial demonstration park. The LSI values of cultivated lands showed a consistent increase, which may be due to the influence of influence of management practice and the rational and effective strategies for cultivated lands. The LSI values of the remaining landscape types showed an increasing and then decreasing trend, this fluctuation indicates that the rapid increase of various landscape types occurred in the pre-development period, and the relationship between landscape types within the patches became more optimized in the late development period.

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IJI is generally used to show the adjacency between patch types (Su, 2019). In the eco-industrial demonstration park, the IJI index for impervious surfaces, forest land, bare land and waters showed a trend of first decreasing and then increasing from 2010 to 2019. This indicates that the patch boundaries of various land use types are more permeable and more connected between neighboring landscape types. The IJI index for cultivated land showed a decreasing trend, this fluctuation may come from the impact of the cropland policy, which makes cultivated land patches more independent.

Table 3. *Chart of the landscape pattern index of landscape type level in Zhengzhou Economic Development Zone from 2010 to 2019*

Landscape type	Year	PLAND/%	NP	PD	LPI	LSI	IJI
Impervious surfaces	2010	28.8034	209	1.5027	7.6632	29.6532	98.8286
	2015	34.0572	8081	58.2497	9.6056	170.4985	93.7988
	2019	17.1093	1519	11.096	1.22	73.7218	96.1915
Cultivated land	2010	46.3745	550	3.9545	31.3014	44.0766	98.6279
	2015	18.0717	1081	7.7921	2.0116	55.696	97.2189
	2019	12.3397	2741	20.0225	1.2271	89.4524	94.5573
Forest land	2010	23.522	602	4.3284	5.4204	51.6508	97.7423
	2015	37.7477	7826	56.4116	5.2783	183.3718	93.6642
	2019	54.0668	2085	15.2305	49.9486	92.2689	97.3186
Bare land	2010	0.5941	27	0.1941	0.0852	12.8942	96.4499
	2015	9.4791	1325	9.5509	0.7767	70.5934	95.1317
	2019	15.3454	1266	9.2479	1.9265	59.0014	96.7815
Waters	2010	0.7059	6	0.0431	0.5453	5.1337	98.7042
	2015	0.6442	114	0.8217	0.0723	24.1915	93.5969
	2019	1.1389	92	0.672	0.1711	19.6366	96.0682

PLAND: percent of landscape; NP: number of patches; PD: patch density; LPI: largest path index; LSI: landscape shape index; IJI: interspersion and juxtaposition index

Landscape level pattern index analysis

The landscape pattern index at the regional level was analyzed, as shown in *Table 4*. Between 2010 and 2019, a considerable increase in NP (5441) and PD (39.0963) values was observed. This rise reveals increased landscape fragmentation in the study area, which led to a uniform spatial distribution. The expansion of human activities in the natural landscape gradually strengthened and consequently enhanced the interference with the landscape area. The region experienced a high degree of landscape development, which resulted in the ecological transformation of the industrial park.

CONTAG was used as a tool to assess the aggregation and development trends of different patch types within the landscape. Between 2010 and 2019, this index initially decreased from 50.8915 in 2010 to 33.4367 in 2015 and then increased to 41.596 in 2019. These fluctuations indicate that in the first five years, the parks displayed a high degree of fragmentation and a weakened level of aggregation, which meant limited connectivity between landscape areas. However, in the latter half of the decade, the parks matured, leading to increased landscape connectivity and strengthened agglomeration between different areas. The SHDI and SHEI for the study area from 2010 to 2019 exhibited a similar trend of initially increasing and then decreasing (Su, 2019). This trend suggests a

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correlation between landscape diversity and its fragmentation degree. In the initial five years, as the parks developed, landscape diversity increased, resulting in a positive correlation with fragmentation. In the latter half of the decade, as the landscape types matured, fragmentation decreased, and the distribution of landscape types became increasingly uniform.

Table 4. *Chart of the landscape pattern index of landscape level in Zhengzhou Economic Development Zone from 2010 to 2019*

Year	NP	PD	LSI	IJI	CONTAG	SHDI	SHEI
2010	1493	10.7242	25.6010	52.2456	50.8915	1.1206	0.6963
2015	5562	40.0950	59.3352	60.0267	33.4367	1.2995	0.8074
2019	6934	49.8205	63.0788	51.1846	41.5960	1.0682	0.6637

NP: number of patches; PD: patch density; LSI: landscape shape index; IJI: interspersion and juxtaposition index; CONTAG: landscape sprawl index; SHDI: Shannon's diversity index; SHEI: Shannon's homogeneity index

Evaluation of ecosystem service value measurement

From 2010 to 2019, Zhengzhou Economic Development Zone showed a continuous increase in the total value of ecosystem services (ESV), which reached 13.3009 billion yuan. This period witnessed a consistent growth in forest land's ESV, which accounted for 3.997%, 53.558%, and 95.34% in 2010, 2015, and 2019, respectively. The ESV of cultivated land showed a continuous decline and had proportions of 45.813%, 28.695%, and 24.029% in 2010, 2015, and 2019, respectively. Between 2015 and 2019, the decline in the ESV of cultivated land stabilized due to the promulgation of state policies related to permanent basic farmland. During this time, Zhengzhou Economic Development Zone focused on preserving permanent basic farmland while gradually restoring and stabilizing existing forested cultivated land ecosystems. This approach not only facilitated the preservation of forested cultivated land but also contributed to the sustainable development of the entire forested cultivated land system.

The waters ESVs presented a consistent upward trend from 2010 to 2019. The ESV percentages for 2010, 2015, and 2019 were 5.418%, 5.862%, and 10.242%, respectively. Although 2010 had the highest percentage among the studied years, the overall ESV for this year was the lowest. In response to these trends, the eco-industrial park in Zhengzhou Economic Development Zone strictly controlled its wastewater discharge, arranged monitoring sites, prepared water pollution prevention plans, and managed the Butterfly Lake water system. These initiatives have not only safeguarded the waterscape but also promoted its development. The total amount of bare land ESV in 2010 and 2015 reached 1297.8 and 1053.9 million yuan (*Table 5*), respectively. This result indicates that large portions of cultivated and forest land in Zhengzhou Economic Development Zone were transformed from bare land, resulting in an increase in ecosystem service value during these periods.

Coupling coordination analysis

From 2010 to 2019, Zhengzhou Economic Development Zone witnessed remarkable advancements in socioeconomic and ecological domains (*Table 6*), u_1 and u_2,

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respectively. In 2010, the socioeconomic development level (u_1) was low at 0.001. During this period, the zone received approval to initiate the construction of eco-demonstration industrial parks. The zone had a singular industry focus and was inefficient. By 2015 and 2019, the economic development level increased, with the socioeconomic development indices reaching 0.681 and 1.043, respectively. The ecological environment development level (u_2) in 2010 was 0.250; this value highlights the environmental challenges faced by the zone. This period was characterized by the predominance of agricultural land. By 2015, the u_2 index rose to 0.630, and by 2019, it further increased to 0.816. The u_2 ecosystem development level increased by 226.4% compared with its 2010 baseline.

Table 5. *Ecosystem service value in Zhengzhou Economic Development Zone during 2010–2019*

Landscape Type	ESV/Billions		
	2010	**2015**	**2019**
Forest land	3.997	53.558	95.34
Cultivated land	45.813	28.695	24.029
Waters	5.418	5.862	10.242
Bare land	12.978	10.539	3.399
Total	68.206	98.654	133.009

ESV: ecosystem services value

Table 6. *Comprehensive index, coupling coordination degree, and grade of socioeconomic development and eco-environmental system in Zhengzhou Economic Development Zone*

Year	u_1	u_2	C	T	D	Coupling coordination level
2010	0.001	0.250	0.132	0.126	0.129	Severe disorder
2015	0.681	0.630	0.999	0.656	0.809	Good coordination
2019	1.043	0.816	0.993	0.929	0.960	Quality coordination

u_1: socioeconomic development level; u_2: ecological environment development level; C: coupling degree; T: comprehensive coordination index; D: coupling coordination degree

From 2010 to 2019, a remarkable transformation occurred in the socioeconomic system and ecosystem synergy of Zhengzhou Economic Development Zone. In 2010, the coupling development between the socioeconomic level and the ecosystem was weak, with a D value of only 0.129, indicating a serious dysfunctional state where mutual promotion was lacking. By 2015, notable progress was achieved, and the D value surged to 0.809, marking a shift from dysfunction to good coordination between the two elements. This positive trend continued, and by 2019, the D value reached 0.960, indicating high-quality coordination between the socioeconomic system and the ecosystem. This progression highlights the symbiotic relationship between economic development and ecological advancement in Zhengzhou Economic Development Zone. The ecological environment nurtures economic growth and provides a strong foundation for attracting high-quality enterprises. This mutually beneficial relation further promotes the development of the regional economy.

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Discussion

The transformation of land use in Zhengzhou Economic Development Zone exhibited a consistent increase in impervious surfaces over the years, with notable shifts in dynamic patterns. However, the change did not negatively affect the living quality of the residents in the park nor the ecological environment. This achievement can be attributed to the conversion of bare land and cultivated land into forest land and waters. These efforts reduced the wastage of land resources and increased the ecological benefits of the park. In future development, the planning of land use in ecological industrial parks needs to be approached from a sustainable development perspective, and the park should make the synergistic development of ecology and economy its priority (Liu et al., 2020). This task requires a careful reassessment of the land use structure and methods in the park and the avoidance of hazardous construction. An integral aspect of this approach involves harmonizing the spatial layout of various landscapes and enhancing the environmental quality of the surrounding ecological resources. By improving the regional ecological environment, the park can substantially enhance the value of its ecosystem services.

The transformation of the landscape pattern of Zhengzhou Economic Development Zone is evident. Various types of landscape patches in the region have achieved a balanced distribution. The connectivity between these patches has strengthened, forming an effective radiating pattern wherein different landscape patch types influence one another. The focus is on strengthening the construction and management of urban green spaces to further enhance the area (Jiang et al., 2023). In Zhengzhou Economic Development Zone, efforts are underway to establish a diverse and interconnected network of green spaces. This approach involves creating a green-space structural model that incorporates the elements corridor, belt, and point. A multilevel green space system is created by combining these elements. Such a system incorporates parks and city squares lined by waterfronts, roads, and protective greenery as focal points. Large ecological green spaces are integrated seamlessly into the landscape. The concept of sponge city is also embraced. The natural environmental characteristics of urban green spaces endow them with the functions of rainwater retention, infiltration, and purification, which is partially consistent with the measures of controlling rainwater in sponge cities and is an important carrier of sponge city construction (Gao et al., 2023). Along the riverbanks in Zhengzhou Economic Development Zone, ecological riverfront buffer zones are being constructed. These zones serve a dual purpose by purifying rainwater and allowing it to naturally infiltrate the ground before reaching the river, thereby improving water quality.

The ESVs of cultivated land and bare land have been steadily decreasing since 2010, whereas the ESVs of forest land and waters have been gradually increasing. Comprehensive measures have been implemented to address these trends and promote environmental well-being. Dust pollution prevention and control efforts have been intensified to enhance the air quality in the park. Rigorous water quality monitoring has been established, and the water pollution control facilities operated by water-related enterprises are strictly supervised. Increased efforts have been directed toward investigating and managing outfalls to strengthen the prevention and control of water pollution and enhance the overall water quality in the area (Liu, 2020). A systematic approach has been adopted to prevent and control soil pollution. Collaborative efforts are underway to conduct detailed investigations of soil pollution in agricultural lands, which can lead to the development of robust soil environment monitoring capabilities (Gao, 2019). This collective endeavor aims to maintain the overall quality of the soil environment at a stable level and effectively reduce soil environmental risks. The park has also focused on

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enhancing its environmental risk management capacity. This task includes intensive training for emergency personnel and regular emergency drills to ensure preparedness. In essence, the whole production process of the eco-industrial demonstration park constitutes a huge and complex industrial chain (Wang, 2018). Stringent supervision of pollutants is being implemented, and an Internet management system based on the characteristics of the region has been established for solid waste pollution prevention and control. The treatment of hazardous wastes has been standardized to alleviate functional pressures in the region and ensure the safety of the industrial chain cycle.

Over the past decade, Zhengzhou Economic Development Zone has witnessed remarkable progress in its economic development and ecosystem. From 2010 to 2019, the socioeconomic development composite index of the zone surged from 0.001 to 1.043. The ecosystem development composite index experienced a notable increase from 0.250 to 0.816. The coupled degree of coordination increased from 0.129 to 0.960. This upward trend was further underscored by the consistent expansion of the industry types and the gradual improvement in industrial efficiency in the park. As time passed, the mutual promotion effect between socioeconomic development and ecosystem development became increasingly pronounced. Regions also need to improve the quality of the ecological environment while ensuring economic development, and promote the healthy and coordinated development of ESV and the economy (Chen et al., 2023). This synergy catapulted the economic system of the zone to new heights and provided a conducive environment for regional enterprises. It has driven the neighboring economic market as well. Embracing a vision of green development, the zone is actively building a robust industrial chain and enhancing the value of supply chains. Emphasis is placed on digital transformation and the development of informationization, intelligentization, and clustering within enterprise communities. The zone is strategically focusing on the unique characteristics of the digital era. It integrates innovation into the composition of enterprises residing in the eco-industrial demonstration park. Furthermore, the zone is implementing forward-thinking strategies, such as intelligence+, green+, and culture+. These initiatives not only drive innovation and intelligence within enterprises but also prioritize sustainability and cultural enrichment, thus ensuring a holistic approach to development.

Conclusions

In this study, optimization strategies were proposed based on the results on landscape patterns and changes in ecosystem service values. First, the regional land planning for the eco-industrial demonstration park should be revised. The land use structure and method should be optimized while focusing on the improvement of the ecological environment. Second, the ongoing effort to construct an eco-green space should be intensified to establish a robust urban eco-greenland network for improving the overall urban landscape (Li et al., 2022). Third, the environmental management within the park should be strengthened. Environmental quality should be emphasized, and effective environmental risk management and monitoring practices should be implemented. Last, the advantageous location of the park should be utilized to create a sustainable ecological industrial chain that will support the growth of an environmentally balanced industrial cluster that encourages interactions among the economy, ecology, and culture (Luo, 2021). These undertakings can facilitate the integration of regional industries with the ecological environment, resulting in the synergistic development of the socioeconomic system and ecological environment.

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