Article

Trade-off and coordination between development and ecological protection of urban agglomerations along rivers: a case study of urban agglomerations in Shandong section of the lower Yellow River

Anbei Liu [1], Tingting Yan [1,*], Shengxiang Shi [1], Weijun Zhao [1], Sihang Ke [1] and Fangshu Zhang [1]

[1] School of Civil Engineering and Geomatics, Shandong University of Technology, Zibo 255000, China; 20120905047@stumail.sdut.edu.cn (A.L.); Yanting@sdut.edu.cn (T.Y.); 21110905002@stumail.sdut.edu.cn (S.S.); zhaoweijun@sdut.edu.cn (W.Z.); 20110905010@stumail.sdut.edu.cn (S.K.); 20120905057@stumail.sdut.edu.cn (F.Z.)
Corresponding author E-mail: Yanting@sdut.edu.cn (T.Y.)

Abstract: The rapid development of urban agglomerations along rivers has a great impact on the realization of rivers, urban ecological quality and human well-being. The quantitative research on the intensity change of land use structure and the Ecosystem service supply (ESS) in this geographical unit is still limited. The results showed that: (1) the farmland area continued to decrease and the construction land area continued to increase in the past 20 years, and the intensity of land use change was the highest from 2005 to 2010; (2) ESS continues to rise in the past 20 years, and the income in 2020 will be 11.142 billion yuan, an increase of 31.13%. The "low-value area" is mainly located in Liaocheng City, Dezhou City and Tai 'an City, with plain terrain as the main type of land use; the "high-value area" is primarily situated in the counties and cities along the Yellow River, encompassing the northern Haikou region and the southeastern hilly mountainous areas. The predominant land use types in these regions are waterbody, forestland, and grassland; (3) The ESSV concentration areas were primarily localized in the northern estuary area and along the Yellow River displaying a scattered point-like pattern. Over time, the spatial distribution of hot spots became increasingly concentrated, transitioning from points to planes. Conversely, the cold spots initially increased in number before subsequently decreasing. The waterbody was the most sensitive factor of ESSV; (4) Under the comprehensive action of multiple factors, ESSV showed significant spatial heterogeneity, in which NDVI and POP had the strongest explanatory power. The project aims to offer a scientific foundation for optimizing soil spatial patterns, enhancing ecological management, and safeguarding urban agglomeration in the Lower Yellow River region.

Keywords: Lower Yellow River; Land use change; Ecological response; Geographic detector

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Received: date
Revised: date
Accepted: date
Published: date

1. Introduction

In the in-depth study of the risks of ecosystem service supply and demand brought by the rapid urbanization of urban agglomerations, it is found that the conflict between economic development and ecological protection of urban agglomerations along rivers is particularly prominent as a special geographical unit [1]. Economic prosperity has led to continuous urban construction and industrial expansion, encroaching upon natural ecological spaces. This encroachment directly impacts the water quality, water quantity, and biodiversity of rivers. Additionally, it causes a range of ecological and environmental issues, including the reduction of urban green spaces and the exacerbation of the heat island effect. These changes have undoubtedly intensified the conflict between both demand and supply for urban ecosystem services, posing a serious threat to residents' quality of life and human well-being [2]. However, few quantitative studies have been conducted on the intensity change of urban agglomerations along rivers during the rapid transformation of land use structure and its impact on ecosystem service supply [3]. At present, China takes ecological protection and high-quality development of the Yellow River Basin as a major national strategic background, and strengthening ecological governance and promoting the development of the basin is the main goal at present. [4] Shandong Province, the sole coastal province in the lower reaches of the Yellow River, serves as a crucial focal point for this study [5].

Ecosystem services (ES) refer to the benefits directly or indirectly obtained by human beings from the structure, process and function of the ecosystem, which are mainly divided into supply services, cultural services, regulation services and support services [6]. Bateman et al. found that the comparable economic benefits of ecosystem services can be measured by calculating the ecosystem supply value (ESS) of ES, providing decision support for planners and promoting biodiversity and sustainable development [7]. Land use change is the main driving force for the quantification of ESS value assessment, and changes in land use area and type affect the value change of regional ecosystem [8]. The research of land use change mainly focuses on the analysis of quantitative structure characteristics and spatial position changes. In the analysis of quantitative structure characteristics, the commonly used methods include transfer matrix [9] and dynamic attitude of land use [10]. However, there are limitations in the application of these methods: the transfer matrix mainly analyzes the difference in the conversion scale between land use categories in a certain period [11]. The dynamic attitude of land use is limited to the analysis of unidirectional conversion. Therefore, an intensity analysis framework was proposed based on transfer matrix, systematically comparing the difference between observed intensity of change and uniform intensity of change at all levels by dividing time intervals, categories and transformation modes, in order to provide deeper insights [12].

Foreign scholar Costanza[6] et al. took the initiative in developing the quantified Ecosystem Services Value for assessment [13], and this method was quickly adopted around the world. Domestic scholar Xie Gaodi et al. found that the evaluation method had defects when applied in China [14]. Based on the type of ecosystem and the characteristics of ecosystem service supply value in China, a scale of ecosystem service value per unit area suitable for China was established. Considering the temporal and spatial differences in ecosystem type and quality, the table of equivalent factors of ecosystem service supply value was revised to provide a more comprehensive and objective assessment method. The research space includes national [15], provincial [16], city and county [17], ecosystem [18] and other scales, and the driving factors that affect the ESSV are determined from the aspects of natural factors and human economic factors. From the perspective of river basins, the Yangtze River Basin [19], the Pearl River Basin [20] and the Yellow River Basin in China all constitute a broad scope of discussion. These studies mainly focus on the spatio-temporal evolution of land use patterns and the quantitative evaluation of ecosystem service supply value. However, the current in-depth analysis of the potential impact factors is still insufficient, and there are few reports on the exploration of the drivers of spatial heterogeneity of the geographic unit ESSV in urban agglomerations along rivers [21]. Most of the studies on land use change and its ecological effects in the lower reaches of the Yellow River Basin focus on the calculation of the value of ESSV and its relationship with land use change, while the studies on spatial heterogeneity and its driving factors are relatively scarce. The geographical detector is an effective method to reveal the driving factors of spatial heterogeneity of a certain phenomenon, as well as the driving contributions of single factor and double factor interaction to spatial heterogeneity [22].

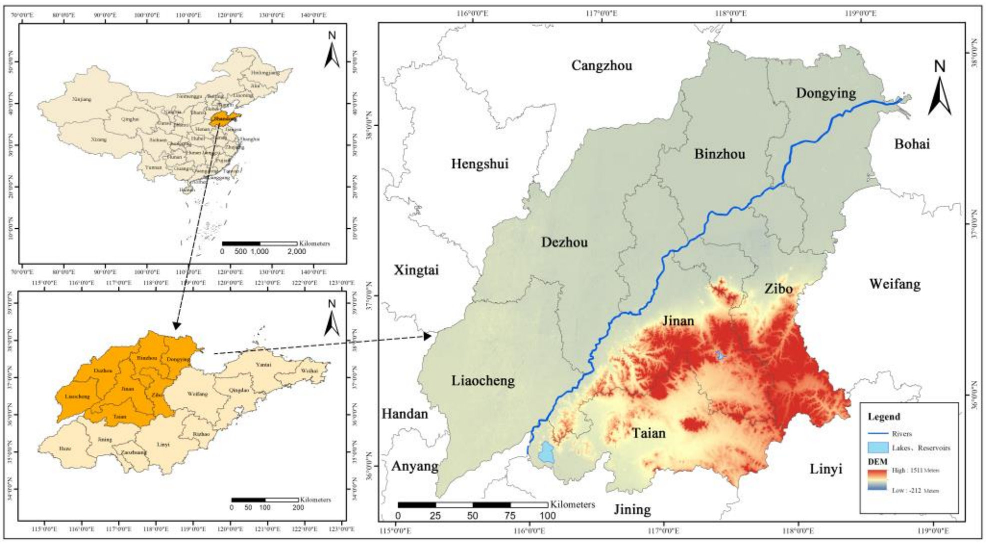
Therefore, the purpose of this study was to analyze the interaction between the intensity of land use change and the value of ecosystem service supply value, and to explore the driving factors of spatial differentiation affecting the value of ecosystem service supply value by using geographic probes, which provided an important basis for the assessment of ecological environmental protection effectiveness, ecological function zoning, environmental and economic accounting and ecological compensation decision-making of urban agglomeration along rivers. It plays an active role in ecological protection and high-quality development of the Yellow River in China.

2. Materials and Methods

2.1. Study Area

In this study, the urban agglomeration in the Shandong section of the lower Yellow River in China was selected as the research area. This area was defined according to actual administrative boundaries, encompassing seven prefecture-level cities—Liaocheng, Tai'an, Jinan, Dezhou, Binzhou, Zibo, and Dongying—and 55 county-level administrative regions (including municipal districts) under their jurisdiction, covering a total area of 59,100 square kilometers. As of 2020, the total population of the region is 37.1156 million, accounting for 2.63% of the total population of the country, and has a high level of urbanization. The research region has a diversified terrain that includes plains, mountains, and hills. The terrain is high in the southeast and low in the northwest, and the elevation ranges from -212 meters to 1511 meters. In view of the high sediment content of the lower reaches of the Yellow River, the channel is prone to siltation, and the river bed is gradually raised, which increases the risk of flood disaster and poses a potential threat to the hydrological and ecological environment. However, with the continuous promotion of the construction of green ecological corridors in the lower Yellow River and the continuous improvement of flood control and disaster reduction engineering system, the ecological environment quality in the region has been significantly improved, and ecological security has been effectively guaranteed.

Figure. 1. Location of the study area.



2.2. Data source and processing

The study included five periods: 2000, 2005, 2010, 2015 and 2020. The remote sensing monitoring data of land use change were collected from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn) with a spatial resolution of 30×30 m. The data were processed by ArcGIS, such as mask extraction and clipping. According to the classification system of Land Use and Land Cover Change (LUCC) of the Chinese Academy of Sciences, the land use types of each year were reclassified, and six types of land use were obtained: farmland, forestland, grassland, waterbody, construction land and unused land. DEM data is obtained from GDEMV2 30M of Geospatial Data Cloud Platform (http://www.gscloud.cn/). Temperature and precipitation data from Shandong statistical yearbook (http://tjj.shandong.gov.cn/col/col6279/). Population and Gross Domestic Product data are from the Resources and Environment Data Cloud Platform (http://www.resdc.cn/) of the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, with a spatial resolution of 1km (2000-2020). For unified spatial reference, the above data are converted to the Krasovsky_1940_Albers projection coordinate system.

2.3. Intensity Analysis

Aldwaik et al. [12] proposed a strength analysis method based on the Markov matrix, including three levels of analysis: time interval, category and transformation. The program is implemented in Excel 2007 (https://sites.google.com/site/in-tensityanalysis/).

The time interval level enables the analysis of the rate of land use change over specified periods. The mathematical expression is formulated as follows:(St represents the overall intensity of land use change during period t, U denotes the average intensity of S_t over time period t, and T indicates the duration of the time period):

$$S_t = \frac{\left\{\sum_{j=1}^{J}\left[\left(\sum_{j=1}^{J} C_{tjj}\right) - C_{tjj}\right]\right\} / \left[\sum_{j=1}^{J}\left(\sum_{j=1}^{J} C_{tjj}\right)\right]}{Y_{t+1} - Y_t} \times 100\% \quad (1)$$

$$U = \frac{\sum_{t=1}^{T-1}\left\{\sum_{i=1}^{J}\left[\left(\sum_{i=1}^{J} c_{tjj}\right) - C_{tjj}\right]\right\} / \left[\sum_{j=1}^{J}\left(\sum_{i=1}^{J} C_{tjj}\right)\right]}{Y_T - Y_1} \times 100\% \quad (2)$$

The category level can be utilized to assess the intensity of land use conversion within specific time intervals. The specific mathematical expression formula is as follows: (G_{tj} is the transfer intensity of land use type j in time period t, L_{ti} is the transfer intensity of land use type i in time period) :

G_{tj}

$$G_{tj} = \frac{\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tjj}\right] / \left(Y_{t+1} - Y_t\right)}{\sum_{i=1}^{J} C_{tij}} \times 100\% \quad (3)$$

$$L_{ti} = \frac{\left[\left(\sum_{j=1}^{J} C_{tij}\right) - C_{tii}\right] / \left(Y_{t+1} - Y_t\right)}{\sum_{j=1}^{J} C_{tij}} \times 100\% \quad (4)$$

The transformation level can analyze the initiation of land use type transformation within a specific time interval. The specific mathematical expression formula is as follows (R_{tim} for the conversion intensity of ground class i to specific ground class n in time t, W_{tn} for the average conversion intensity of other ground classes to specific ground class n in time t, C_{tin} for the conversion scale area of ground class i to specific ground class n in time t, Q_{tm}j for the conversion intensity of specific ground class m to specific ground class j in time t, V_{tm} for the average conversion intensity of specific land class m to land class j during the period t) :

$$R_{tin}=\frac{\left[\left(\sum_{i=1}^{J}C_{tin}\right)-C_{tnn}\right]/\left(Y_{t+1}-Y_{t}\right)}{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J}C_{tij}\right)-C_{tnj}\right]}\times 100\% \tag{5}$$

$$W_{\mathrm{tn}}=\frac{\left[\left(\sum_{i=1}^{J}C_{tin}\right)-C_{tnn}\right]/\left(Y_{t+1}-Y_{t}\right)}{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J}C_{tij}\right)-C_{tnj}\right]}\times 100\% \tag{6}$$

$$Q_{\mathrm{tmj}}=\frac{\left[\left(\sum_{j=1}^{J}C_{tmj}\right)-C_{tmn}\right]/\left(Y_{t+1}-Y_{t}\right)}{\sum_{i=1}^{J}\left[\left(\sum_{j=1}^{J}C_{tij}\right)-C_{tim}\right]}\times 100\% \tag{7}$$

$$V_{tm}=\frac{\left[\left(\sum_{i=1}^{J}C_{tmj}\right)-C_{tmm}\right]/\left(Y_{t+1}-Y_{t}\right)}{\sum_{I=1}^{J}\left[\left(\sum_{\mathrm{i}=1}^{J}C_{\mathrm{tij}}\right)-C_{tim}\right]}\times 100\% \tag{8}$$

2.4. Ecosystem Service supply (ESS) calculation

In this study, land use types are divided into farmland, forest land, grassland, water body, construction land and unused land. Construction land is not considered in this assessment due to its limited contribution to ecological services [6]. Based on the "equivalent value of ecosystem services per unit area of Chinese ecosystem" created by Xie Gaudi et al. [14] (Xie Gaudi et al.), this study calculates the supply value of ecosystem services in the lower Yellow River region [14] and uses two climate productivity factors, temperature and precipitation, to make regional revisions to the supply value equivalent of ecological services in the lower Yellow River region of the Shandong urban agglomeration. The specific calculating formula is as follows:

$$\mathrm{L}=3000+25\mathrm{t}+0.05\mathrm{t}^{3} \tag{9}$$

$$\mathrm{V}=1.05\mathrm{r}/\sqrt{1+(1.05\mathrm{r}/\mathrm{L}+1)^{2}} \tag{10}$$

$$\mathrm{NPP}=30\times\left[1-e^{-0.0000695(V-20)}\right] \tag{11}$$

$$\mathrm{S_q}=\mathrm{NPP_a}/\mathrm{NPP_q} \tag{12}$$

$$E_x=E_y\times S_q \tag{13}$$

$$\mathrm{ESSV}=\sum_{i}^{n}A_i\times \mathrm{E_x} \tag{14}$$

Where: t represents the annual average temperature, ℃; r represents the average annual precipitation, mm; L represents the annual average evaporation, mm; V represents the annual actual evaporation, mm; S_q is the climate difference coefficient; NPP_a is the climatic productivity of the study area, and NPP_q is the national climatic productivity. E_x is the economic value of the unit equivalent factor in the study area, Yuan · hm^{-2}; E_y is the economic value of the national unit equivalent factor, Yuan · hm^{-2}, ESSV is the value of ecosystem service supply in the study area, yuan, i is the type of land use, n is the quantity of land use type; A_i is the area of type i land use. According to the above calculation, the climate difference index S_q of the study area for the years 2000, 2005, 2010, 2015 and 2020 is 0.36, 0.49, 0.41, 0.39 and 0.45, respectively. The average value of 0.43 is taken as the climate productivity from 2000 to 2020. Climate productivity is calculated using an average value of 0.43 from 2000 to 2020. The unit ecosystem service supply equivalent factor in the research region has an economic value of 189.21 Yuan · hm-2 ·. Thus, the value of ecosystem service supply per unit area of the research region was calculated (Table 1).

Table 1. The ecological service supply value per unit area of the study area.

Primary Type	Secondary Type	Farm	Forest	Grassland	Wetland &Rivers and Lakes	Desserts
	Land Use	Farmland	Forestland	Grassland	Waterbody	Unused Land
Supply services	Food prduction	209.07	47.77	44.15	123.93	0.95
	Raw material production	46.36	109.74	64.96	69.06	2.84
	Water resources supply	-246.91	56.76	35.95	1029.28	1.89
Regulatory services	Gas regulation	168.39	360.91	228.31	252.59	12.30
	Climate regulation	87.98	1079.90	603.57	557.21	9.46
	Environment purification	25.54	316.45	199.30	865.62	38.79
	Hydrological regulation	282.86	706.69	442.11	11964.47	22.70
Support services	Soil conservation	98.39	439.43	278.13	306.51	14.19
	Nutrient cycle maintenance	29.33	33.58	21.44	23.65	0.95
	Protection of biodiversity	32.17	400.17	252.91	985.77	13.24
Cultural services	Provision of aesthetic landscape	14.19	175.49	111.63	626.27	5.68
	Total	747.37	3726.89	2282.46	16804.37	122.98

Note: Units, Yuan·hm^{-2}

2.5. Sensitivity Analysis

Ecological sensitivity refers to the degree of response of ecological environment to human activities and natural environment changes [23]. In order to evaluate the applicability of the ecosystem service supply value coefficient, the sensitivity index was selected as an important index, and the elasticity was measured by adjusting the ecosystem service supply value coefficient up and down by 50% to judge whether the research results were accurate and credible. The specific calculation formula is as follows:

$$CS = \left| \frac{\left(P_{ESSV_j} - p_{ESSV_i}\right) / P_{ESSV_i}}{\left(VC_{jk} - VC_{ik}\right) / VC_{ik}} \right| \tag{15}$$

In the formula, P_{ESSVj} and P_{ESSVi} are ESSV before and after the adjustment of the ecological service supply value coefficient respectively, and VC_{jk} and VC_{ik} are the ecological service supply value coefficient before and after the adjustment of the k land class respectively. When CS (Sensitivity index) is greater than 1, it means that the ESSV has a certain elasticity to the value coefficient, and the accuracy and reliability of the research results are low. When CS is less than 1, it indicates that the ESSV is inelastic to the value coefficient, and the research results are accurate and reliable.

2.6. Cold and hot spot analysis

Hot spot analysis has been widely used in ecological environment analysis, where hot spot and cold spot characterize high-value space and low-value space where significant aggregation occurs, respectively. In this study, the hot spot analysis tool (Getis-Ord

Gi*) in ArcGIS 10.8 was used for analysis. The Z-value represented the multiple of standard deviation, and the P-value represented the probability. The specific calculation formula is as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{x} \sum_{j=1}^{n} w_{i,j}}{\sigma \sqrt{n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2}} \tag{16}$$

G_i^* is the local autocorrelation index of region i, $W_{i,j}$ is the spatial weight system of the i and j geospatial units, X_j is the ecological environment quality index, and σ is the standard deviation.

2.7. Geographic Detector

Geographic detector is a statistical method that reveals the drivers of explained variables based on spatial differentiation [24], and can quantify the effect of drivers on the spatial differentiation of ecosystem service supply value (ESSV). This study considered the actual situation of the study area and selected 2 categories of 7 driving factors. The natural driving factors were temperature, precipitation and NDVI, while the human driving factors were GDP, POP, night light intensity and distance from the Yellow River. The natural discontinuous point method was used for discretization and was divided into 10 levels. The precise formula for calculation is as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \delta_h^2}{N \delta^2} \tag{17}$$

In the formula, q represents the influence of a certain driving factor, while σ^2 and σ_h^2 represent the variances of the research region and the sub-area respectively, and N and N_h represent the sample sizes of the study area and the sub-area respectively. The value range of q is [0,1], and the greater the value of q, the greater the explanatory power of driving factors to ESSV, and vice versa.

3. Results

3.1. Spatiotemporal evolution of land use

The farmland area in the study area is the largest, accounting for 78.53% of the total area in 2000. Next is construction land, accounting for 11.24% in 2020. The main change trend of land use types in the study area from 2000 to 2020 is that the area of farmland, grassland, and unused land gradually decreases, while the area of forestland, construction land, and waterbody gradually increases (Figure 2-3). Among them, the decrease in farmland is the largest, 7.32%, the increase in construction land is the largest, 76.59%, and the overall change of waterbody is the smallest. Mount Tai stands at the intersection of Jinan, Zibo, and Tai 'an in the southwest of the study area. The terrain is characterized by rugged and mountainous landscapes. The primary land use types are forestland and grassland, both of which showed a moderate increasing trend from 2000 to 2020. The waterbody is mainly distributed along the Yellow River, forming a convergence at the estuary, and the overall area increases along the river and the coast. Affected by the location of central urban areas of cities and counties in the study area, the construction land is distributed in a point pattern, and the area continues to expand outward from 2000 to 2020. Within the delineated boundaries for urban development in Jinan City and Zibo City, the area gradually shows a planar distribution as social and economic development progresses. The trend in the change of unused land area was not significant.

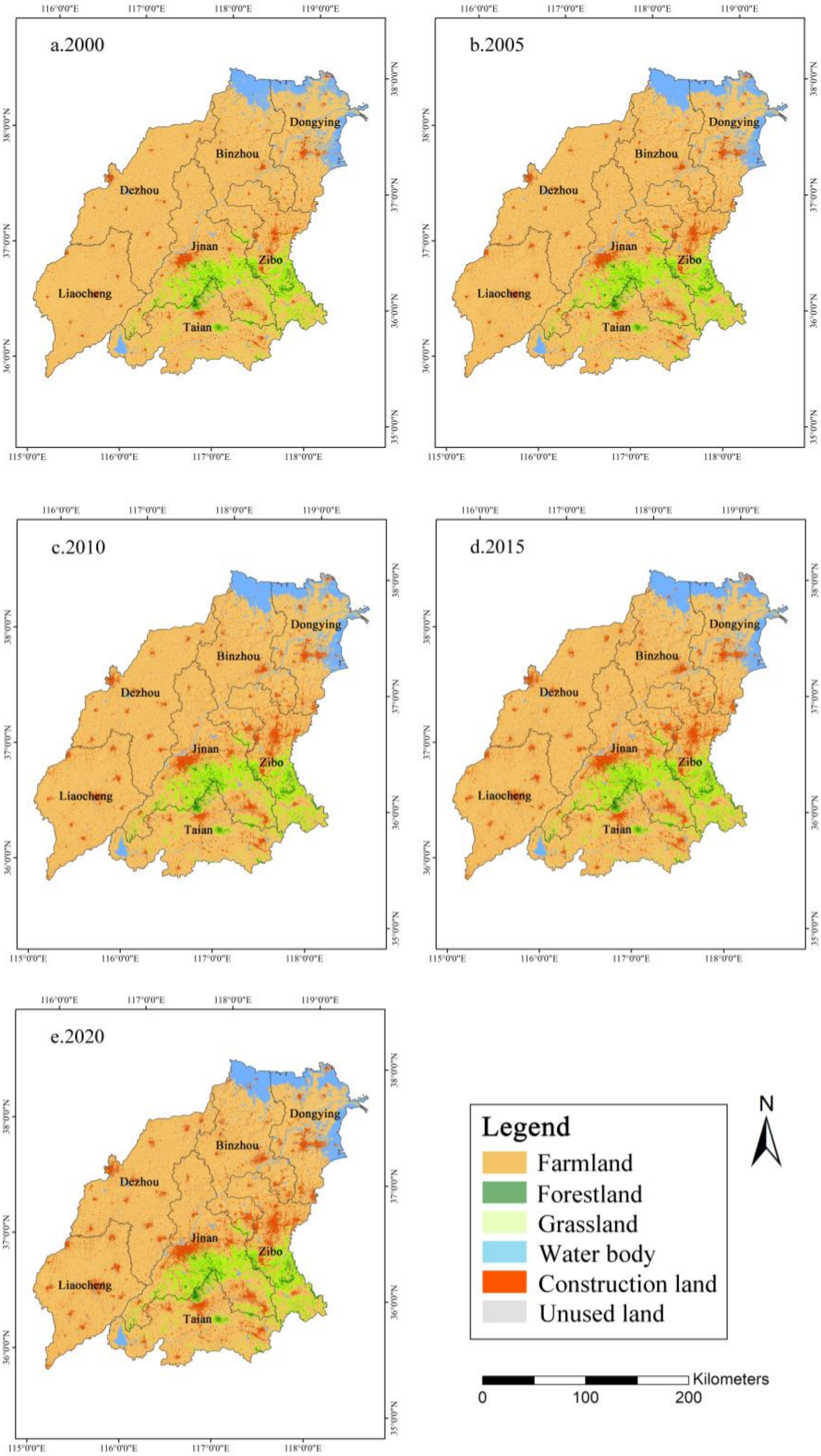


Figure. 2. The land use of the study area in 2000-2020.

The rapid expansion of construction land primarily encroaches on farmland areas, reflecting the process of rapid urbanization. However, high-intensity human activities have led to further environmental degradation and increased ecosystem vulnerability. The transformation of farmland into waterbody reflects the effectiveness of ecological governance in the Yellow River Basin (Figure 2-3). The spatial and temporal distribution of land use is consistent with natural and social conditions.

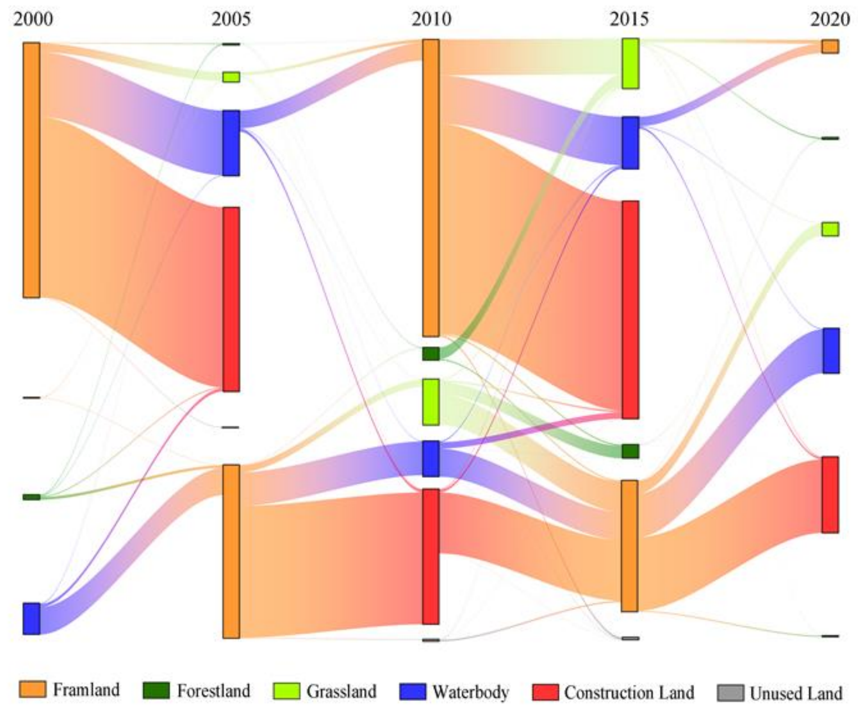


Figure. 3. Sankey map of land use change from 2000 to 2020.

3.2. Figures, Tables and Schemes

3.2.1. Interval level

During 2000-2005 and 2010-2015, the average annual change area accounted for 0.51% and 0.80% of the study area, and the overall development showed an accelerating trend. During 2005-2010 and 2015-2020, the average annual change area accounted for 0.35% and 0.26% of the study area, and the development was relatively slow. The acceleration of development from 2000 to 2005 was closely related to the rapid development of urban economy. From 2010 to 2015, the area and rate of land change reached the maximum due to the Policy of the Connection between the Increase of Urban Land and the Decrease of Rural Construction Land (Figure 4).

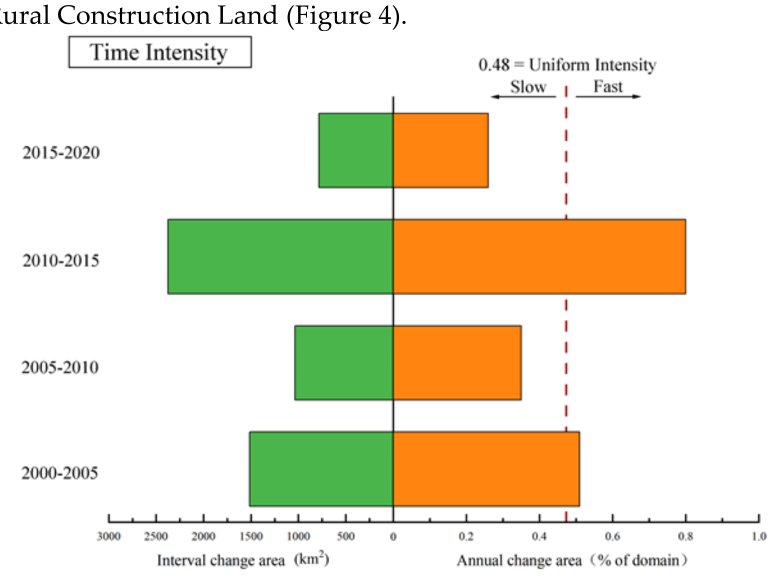


Figure. 4. Time intensity analysis for four time intervals: 2000-2005, 2005-2010, 2010-2015, 2015-2020

3.2.2. Category level

During 2000-2005, the loss intensity of all types of land was small and did not exceed the average intensity, and the largest loss area was farmland. The income intensity of waterbody, construction land and unused land is greater than the average value, and the unused land has the largest income. Although forestland and grassland also have a certain intensity of return, they were not greater than the average.

By comparing the data of 2000-2005 with that of 2005-2010, the transformation intensity of various land use types showed a significant increase during the latter period. Except farmland, the intensity of loss and gain in other land use types exceeded the average level over this time, with the most substantial intensity of loss and gain occurring on unoccupied land. The loss of farmland is the first, followed by the highest gain of construction land, reflecting the rising trend of urbanization. In terms of the unbalanced difference between "gain" and "loss" of land use type, the performance of 2005-2010 is particularly outstanding. From 2010 to 2015, the differences were mainly concentrated in farmland, construction land and waterbody. The income intensity and area of construction land reached the peak, while the area of farmland showed the largest loss. Between 2015 and 2020, the income intensity of unused land, waterbody and construction land has increased, while farmland still remains the largest loss area. Based on the data from 2000 to 2020, it is found that the gain intensity of waterbody, construction land and unused land is generally higher than the average intensity, while the loss area of farmland is always the largest. Other terrestrial classes show unstable change patterns, which indicates that the dynamic changes of local classes are uneven and changeable at the class level.

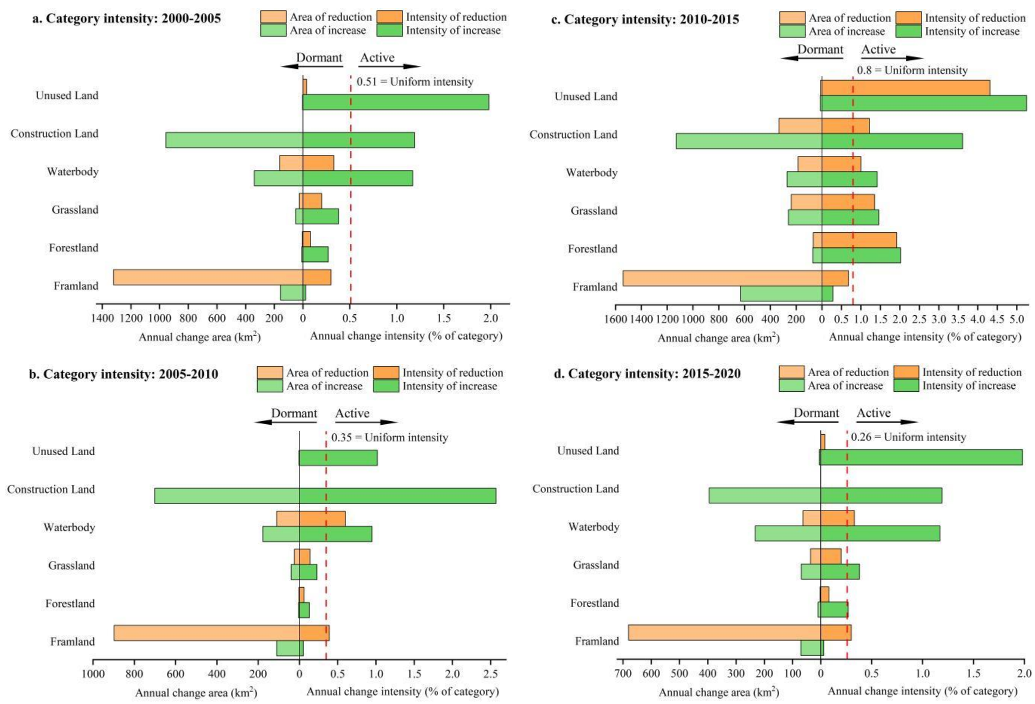


Figure. 5. The category intensity of 2000-2005, 2005-2010 and 2010-2015 are shown in figure a, b, c and d, respectively.

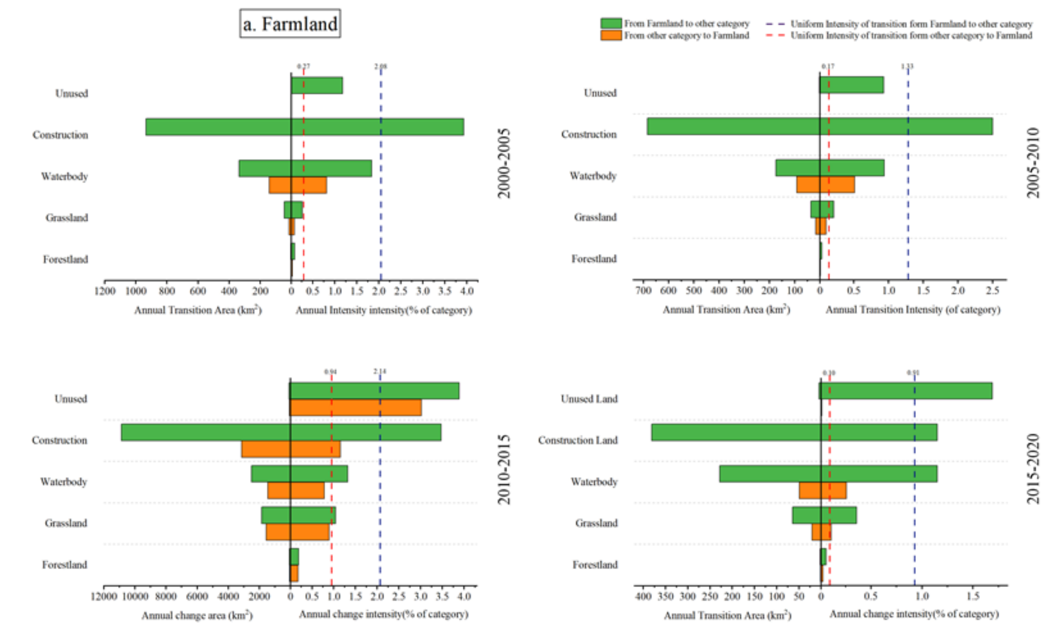
3.2.3. Transformation level

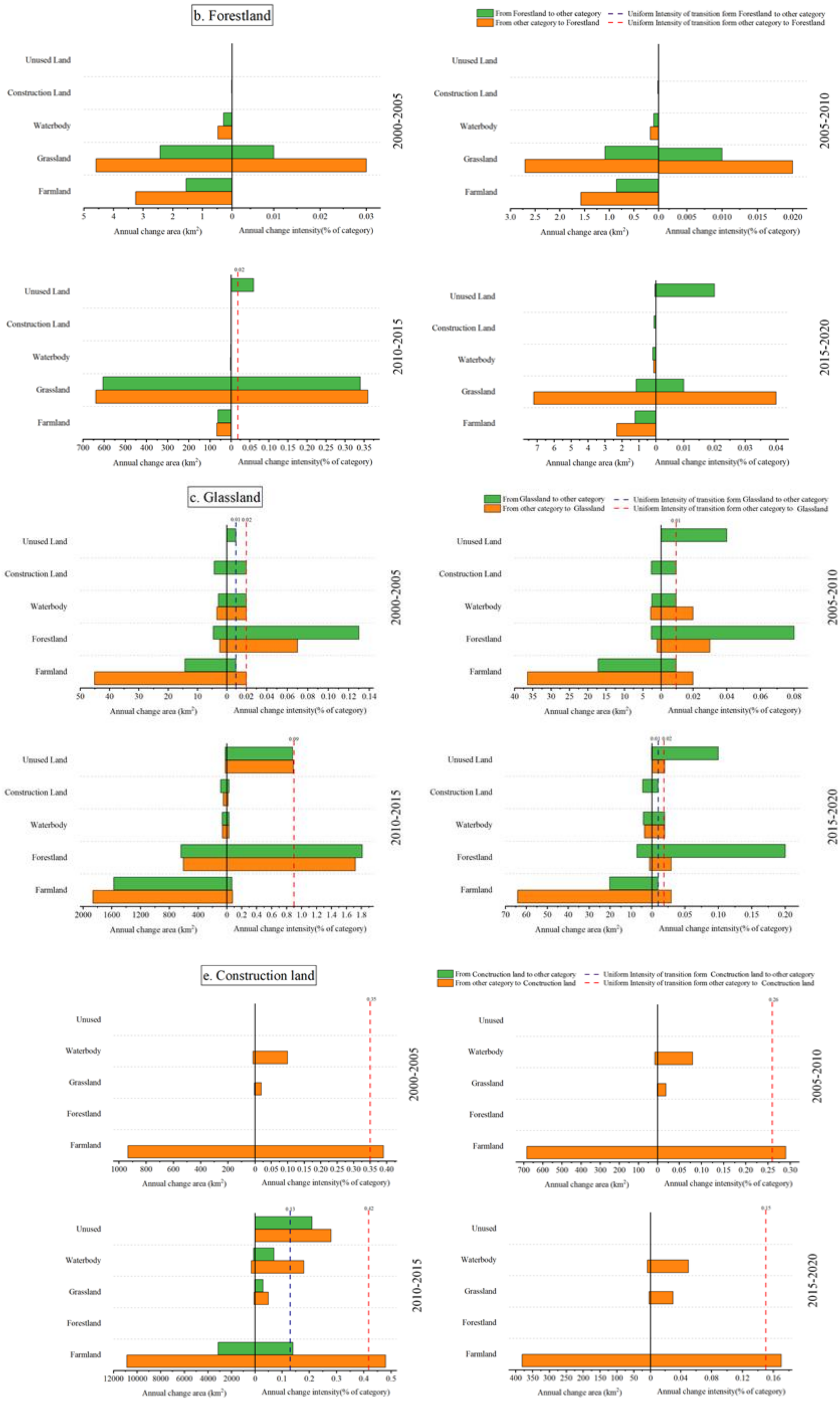
The evolution trend of land use types showed significant changes in the four time intervals. From the perspective of the reduction mode at the transformation level, the intensity of farmland conversion (Figure 6a) into construction land during the four time intervals exceeded the average intensity, indicating significant expansion of construction land during this period, resulting in the occupation of farmland. The intensity of the transformation into waterbody gradually increased due to the further development of the Yellow River regulation action and the consolidation of the later results. From 2010 to 2020, the intensity of conversion to unused land increased more than the average intensity, due to the accelerated urbanization process caused by the loss of rural labor and land wastage.

From the perspective of the increasing pattern of transformation levels, taking waterbody as an example (Figure 6d), the intensity of the transformation from farmland to waterbody was the highest in the four-time intervals, all of which exceeded the average intensity, and the other land classes were all less than the average intensity, except that the unused land had a larger transformation intensity during 2010-2015. Combined with spatial analysis, it can be seen that with the development of ecological remediation actions in the coastal areas of Binzhou City and Dongying City in the north, farmland has been continuously transformed into wetlands, which has promoted the improvement of ecological environment.

The conversion between forestland (Figure 6b) and grassland (Figure 6c) was frequent and more intense than average, which reflected the effectiveness of ecological restoration and land management. Simultaneously, there is also conversion of farmland to grassland and forestland, but the conversion area is unstable, influenced by policies such as "returning farmland to forest" and "returning farmland to grassland," as well as ecological management practices in the Lower Yellow River region.

The transfer of land use types in the study area was mainly concentrated from 2000 to 2015, during which the significant growth of construction land and the significant reduction of farmland were reflected, which was closely related to the strong demand for construction land in the urban development stage and the implementation of the Policy of the "Connection between the Increase of Urban Land and the Decrease of Rural Construction Land". The period from 2010 to 2015 is the transitional period, and there is a two-way transition trend among all land use types. From 2015 to 2020, urban development was gradually stable, the area converted to construction land decreased, and the waterbody area showed an increasing trend but was not significant.




b. Forestland
From Forestland to other category
From other category to Forestland
Uniform Intensity of transition form Forestland to other category
Uniform Intensity of transition form other category to Forestland
Unused Land
Construction Land
Waterbody
Grassland
Farmland
2000-2005
2005-2010
2010-2015
2015-2020
Annual change area (km²)
Annual change intensity(% of category)
c. Glassland
From Glassland to other category
From other category to Glassland
Uniform Intensity of transition form Glassland to other category
Uniform Intensity of transition form other category to Glassland
Forestland
e. Construction land
From Conctruction land to other category
From other category to Conctruction land
Uniform Intensity of transition form Conctruction land to other category
Uniform Intensity of transition form other category to Conctruction land
Unused

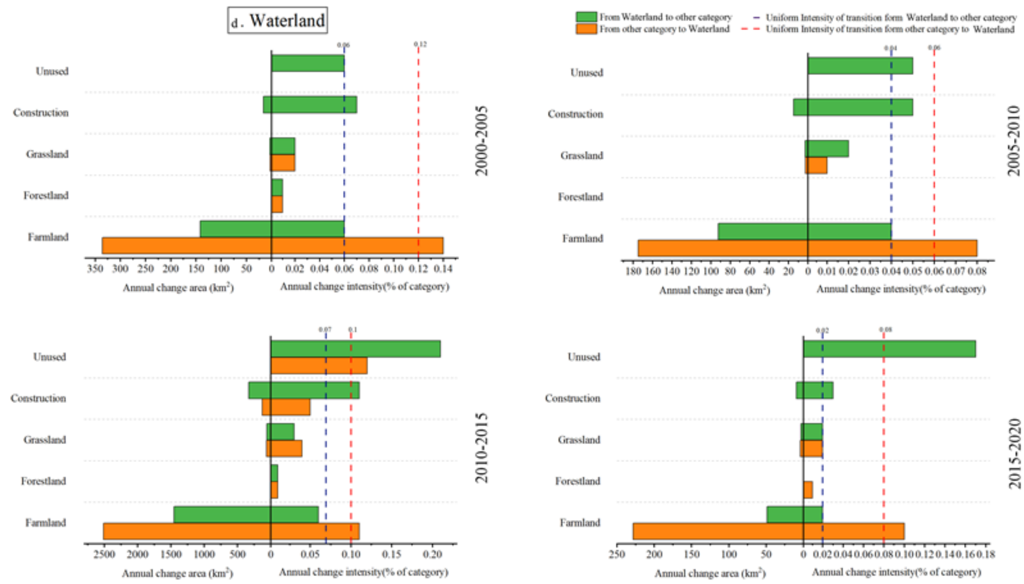


Figure. 6. Transition intensity is given category gains during five-time intervals. The green line and orange line in the figure represent the intensity of the transition from M to other categories and from other categories to M, respectively.

3.3. Analysis of the change of Ecosystem Service Supply Value

3.3.1. Spatial and temporal pattern of Ecosystem Service Supply Value

From 2000 to 2020, the supply value of ecosystem services (ESSV) has shown a steady increase. The specific figures were 8.497 billion yuan, 8.833 billion yuan, 8.935 billion yuan, 8.938 billion yuan and 11.142 billion yuan respectively. During the period from 2015 to 2020, the growth rate of ESSV is particularly significant, which highlights the positive effect of the study area in enhancing the supply value of ecosystem services. From the perspective of land use types, apart from continuous growth in waterbody, the ESSV of other land use types showed a downward trend, primarily due to the loss of farmland, grassland, waterbody, unused land, and other types of land to the expansion of construction land. The ESSV of waterbody dominates the study area and makes the largest contribution, accounting for 59.42% in 2020, followed by farmland, accounting for 25.92%. This change was mainly attributed to the effective implementation of comprehensive remediation actions in the lower Yellow River, which significantly maintained and improved the ecological environment in the study area.

When discussing the spatial distribution and visual expression of ESSV, a 1.5×1.5km grid was selected in the study. The spatial distribution map of ESSV was created by summing the ESSV of different land use types in each grid, and it was categorized into five groups using the natural breakpoint method. The "low-value area" is mainly located in Liaocheng City, Dezhou City and Tai 'an City, with plain terrain as the main land use type, while the "high-value area" is located along the Yellow River and in the northern estuary area, with waterbody as the main land use type. Furthermore, the mountainous and hilly areas in the southwest also exhibit relatively high ESSV values, primarily attributed to the abundant forestland and grassland resources in the region. On the whole, the spatial distribution of ESSV is consistent with the distribution trend of ESSV of a single land use type in a single grid. For a mixed grid containing multiple land use types, its ESSV shows a certain spatial transition.

Based on 55 counties (including municipal districts) in the study area, the temporal and spatial characteristics of ecosystem service supply value in the lower Yellow River region during 2000-2020 were further analyzed. The spatial distribution of ESSV changed little from 2000 to 2005, which was mainly caused by the increase of water body area in

Dongying Estuary area, northern Lijin County, Dongying District and western Kenli District. There was no significant change in the spatial distribution of ESSV from 2005 to 2010. From 2010 to 2015, the waterbody area of Dongying Hekou District and northern Lijin County continued to increase, and the management along the Yellow River in Tianqiao District of Jinan began to take effect, and the supply value of ecosystem services increased. From 2015 to 2020, with comprehensive supervision of soil and water conservation efforts in the Yellow River Basin, the supply value of ecosystem services in the area along the Yellow River increased significantly. The increase of waterbody in the estuary area of Dongying City also made the supply value of ecosystem services reach the highest point in the past years.

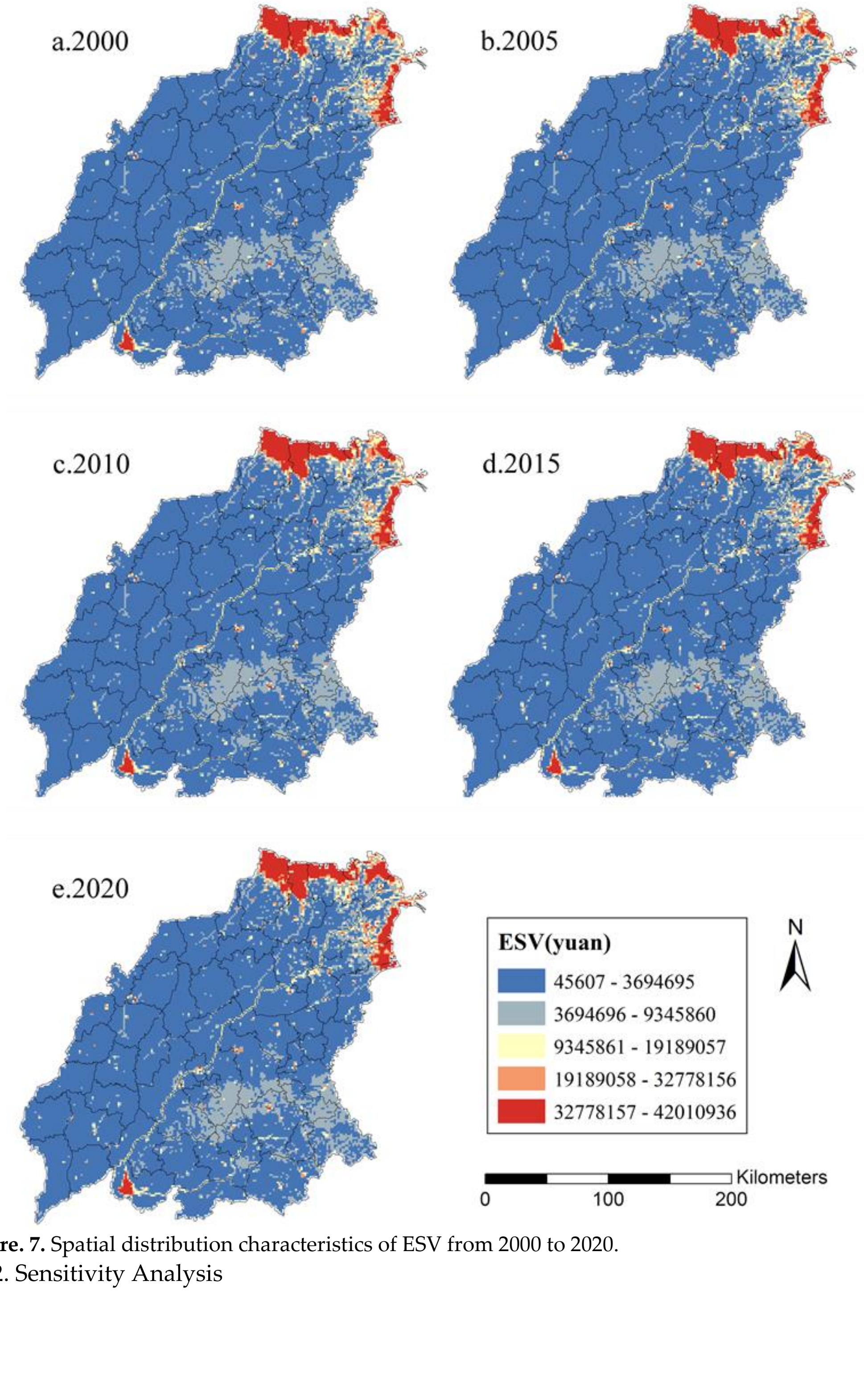


Figure. 7. Spatial distribution characteristics of ESV from 2000 to 2020.

3.3.2. Sensitivity Analysis

In the analysis of the plus or minus 50% adjustment for the ecosystem service supply value (ESSV) coefficient of all types of land use in the study area, the sensitivity index (SI) of ESSV to the value coefficient remained stable below 1 in five consecutive interval years (Table 2). This stable trend strongly suggests that ESSV in the study area is less sensitive to fluctuations in the value coefficient, thus improving the reliability and robustness of the study results. In-depth analysis showed that the value coefficient of ecological service supply (CS value) of water body showed an increasing trend year by year, while the CS value of farmland showed a decreasing trend year by year. In addition, although the CS values of woodland and grassland also decreased, the change was not significant. Combined with recent water protection policies and actions implemented in the Yellow River Basin, this trend reflects the positive impact of ecological protection policies on the supply value of ecosystem services, particularly in water protection areas.

Table 2. Sensitivity index of ESSV in the study area.

Ecosystem	VC	2000	2005	2010	2015	2020	2000-2020
Framland	VC±50%	0.255	0.244	0.238	0.232	0.223	-0.032
Forestland	VC±50%	0.019	0.018	0.018	0.018	0.018	-0.001
Grassland	VC±50%	0.057	0.057	0.057	0.057	0.056	-0.002
Waterbody	VC±50%	0.419	0.431	0.437	0.443	0.453	0.034
Unused Land	VC±50%	0.000	0.000	0.000	0.000	0.000	0.000

3.3.3. Cold and Hot Spot Analysis

To deeply explore the interrelation between ecosystem service supply value (ESSV) and land use change, the cold and hot spot analysis method was employed to overlay ESSV in the study area, revealing its spatial clustering characteristics. From 2000 to 2020, the cold and hot spots of ESSV in the study area are concentrated in the northern Yellow River estuary area and the surrounding areas, while the cities and counties in the study area show a scattered pattern (Figure 8).

A series of significant patterns and trends can be observed in the spatial distribution of ecosystem service supply value (ESSV) in the study area from 2000 to 2020. From 2000 to 2005, ESSV hotspots mainly focused on the northern part of the study area, including Hekou County in Dongying City, Diao Township in the northern enclave of Lijin County, the northern part of Wudi County and the northeastern part of Kenli County. The formation of these hot spots is mainly due to the transformation of farmland to water, which significantly improves the ESSV of the region. The cold spots are concentrated in Zhanhua District of Binzhou City, Zouping City, Dongying City, and Zhangdian District of Zibo City, which is attributed to the conversion of extensive farmland and waterbody into construction land, leading to pronounced cold spots. From 2005 to 2010, the range of ESSV hotspots expanded significantly, covering 28 counties in the north of the study area, and forming a point-like distribution in the western and southern counties such as Xiajin County, Wucheng County and Gaotang County. At the same time, the number and extent of cold spots also increased in the central and southern parts of the study area, which is mainly attributed to the destruction and replacement of the original ecosystem by the high-intensity development of construction land. From 2010 to 2015, affected by the Yellow River basin protection policy, hot spots such as the coastal estuary area, Kenli County and Lijin County showed a trend of connecting points, and the number and scope of cold spots decreased, concentrated in Dongying City, Wudi County and Huaiyin District of Jinan City. The overall development of the city is gradually stable. From 2015 to 2020, the hot spots in the northern part of the study area were distributed in a planar manner, and their range and number increased. The cold spots are few and scattered. This illustrates the importance of the conversion of arable land to water for the value of ESSV.

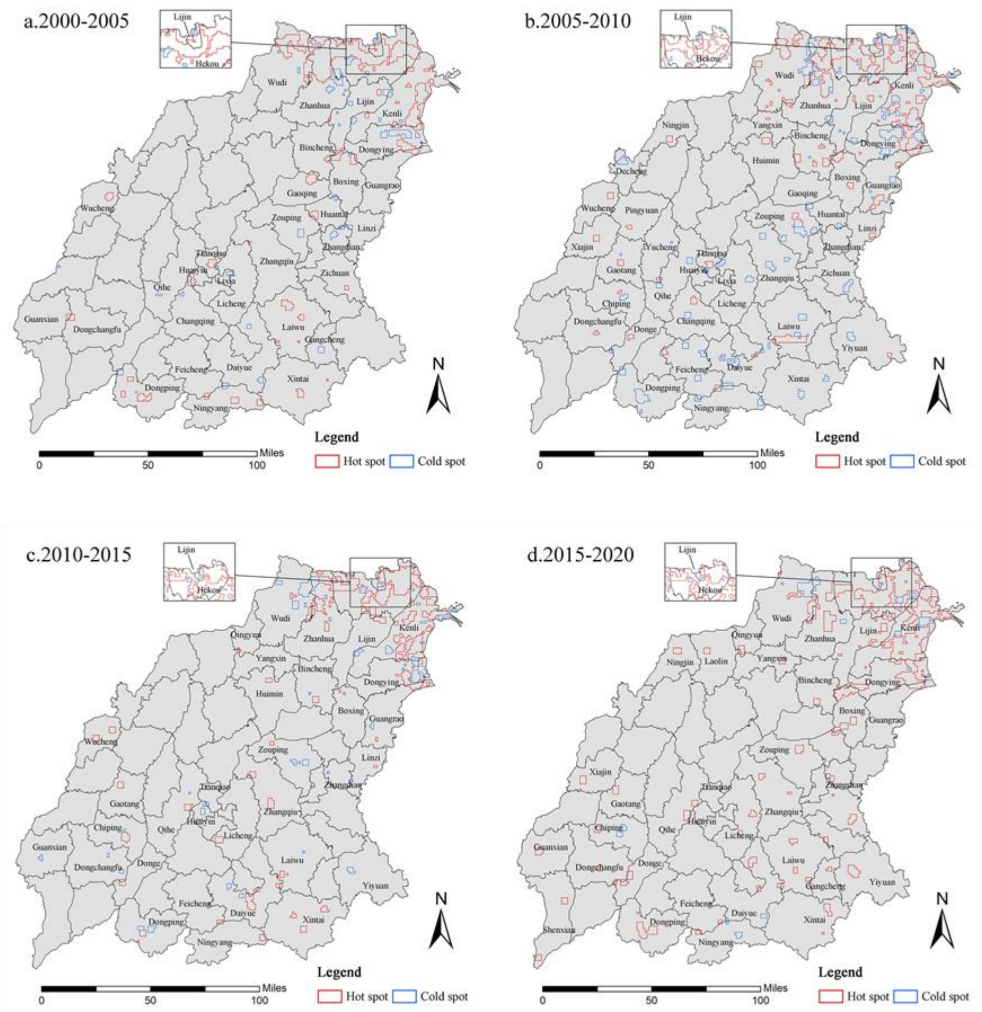


Figure. 8. The land use type transfer and distribution of ESV hotspots fo the study area.

3.4. Driving analysis of spatial differentiation of Ecosystem Service Supply Value

3.4.1. Single factor detection analysis

With ecosystem service supply value (ESSV) as the dependent variable, 7 driving factors including population (X1), average land GDP (X2), precipitation (X3), air temperature (X4), normalized vegetation index (X5), night light index (X6) and distance from the Yellow River (X7) were selected as independent variables from natural environmental factors and social-economic factors. Quantitative analysis was conducted using the "Factor Detector" and "Interaction Detector" functions in the GeoDetector tool. The explanatory power q values of ecosystem service supply drivers from 2000 to 2020 are shown in Figure 9. From the perspective of the overall ranking of factor influence, NDVI, population, temperature and precipitation are the most influential factors from 2000 to 2020, while GDP, night light index and distance from the Yellow River have a certain impact on the supply value of ecosystem services, but the impact is small. Except for the population with the largest q value affecting the ecosystem service supply value in 2000, the largest q value from 2005 to 2020 is NDVI. This reflects that the rapid economic and social development caused by population growth around 2000 has a great impact on the supply value of ecosystem services. After 2005, the supply value of ecosystem services changed mainly due to the influence of natural factor NDVI.

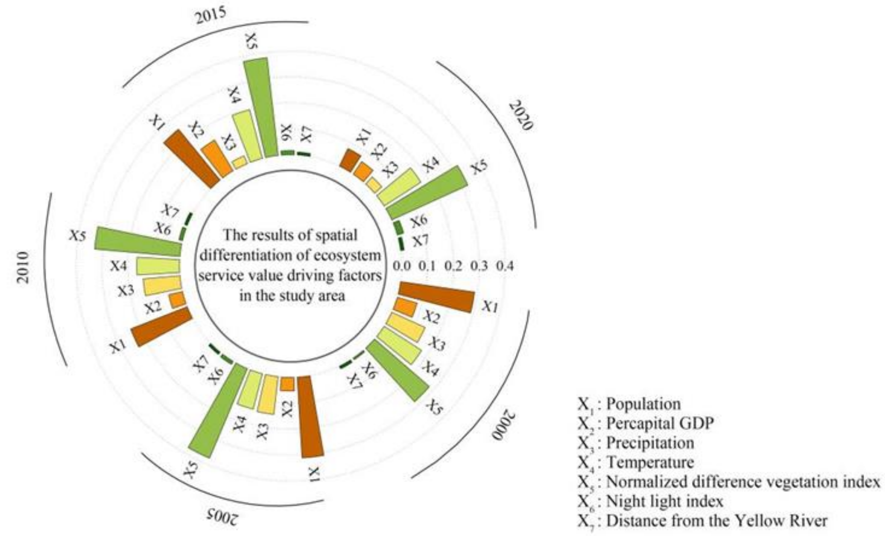
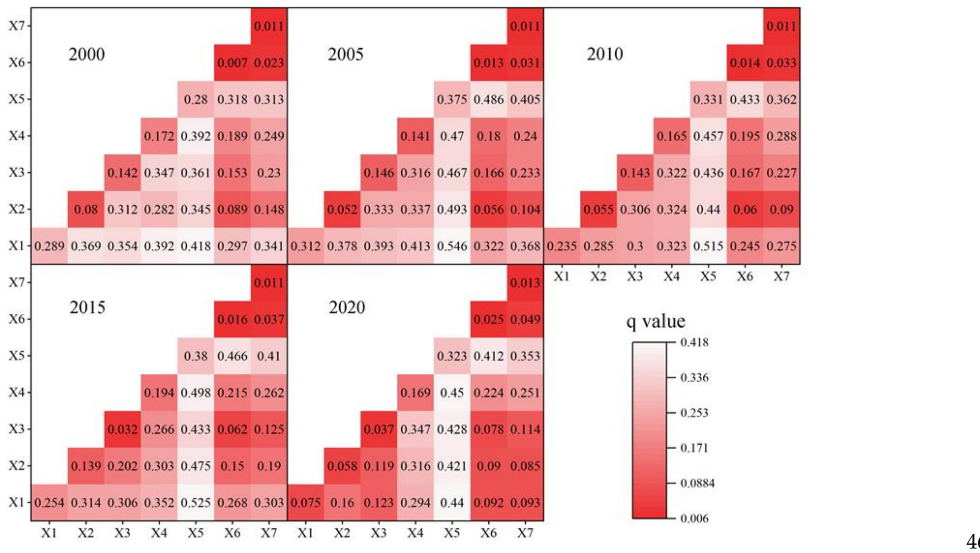


Figure. 9. The results of spatial differentiation of ecosystem service value driving factors in the study area.

3.4.2. Factor interaction detection and analysis

From 2000 to 2020, each driving factor's interaction on the ecosystem service supply value shows nonlinear enhancement and double enhancement, with no independent interaction or nonlinear weakening. This suggests that spatial differentiation in ecosystem service supply value in the study area results from the combined effects of various driving factors rather than a single factor (Figure 10). It can be seen from the figure that the explanatory power of the interaction of driving factors in different years is different. The interaction between NDVI and population has the strongest effect from 2000 to 2015, with a maximum value of 0.546 in 2005, and the interaction between NDVI and temperature has the strongest effect in 2020, with a maximum value of 0.45. At the same time, the explanatory power of population(POP) and per capital GDP factors has increased, indicating that natural factors and social factors work together to change the ecosystem service supply value (ESSV). The interaction of NDVI, POP and other factors has a great impact on the ESSV, which is due to the influence of population policy and the Yellow River regulation action during 2000-2020. A comprehensive analysis of the interaction of POP, per capital GDP, precipitation, air temperature, normalized vegetation index, night light index, distance from the Yellow River and the changes of the single explanatory power q value can be concluded that the future change of ESSV in the study area will be a state of multi-factor synergistic influence.



Note: X_1:Population; X2:Per capital GDP; X3:precipitation; X4:Temperature;X5:Normalized difference vegetation index; X6:Night light index; X7:Distance from the Yellow River.

Figure. 10. The interactive driving effect of driving factors from 2000 to 2020

4. Discussion

In the time span from 2000 to 2020, the land use structure of urban agglomerations in the lower Yellow River has undergone significant transformation. With the acceleration of urbanization and the deep impact of human activities on land resources, the farmland area shows a trend of continuous reduction, and its main flow is waterbody and construction land. Specifically, the area of construction land has experienced significant growth during this period, aligning with the accelerated urbanization observed in the Lower Yellow River region from 1990 to 2020, as detailed in the research by Li Xin et al. [25]. This growth reflects the substantial demand for land resources driven by urbanization and industrialization processes. Under the active promotion of ecological protection policies, the water body area also shows a steady upward trend [26], which is consistent with the implementation of ecological political work in the region. Compared with waterbody and construction land, the changes of grassland and forestland are relatively weak, and there is a certain conversion phenomenon between them. The growth of forestland is mainly due to the conversion of grassland, while the reduction of grassland is partly due to the conversion of farmland and unused land. The conclusion that the area of farmland, unused land and grassland gradually decreases, while the area of construction land, waterbody and forestland gradually increases is consistent with the research conclusion of Zhang Pengyan [22] et al.

Land use intensity analysis has shown higher accuracy in quantifying the internal structural changes of regional urban land use types and the effects of human activities, which has been verified in the study of Ding Xue et al. [27]. Despite its significant advantages, intensity analysis has not fully captured the spatial dimension of change intensity across all levels, thereby limiting its ability to reveal the influence of spatial adjacency on land use change. Therefore, future research should focus on solving this difficult problem in order to reveal the spatial dynamics of land use change more comprehensively.

Spatio-temporal changes of land use further affect the spatial differentiation of ecosystem service supply value (ESSV). From 2000 to 2020, the ESSV shows a trend of continuous increase, but the growth rate is characterized by heterogeneity. This finding is different from the previous research of Liu Chang [28] et al. The reason is mainly due to the difference in the definition of the study area: the former covers the whole of Henan and Shandong provinces in the lower reaches of the Yellow River, while the present study precisely focuses on some cities in Shandong Province in the lower reaches of the Yellow River. This difference reveals the heterogeneity in the spatial distribution of ESSV, and highlights the importance of spatial scale selection for in-depth understanding of ecological protection and promoting high-quality development strategies in this region. Compared with relevant studies in the Shandong section of the Yellow River Basin [29], both of them discussed the relationship between land use change and ESSV in the study area by means of land use transfer matrix and analysis of ecosystem service supply value change, etc. In this paper, land intensity analysis, cold and hot spot analysis of ecosystem service supply value and geographical detector analysis were added. It is helpful to discover the relationship between land use type change and ecological response from the perspective of time and space, and explore its driving factors.

By comparing the research on the value of land use and ESSV in the lower Yellow River, the study has some limitations in the selection of time scale. By not including pre-2000 historical data, the analysis may not fully reveal the long-term evolution of land use and its response to ecosystem services in the study area. To further enhance the comprehensiveness and depth of the study, future studies should consider expanding the time horizon to more fully understand and assess land use dynamics and their potential impacts on the ESSV in the lower Yellow River region.

5. Conclusions

During 2000-2020, the farmland area in the study area continues to shrink, while the construction land area shows a steady growth trend. From 2005 to 2010, the intensity of land use change reached its peak. Meanwhile, the ecosystem service supply value (ESSV) in the study area has continued to develop over the last two decades, reaching a 31.13% increase by 2020, with an overall revenue of 11.142 billion yuan. In terms of spatial distribution, the "low value area" of ESSV change is primarily concentrated in western and southwestern regions dominated by plain terrain, where farmland is the predominant land use type. The "high value area" is distributed in regions along the Yellow River, the northern estuary, and the southeastern mountainous and hilly areas, where land use is primarily waterbody, forestland, and grassland. The geographical distribution of low-value and high-value ESSV areas breaks through the boundaries of traditional administrative divisions. This spatial pattern not only reveals the regional characteristics of ecosystem service supply value, but also has important typical significance and reference value for promoting regional coordination and comprehensive management of ecological protection policies. Further analysis shows that the cold and hot spots of ESSV mainly gather in the northern estuary and the Yellow River flowing through the area, and show a spot-like distribution. The spatial distribution of these hot spots gradually tends to be concentrated, forming a continuous surface area, while the number of cold spots increases first and then decreases under the influence of urban economic development and subsequent ecological management measures. In addition, the transfer of different types of land to construction land and waterbody is the most important land use transformation mode in the cold and hot spot of ESSV, and the waterbody is the most sensitive to the change of ESSV. Considering various influencing factors, including natural factors and human activities, it was found that the ESSV in the study area exhibited significant spatial differences, particularly in the interaction between NDVI and population. This also provides a strong scientific basis for formulating more targeted ecological protection strategies in the future, which is conducive to promoting regional sustainable development.

Author Contributions: Conceptualization, A.L. and T.Y.; methodology, T.Y and W.Z.; software, S.S. and A.L.; validation, A.L., S.K. and F.Z.; formal analysis, A.L.; investigation, S.K.; resources, S.S.; data curation, A.L.; writing—original draft preparation, A.L.; writing—review and editing, W.Z. and A.L.; visualization, A.L.; supervision, W.Z.; project administration, T.Y.; funding acquisition, T.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (41907050); and the Natural Science Foundation of Shandong Province (ZR2023QD030).

Data Availability Statement: The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chen, Z.; Zhang, Q.; Li, F.; Shi, J. Comprehensive Evaluation of Land Use Benefit in the Yellow River Basin from 1995 to 2018. *Land* **2021**, *10*, 643-664, https://doi.org/10.3390/land10060643.
2. Wang, B.; Yang, X.; Dou, Y.; Wu, Q.; Wang, G.; Li, Y.; Zhao, X. Spatio-Temporal Dynamics of Economic Density and Vegetation Cover in the Yellow River Basin: Unraveling Interconnections. *Land* **2024**, *13*, 475-496, https://doi.org/10.3390/land13040475.
3. Cao, Y.; Wang, C.; Su, Y.; Duan, H.; Wu, X.; Lu, R.; Su, Q.; Wu, Y.; Chu, Z. Study on Spatiotemporal Evolution and Driving Forces of Habitat Quality in the Basin along the Yangtze River in Anhui Province Based on Invest Model. *Land* **2023**, *12*, 1092-2109, https://doi.org/10.3390/land12051092.
4. Chang, L.; Shuheng, Z.; Rong, Z.; Xinhan, Q.; Guanglong, D. Land Space Dynamic Changes and Cross-Sensitivity of Ecological Service Function in the Lower Yellow River Reaches. *Journal of Agriculture Resources and Environment* **2023**, *40*, 976-992, https://doi.org/10.13254/j.jare.2022.0604.
5. Cui, J.; Zhu, M.; Liang, Y.; Qin, G.; Li, J.; Liu, Y. Land Use/Land Cover Change and Their Driving Factors in the Yellow River Basin of Shandong Province Based on Google Earth Engine from 2000 to 2020. *IJGI* **2022**, *11*, 163-180, https://doi.org/10.3390/ijgi11030163.
6. Costanza, R.; d'Arge, R.; De Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'neill, R.V.; Paruelo, J. The Value of the World's Ecosystem Services and Natural Capital. *nature* **1997**, *387*, 253–260, https://doi.org/10.1038/387253a0.
7. Bateman, I.J.; Harwood, A.R.; Mace, G.M.; Watson, R.T.; Abson, D.J.; Andrews, B.; Binner, A.; Crowe, A.; Day, B.H.; Dugdale, S.; et al. Bringing Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom. *Science* **2013**, *341*, 45–50, https://doi.org/10.1126/science.1234379.
8. Hasan, S.S.; Zhen, L.; Miah, Md.G.; Ahamed, T.; Samie, A. Impact of Land Use Change on Ecosystem Services: A Review. *Environmental Development* **2020**, *34*, 100527, https://doi.org/10.1016/j.envdev.2020.100527.
9. Zhang, C.; Zhao, L.; Zhang, H.; Chen, M.; Fang, R.; Yao, Y.; Zhang, Q.; Wang, Q. Spatial-Temporal Characteristics of Carbon Emissions from Land Use Change in Yellow River Delta Region, China. *Ecological Indicators* **2022**, *136*, 108623, https://doi.org/10.1016/j.ecolind.2022.108623.
10. Zhao, Q.; Wen, Z.; Chen, S.; Ding, S.; Zhang, M. Quantifying Land Use/Land Cover and Landscape Pattern Changes and Impacts on Ecosystem Services. *International journal of environmental research and public health* **2020**, *17*, 126, https://doi.org/10.3390/ijerph17010126.
11. Qiao, W.; Sheng, Y.; Fang, B.; Wang, Y. Land use evolution information mining in highly urbanized areas based on transfer matrix: A case study of Suzhou, Jiangsu Province *Geographical research* **2013**, *32*, 1497-1507.
12. Aldwaik, S.Z.; Pontius Jr, R.G. Intensity Analysis to Unify Measurements of Size and Stationarity of Land Changes by Interval, Category, and Transition. *Landscape and urban planning* **2012**, *106*, 103–114, https://doi.org/10.1016/j.landurbplan.2012.02.010.
13. Gaodi, X.; Lin, Z.; Chunxia, L.; Yu, X.; Wenhua, L.I. Applying Value Transfer Method for Eco-Service Valuation in China. *Journal of Resources and Ecology* **2010**, *1*, 51–59, https://doi.org/10.3969/j.issn.1674-764x.2010.01.007.
14. Xie, G.; Zhang, C.; Zhang, L.; Chen, W.; Li, S. Improvement of the Evaluation Method for Ecosystem Service Value Based on per Unit Area. *Journal of natural resources* **2015**, *30*, 1243–1254, https://doi.org/10.11849/zrzyxb.2015.08.001.
15. Song, W.; Deng, X. Land-Use/Land-Cover Change and Ecosystem Service Provision in China. *Science of the Total Environment* **2017**, *576*, 705–719, https://doi.org/10.1016/j.scitotenv.2016.07.078.
16. Wu, C.X.; Feng, Y.Z.; Zhao, H.; Bao, Q.; Lei, Y.Q.; Feng, J. Study on Ecosystem Service Value of the Yellow River Basin in Gansu Province Based on Land Use Change. *J. Desert Res* **2022**, *42*, 304–316, https://doi.org/10.7522/j.issn.1000-694X.2022.00130.
17. Li, Y.; Feng, Y.; Guo, X.; Peng, F. Changes in Coastal City Ecosystem Service Values Based on Land Use—A Case Study of Yingkou, China. *Land Use Policy* **2017**, *65*, 287–293, https://doi.org/10.1016/j.landusepol.2017.04.021.
18. Huang, J.; Hou, L.; Kang, N,; Liu, H.; Lv, X.; Zhang, Y.; Qiu, H.; Gong, Y.; Nan, Z. Research on evaluation of economic value of grassland ecosystem services. *Chinese engineering science* **2023**, *25*, 198–206, https://doi.org/10.15302/J-SSCAE-2023.01.015.
19. Wang, Y.; Gu, X.; Yu, H. Spatiotemporal Variation in the Yangtze River Delta Urban Agglomeration from 1980 to 2020 and Future Trends in Ecosystem Services. *Land* **2023**, *12*, 929-948, https://doi.org/10.3390/land12040929.
20. Liu, W.; Zhan, J.; Zhao, F.; Yan, H.; Zhang, F.; Wei, X. Impacts of Urbanization-Induced Land-Use Changes on Ecosystem Services: A Case Study of the Pearl River Delta Metropolitan Region, China. *Ecological Indicators* **2019**, *98*, 228–238, https://doi.org/10.1016/j.ecolind.2018.10.054.
21. Cai, Z.; Zhang, Z.; Zhao, F.; Guo, X.; Zhao, J.; Xu, Y.; Liu, X. Assessment of Eco-Environmental Quality Changes and Spatial Heterogeneity in the Yellow River Delta Based on the Remote Sensing Ecological Index and Geo-Detector Model. *Ecological Informatics* **2023**, *77*, 102203, https://doi.org/10.1016/j.ecoinf.2023.102203.
22. Zhang, Y.; Geng, W.; Yang, D.; Li, Y.; Zhang, Y.; Qin, M. Spatiotemporal evolution of land use and ecosystem service value in the lower Yellow River region. *Transactions of the Chinese Society of Agricultural Engineering* **2020**, *36*, 277–288, https://doi.org/10.11975/j.issn.1002-6819.2020.11.033.
23. Ou, Y.; Wang, X.; Miao, H. Ecological environmental sensitivity and its regional differences in China. *Acta Ecologica Sinica* **2000**, *20*, 9–12.
24. Wang, J.; Xu, C. Geodetectors: Principles and prospects. *Acta Geographica Sinica* **2017**, *72*, 116-134, https://doi.org/10.11821/dlxb201701010.
25. Li, X.; Chen, D.; Zhang, B.; Cao, J. Spatio-temporal Evolution and Trade-off/Synergy Analysis of Ecosystem Services in Regions of Rapid Urbanization: A Case Study of the Lower Yellow River Region. *Environmental Science* **2024**, *11*, 1895-1911, https://doi.org/10.13227/j.hjkx.202309242.

26. Yu, F.; Fang, L. Issues Regarding the Ecological Protection and High-quality Development of Yellow River Basin. *China Soft Science* **2020**, *6*, 85–95.
27. Ding, X.; Zhao, W.; Yan, T.; Wang, L. Response of Ecosystem Service Value to Spatio-Temporal Pattern Evolution of Land Use in Typical Heavy Industry Cities: A Case Study of Taiyuan City, China. *Land* **2022**, *11*, 2035, https://doi.org/10.3390/land11112035.
28. Liu, C.; Tan, Z.; Zhang, X.; Sun, X.; Qie, Y.; Chen, S.; Liu, L. Ecosystem service value and carbon storage of the riparian zone in the lower Yellow River from 2000 to 2020. *Journal of Water Resources & Water Engineering* **2024**, *35*, 90–100, https://doi.org/10.11705/j.issn.1672-643X.2024.01.11.
29. Li, S.; Wang, P. The impact of land use change on the value of ecosystem services in the Shandong section of the Yellow River basin. *Ecological Science* **2023**, *42*, 144–155, https://doi.org/10.14108/j.cnki.1008-8873.2023.06.015.