Impacts of regional land-use patterns on ecosystem services in the typical agro-pastoral ecotone of northern China

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ABSTRACT

A comprehensive understanding of the spatial-temporal evolution and driving forces on ecosystem services (ESs) is essential for the agro-pastoral ecotone’s ecological security in northern China. However, the land-use pattern (LULC) agglomeration with spatial differentiation in the pastoral and agricultural areas has been rarely concerned. Taking distinct LULC (1980–2018) in Chifeng as an example, we compared four crucial categories of ESs with InVEST. Using SEM, we further contrasted the effects of several variables on regional ES variations in pastoral-dominated (North) and agriculture-dominated (South) regions, respectively. Results revealed the conversion between forest and grassland oriented the LULC transformation in the North. In contrast, human-activity-oriented land tended to occupy environmentally sensitive places in the South. Similar ES variations were supplied with the North outperforming the South when soil conservation was omitted. As for the impacts of regional ES variations, the natural and LULC policies both showed positive effects, whereas the anthropogenic factors showed positive in the North, which was negative in the South. Therefore, the ecologically-maintained-dominant and ecologically-restored-dominant strategies should be separately adopted in the North and South. Our study provided appropriate regional ecological management suggestions for balancing the LULC-driven conflicts between ecological protection and regional development.

Introduction

Ecosystem services (ESs) (Ehrlich, E.a.h, and P 1977) are the products and benefits that people obtain directly or indirectly from ecosystems (Daily 1997). As the natural capital and material basis of human survival and development (Costanza et al. 1997) the ESs provide crucial support for human well-being, play an essential role in coping with regional changes and carrying out sustainable regional development planning. As the necessary carrier of the natural ecological and human social environment, land-use patterns had always been the closest link between humans and the natural ecosystems. With the accelerated global urbanization process, more frequent human activities have led to rapid changes in regional land use/land cover (LULC), which will inevitably change the structure and function of ecosystems in the short term (He et al. 2019a; Wang et al. 2021a). In recent years, the worldwide human-activity-oriented ecosystem degeneration rate has been nearly 60%, according to the Millennium Ecosystem Assessment released by the United Nations 2005. Along with China quickly transforming its social economy and accelerating urbanization, regional LULC has also dramatically changed (Liu et al. 2010), reshaping the natural landscape on the surface and profoundly influencing the expected realization of regional ESs (Dadashpoor, Azizi, and Moghadasi 2019; Zhang, Zhao, and Gu 2014). Therefore, understanding the spatial-temporal evolutionary trends of regional ESs and further exploring ecosystem degradation’s driving factors help policymakers formulate effective protection policies and management plans.

Such activities are vital for the areas in ecologically fragile regions (Fang et al. 2022), where regional development and the environment have been in a delicate balance for a long time. The development potential of these regions is limited, and their ecosystem resilience is weak. They were significantly influenced when the external conditions change unfavorably. Thus, many ecologically fragile areas have faced economic development and ecological protection trade-offs (Panayotou 2016). The agro-pastoral ecotone of northern China (36°01′-49°36′N and 100°45′-124°42′E) (Zhao et al. 2002) has historically been seen as one of the most intense human-environment conflict regions (Han et al. 2018), well-
known as the specific ecologically fragile region by the public. As the interface of agricultural biotechnologies and animal husbandry in China, this region is a substantial production base for high-quality agricultural and livestock products. It provides its residents with economically attainable wares (grain, livestock products), and intrinsic ESs (water retention, soil conservation, carbon fixation, maintenance of biodiversity, climate regulation, degradation of pollutants, etc.) (Liu et al. 2021a). Meantime, this region obstructs southward and eastward desertification to a certain extent as an ecological security barrier, protecting the east-central part from wind and sand and the west from loss of water retention. By the end of 2019, there were more than 70 million people in the agro-pastoral ecotone of northern China, and the maintenance of its ecological security was determined to be significant for China's sustainable development. However, the contradiction between grain production, animal husbandry, urbanization, and environmental protection has been prominent in this region. The conversions of farmland, grassland, and built-up land have been frequent, among which unreasonable land use leads to increasing pressure on resources and the environment, which has profoundly impacted regional development and ESs for a long time. Till now the boundary of the agro-pastoral ecotone moved mainly because of the climate change (Junhui and Jixi 2008) and the decrease of grassland is 6487.79 km² from 2000 to 2018 (Liu, Wang, and Pei 2021b). Therefore, it is necessary to analyze the LULC patterns driven by human activity modes and identify the impacts of LULC changes on ESs in the agro-pastoral ecotone for sustainable regional land-use development in the future.

The continuous degradation in the agro-pastoral ecotone and the decline or loss in regional ESs has led to a greater awareness of the importance of regional ecosystems (Yang et al. 2020). In general, existing studies on the spatial-temporal evolution of regional ESs triggered by land-use patterns in these areas mainly focus on several aspects. 1) Analyze regional degradation from a microscopic perspective (Chen et al. 2021; Yao et al. 2019; Zhou et al. 2007). Such studies analyzed changes in soil structure and elements, biological and ecological mechanisms and biogeochemical processes at the mechanism level. However, such methods rely on selecting samples, which involves the selection of experimental regions, and there is uncertainty to some extent. Previous results can only have reference value and significance for the region at this time, and it is not easy to adapt to different landscape scales. 2) Evaluate the spatial-temporal variation of regional ESs with statistical and mechanical models to quantify the relationships between ecosystem degradation with a single independent variable (Peng, Wang, and Fan 2017), such as climate, urbanization, or terrain. However, this method is relatively simple, and the evaluation results are often one-sided. More sophisticated techniques are gradually replacing them. 3) Monitor LULC changes and study the regional ESs patterns in a large area or at a large scale using remote sensing images (2021; Li et al. 2017; Liu et al. 2021c). However, these studies always treat the study area as the one without concerning the LULC agglomeration with spatial differentiation in the pastoral and agricultural areas, respectively. The variations in ESs caused by the mutual transformation between different LULC modes (pastoral-dominated and agriculture-dominated modes) are also different. Therefore, it is necessary to understand the impacts of distinct land-use patterns on regional ecosystem services based on specific human activity models in the typical agro-pastoral ecotone of northern China.

The application of geospatial analysis techniques in this study ensures the realization of this goal. The Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model was used to assess ESs and has been widely used to illustrate ES results spatially on a map. Currently, the InVEST model is mainly adopted to conduct a quantitative evaluation and trade-offs on synergies of ESs and ecosystem management (Polasky et al. 2011). In this paper, four InVEST sub-models, including the Water Yield model (WY), Sediment Delivery Ratio model (SDR), Carbon model (C) and Habitat Quality model (HQ), were selected for the ESs assessment according to the ecological management needs of the study area. In addition, Structural Equation Modeling (SEM) create complex variables prediction models to explain the direct and indirect interactions among the factors and the results of a traditional multivariate statistical analysis. Considering that this regional ecological function degradation results from the interaction among the natural environment, human activities and land-use policies (Corbau et al. 2019; Hu and Nacun 2018; Ma et al. 2018), the SEM was used to explore the compound factors and interactions affecting ESs changes in this study.

LULC is an unavoidable aspect for humans to engage in economic production activities. Reasonable LULC should reduce the negative environmental impact while promoting economic growth, especially in the regions of the agro-pastoral ecotone (Ding, Wang, and Wu 2007; Fu et al. 2015; Xu et al. 2020). Therefore, this study put forward a feasible and replicable LULC decision-making framework for the agro-pastoral ecotone of northern China, based on the LULC transfer matrix and spatial quantification tools for ESs. SEM was also used to reveal the different impact mechanisms between various types of LULC.
mode and ESs variation in the pastoral-dominated and agriculture-dominated regions, which provide technical support for land use decision-makers to formulate locally adapted policies in the above distinct areas. Our study is not only contributed to a more thorough understanding of the pastoral-dominated and the agriculture-dominated land-use patterns driven ESs variation in the typical agro-pastoral ecotone of northern China, but also will be beneficial to put forward suggestions for specific stakeholders (such as farmers, urban residents and nomads) for different LULC modes, so as to achieve a balance between economic growth and ecological protection in the agro-pastoral ecotone of northern China. Due to its particular geographical location and different land-use patterns between the North (Pastoral-dominated region) and South (Agriculture-dominated region), Chifeng, a specific area in the agro-pastoral ecotone of northern China, was selected as the study site. The study’s objectives are to: 1) identify the distinct land-use patterns in Chifeng’s pastoral-dominated and agriculture-dominated regions from 1980 to 2018; 2) quantify various ESs by using the InVEST model and differentiate the spatial-temporal variation of the typical ESs, including water retention(WR), soil conversion(SR), carbon storage(C), habitat quality(HQ) in North and South of Chifeng; 3) explore the spatial heterogeneity in the influential factors of ESs variation between the North and South.

Material and methods

Study area

The city of Chifeng (41°17’10“–45°24’15“ N and 116°21’07“–120°58’52“ E), located in the transition zone from the Inner Mongolia Plateau to the Liaoh平原, is a typical agro-pastoral ecotone of northern China, with a total area of 90,021 km² (Aiping and Hua 2008) (Figure 1). Chifeng belonged to a temperate semiarid continental climate zone, with significant seasonal climate fluctuations. The annual temperature increases from northwest to southeast, and the average yearly precipitation has been around 381 mm for the last 30 years. Chifeng, historically, has been a gathering area of traditional nomadic and farming nationalities. According to Chifeng Urban Master Plan (2012–2030), The North occupies 60.16% of the whole region, including five suburban districts(Ar Horqin Banner, Bairin Left Banner, Bairin Right Banner, Linxi County, and Hexigten Banner), which have been an excellent traditional pasture since ancient times. As one of China’s top food production bases, the South, occupying 39.84% of the region, is covered by farmland and

Figure 1. The location of Chifeng, China. Note: The map was drawn based on the standard base map provided by the National Platform for Common Geospatial Information Service (Map No.: GS(2019) 1822) without any edition on the boundary of China.
|                                | Ar Horqin Banner | Bairin Left Banner | Bairin Right Banner | Linxi County | Hexigten Banner | Ongniud Banner | Songshan | Hongshan | Yuanbaoshan | Harqin Banner | Ningcheng County | Aohan Banner |
|--------------------------------|------------------|--------------------|---------------------|--------------|----------------|---------------|----------|----------|-------------|---------------|--------------------|--------------|
| Population (person)            | 292,285          | 340,020            | 182,152             | 230,088      | 247,899        | 605,483       | 600,184  | 350,133  | 318,086     | 345,253        | 605,563            | 605,483      |
| Pastoralists rate (%)          | 41.77%           | 37.42%             | 49.04%              | 5.15%        | 13.73%         | 5.98%         | 22.19%   | 18.17%   | 13.73%      | 45.14%         | 12.82%             | 6.03%        |
| Urbanization rate (%)          | 20.62%           | 20.91%             | 33.01%              | 35.77%       | 23.24%         | 23.68%        | 34.18%   | 76.55%   | 51.25%      | 32.40%         | 25.01%             | 18.82%       |
| Per capital GDP (yuan)         | 49,482           | 45,838             | 52,842              | 50,002       | 82,077         | 35,252        | 50,260   | 81,721   | 73,939      | 30,252         | 38,198             | 37,018       |
| Students (person)              | 12,606           | 15,536             | 8417                | 9043         | 8162           | 16,255        | 34,280   | 20,225   | 16,238      | 14,605         | 24,833             | 24,857       |
includes seven suburban districts (Hongshan District, Songshan District, Yuanbaoshan District, Ningcheng County, Karqin Banner, Ongniud Banner, and Aohan Banner) (Table 1). Up until 2021, Chifeng has obtained an urbanization rate of 49.38%. Extreme fragile ecosystems and intense human activities have led to severe competition between the economy and ecology. Due to the distinct LULC patterns, there are pronounced regional differences in the development level and the degradation degree of ecologically fragile areas in the North and South. Since 2000, various policies and projects, such as the Beijing-Tianjin Sand-storm Source Project and the Returning Farmland to Forest and Grassland, has been conducted. Moreover, various regulations such as the Regulations on Grazing Prohibition, Rest Grazing and Balance between Forage and Animal in Chifeng have also been implemented. Till now, it is a necessary and comprehensive task that balancing economic and social development with healthy ecological development in the typical agro-pastoral ecotone of northern China. Understanding the spatial-temporal ESs variation driven by distinct regional land-use patterns and identifying the different driving mechanisms in the pastoral and agriculture region, respectively, is a priority for achieving these goals.

**Analysis framework for identifying the impacts of distinct land-use patterns on regional ESs**

This study aimed to have a more thorough understanding of distinct land-use patterns in the typical agro-pastoral ecotone of northern China, which could help policymakers formulate effective protection policies and regional management plans. The framework of the study was shown in Figure 2. After data processing, taking Chifeng’s pastoral-dominated and agriculture-dominated regions as examples, the historical LULC data were used to identify the regional distinct land-use pattern, and then, various ecosystem services were quantified by the InVEST model. Using SEM, we further contrasted the effects of several variables on regional ES variations in pastoral (North) and agriculture-dominated (South) regions, respectively. Detailed explanations of each step are provided in the subsequent sections.

**Data source and processing**

All the data in this study came from data product service websites, namely Resource and Environment Science and Data Center of Chinese Academy of Sciences, Figureshare database, the Cold and Dry Zone Science Data Center and Chifeng Statistical Yearbook and the Inner Mongolia Statistical Yearbook.

This study collected eight LULC maps with a spatial resolution of 30 m in 1980, 1990, 1995, 2000, 2005, 2010, 2015 and 2018. According to the national classification standard of LULC status, the LULC types in Chifeng were divided into six categories: farmland, forest, grassland, water, built-up land (urban) and bareland. The detailed introduction of all the parameters of InVEST models and SEM can be seen in Table 2. The meteorological parameters of each period used in this paper were interpolated by using the average values of each standard year and the two years before and after to overcome the influence of single-year meteorological extremes. This study unified all spatial data projections under the UTM projection system with the spatial resolution as follows.

**Methods**

**Mapping of ESs by InVEST models**

Four ESs were selected for the assessment by InVEST models: water yield (WY), sediment delivery ratio (SDR), carbon (C) and habitat quality (HQ). All four ESs’ results were assessed and spatially mapped at a resolution of 1 km.

**Water yield model**

Water retention capacities of ecosystems are closely related to human production and living behavior, affecting human well-being. Specifically, water resources are one of the critical limiting factors for agricultural and pastoral development. The water retention measurements in this study were obtained by adopting the extended model provided by Bai (Bai, Ochuodho, and Yang 2019), using InVEST water yield model, based on the water balance equation, water production minus actual evapotranspiration, and surface runoff. The specific calculation equations were:

\[
WR_{ij} = Y_{ij} - \text{Runoff}_{ij} \tag{1}
\]

\[
Y(x) = \left(1 - \frac{\text{AET}(x)}{P(x)} \right) \cdot P(x) \tag{2}
\]

\[
\text{Runoff}_{ij} = P(x) \times C_j \tag{3}
\]

Where \(WR_{ij}\) is the water retention (mm) of land use type \(j\) in the raster cell \(x\). \(Y_{ij}\) (Liu et al. 2019a) is the water yield (mm), \(AET(x)\) denotes the actual annual evapotranspiration (mm) of \(x\) in the raster cell, and \(P(x)\) denotes the average annual precipitation (mm) of \(x\) in the raster cell. \(\text{Runoff}_{ij}\) is the surface runoff volume on the raster data, and \(C_j\) is the type \(j\) land use type of the surface runoff coefficient.

**Sediment delivery ratio model**

Various factors such as anthropogenic disturbances and global climate change can degrade vegetation and intensify soil erosion, and excessive soil erosion
can decrease soil fertility and agricultural and livestock productivity. In this study, the modified Revised Universal Soil Loss Equation (RUSLE) (Rao et al. 2015) was used to estimate soil retention in the northern pastoral and southern agricultural areas of Chifeng using InVEST sediment delivery ratio model with the following equations:

\[ SC_i = RKLS_i - USLE_i \]  \hspace{1cm} (4)

\[ RKLS_i = R_i \times K_i \times LS_i \]  \hspace{1cm} (5)

\[ USLE_i = R_i \times K_i \times LS_i \times C_i \times P_i \]  \hspace{1cm} (6)

\[ R_i = \alpha P_i^\beta \]  \hspace{1cm} (7)

\[ K = \left\{ \begin{array}{ll}
0.2 + 0.3 \exp[-0.2565N_i (1 - S_i)] \\
0.25C_i \exp(-3.72 - 2.95S_i)
\end{array} \right\} \left( \frac{S_i}{C_i + \exp(-3.72 - 2.95S_i)} \right)^{0.3} \times \left( \frac{1}{c + \exp(-3.72 - 2.95S_i)} \right) \times 0.1317 \]  \hspace{1cm} (8)

Where \( SC_i \) is the soil retention of raster \( i \) (t·ha⁻¹·yr⁻¹), which means the difference between the potential soil erosion
minus the actual erosion (Xu et al. 2019). RKSLS is the total potential soil erosion per year in the raster cell i (t ha⁻¹ yr⁻¹), and USLE is the total actual soil erosion in the raster cell i (t ha⁻¹ yr⁻¹). RI is the precipitation erodibility factor (MJ mm (ha hr)⁻¹) (Zhang and Fu 2003), using the mean annual precipitation (P) with α = 0.0534 and β = 1.6548. KI is the soil erodibility factor (ton ha⁻¹ MJ⁻¹ ha⁻¹ mm⁻¹), using by Williams created EPIC (He et al. 2019b; Williams, Jones, and Dyke 1984). LS is the slope length factor, came from DEM data. Ci is the vegetation cover and crop management factor, and Pi is the soil and water conservation measure factor (Bhattarai and Dutta 2007; Huang et al. 2018; Yin et al. 2018; Zhao et al. 2014).

Carbon model

In this study, the InVEST carbon model was used to estimate the spatial and temporal evolution characteristics of carbon fixation in Chifeng, which was calculated as follows:

$$C_{\text{total}} = \sum_{i=1}^{n} C_i \times A_i$$  \hspace{1cm} (9)

$$C_i = C_{i, \text{above}} + C_{i, \text{below}} + C_{i, \text{soil}} + C_{i, \text{dead}}$$  \hspace{1cm} (10)

Where $C_{\text{total}}$ is the total carbon storage (Mg C) of the raster cell i land-use type in the region; $A_i$ is the area of the ith land-use type. $C_i$ is the carbon density (Mg C/ km²) of the raster i land use, which includes above-ground biomass ($C_{i, \text{above}}$), belowground biomass ($C_{i, \text{below}}$), and soil biomass ($C_{i, \text{soil}}$), and dead organic matter ($C_{i, \text{dead}}$) (Chu et al. 2019).

Habitat quality model

Habitat quality is the ability of the ecosystem to provide suitable and persistent living conditions for individuals and populations (Hall, Krausman, and Morrison 1997). It is a vital representation of biodiversity (Li et al. 2020). In this study, the equations of the habitat quality model shows below:

$$Q_{ij} = H_j \left(1 - \left(\frac{D_{ij}^2}{D_{ij}^2 + k^2}\right)\right)$$  \hspace{1cm} (11)

$$D_{ij} = \sum_{r=1}^{R} \sum_{y=1}^{Y} \left(\frac{W_r}{\sum_{r=1}^{R} W_r}\right) = r_y i_{xy} \beta_y S_y$$  \hspace{1cm} (12)

$$i_{xy} = 1 - \left(\frac{d_{xy}}{d_{\text{max}}}\right)^k$$  \hspace{1cm} (13)

$$i_{xy} = \exp\left(-\left(\frac{d_{xy}}{d_{\text{max}}}\right)^l\right)$$  \hspace{1cm} (14)

Where $Q_{ij}$ is the habitat quality index of raster $x$ in habitat type $j$, $H_j$ is the habitat suitability of habitat type $j$, and $k$ and $z$ are scaling factors, where $k$ is the half-saturation constant and $z$ is the normalization constant. $d_{ij}$ is the total threat level of raster $x$ in habitat type $j$, $r$ is the habitat threat factor, $y$ is all rasters on the $r$-threat raster map, $W_r$ is the weight of threat factor $r$, $r_y$ is the threat intensity of raster $y$, $\beta_y$ is the accessibility level of raster $x$, and $S_y$ is the sensitivity of habitat type $j$ to threat factor $r$. $i_{xy}$ is the threat level of $r_y$ to habitat raster $x$, and $d_{xy}$ is the linear distance between raster $x$ and $y$, $d_{\text{max}}$ is the maximum action distance of threat $r$.

Structural equation modeling

Numerous studies have found that regional ecosystem change factors could be grouped into climatic (Grimm et al. 2013; Peters et al. 2019), anthropogenic (Alberti et al. 2003), and regional policy elements (Asah et al. 2014; Pan et al. 2020) (Figure 3). The climatic factors reflected the changing characteristics of the natural ecological background of the study area. In this
study, the climatic factors were characterized by two indicators: temperature and precipitation (Zhang et al. 2016). The anthropogenic factors reflected the influence of the developed degree of socio-economic and intense human activities on the ESs of the study area (Cumming et al. 2014). In this study, the socio-economic factors were the summation of the urbanization rate (the proportion of the urban population to the total population) (Wu 2014), per capita GDP (regional socio-economic development level) (Dinda 2004), road network density (regional transportation development scale) (Forman and Alexander 1998), and educational attainment (number of students in secondary schools) (Liu 2004) in the study site. The formulation of land use policies was influenced by the natural conditions of the region and the level of regional development but also had a strong government orientation. So the proportion of each primary land use type in each period could reflect the impact of the overall land-use policies on the regional ESs’ changes (Yang et al. 2018). The policies are distinguished by different impacts on the ecological background in the region: 1) positively, such as the Conversion of Cropland to Forest and Grassland Program (Qiu et al. 2011), Beijing-Tianjin Sandstorm Source Control Project (Wang et al. 2021b), the Closure of Mountains and Grazing Prohibition, etc. 2) negatively, such as Emphasizing Agriculture over Pastoral, Emphasizing Production to Ecology, etc. 3) positively and negatively in the same period, such as Rapid Urbanization and Vigorous Implementation of Ecological Protection Projects.

We chose three significant elements of climate, socio-economics, and regional policies to subject to the factor analysis and dimensionality reduction of the subordinate indicators using SPSS 24.0. The results of factor analysis were introduced into the structural equation modeling (Amos 26.0) to explore the differences in the influence mechanisms of the three major types of elements on the changes of ESs in the North and South of Chifeng from 1980 to 2018 according to the differences in path coefficients (Table 3).

Results

Identifying the distinct land-use patterns in the North and South

Figure 4 and Figure A1 showed the changes in land use ratios in the North and South of Chifeng. From 1980 to 2018, although grassland is still the dominant land use type in the North, but it has experienced a significant decrease from 61.74% (1980) to 48.27% (2018). The land use has substantially shifted to forest, farmland, and bareland, accounting for 46.36%, 30.79%, and 20.17% of the transferred area, respectively, by which the forest in the region gradually has become the second-largest land-use type in the North. Forest increased from 13.95% (1980) to 22.03% (2018) (from 7556.72 km² to 11,929.27 km²), and the areas designated as farmland, urban, water, and bareland in the region increased by 4.24%, 1.34%, 1.47%, and 8.09%, respectively.

In comparison, the farmland in the South increased significantly during 1980–2018, from
32.34% to 35.47% (from 11,599.51 km² to 12,721.75 km²), gradually overtaking grassland as the dominant land-use type in the southern region. 2528.77 km² of grassland, 445.69 km² of forest, 233.04 km² of water, and 191.45 km² of bareland (represented by ecological land shifting to farm-land), contributed significantly to the total size of farmland in the South. Meanwhile, the area of built-up land in the south, including urban and rural areas, increased by 36.73%, from 1026.01 km² to 1402.89 km², transforming from 428.01 km² of farmland and 204.36 km² of grassland, indicating the rapid urbanization of the region. In addition, 2470.05 km² of grassland and 626.24 km² of

Figure 4. Land use transfer matrix in the different regions of Chifeng.
farmland were converted to forest, and the existing forest also increased significantly.

Overall, both the North and South experienced a significant reduction in grassland from 1980 to 2018. However, the decrease in grassland in the North was due to an overwhelming conversion to the forest, with a small portion of the grassland converted to farmland and bareland and a slight but modest increase in built-up land. In contrast, the reduction of grassland in the South led to an increase in forest and a more incredible conversion of grassland to farmland, with a concomitant increase in bareland. Congruently, the area of urban land in the region increased significantly over 38 years, with a large proportion of land converted from farmland. The changing patterns of land-use types, such as urban encroaching on arable land and arable land further encroaching on grassland and other ecological spaces, were evident in the region.

**Mapping spatial-temporal variation of ESSs**

**Water retention**

The per capita water retention capacity in Chifeng varied between 0–500 m$^3$/hm$^2$ during 1980 to 2018 (Figure A2). The areas with higher water retention capacity in Chifeng were distributed in the forest, grassland, and farmland in the northern agricultural and pastoral regions. The multi-year average spatial distribution and statistical analysis were performed to distinguish the differences in water retention between different regions (Figure 5). From 1980 to 2018, the multi-average of the North (43.45 m$^3$/hm$^2$) was higher than the South (34.46 m$^3$/hm$^2$). The total amount of water retention in the North increased from $1.21 \times 10^8$ m$^3$ to $3.17 \times 10^8$ m$^3$ (an increase of 163%), while the South increased from $4.97 \times 10^7$ m$^3$ to $1.08 \times 10^8$ m$^3$ (a rise of 88.47%). So did the regional average water retention capacity, which the North performed better than the South in most of the study period except for 2005–2010.

**Soil conservation**

From 1980 to 2018, soil conservation had changed slightly in Chifeng, remaining between 11–22 t/hm$^2$ (Figure A3). The high-value areas were few and sporadically distributed in the Chifeng’s northern, western, and southwestern parts. The multi-year average spatial distribution and statistical analysis were utilized to distinguish further the differences in soil conservation between the North and South (Figure 6). The storage and average soil conservation in different regions fluctuated from 1980 to 2018. The average soil conservation capacity in the north was slightly lower than in the south, but the total amount of soil conservation grew faster. From 1980 to 2018, the multi-average of soil conservation in the North (13.63 t/hm$^2$) was a bit lower than the South (19.26 t/hm$^2$). The total amount of soil conservation in the North increased from $5.67 \times 10^7$ m$^3$ to $8.79 \times 10^7$ m$^3$, with an increase of 55.12%. In contrast, the soil conservation in the South increased from $5.00 \times 10^7$ m$^3$ to $6.62 \times 10^7$ m$^3$, with a rise of 32.32%.

**Carbon fixation**

From 1980 to 2018, the average carbon fixation in Chifeng was maintained between 3.25–253.12 MgC/hm$^2$, with high-value areas distributed in the study area’s northern, western and southwestern forests (Figure A4). The multi-year average spatial
distribution and statistical analysis were conducted
to distinguish further the differences in carbon fixation
between the North and South (Figure 7). The average of
carbon fixation capacity and carbon storage in different
regions showed a slowly increasing trend. From 1980 to 2018,
the multi-average carbon fixation in the North (83.06 MgC/hm$^2$)
was higher than in the South (83.06 MgC/hm$^2$), and the growth rate
had an increased slope. What’s more, the carbon storage in the North increased from $4.15 \times 10^8$
MgC to $5.04 \times 10^8$ MgC, with an increase of 21.50%;
while the carbon storage in the South increased from $2.61 \times 10^8$
MgC to $2.94 \times 10^8$ MgC, with an increase of 12.93%. So did the regional average carbon fixation capacity, which the North performed better than the South during 1980–2018.

**Habitat quality**
From 1980 to 2018, the overall habitat quality of Chifeng did not change drastically, decreasing from 0.74 to 0.72, with a slight decrease in biodiversity. However, regional differences were observable; areas with high values of habitat quality were distributed in the northern and southern forest and grassland areas. Conversely, the desert habitat quality in the north part of the agricultural area was lower (Figure A5). The multi-year average spatial distribution and statistical analysis were performed to characterize further the differences in habitat quality between the North and South (Figure 8). From 1980 to 2018, the multi-average of habitat quality in the North (0.777) was higher than in the South (0.672), which was gradually decreased from 0.781 to 0.762; while the South was dropped from 0.678 to 0.666.

Ecosystem services in Chifeng’s northern and southern regions changed throughout the study, with the North outperforming the South when soil conversation was omitted. From 1980 to 2018, the ecological and environmental conditions of the North was better, and the multi-average of ESs except soil conversation were higher than in the South. What’s more, the total water retention, soil conservation and carbon storage of the North increased by 163%, 55.12%, and 21.50%; and overall habitat quality was higher, decreasing from 0.781 to 0.762 from 1980 to 2018. In comparison, the total water retention, soil conservation and carbon storage of the South increased by 88.47%, 32.32% and 12.93%; and the overall habitat quality was lower, decreasing from 0.678 to 0.666 from 1980 to 2018.

**Driving factor analysis**
Structural equation modeling (SEM) was constructed according to the distribution of different banner areas in the North and South to investigate the differences in the influence of various factors on ESs. The parameters of the SEM met all the testing requirements (model overall CMIN/DF<3, $p > 0.05$, and each parameter $p < 0.05$). The results of path analysis were depicted in Figure 9.

For the North of Chifeng, climate, human activities, and regulatory policies all showed a significant positive contribution to the ESs in the region, with path coefficients of 0.408, 0.353, and 0.283. Climate had a direct influence coefficient of 0.408, showing a highly significant correlation, indicating that climate was a limiting factor for the function of ESs in the region. Simultaneously, land-use patterns under the influence of long-term ecological policies and progressive improvement of socio-economic conditions in the region positively affected the region’s ecosystem service capacity.

For the South of Chifeng, the three main factors of climate, human activities, and regulatory policies showed significant differences in how they affected the region’s ESs. Similar to the North, climatic conditions in the South affected positively of the region’s ecosystem services, with a path coefficient of 0.272. Land-use patterns under the influence of environmental policies in the region also contributed to the changes in the ecological environment in the region. However, the increase in the socio-economic level of the region led to significant increases in the disturbance of the natural environment by human activities, which had a significant adverse effect on various ecosystem services in the region, with a path coefficient of $-0.353$. The contribution of single factors to changes in ESs was more outstanding than climate and policy factors but less than the sum of both. Human activities’ destruction of ESs was the main driver of overall changes in the South. However, climate conditions and the implementation of regional environmental protection policies weakened the adverse effects of human activities on ESs.

**Discussion**

**Impact of distinct land-use patterns in the different regions of Chifeng**
From 1980 to 2018, the distinct land-use patterns in the North and South of Chifeng changed by differing degrees. The conversion of forest and grassland dominated the North. At the same time, the South showed a land-use conversion trend toward urban, farmland, and bareland, intruding on grassland and other ecologically rich spaces. The reason is that the North’s land-use patterns were dominated by ecological protection, which was manifested in the mutual transformation between grassland and forest directly inspired by policies such as the Conversion of Cropland to Forest and Grassland Program, the Beijing-Tianjin Sandstorm Source Control
Project, and the construction of the Three-North Shelter Forests Program. At the same time, human activities intensified the disturbance of ecological land in the region, which was reflected in an increased demand for farmland and urban. However, the growth rates remain at a manageable level. Although the Beijing-Tianjin Sandstorm Source Control Project grew forest in the South, land-use patterns displayed the encroachment of productive land on ecological land. The part underwent rapid urbanization (Liu et al. 2019b), with the urbanization rate increased from 13.75% to 32.93% from 1980 to 2018. The encroachment of urban construction land on farmland and ecological land requirements was observed, and the consumed farmland rapidly approached the bordering ecological space dominated by grassland.

Overall, similar ES variations were supplied in the North and South of Chifeng. All the service abilities
have been increased except habitat quality from 1980 to 2018. However, the changes in ESs caused by the mutual transformation between different types of LULC were also various, with the North outperforming the South when soil conservation was omitted. It is inextricably linked to the differentiated influencing mechanisms between the two regions. Firstly, the two main natural factors, temperature and precipitation, positively impacted ESs from 1980 to 2018 in the North and South of Chifeng. The improved climatic conditions contributed to the ecological environment’s changes (Pei et al. 2022), which helped the growth and survival of plants and animals in the study area and the dominant shifts in the ecosystem. Secondly, with the agro-pastoral ecotone as an essential ecological security barrier in northern China, the implementation of a series of environmental protection projects in the region, such as the Three-North Shelter Forests Program and Conversion of Cropland to Forest and Grassland Program policies, had a positive impact on the ecological environment. Thirdly, the
differences between the socio-economic levels between the two regions produced opposed results in the ESs.

As for the North, the population scale was relatively small compared to the South, and the level of economic development and road network density were reasonably different from the South, so the intensity of anthropogenic activities on natural disturbances was relatively small. Afterward, the long-term pastoral production mode in the North was much less intrusive to the natural background than agriculture’s destruction of the natural environment despite overgrazing, and land clearing occurred for some time. In addition, the publicity from the environmental protection policies made the concept of Lucid waters and lush mountains invaluable assets (Qin et al. 2018), deeply rooted in the general public’s mind. With improved education levels in the region, people’s recognition and participation in ecological protection gradually increase. Improving the socio-economic status also made residents recognize the benefits of environmental protection projects, which were more conducive to attracting people to participate in the cause of regional ecological protection (Vilar et al. 2020).

In contrast, the South was the center of economic and social development in Chifeng, with substantial increases in urbanization rates, per capita GDP, and road network density from 1980 to 2018. The rapid expansion of urbanization had varying degrees of negative impacts on the region’s ecology. Even though the education level increased people’s awareness of environmental protection policies (Foo 2013), economic development and improvement of residents’ living standards caused increased conversion of farmland to urban, increased ecosystem fragmentation, and increased social developmental demands on natural ecosystems, this resulted in indirect impacts of human factors on land use and direct adverse effects on ESs.

**Limitations and uncertainties**

The land-use patterns of the North and South of Chifeng had differing degrees of variability. Yet, the two regions were still transitional integrated, making it impossible to separate them. Future studies require the spatio-temporal identification and in-depth mechanical analysis of the transitional space between agriculture and pastoral to bridge the knowledge gap. Additionally, since Chifeng is experiencing a stage of rapid urbanization and development, relevant departments need to balance the relationship between social-economic growth and ecological protection, plan the structure of the town, optimize the system of ecological sensitive areas such as farmland, forest, grassland, and water, and focus on protecting the grassland resources in the region. These efforts achieve a win-win situation, increasing the regional ESs and improving the socio-economic level.

**Implications and suggestions**

Comprehensive analysis of the impact of differences in land-use patterns on regional ecosystem services’ evolutionary characteristics and driving mechanisms in Chifeng allowed the development of environmental protection policies for the North and South, according to local conditions. The North received a recommendation

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**Figure 9.** Structural equation modeling of the different regions of Chifeng (a: North, b: South) (probability: *p < 0.001; ***p < 0.01; **p < 0.05; *p < 0.1).
to continue carrying out ecological land protection work based on ensuring a stable ecological status quo, steadily fulfilling ecological protection projects such as afforestation, maintaining the grassland carrying capacity, scientifically developing the animal husbandry industry, guaranteeing ecological priority and green development, and increasing the comprehensive benefits of forest and grassland resources. At the same time, it is also necessary to cautiously promote the development of urbanization in the North and counties to improve residents’ living standards.

The increase of human activities in the South had significant negative impacts on ESSs, so the recommendation for the part was to strengthen the protection and management of ecologically sensitive land, strengthen the implementation and supervision of environmental protection projects, implement grid-based management of farmland, and promote the construction of high-quality farmland. Moreover, we should make ecologically restored-dominant strategies to protect the environment and increase pollution prevention and control efforts. Concurrently, the South was also advised to continue to protect the economic development level, and vigorously promote urban and rural economic construction to drive the sustainable development of the city’s ecology.

Conclusions

This study aimed to have a more thorough understanding of distinct land-use patterns in the typical agropastoral ecotone of northern China, which could help policymakers formulate effective protection policies and regional management plans. Based on ArcGIS and InVEST models, this study quantitatively analyzed the differential impacts of the spatial and temporal evolutionary characteristics of ESSs in Chifeng due to different land-use patterns in the North and South from 1980 to 2018. Results revealed the conversion between forest and grassland controlled the land use transformation of pastoral-dominated regions (North). In contrast, the agricultural-dominated region (South) showed a trend of the human-activity-oriented land occupying ecologically valuable spaces. The variations of ESSs showed similar trends, with significant differences in the magnitude of growth or decline that the North performed better than the South when soil conservation was omitted. The natural factors and land use policies showed positive effects on ESSs, whereas the anthropogenic factors in the north had a positive impact, which is negative in the South. Our policy implications recommended that ecologically maintained-dominant and ecologically-restored-dominant strategies be adopted in the North and South.

This study proposed sustainable development requirements for Chifeng, a specific region in the agropastoral ecotone of northern China, as it is particularly important to balance regional development and ecological protection, especially for the ecologically fragile areas, which is particularly important in the densely populated eastern counties. In our policy implications, we suggested that the central government should formulate macro strategies that combine regional ecological conditions and development capabilities to execute more balanced and coordinated overall development planning as well.

Disclosure statement

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Author contributions

G W and Y Z conceived the general idea of the paper. LY.Q, Y Z and HM.C analyzed and wrote the manuscript. All authors analyzed and discussed the results. All authors have read and agreed to the published version of the manuscript.

Availability of data and materials

The data supporting this study’s findings are available from the corresponding author, Yu Zhao, upon reasonable request.

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Figure A1. Land use and land cover change in the different regions of Chifeng.
Figure A2. Spatial distribution of water retention in the different regions of Chifeng.

Figure A3. Spatial distribution of soil conservation in the different regions of Chifeng.
Figure A4. Spatial distribution of carbon fixation in the different regions of Chifeng.

Figure A5. Spatial distribution of habitat quality in the different regions of Chifeng.