Coupled and Coordinated Relationship between Land-Use Cover Change and Ecosystem Services Value in Horqin Sandy Land

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Abstract: In this study, an ecosystem service value evaluation method was applied to establish a coupling coordination degree model, quantify the coupling and coordination relationship between land-use cover change and ecosystem service value changes, and examine the impacts of different driving factors on ecosystem service value changes. The results were as follows. (1) In 2020, the coupling degree between these two variables peaked at a level above 0.9. (2) Their coupling degree was one in 2000, indicating a transformative shift and the entry into a new stage during this period within the study area. This study provides valuable information for the development of ecological compensation and restoration strategies within Horqin Sandy Land’s ecological civilization construction and development plan.

Keywords: land-use cover change; ecosystem service value; coupling degree; driving force

1. Introduction

Ecosystems are complex and dynamic systems formed within a specific geographical region through continuous interactions and exchanges of material energy between organisms and the natural environment [1–4]. Ecosystem services comprise the diverse environmental conditions and benefits that can be sustained and fulfilled by humans within an ecosystem [5,6]. Given the increasing demands of humanity and the growing pressures exerted by human activities on ecosystems, it is crucial to enhance the quality and sustainability of ecosystem services to facilitate the mutual development of both ecosystems and human society [7,8]. As human activities continue to expand and deepen, the significance of ecosystem services becomes increasingly prominent [9,10]. Land-use cover change (LUCC) refers to the conversion of natural vegetated landscapes into urban, agricultural [11,12], or other anthropogenic-dominated land uses, primarily driven by natural dynamics or human-induced pressures [13,14]. The ecosystem services value (ESV) represents an economic evaluation of the services and natural capital provided by an ecosystem, reflecting the ecological benefits resulting from LUCC. It is crucial to protect, restore, and sustainably use terrestrial ecosystems and their services as explicitly stated in the United Nations’ 17 Sustainable Development Goals to be achieved by 2030 [15]. However, according to the United Nations Millennium Ecosystem Assessment report, global ecosystem degradation currently stands at approximately 60%, with human activities identified as the root cause of this phenomenon. Over time, population growth, excessive resource exploitation, and escalating environmental pollution have significantly impacted ecosystems [16,17], rendering them increasingly vulnerable to external disturbances. The global environmental crisis not only disrupts the normal functioning of ecosystems but also poses a significant threat to human health. In light of this, public awareness has gradually shifted from solely valuing the market-use value of natural environmental resources to recognizing the detrimental impacts on ecosystem services’ functional benefits [18].
myopic behavior has inflicted severe damage upon ecosystem stability, thereby jeopardizing the ecological foundation that is essential for human survival and development. The numerous conveniences brought about by scientific and technological advancements are no substitute for the diverse benefits provided by natural ecosystems, such as high air quality, water availability, climate regulation, and soil conservation [19]. The survival and development of human society must be based on the safeguarding of ecosystems. Hence, it is imperative to enhance public comprehension regarding the genuine value of ecosystems, bolster ecological environment-protection efforts, and foster the harmonized and sustainable advancement of socioeconomic systems and ecological environments [20]. This not only facilitates a more profound understanding among the public concerning the authentic worth of ecosystem services but also furnishes valuable guidance and reference for various stakeholders, thereby further propelling the comprehensive implementation and execution of ecological preservation endeavors alongside sustainable development work.

In recent years, a plethora of scholars has conducted analyses on LUCC (land-use and land-cover change) and ESV (ecosystem services valuation). For instance, Adjei’s investigation into the drivers of land-cover change in Alabama provides foundational insights for projecting future scenarios across diverse economic and policy landscapes [21]. Utilizing a high-resolution land-change model, Calderón-Loor forecasts forthcoming land-use transitions in Australia over the coming decade [22]. Studies highlight the synergistic impacts of human activities and climate change on land-use dynamics, influencing groundwater resources to varying degrees [23]. Furthermore, machine-learning models offer predictive capabilities for tracking trends in land-use change [24,25], thereby facilitating their integration into holistic frameworks for land-use planning initiatives [26,27]. Shiferaw’s analysis of forest cover’s influence on ESV underscores the efficacy of robust forest-conservation strategies in mitigating pressures on ecosystem services [28].

Horqin Sandy Land, situated on the periphery of China’s monsoon region, exhibits distinct continental characteristics and is a typical agro-pastoral ecotone in Northern China. Its exceptional geographical location and topographic features contribute to its diverse and intricate natural environment evolution and ecological balance maintenance, as well as human production and livelihood adaptability. In recent decades, exacerbated by climatic characteristics and escalating anthropogenic activities, desertification within the Horqin Sandy Land has intensified significantly, rendering it one of the country’s regions most severely affected by desertification. The prevention and control of desertification have emerged as global environmental governance concerns that profoundly impact the future development and survival of humanity. The degraded land environment has lost its essential ecological functions, which are necessary for maintaining ecological balance, posing a significant threat to microorganisms, animals, and plants, with a consequent decline in their populations or even their complete disappearance. The exacerbation of land desertification, coupled with diminishing soil fertility and productivity, has led to reduced crop growth and yield decline, severely impeding local agricultural and animal husbandry development. Faced with such challenges, farmers and herdsmen are compelled to engage in ecological migration in search of a more suitable environment to sustain their livelihoods. This results in a detrimental cycle of “land degradation migration re-degradation”, which further exacerbates desertification and considerably threatens the ecological balance and sustainable development of the region. Moreover, desertification intensification also hampers the local economy’s growth potential, leading to a decline in regional ESVs. Consequently, numerous scholars have been attracted to the quantitative assessment of ESVs for land desertification control in Horqin Sandy Land as the foundation for protecting and restoring the fragile ecological environment within this area [29–31].

Therefore, this study investigates the Horqin Sandy Land, exploring the interconnected dynamics between LUCC and shifts in ESV. Utilizing “3S” technologies and field surveys, the analysis involves interpreting and analyzing remote-sensing data spanning various temporal intervals to delineate the spatiotemporal evolution of land use. The equivalent factor method is applied, adjusting factors and value coefficients based on grain prices and
biomass, to evaluate ESVs and their fluctuations within the study area. Principal component analysis and multiple linear regression are employed for the quantitative assessment of influencing factors, elucidating the primary drivers behind changes in ESVs. Drawing upon land and ecological analyses, a coupling coordination model is developed to integrate the relationship between LUCC and alterations in ESV. This research provides valuable data for formulating ecological compensation and restoration plans in line with the principles of ecological civilization construction and development in Horqin Sandy Land. Moreover, it significantly contributes to promoting the coordinated development of ecology and economy in this region while enhancing its overall competitiveness.

2. Materials and Methods

2.1. Study Area

The research area is situated in the western part of the Northeast Plain of China (42°31′–44°50′ N, 118°31′–124°18′ E), at the confluence of the Greater Khingan Mountains and the eastern extension of the Yanshan Mountains [32], covering a total land area of 64,387.22 km². In terms of administrative divisions, this study covers 17 banners (counties) within the Eastern Mongolian region, primarily concentrated in Tongliao City and Chifeng City, as well as certain portions of Western Jilin Province and Northwestern Liaoning Province (Figure 1). The climate is a temperate continental monsoon climate, and the study area is situated within the temperate-to-semi-arid regions. The annual average temperature is 5.7 °C, with precipitation ranging from 343 to 500 mm per year. The mean atmospheric humidity ranges between 50% and 55%, and the relative humidity fluctuates between 0.3 and 0.5%. The dryness coefficient varies from 1.0 to 1.8, and the annual average wind speed measures between 3.5 and 4.5 m/s. The zonal soils in the study area primarily consist of dark-brown soil, chestnut calcareous soil, and black-loam soil. Non-zonal soils predominantly comprise sandy soil, meadow soil, and saline alkali soil. The zonal vegetation undergoes a transition from typical grazing lands to sparsely forested grazing lands, characterized by representative plant species, such as natural camphor pine, large needle grass, ice grass, birch, poplar, Artemis frigidus, and elm.

![Figure 1. Geographical location of Horqin Sandy Land.](image)

2.2. Data Sources

Remote-sensing image data with a spatial resolution of 30 × 30 m were obtained from the Resource and Environment Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/). Considering the geographical characteristics of the study area and the research requirements, the land-use types were classified into the following seven primary categories: farmland, forest land, grazing land, water area, wetland, construction land, and desert [33] “Land Use Status Classification” standard, using the ArcGIS 10.2. After interpretation and clipping, six-period land-use-type datasets for the study area for 1980, 1990, 2000, 2010, 2020, and 2023 were acquired. The data for 2023 were solely used for analyzing the current land-use status in this region.
Meteorological data were sourced from the National Meteorological Science Data Center (https://data.cma.cn) and primarily comprised annual datasets obtained from 12 meteorological stations in the Inner Mongolia Autonomous Region, spanning the period from 1980 to 2020. The collected meteorological data predominantly encompasses temperature, precipitation, and wind speed, serving as natural indicators for assessing changes in ESVs and analyzing the underlying natural driving forces behind ESV fluctuations.

Socioeconomic data primarily encompassed population statistics, GDP figures, per capita disposable income, agricultural production, and other relevant aspects of the key counties within the study area. These data were predominantly sourced from the “Statistical Yearbook of the Inner Mongolia Autonomous Region” (https://tj.nmg.gov.cn/). Population and GDP statistics were specifically selected from this source as indicators of human factors influencing changes in ESVs, enabling an analysis of anthropogenic driving forces behind ESV fluctuations.

2.3. Methods

2.3.1. Revision of ESV Equivalent Factors and Value Coefficients

Revision Based on Biomass

Due to the unique geographical location and distinct seasonal climate of the study area, the vegetation types, climatic characteristics, and land-use patterns differ from those at the national level. This makes it imperative to further refine and enhance the ESV coefficients in accordance with the actual conditions. From an ecological standpoint, construction activities on land typically result in ecosystem degradation or disruption, leading to diminished ecological service functions. Therefore, the inclusion of construction land in the calculation of ecosystem services was not considered in this study. For the farmland, the biomass correction factor was determined based on both geographical location and the scope of the study area, with an average value of 0.76 for the provinces of Inner Mongolia, Jilin, and Liaoning provinces. As the study area is situated in a northern region dominated by dryland cultivation, other functional value equivalents were chosen for dryland ecosystems. Because the forest vegetation in the study area consists of alternating temperate broad-leaved forests and coniferous forests, therefore, a mixed broad-leaved and coniferous forest biomass correction factor was selected for forest ecosystems. The grazing land primarily comprises meadow and shrub grazing-land types; therefore, an average value representing both types was chosen as the biomass correction factor for grazing-land ecosystems.

Revision Based on Grain Prices

The ESV equivalent factor represents the economic value of the natural grain output from 1 hectare of farmland within 1 year. Based on the analysis results, the economic value of 1 ESV equivalent factor is equal to 1/7 of the average market value of grain in the region. To mitigate potential influences, such as fluctuations in grain prices and currency inflation, on the estimation results, we adopted the average grain price in the study area over multiple years (CNY 1.19 per kilogram), while considering an average grain yield of 6194.04 kg per hectare. Using Equation (1), we calculated that one ESV equivalent factor in our study area amounts to a value of CNY 1052.987.

\[ M = (m \times n) \]  

where \( M \) is the value of one ESV equivalent factor in the study area; \( m \) is the average unit price of major grains in the study area; and \( n \) is the average grain yield per hectare of land in the study area.

The basic price of ecosystem service functions in the study area was calculated using Equation (2), and it was integrated with the revised unit area ESV equivalent within the study area.

\[ D_i = M \times d_i \] 

where \( D_i \) is the basic price of ecosystem service function \( i \).
where $D_i$ is the ESV coefficient; $M$ is different ecosystem service function value equivalent factors; and $d_i$ represents 11 ecosystem service functions, namely food production, raw-material production, water supply, gas regulation, climate regulation, environmental purification, horological regulation, soil conservation, nutrient-cycling maintenance, biodiversity, and aesthetic landscape.

2.3.2. Calculation Method of ESV

The value of ecosystem services per unit area and the total value in the study area were calculated by applying the ESV coefficients derived from Equations (3) and (4). ESV coefficients are determined by the following expressions:

$$ESV_j = \sum_{j=1}^{k} A_j \times VC_j$$  \hspace{1cm} (3)

$$ESV = \sum_{j=1}^{k} ESV_j$$  \hspace{1cm} (4)

where $j$ represents the six ecosystem categories of farmland, forestland, grazing land, water area, desert, and wetland; $VC_j$ is the total service value coefficient of ecological functions per unit area of the land-use type in the study area (CNY/hm$^2$); $A_j$ is the area of the land-use type in the study area (hm$^2$); and $k$ is the number of land-use types in the study area [11].

2.3.3. Construction and Standardization of Indicator System

Considering the prevailing conditions of the study area, encompassing its socio-economic context, environmental ecology, and economic status, data on land-use types from 1980 to 2020 were employed to establish an indicator system for assessing LUCC. The ESV of the study area was calculated using the equivalent factor method in accordance with local development and environmental conditions. Furthermore, production service value data pertaining to different land-use types from 1980 to 2020 were selected to construct the ESV indicator system [34].

To ensure the accuracy and scientific rigor of the study, the land-use and ESV data within the study area were standardized. This standardization process eliminates any dimensional disparities among different indicators, thereby establishing a unified scale for all data and facilitating subsequent statistical analysis and comparison. In this study, we adopted the “Z-score standardization” method, which can be mathematically represented as follows [35]:

$$Z = \frac{x - \mu}{\sigma}$$  \hspace{1cm} (5)

where $Z$ is the indicator value after standardization; $x$ is a value in the original data; $\mu$ is the mean of the original data; and $\sigma$ is the standard deviation of the original data. The standardized values fluctuate around 0. Values greater than 0 mean that the indicator is higher than the overall average level. Conversely, values below 0 indicate that the indicator is below the average level [36].

2.3.4. Coupling-Degree Evaluation Model

In this study, the coupling coordination degree model was employed to deeply analyze the coupling degree between LUCC and ESVs in the study area from 1980 to 2020 using the following equation [37]:

$$E = \sum_{i=1}^{n} U_i \times W_i$$  \hspace{1cm} (6)

where $E$ is the comprehensive index function of LUCC, reflecting the overall level of land use in the study area (the higher the value, the higher the level of land use and vice versa); $U_i$ is the weight of the i-th indicator in the land-use type in the study area, reflecting the importance of the indicator in the comprehensive evaluation of land use; $W_i$ is the standardized value of the i-th indicator in the land-use type in the study area (standardization eliminates dimensional differences among different indicators, making
them comparable under the same evaluation system); and n is the land-use type in the study area [38].

\[ G = \sum_{i=1}^{n} X_i \times Y_i \]  

(7)

where G is the comprehensive index function of ESVs, reflecting the quality of the ecological environment in the study area (large values indicate that the ecological environment of the study area is in good condition); \( X_i \) is the weight of the i-th ESV indicator in the study area, reflecting its importance in the overall evaluation; \( Y_i \) is the standardized value of the i-th ESV indicator in the study area; and n is the number of ESVs, corresponding to changes in different land-use types in the study area [39].

Based on the LUCC and ESV change index values of the study area, a model was constructed to analyze and evaluate the coupling degree between LUCC and ESVs in the study area using the following equation [40]:

\[ C = |G \times E \times [(G + E)/2]^{-2}|^2 \]  

(8)

where C is the coupling degree with a value range of [0, 1], and 2 is the adjustment coefficient [41]. The value of C directly reflects the coupling strength between LUCC and ESV changes in the study area. Large values indicate that the coupling relationship between the two is tight and the interaction is significant. Low values indicate that the coupling degree between the two is small, suggesting that the mutual relationship between LUCC and ESV changes in the study area decreases.

3. Results

3.1. Spatial and Temporal Distribution of Land Use

Between 1980 and 2020, the farmland area in the study region exhibited a continuous expansion (Figure 2), with a total growth of 733.58 km². The most substantial increase was observed between 1990 and 2000, resulting in an additional area of 367.06 km². This trend reflects the escalating demand for arable land driven by population growth and advancements in agricultural technology. Concurrently, the construction land area expanded from 945.97 km² in 1980 to 1565.79 km² by 2020. Notably, the largest surge occurred between 2000 and 2010, witnessing an expansion of infrastructure-related areas by approximately 329.82 km², thereby highlighting the accelerated urbanization along with increasing demands for housing and transportation.

![Figure 2. Change trend of land use types in Horqin Sandy Land from 1980 to 2020.](image-url)
climate change, and policy implementations such as farmland conversion to forest and grazing-land restoration.

The forestland area exhibited a fluctuating pattern characterized by periods of decline–growth–decline. It decreased by 207.52 km$^2$ from 1980 to 2000, followed by an increase of 664.16 km$^2$ between 2000 and 2010, and a subsequent decrease of 722.68 km$^2$. Overall, it underwent a net decrease of approximately 265.99 km$^2$ over the span of four decades due to fluctuations in forest-management strategies and variations in ecological protection strategies.

The wetland and water areas both initially declined and then increased. However, their overall changes in total area differed. Specifically, the wetland area experienced a decrease of 98.88 km$^2$ between 1980 and 2000 and a subsequent increase of 436.04 km$^2$, resulting in an overall net increase of 337.17 km$^2$. In contrast, the water area decreased by 194.87 km$^2$ between 1980 and 2010, followed by a modest increase of only 25.62 km$^2$, leading to an overall net decrease of 169.25 km$^2$ over the entire period under consideration (1980–2010). These fluctuations can be attributed to various factors, such as changes in water resource allocation, climate-change dynamics, and the implementation of ecological protection policies.

The desert area exhibited an initial increase, followed by a subsequent decrease. It increased by 64.44 km$^2$ between 1980 and 2000 and decreased by 365.35 km$^2$ after the year 2000, with a total net reduction of 300.91 km$^2$ over the span of four decades, reflecting commendable human accomplishments in land use and ecological preservation.

The farmland in the study area is predominantly distributed across the Songliao Plain to the east, along the West Liaoh River in the central region, and within the Songliao watershed to the north. These regions exhibit a level topography and have fertile soil, thereby providing optimal conditions for agriculture (Figure 3). Grazing land is primarily distributed in elevated areas such as the Qilaotu Mountain and the Lunuerhu Mountain, located in the western and southern parts of the study area, respectively. These regions are characterized by favorable temperatures and abundant precipitation, creating optimal conditions for grazing land. The coexistence of desert and grazing land within a similar distribution range reflects the intricate ecological diversity found in the study area. Forest land and farmland are interdependent, predominantly occupying the West Liaoh Plain situated in the central and eastern regions. These forest lands not only provide crucial ecological services, such as wind protection, soil stabilization, and water conservation, but also serve as valuable sources of timber and forest products for the local residents. The main water flow in the study area is predominantly from west to east, with the Xilamulun River and its tributaries, namely the Laoha River and the Jiaolai River, converging into the West Liaoh River before ultimately connecting with the East Liaoh River. This intricate river network forms a distinctive hydrological pattern within the research region. Wetlands are primarily distributed along rivers, encompassing marshlands and swamps, including the Hongshan Reservoir located in the southern part of the study area. These wetland ecosystems not only serve as crucial habitats for various animals and plants but also fulfill vital ecological functions, such as climate regulation and water purification. The construction land is mainly concentrated in both the eastern and central regions of this study area, forming an urbanized zone centered around Tonglia City and Chifeng City. Urbanization has attracted substantial population influxes alongside industrial development, thereby stimulating economic growth throughout the surrounding areas.
3.2. Analysis of LUCC

Between 1980 and 2020, the total area of land-use transfer amounted to 21,910.64 km² (Figure 4), with a gradual decrease. In terms of transfer-out, grazing land accounted for the largest area transferred out, primarily flowing into farmland and desert areas (Table 1). Specifically, the area transferred to farmland was 5132.57 km², whereas that transferred to desert reached 3323.52 km². Additionally, transfers were observed towards forest land (1234.46 km²), wetland (837.58 km²), construction land (216.30 km²), and water areas (55.24 km²), accounting for 11.43%, 7.76%, 2%, and 0.51%, respectively. Farmland ranked second in terms of transfer out, with an area of 36,498.88 km², mainly flowing into grazing land, which accounted for approximately 43.60% of the total grazing-land transfer-out area. The subsequent area consisted of forest land, encompassing a transfer-out region measuring 1081.39 km², which accounted for 29.63% of the grazing-land transfer-out area. The areas converted to construction land, wetland, desert, and water bodies amounted to 386.65, 289.54, 253.40, and 47.40 km², respectively. Notably, the desert transfer-out area amounted to 3488.91 km², with a predominant flow towards grazing land, covering an area of 1591.50 km² in total extent. Furthermore, the desert was converted into farmland (13.61%), wetland (8.10%), forest land (4.35%), construction land (3.00%), and water bodies (0.93%). The wetland transfer-out area measured 1552.91 km², and the wetland was primarily converted to farmland and grazing land, with conversion areas of 761.63 and 435.88 km², respectively. The proportions of wetland transferred to desert, water area, forest land, and construction land were 10.05%, 6.15%, 4.81%, and 1.88% respectively. The transfer-
out area of forest land amounted to 1321.04 km$^2$, and forests were mainly transitioned into farmland and grazing land, with conversion areas of 743.66 and 387.55 km$^2$, respectively, accounting for a total of approximately 29.34%. The proportions of forest land converted to wetland, desert, construction land, and water area were 7.59%, 3.85%, 2.02%, and 0.91%, respectively. The transfer-out area of the water area was 634.63 km$^2$, and water areas were primarily converted to wetlands, with a transfer area of 333.97 km$^2$. The proportions of water area converted to farmland, desert, grazing land, forest land, and construction land were 18.87%, 14.16%, 11.15%, 2.36%, and 0.83%, respectively. The transfer-out area of construction land was 463.61 km$^2$, and construction land was mainly converted to farmland, with a transfer area of 230.92 km$^2$. The proportions of construction land transferred to grazing land, forest land, desert, wetland, and water area were 22.28%, 16.60%, 7.37%, 3.67%, and 0.26%, respectively.

![Chord diagram of land-use transfer matrix in the study area.](image)

**Table 1. Dynamic attitude of land-use in Horqin Sandy Land.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Farmland</th>
<th>Forest Land</th>
<th>Grazing Land</th>
<th>Water Area</th>
<th>Wetland</th>
<th>Desert</th>
<th>Construction Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980–1990</td>
<td>0.1699%</td>
<td>−0.0803%</td>
<td>−0.0548%</td>
<td>−0.1280%</td>
<td>−0.4242%</td>
<td>0.0121%</td>
<td>0.5430%</td>
</tr>
<tr>
<td>1990–2000</td>
<td>0.3732%</td>
<td>−0.1767%</td>
<td>−0.1718%</td>
<td>−0.0055%</td>
<td>−0.3127%</td>
<td>0.0253%</td>
<td>0.8407%</td>
</tr>
<tr>
<td>2000–2010</td>
<td>0.1016%</td>
<td>−0.0452%</td>
<td>−0.2147%</td>
<td>−2.0220%</td>
<td>2.5278%</td>
<td>−0.0960%</td>
<td>3.0505%</td>
</tr>
<tr>
<td>2010–2020</td>
<td>0.0956%</td>
<td>−0.0288%</td>
<td>−0.0848%</td>
<td>0.3555%</td>
<td>0.7284%</td>
<td>−0.1149%</td>
<td>1.0969%</td>
</tr>
<tr>
<td>1980–2020</td>
<td>0.7586%</td>
<td>−0.3276%</td>
<td>−0.5166%</td>
<td>−1.8486%</td>
<td>2.4677%</td>
<td>−0.1751%</td>
<td>6.5522%</td>
</tr>
</tbody>
</table>
From the perspective of conversion, the largest farmland area was 7463.20 km$^2$, and the largest grazing area was 5132.57 km$^2$. The other areas were transferred from wetland, forest land, desert, construction land, and water area, with proportions of 10.21%, 9.96%, 6.36%, 3.09%, and 1.60%, respectively. The transferred grazing area ranked second, with 5031.71 km$^2$, and the area transferred from desert and farmland accounted for 2442.71 and 1591.50 km$^2$, respectively. The other areas transferred from wetland, forest land, construction land, and water areas accounted for 8.66%, 2.05%, and 1.41%, respectively. The transferred desert area accounted for 3907.98 km$^2$, ranking third, and grazing land, farmland, wetland, water area, farmland, and construction land accounted for 85.04%, 6.48%, 4.00%, 2.30%, 3.09%, and 0.87% of the transferred area, respectively. The transferred area of forest land was 2634.18 km$^2$, and the transferred areas of grazing land, farmland, desert, construction land, wetland, and water area accounted for 46.86%, 41.05%, 5.76%, 2.92%, 2.83%, and 0.57%, respectively. The transferred wetland area was 1861.22 km$^2$, and the transferred areas of grazing land, water area, farmland, desert, forest lands, and construction land accounted for 45.00%, 17.94%, 15.56%, 15.19%, 5.39%, and 0.91%, respectively. The transferred area of construction land was 768.85 km$^2$, and this land-use type was transferred from farmland, grazing land, desert, wetland, forest land, and water areas, accounting for 50.29%, 28.13%, 13.62%, 3.79%, 3.47%, and 0.69%, respectively. The transferred water area was the smallest one with 243.50 km$^2$, with transfer rates of 39.21%, 22.69%, 19.47%, 13.26%, 4.88%, and 0.50%, respectively, for wetland, grazing land, farmland, desert, forest land, and construction land.

3.3. Changes in Service Values of Different Ecosystem Types

The total value of ecosystem services in the study area decreased by 2.60% between 1980 and 2020, amounting to CNY 15.82 billion. However, the overall change was not statistically significant (Table 2). From 1980 to 1990, the total ESV experienced a decline of CNY 6.46 billion. During this period, there were decreases in the ESVs of woodland, grazing land, wetland, and water, while slight increases were observed for farmland and desert areas. The changes in ESVs during this decade were primarily driven by alterations in farmland, wetland, and water. Between 1990 and 2000, there was a decrease of approximately CNY 6.87 billion in the total value of ecological services. Similar to the previous period, the woodland, grazing land, wetland, and water exhibited a decline, while there was a slight increase in the ESVs of farmland and desert by CNY 1.52 and 0.05 billion, respectively. The changes in ESVs during this decade were primarily driven by fluctuations in farmland and wetland areas. From 2000 to 2010, the study area experienced a decrease in ESVs of CNY 10.56 billion. Except for farmland and water, all other land types showed increases, with wetlands showing the highest increase of CNY 17.55 billion and water the most pronounced decline of CNY 24.16 billion. The total ESV of the study area increased by CNY 8.07 billion from 2010 to 2020. Specifically, there was a decrease in the ESVs for woodland, grazing land, and desert areas, while wetland and water areas experienced increases of CNY 6.34 and 3.39 billion, respectively. Consequently, the changes in ESVs during this period were primarily driven by alterations in wetland and water coverage. The total ESV in the study area decreased by CNY 15.82 billion, approximately 2.60%, from 1980 to 2020. Except for farmland and wetland, all other types experienced a decline, which was most pronounced for water areas (CNY 22.39 billion). The changes and transfers in wetland, water, and farmland areas primarily influenced the variations in ESVs over these four decades.
### Table 2. Value of individual ecological service functions in the study area from 1980 to 2020 (100 million CNY/year).

<table>
<thead>
<tr>
<th>Year</th>
<th>Statistical Item</th>
<th>Food Production</th>
<th>Raw-Material Production</th>
<th>Water Supply</th>
<th>Gas Regulation</th>
<th>Climate Regulation</th>
<th>Environmental Purification</th>
<th>Biological Regulation</th>
<th>Soil Conservation</th>
<th>Nutrient-Cycling Maintenance</th>
<th>Biodiversity</th>
<th>Aesthetic Landscape</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>ESV contribution rate level</td>
<td>15.14</td>
<td>16.22</td>
<td>17.94</td>
<td>48.27</td>
<td>114.70</td>
<td>47.055</td>
<td>220.61</td>
<td>60.85</td>
<td>5.14</td>
<td>55.49</td>
<td>27.05</td>
<td>609.36</td>
</tr>
<tr>
<td>1990</td>
<td>ESV contribution rate level</td>
<td>15.19</td>
<td>16.18</td>
<td>17.64</td>
<td>48.01</td>
<td>113.80</td>
<td>47.479</td>
<td>197.51</td>
<td>60.57</td>
<td>5.13</td>
<td>54.74</td>
<td>26.64</td>
<td>602.90</td>
</tr>
<tr>
<td>2000</td>
<td>ESV contribution rate level</td>
<td>15.36</td>
<td>16.13</td>
<td>17.44</td>
<td>47.57</td>
<td>112.02</td>
<td>46.840</td>
<td>195.46</td>
<td>60.12</td>
<td>5.11</td>
<td>53.80</td>
<td>26.17</td>
<td>596.03</td>
</tr>
<tr>
<td>2010</td>
<td>ESV contribution rate level</td>
<td>15.39</td>
<td>16.17</td>
<td>16.69</td>
<td>47.70</td>
<td>111.68</td>
<td>46.578</td>
<td>183.21</td>
<td>60.29</td>
<td>5.15</td>
<td>55.49</td>
<td>27.19</td>
<td>585.47</td>
</tr>
<tr>
<td>2020</td>
<td>ESV contribution rate level</td>
<td>15.52</td>
<td>16.22</td>
<td>17.16</td>
<td>47.61</td>
<td>111.49</td>
<td>46.953</td>
<td>188.57</td>
<td>60.46</td>
<td>5.14</td>
<td>56.31</td>
<td>27.73</td>
<td>595.54</td>
</tr>
</tbody>
</table>

#### 3.4. Changes in Individual ESVs

The order of individual service values and contribution rates of ecological services in the study area remained unchanged over the 40-year period (Table 2). In terms of the magnitude of change, hydrological regulation exhibited the highest decrease, amounting to CNY 12.04 billion. Compared to 1980, the service values and contribution rates of food production, aesthetic landscape, biodiversity, and nutrient cycling were higher and increased in 2020. However, other ecological service functions experienced a decline in their individual service values and contribution rates during this period. From 1980 to 2020, hydrological regulation consistently ranked first in terms of its contribution rate to the ecosystem functions in the study area, closely followed by other functions, such as climate regulation and soil conservation, which consistently had the top three, with contribution rates of 61.73%, 61.68%, and 60.66% respectively, accounting for over 60% of the overall service value. Among the individual indicators of ecological service functions in the study area during this period, water supply, raw-material production, food production, and nutrient cycling exhibited lower levels of contribution, ranking at positions 8, 9, 10, and 11, respectively. This indicates that the provision of ecosystem services was considerably less pronounced than the regulation of services and supporting services. From the perspective of changes in the value of individual ecosystem services in the study area, the total ESV of the study area decreased by CNY 646 million in 1980–1990, and the other individual values decreased, except for the increase of CNY 0.053 million in food production. During 1990–2000, the total value of ESV in the study area was still decreasing, with a value of CNY 687 million, except for the increase in food production by CNY 17 million. The other individual values experienced a decrease. From 2000 to 2010, the total ESV in the study area decreased by CNY 1.056 billion. Although the individual values of aesthetic landscape, biodiversity, nutrient-cycle maintenance, soil conservation, gas regulation, raw-material production, and food production all increased by CNY 310 million, the single value of hydrologic regulation alone decreased by CNY 1.227 billion. Therefore, the total value of ecosystem services in the study area was still decreasing. From 2010 to 2020, the total ESV in the study area increased by CNY 807 million, and the values of all individual functions of ecological services increased. This is mainly due to the restoration of wetland and water areas and the reduction in desert area. Therefore, the increase in the ESV during this decade also indicates that the ecological environment of the study area has improved, and the implementation of policies, such as returning farmland to forest, controlling sand sources, and restoring grazing land ecology, has achieved initial results.
3.5. Analysis of the Coupling and Coordination Relationship between LUCC and ESV

Between 1980 and 1990, the LUCC and ESVs of the study area exhibited a high level of coupling (Table 3), and the coupling degree continuously increased, indicating a trend towards a new orderly development by 2000. From 2010 to 2020, the degree of coupling increased, transitioning from a running-in stage to a high-level coupling stage. Notably, in 2020, the LUCC-ESV coupling degree peaked. In terms of coordination, during the period from 1980 to 1990, moderate levels of coordination were demonstrated, as both LUCC and ESV were in a phase characterized by coordinated development. The coordination degree exhibited a range of changes, from 0.6964 to 0.6187, indicating a decrease of 0.0777 and rapidly declining by 0.2768 in the year 2000, leading to a moderately imbalanced state. However, subsequently, the coordination degree began to recover and increased from 0.5063 in the year 2010 to 0.8347 in the year 2020, with a shift towards high coordination during the recovery phase. Furthermore, there were also noticeable changes in ESVs due to land-use alterations, with an initial decline followed by a subsequent increase. Due to a lack of environmental awareness and the prioritization of population and economic development in the initial two decades, the degree of coordination continuously declined until environmental protection attracted more attention in the 21st century. The coordination degree exhibited a consistent upward trend, indicating positive changes in terms of land-use structure and effective protection and restoration measures, which resulted in a fundamental harmony between LUCC and the ecological environment.

Table 3. Degree of coordinated development of coupled LUCC and ESV in study area.

<table>
<thead>
<tr>
<th>Year</th>
<th>Coupling Degree C</th>
<th>Coupling Phase</th>
<th>Coupling Degree D</th>
<th>Coordination Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>0.8332</td>
<td>High-level coupling stage</td>
<td>0.6964</td>
<td>Moderate Coordination</td>
</tr>
<tr>
<td>1990</td>
<td>0.8765</td>
<td>High-level coupling stage</td>
<td>0.6187</td>
<td>Moderate Coordination</td>
</tr>
<tr>
<td>2000</td>
<td>1</td>
<td>Trend towards new and orderly development</td>
<td>0.3419</td>
<td>Moderate imbalance</td>
</tr>
<tr>
<td>2010</td>
<td>0.5884</td>
<td>Run-in stage</td>
<td>0.5063</td>
<td>Basic coordination</td>
</tr>
<tr>
<td>2020</td>
<td>0.9955</td>
<td>High-level coupling stage</td>
<td>0.8347</td>
<td>High coordination</td>
</tr>
</tbody>
</table>

The sustainable development of the study area is closely linked to changes in land use and ESVs. Adjusting land-use types within the study area will inevitably result in corresponding changes to its natural ecosystems, in turn affecting the ESVs provided by these ecosystems. This mutually causal and interdependent relationship has a profound impact on achieving sustainable development goals within the study area. The study revealed a direct correlation between changes in land-use structure and the overall valuation of ecosystem services. Specifically, alterations in water areas, wetlands, grazing lands, and forested regions were primarily responsible for variations in ESVs from 1980 to 2020. Notably, modifications in wetland and water areas emerged as the key driving factors of these changes, significantly contributing (69.46%) to fluctuations in ESVs. Among them, changes in water area had the most significant impact on ESVs, accounting for 38.06% of the total contribution rate, followed by wetland area changes with 31.40%. The contribution rates of grazing land, forestland, farmland, and desert to ESV changes accounted for 13.92%, 10.87%, 5.15%, and 0.59%, respectively. An irrational land-use structure was the main factor contributing to the decline in the total ESV within the study area. Human activities are the key factors impacting land-use-type changes, subsequently impacting ESVs. With urbanization progressing and population growth occurring alongside unsustainable water resource use, there is a continuous reduction in water areas, forested areas, and grazing-land areas, while the construction land and farmland areas are increased. This imbalanced land-use structure necessitates urgent rectification. To optimize the land-use structure, it is imperative to reduce and optimize construction land, rehabilitate grazing land and forest areas, explore new water sources while conserving existing ones, prioritize water conservation as a strategic approach, and expand water bodies to enhance ecosystem stability and service functions. Because of the unique economic policy advantages of the
study area, it is important to foster continuous positive development in the region. In this process, strengthening the construction of the ecological environment is also crucial. It is necessary to effectively protect forestland and grazing land by implementing measures such as safeguarding natural forest resources and practicing rotational grazing on grazing lands. Simultaneously, in economic development and urbanization construction, it is essential to enhance land intensification levels and prevent a decline in ESVs that result from a lag in the land-use structure. Ensuring the rationality and coordination of the land-use structure becomes imperative for achieving the sustainable development of the ecological environment on drivers of changes in ESV in Horqin Sandy Land.

3.6. Study of Driving Factors

3.6.1. Wind Speed

The meteorological data utilized in this study originate from the National Meteorological Science Data Center (https://data.cma.cn//), drawing upon annual datasets spanning 1980 to 2020 from 12 meteorological stations situated within the Inner Mongolia Autonomous Region. These datasets encompass critical variables, including temperature, precipitation, and wind speed, which are crucial for assessing natural indicators of ecosystem service value dynamics and elucidating their underlying natural drivers. The annual average wind speed in the study area exhibited a fluctuating increasing trend. From 1980 to 1990, the average wind speed was 3.07 m/s, while from 2010 to 2020, it reached 3.33 m/s, which is slightly lower than the long-term average of 3.43 m/s. During the period of 1990–2000, there was an increase in the average wind, which reached 3.88 m/s, followed by a slight decrease to an average of 3.50 m/s from 2000 to 2010, both surpassing the long-term average. The increase in wind speed had both positive and negative impacts on the ESVs in the study area. It facilitated the dispersion of air pollutants, thereby enhancing gas regulation and environmental purification processes. The negative impact is evident in the study area’s location within the transitional zone between semi-humid and semi-arid regions. The escalation of wind velocity will result in heightened ground evaporation, leading to a decline in groundwater content, an expansion of sandy land areas, and a further reduction in ESVs.

3.6.2. Temperature

The annual average temperature in the study area showed a fluctuating upward trend, with an average of 6.45 °C from 1980 to 1990 and 6.78 °C from 2010 to 2020, both lower than the long-term average of 6.89 °C. However, the average temperatures were higher than the long-term average during two other periods: at 7.08 °C from 1990 to 2000 and 7.2 °C from 2000 to 2010. The temperature increase had both positive and negative impacts on the ESVs of the study area. On the one hand, higher temperatures lead to an earlier snowmelt, ensuring sufficient irrigation water and an earlier spring planting time, thereby facilitating crop growth. On the other hand, elevated summer temperatures can enhance water evaporation, resulting in a warmer and drier climate. This accelerates land desertification, reduces wetland areas, and consequently diminishes ESVs.

3.6.3. Precipitation

The annual precipitation in the study area exhibited a “rise-fall-rise” trend. From 2000 to 2010, the recorded precipitation was 290.18 mm, which was below the long-term average of 349.65 mm. However, during the other periods, precipitation exceeded the long-term average, with values of 345.45 mm from 1980 to 1990, 382.14 mm from 1990 to 2000, and 376.88 mm from 2010 to 2020. Notably, there was a significant fluctuation in precipitation within the study area from 1980 to 2020. Increased rainfall plays a crucial role in fostering grazing land and natural forest growth while also promoting advancements in agriculture, animal husbandry, and forestry. The expansion of water bodies and wetlands can effectively mitigate soil desertification and degradation, whereas reduced precipitation may result in the shrinkage of natural lakes and seasonal lakes, impacting irrigation for
farmland and, consequently, leading to decreased grain production. Additionally, it can also contribute to the proliferation of grazing land and forest pests and diseases, posing threats to ecosystem development and diminishing their ecological value.

3.6.4. Evaporation Amount

The annual evaporation in the study area exhibited an overall increasing trend. However, when considering the mean values for each stage, it initially increased and then decreased, although the downward trend was not pronounced. From 1980 to 1990, evaporation was 55.41 mm, which was lower than the multi-year average precipitation of 71.66 mm during this period. Subsequently, from 1990 to 2000, it increased to 67.84 mm. From 2000 to 2010 and from 2010 to 2020, evaporation was 81.39 and 79.18 mm, respectively, and both values exceeded their respective multi-year averages. The amount of evaporation is closely correlated with temperature, precipitation, sunshine duration, and other environmental factors. The combined impact of these natural variables resulted in a decrease in the areas of wetlands and water bodies. Wetlands, as vital components of ecosystems, are intricately intertwined with these environmental factors, mutually depending upon and promoting each other. Alterations to wetland landscapes not only lead to a reduced water supply within the ecosystem but also disrupt biota habitats, threatening the survival of numerous species. Simultaneously, such changes further exacerbate rising temperatures, consequently intensifying evaporation rates and perpetuating a detrimental cycle. Driven by this mechanism, the continuous increase in temperature and a decreasing water availability gradually lead to the transformation of original marsh wetlands into grazing land and farmland. This process accelerates land desertification, further compromising the self-restoration capacity of the ecosystem and exerting a significant and profoundly negative impact on ecosystem stability and biodiversity.

3.6.5. Population

Socioeconomic data integrates population figures, GDP metrics, per capita disposable income levels, agricultural production statistics, and related parameters pertaining to the primary banner counties of the Horqin Sandy Land. These data are predominantly sourced from the “Statistical Yearbook of Inner Mongolia Autonomous Region” (https://tj.nmg.gov.cn/), selected to serve as anthropogenic indicators illuminating the impact of human activities on changes in ecosystem service values. Among the socio-economic factors, population is the most critical and dynamic element driving changes in ESVs due to its high degree of mobility. Over the study period, significant fluctuations were observed in the population of the study area, with an increase from 5.9569 million in 1980 to 7.4322 million in 2020. Notably, the highest value was observed in occurred in 2009, reaching a peak of 7.729 million. Over the past 29 years, the total population has increased by 1.7721 million, with a growth rate of 29.74%. This surge in population engenders an augmented demand for land, water, and other natural resources. The relentless expansion of the population places immense pressure on the ecosystem, resulting in excessive exploitation of land and water resources and a decline in biodiversity. These factors can potentially induce alterations in the ecosystem’s structure and undermine its functional capacity. After 2009, the study area experienced a relative lag in economic development, leading to inadequate infrastructure in sectors such as education and healthcare. Consequently, there was a significant out-migration of residents and a subsequent decline in population. This resulted in a downward trajectory for ESVs. However, advancements in technology and increased agricultural efficiency have deepened people’s environmental awareness, fostering a greater participation in ecological conservation efforts. As a result of these combined influences, the total ESVs within the study area exhibited signs of recovery over the past decade.

3.6.6. Gross National Product

The gross national product (GNP) is another important socio-economic factor that affects changes in ESVs. The degrees of land development, land-use types, and efficiency
are directly related to the level of regional economic development. Land is one of the key factors limiting changes in ESVs, and economic development, in turn, affects ESVs. This is particularly significant in ecologically sensitive areas, such as the study area.

From 1980 to 2020, the GNP of the study area increased continuously from CNY 1.71 billion in 1980 to CNY 304.02 billion in 2020, an increase of approximately 178 times, with a total growth of CNY 302.32 billion. Such growth is often accompanied by a higher demand for land resources, deepening the degree of land development and use, and possible changes in land-use patterns, which have a direct impact on ESVs. For example, the expansion of agricultural land may lead to a decrease in the areas of grazing and forestland, thus reducing climate regulation, soil and water conservation, biodiversity, and other service functions. At the same time, pollution emissions during industrialization and urbanization may also cause damage to the ecosystem, further reducing its service value. However, with the increase in environmental awareness, the protection and restoration of the ecological environment during economic development have become a key focus. The government has increased financial investments in ecology, technology, and other areas; implemented a series of ecological restoration projects, which have alleviated the negative impact of economic development on ESV to some extent; and promoted the positive development of the study area.

These factors exert varying impacts on the ESVs of the Horqin Sandy Land. So, in this study, nine indicators, namely annual precipitation, average annual temperature, average annual wind speed, annual evaporation, total population, gross national product, per capita disposable income, grain production, and livestock numbers from the past 41 years, between 1980 and 2020, were selected to explain the factors influencing changes in ESVs in the study area.

3.6.7. Quantitative Analysis of Each Driving Force

This study conducted KMO and Bartlett tests on nine indicators to assess their suitability for factor analysis. The results indicated a significance level of 0, which is less than the threshold of 0.05. The KMO measure was 0.717, and the approximate chi-square was 580.557 with 36 degrees of freedom. These values collectively suggest strong intercorrelations among the selected factors, rejecting the null hypothesis of Bartlett’s test, thereby supporting the suitability for principal component analysis (Table 4).

Table 4. Characteristic value and principal component contribution rate.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Initial Eigenvalue</th>
<th>Extract the Sum of Squared Loads</th>
<th>Rotating Load Sum of Squares</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Percent Variance</td>
<td>Accumulate%</td>
</tr>
<tr>
<td>2</td>
<td>1.765</td>
<td>19.614</td>
<td>71.313</td>
</tr>
<tr>
<td>3</td>
<td>1.115</td>
<td>12.393</td>
<td>83.706</td>
</tr>
<tr>
<td>4</td>
<td>0.765</td>
<td>8.499</td>
<td>92.205</td>
</tr>
<tr>
<td>5</td>
<td>0.399</td>
<td>4.437</td>
<td>96.642</td>
</tr>
<tr>
<td>6</td>
<td>0.210</td>
<td>2.334</td>
<td>98.976</td>
</tr>
<tr>
<td>7</td>
<td>0.081</td>
<td>0.895</td>
<td>99.870</td>
</tr>
<tr>
<td>8</td>
<td>0.011</td>
<td>0.127</td>
<td>99.998</td>
</tr>
<tr>
<td>9</td>
<td>0.000</td>
<td>0.002</td>
<td>100.000</td>
</tr>
</tbody>
</table>

Principal component analysis (PCA) was employed to derive factor variables, yielding eigenvalues and contribution rates for the principal components. An analysis revealed the extraction of three principal components, which collectively account for 83.706% of the variance in ESV changes within the Horqin Sandy Land. This underscores the substantial explanatory power of these components regarding the underlying dynamics of ecosystem services in the region (Table 5).
Table 5. Composition factor and rotational component factor load matrix.

<table>
<thead>
<tr>
<th>Divisor</th>
<th>Original Factor Load</th>
<th>Factor Load after Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ingredient1</td>
<td>Ingredient2</td>
</tr>
<tr>
<td>X1: average annual wind speed</td>
<td>0.172</td>
<td>0.777</td>
</tr>
<tr>
<td>X2: annual precipitation</td>
<td>0.132</td>
<td>−0.249</td>
</tr>
<tr>
<td>X3: average annual temperature</td>
<td>0.291</td>
<td>0.803</td>
</tr>
<tr>
<td>X4: annual evaporation</td>
<td>0.494</td>
<td>0.283</td>
</tr>
<tr>
<td>X5: gross national product</td>
<td>0.938</td>
<td>−0.298</td>
</tr>
<tr>
<td>X6: number of people</td>
<td>0.815</td>
<td>0.409</td>
</tr>
<tr>
<td>X7: per capita disposable income</td>
<td>0.941</td>
<td>−0.284</td>
</tr>
<tr>
<td>X8: food production</td>
<td>0.977</td>
<td>−0.104</td>
</tr>
<tr>
<td>X9: number of livestock</td>
<td>0.946</td>
<td>−0.168</td>
</tr>
</tbody>
</table>

The analysis from the table reveals that Principal Component 1 exhibits a negative association with average annual wind speed and substantial positive correlations with gross national product (GNP), per capita disposable income, grain production, and livestock quantity, each showing loadings exceeding 0.8. Principal Component 2 demonstrates notable positive associations with factors such as average annual wind speed (loading = 0.864), average annual temperature (loading = 0.790), and annual evaporation (loading = 0.450) while displaying a marginal negative correlation primarily with GDP. Principal Component 3 displays a significant positive correlation with annual precipitation (loading = 0.962) and negative correlations with average annual temperature, population size, and livestock quantity. Based on the component factor load matrix, a score coefficient matrix for each driving factor was derived (Table 6).

Table 6. Component score coefficient matrix for each driving force component.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Ingredient 1</th>
<th>Ingredient 2</th>
<th>Ingredient 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1: Annual Average Wind Speed</td>
<td>0.079</td>
<td>0.585</td>
<td>0.389</td>
</tr>
<tr>
<td>X2: Annual Precipitation</td>
<td>0.061</td>
<td>−0.188</td>
<td>0.875</td>
</tr>
<tr>
<td>X3: Annual Average Temperature</td>
<td>0.135</td>
<td>0.604</td>
<td>−0.181</td>
</tr>
<tr>
<td>X4: Annual Average Evaporation</td>
<td>0.229</td>
<td>0.213</td>
<td>0.173</td>
</tr>
<tr>
<td>X5: Gross Domestic Product (GDP)</td>
<td>0.435</td>
<td>−0.224</td>
<td>−0.048</td>
</tr>
<tr>
<td>X6: Population Size</td>
<td>0.378</td>
<td>0.308</td>
<td>−0.072</td>
</tr>
<tr>
<td>X7: Per Capita Disposable Income</td>
<td>0.436</td>
<td>−0.214</td>
<td>−0.046</td>
</tr>
<tr>
<td>X8: Grain Production</td>
<td>0.453</td>
<td>−0.078</td>
<td>0.026</td>
</tr>
<tr>
<td>X9: Number of Livestock</td>
<td>0.438</td>
<td>−0.126</td>
<td>−0.099</td>
</tr>
</tbody>
</table>

Using the score coefficient matrix for each component, we further calculated the score functions for each driving factor.

\[
Y_1 = 0.079 X_1 + 0.061 X_2 + 0.135 X_3 + 0.029 X_4 + 0.435 X_5 + 0.3.78 X_6 + 0.436 X_7 + 0.453 X_8 + 0.438 X_9 \tag{9}
\]

\[
Y_2 = 0.585 X_1 − 0.188 X_2 + 0.604 X_3 + 0.213 X_4 − 0.224 X_5 + 0.308 X_6 − 0.214 X_7 − 0.078 X_8 − 0.126 X_9 \tag{10}
\]

\[
Y_3 = 0.389 X_1 + 0.875 X_2 − 0.181 X_3 + 0.173 X_4 − 0.048 X_5 − 0.072 X_6 − 0.046 X_7 + 0.026 X_8 − 0.099 X_9 \tag{11}
\]

Based on the above three equations, the scores of the three selected principal components were calculated. To comprehensively evaluate the driving forces of changes in ESVs, it is necessary to calculate and obtain their comprehensive scores. In this process, the ratio of the contribution rate of each principal component to the cumulative variance contribution rate is used as the weight, and the three principal components are weighted
and summed to obtain the equation for calculating the comprehensive score of driving forces:

$$Y = (51.699Y_1 + 19.614Y_2 + 12.393Y_3)/82.706$$  \(12\)

Based on Equations (9)–(12), the resulting table presents principal component scores and composite scores representing the various factors influencing the variability in ESVs in Horqin Sandy Land (Table 7).

<table>
<thead>
<tr>
<th>Year</th>
<th>(Y_1)</th>
<th>(Y_2)</th>
<th>(Y_3)</th>
<th>(Y)</th>
<th>Year</th>
<th>(Y_1)</th>
<th>(Y_2)</th>
<th>(Y_3)</th>
<th>(Y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>−3.24</td>
<td>−1.51</td>
<td>−1.17</td>
<td>−2.528</td>
<td>2001</td>
<td>−0.94</td>
<td>1.09</td>
<td>−1.45</td>
<td>−0.540</td>
</tr>
<tr>
<td>1981</td>
<td>−2.88</td>
<td>−1.43</td>
<td>0.17</td>
<td>−2.112</td>
<td>2002</td>
<td>−0.54</td>
<td>1.24</td>
<td>−1.32</td>
<td>−0.238</td>
</tr>
<tr>
<td>1982</td>
<td>−2.70</td>
<td>−0.58</td>
<td>−1.25</td>
<td>−1.989</td>
<td>2003</td>
<td>−0.24</td>
<td>1.26</td>
<td>−0.72</td>
<td>0.040</td>
</tr>
<tr>
<td>1983</td>
<td>−2.54</td>
<td>−1.03</td>
<td>−0.08</td>
<td>−1.822</td>
<td>2004</td>
<td>0.45</td>
<td>1.03</td>
<td>−0.31</td>
<td>0.473</td>
</tr>
<tr>
<td>1984</td>
<td>−2.75</td>
<td>−1.63</td>
<td>0.25</td>
<td>−2.043</td>
<td>2005</td>
<td>0.97</td>
<td>0.84</td>
<td>0.56</td>
<td>0.879</td>
</tr>
<tr>
<td>1985</td>
<td>−2.57</td>
<td>−2.57</td>
<td>0.85</td>
<td>−2.604</td>
<td>2006</td>
<td>0.99</td>
<td>0.87</td>
<td>0.35</td>
<td>0.867</td>
</tr>
<tr>
<td>1986</td>
<td>−2.54</td>
<td>−1.83</td>
<td>0.39</td>
<td>−1.940</td>
<td>2007</td>
<td>1.21</td>
<td>2.07</td>
<td>−1.61</td>
<td>0.994</td>
</tr>
<tr>
<td>1987</td>
<td>−2.34</td>
<td>−1.60</td>
<td>0.27</td>
<td>−1.780</td>
<td>2008</td>
<td>1.61</td>
<td>1.16</td>
<td>−0.51</td>
<td>1.191</td>
</tr>
<tr>
<td>1988</td>
<td>−2.19</td>
<td>−0.23</td>
<td>−1.41</td>
<td>−1.615</td>
<td>2009</td>
<td>1.23</td>
<td>0.32</td>
<td>−1.51</td>
<td>0.611</td>
</tr>
<tr>
<td>1989</td>
<td>−2.02</td>
<td>0.17</td>
<td>−0.85</td>
<td>−1.334</td>
<td>2010</td>
<td>1.43</td>
<td>−1.04</td>
<td>−0.12</td>
<td>0.622</td>
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The comprehensive score reflecting the ESV in the Horqin Sandy Land has demonstrated a notable upward trajectory over time. Prior to 2002, this score predominantly languished in negative terrain, punctuated briefly by positive spikes in 1997 and 1998, before reverting to negative territory. Post-2002, however, there was a marked shift towards positivity, characterized by a fluctuating pattern of growth, which moderated after 2009. Socioeconomic dynamics, notably economic and technological advancements, have played a pivotal role in steering these changes in ESVs. Concurrently, natural influences, such as temperature and wind speed, also exert significant driving forces in this context.

To elucidate the nexus between changes in ESVs within the Horqin Sandy Land and their underlying drivers, a regression analysis was performed employing IBM SPSS Statistic 27. Independent variables comprised factor scores extracted from principal component analyses of the driving factors spanning 1980 to 2020 within the Horqin Sandy Land. Standardized ESV data served as the dependent variable. The resulting multiple regression equation for ESV (F) in the Horqin Sandy Land, relative to each driving factor (\(Y_1, Y_2, Y_3\)), is presented below:

$$F = -0.122 - 0.392Y_1 - 0.266Y_2 + 0.414Y_3 \quad R^2 = 0.718$$  \(13\)

The analysis reveals that 71.8% of the variability in ESVs within the Horqin Sandy Land can be accounted for by the respective indicators. Furthermore, all regression coefficients were found to be statistically significant at levels below 0.05, thereby validating the robustness of the regression model. Examination of the regression equation reveals a negative coefficient for the independent variable (socio-economic factors), suggesting an inverse relationship between socio-economic development and ESVs in the Horqin Sandy
Land. This observation implies that societal progress may inadvertently exert adverse effects on the local ecological environment. Additionally, coefficients for natural factors exhibit both positive and negative variations, indicating that changes in climate affect ESVs in the Horqin Sandy Land in diverse ways, underscoring the unpredictable nature of climate impacts.

4. Discussion

Numerous studies and applications have been conducted on the value of ecosystem services [42]. Most ecosystem service assessments focus on the ecological level, whereas the social or economic aspects are still largely ignored. The accurate and effective evaluation of the value of ecosystem services is currently a research hotspot [43]. With the increase in human activities, such as agricultural production and urban construction, land-use types have undergone rapid changes [44]. Unreasonable land use directly affects the flow of energy and material cycling in the ecosystem [45], leading to the loss of production and ecological functions and, ultimately, destroying the ecosystem services [46]. Against the background of human activities, the global ecosystem is subjected to continuous degradation. The transformation of land-use types is not only related to changes in ground cover but also has an impact on the function and structure of the ecosystem, which in turn, determines the value of ecosystem services. In this study, by investigating the coupling relationship between LUCC and ESVs, the level of rational use and protection of land resources is improved, the effective governance approaches for land desertification in the study area are expanded, and our understanding of the complexity and vulnerability of the sandy ecosystem is improved. Overall, the improvement and sustainable development of the local ecological environment are promoted.

At the beginning of the 1980s, with the promotion of the household contract responsibility system throughout the country, the “Grazing land Law” was officially established in 1985 to determine the pasture contract system. The study area actively responded to national policies and implemented production responsibility systems, including “livestock ownership”, “contract production”, and “contracting of farmland and pasture”. The implementation of these policies greatly stimulated the production enthusiasm of local farmers and herdsmen and promoted the development of agriculture and animal husbandry. However, at the same time, a large amount of land was reclaimed as farmland, resulting in a significant increase in the area of farmland. In addition, numerous herdsmen shifted from grazing to farming, further intensifying the intensity of land reclamation. These reclamation activities occupied large amounts of grazing land, woodland, and wetland, leading to significant area reductions. The reduction of grazing land, woodland, and wetland not only affects the local ecological balance but also has a negative impact on the value of ecosystem services. These ecosystems play an important role in maintaining soil and water, regulating climate, and maintaining biodiversity. Their reduction may lead to soil erosion, water resource reduction, climate-change intensification, and other issues, which in turn, affect the sustainable development of the entire region. Since the 21st century, the country has been placing great importance on the ecological restoration and protection of the study area, with the implementation of a series of ecological restoration projects in this region, mainly including the third and fourth phases of the Three North Shelterbelt Project, the Beijing–Tianjin Sandstorm Source Control Project, the Grain for Green Project, and the grazing-land Ecological Protection Subsidy and Reward Mechanism. These projects provide economic compensation and technical support to encourage herdsmen to participate more actively in grazing-land protection, with the plan to restore some farmland to woodland and grazing land. This not only strengthens the protection of the existing woodland but also effectively increases vegetation coverage by creating large forest land, reducing the grazing-land destruction caused by overgrazing, improving the local ecological environment, and enhancing the value of ecosystem services in the entire region. In the desert area, work, such as wind prevention and sand fixation, natural grazing-land conservation, and vegetation restoration, has been carried out. In the less hilly
area, the Grain for Green Project has been implemented to create a large forest land area. Consequently, the forest-land area increased rapidly between 2000 and 2010, but inadequate follow-up management led to a decrease in the area of woodland between 2010 and 2020. The wetland continued to increase after 2000, while the desert area continued to decrease after 2000. To some extent, this reflects the implementation of these ecological restoration projects and policies, which have significantly improved the ecological environment of the study area.

The manuscript under review exhibits several notable limitations. The remote-sensing data utilized within the study area exhibit constrained accuracy and lack high-resolution imagery. Consequently, this has impacted the precision of land-use type extraction, resulting in classified outputs displaying a margin of error. The study area’s natural setting precludes perfect alignment with administrative boundaries, introducing inherent inaccuracies in the selection of statistical data. To enhance research precision, future investigations should seek more comprehensive data support to mitigate these discrepancies. The analysis of ESV change has been hindered by a limited selection of indicators. Enhancing the robustness of findings necessitates broadening the scope of driving factors to be employed in subsequent analyses.

5. Conclusions

This study focuses on the Horqin Sandy Land, with emphasis on the development of a coupling coordination degree model based on an analysis of LUCC and ESV change. The aim is to comprehensively analyze the systematic coupling relationship between LUCC and changes in ESVs, providing valuable insights into their inter-dependencies. The conclusions are as follows.

From 1980 to 2020, the main land-use types in the Horqin Sandy Land were grazing land, desert, farmland, and forest land. The changes in land-use structure were moderate, with the most significant changes occurring during the period from 2000 to 2010. The areas of farmland and construction land increased, while the grazing-land area decreased. The forest-land area experienced a fluctuation pattern, with a period of decrease, followed by an increase and a subsequent decrease. The water and wetland areas initially decreased and then increased, whereas the desert areas initially increased and then decreased.

From 1980 to 2020, the total value of ecological services in Horqin Sandy Land decreased and then increased. However, during the last decade, there was a modest increase observed. In this region, the value of forest land accounted for the largest proportion and played a pivotal role in providing ecosystem services, whereas the contribution of desert ecological services was low. The individual contribution rates of ecological service functions in Horqin Sandy Land followed the order of hydrological regulation > climate regulation > soil conservation > biodiversity > gas regulation > environmental purification > aesthetic landscape enhancement > water-supply provision > raw-material production support > food-production facilitation > nutrient-cycle maintenance.

Based on the coupling-degree value of LUCC and ESVs in Horqin Sandy Land from 1980 to 2020, three periods, namely 1980, 1990, and 2020, exhibited a coupling-degree value above 0.8. Furthermore, the value for 2020 exceeded 0.9, indicating an excellent coupling degree during this period. Over the course of these four decades, the coupling-degree value experienced an “up-down-up” pattern. This trend signifies a closely linked transformation in ecological service values alongside changes in land-use patterns driven by human activities. Moreover, it reflects how the ecological environment responds to such alterations. These adjustments have contributed to a more rational land-use structure within Horqin Sandy Land while achieving a harmonious development between LUCC and the ecological environment.

The driving forces of ESV changes in Horqin Sandy Land exhibited an upward trend. Socioeconomic factors played a pivotal role in facilitating the transformation of ESVs, particularly with the advancement of the economy, science, and technology, which led to an increasingly significant impact of human activities on the ecosystem. Socioeconomic drivers
have gained increasing importance. Simultaneously, natural factors, such as temperature and wind speed, also considerably promoted changes in ESVs. A negative correlation was observed between social and economic development and ESVs in Horqin Sandy Land, indicating that climate factors had both positive and negative impacts on these changes. Furthermore, it is worth noting that the alteration of the climate environment remains beyond control.

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