Spatiotemporal differences and influencing factors of high-quality utilization of land resources in the Yellow River Basin of China

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Received: 2 June 2022 / Accepted: 13 July 2022 / Published online: 19 July 2022
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Abstract
High-quality utilization of land resources (HULR) is critical to the security of land ecosystem and sustainable socioeconomic development. To promote HULR, we explored the spatiotemporal differences and influencing factors of HULR in the Yellow River Basin (an important ecological barrier in China) by using entropy method, spatial panel regression model, and geographically and temporally weighted regression model. We found that the HULR values were 0.22 to 0.28 from 2008 to 2019, showing an increasing trend with obvious spatiotemporal differences. The spatial connectivity, technological innovation, industrialization, industrial upgrading, and marketization are important factors influencing HULR, and different factors have different spatial effects in different regions. Therefore, the important principle of HULR is to pursue the sustainable land utilization within the ecological environment carrying capacity, taking into account the unique ecological and socioeconomic conditions of each region. We hope that our study can provide references for HULR around the world.

Keywords High-quality utilization of land resources (HULR) · Sustainable development · Spatiotemporal differences · Spatial regression analysis · Land erosion · Yellow River Basin · Ecological economy

Introduction

Land is an indispensable resource for human society, and high-quality utilization of land resources (HULR) is critical to the security of land ecosystem and sustainable socioeconomic development (Bazame et al. 2018; Liu et al. 2022b). The industrialization and urbanization have greatly changed the utilization of land resources (Fan et al. 2018). These changes directly affected the land ecosystem and are related to the human-land conflicts and sustainable development (Teferi et al. 2013). In September 2015, the United Nations released the Sustainable Development Goals (SDGs), a result-oriented framework for a sustainable development path from 2015 to 2030 that contains 17 goals and 169 targets (United Nations 2015; Zhang et al. 2022). The sustainable land utilization is an important role in the sustainable development path. However, in March 2018, the report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) showed that land degradation threatens the livelihoods of at least 3.2 billion people worldwide and faces an irreversible crisis (IPBES 2018). Sustainable land utilization has received widespread attention around the world.

China has undergone rapid industrialization and urbanization since the “reform and opening-up” policy was implemented in 1978 (Cai et al. 2019). The agglomeration economy and intensive land use have significantly improved the efficiency of land utilization, while the emission of pollutants and the destruction of ecosystems impeded the sustainable land utilization (Cai et al. 2021; Song et al. 2022). As an important “energy basin” in China, the Yellow River Basin accounts for 80% of the national raw coal production, 30% of the total population, and 25% of the total GDP, making great contributions to China’s socioeconomic development (National Bureau of Statistics 1979–2021). Unfortunately, the ecological and environmental problems caused by the
excessive utilization of land resources, such as desertification, soil erosion, and salinization, have hindered the high-quality development of the Yellow River Basin (Ding et al. 2020; Yuan et al. 2022). More importantly, as the Yellow River Basin is an important ecological barrier in China, the destruction of its land ecosystem would threaten the ecological environment of China and the world. Therefore, promoting the HULR is of great significance to achieve high-quality development in Yellow River Basin.

The current literatures on HULR mainly focus on the concept of land resource utilization, the evaluation index system, the evaluation methods, and evaluation results (Liu et al. 2014). The concept of HULR transformed from the initial emphasis on rational use of land resources to comprehensive land utilization involving ecological, economic, social, and ethical aspects (Liu et al. 2010; Qiu et al. 2017). In the evaluation system, scholars established an index system from the perspectives of productivity, safety, protection, economy, and society based on the five evaluation criteria mentioned in the “Sustainable Land Use EvaluationOutline” promulgated by FAO in 1993 (Ochola and Kerkides 2004; Zhao et al. 2021). The evaluation methods included entropy method, analytic hierarchy process, expert investigation method, and comprehensive evaluation method (Liu et al. 2010; Shi et al. 2020). The evaluation results mainly highlighted the main problems of land utilization, such as the degree of land desertification in Alxa League in the upper reaches of the Yellow River (Yan et al. 2009), the degree of soil erosion in Yan’an City in the middle reaches of the Yellow River (Zhang et al. 2018; Cao et al. 2021), and the degree of soil salinization in the Yellow River Delta (Guo et al. 2019). These studies provided important insights into the evaluation of HULR, but there are few studies on the spatiotemporal differences and influencing factors of HULR. This makes it impossible for researchers to provide policy makers with effective policy recommendations to promote sustainable utilization of land resources.

To clarify the spatiotemporal differences and influencing factors of HULR, we selected the Yellow River Basin as the research object, because it is one of the implementation sites of the national ecological protection and high-quality development strategy. We established an evaluation system of HULR by using entropy method and clarified the spatiotemporal characteristics of HULR. Then, we used spatial panel regression model and contribution model to explore the influencing factors of HULR and used geographically and temporally weighted regression (GTWR) model to explore the spatial differences in the effects of different influencing factors in different regions. Finally, we proposed the corresponding policy recommendations for spatiotemporal differences. We hope that our study can provide references for the high-quality utilization of land resources around the world.

Materials and methods

Data sources

The data mainly come from the China City Statistical Yearbook, the statistical yearbooks of the provinces and prefecture-level units in the Yellow River Basin, and national economic development and statistical bulletins for each prefecture-level units, and the map data used are from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences (http://www.resdc.cn). According to the administrative division statistics, the Yellow River Basin involves 9 provinces and 69 prefecture-level administrative units (cities, leagues, and autonomous prefecture). We selected 59 prefecture-level units in 8 provinces (excluding Sichuan) and collected the most recent data available (from 2008 to 2019) (Fig. 1).

Study area

The Yellow River, known as the Great River in ancient China, originates from the Bayan Har Mountains in Qinghai Province, China. It traverses the three major regions of eastern, middle, and western and flows through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong Province. The total length is 5464 km, and the basin area is 794000 km² (Wang et al. 2010). The Yellow River Basin is the main birthplace of Chinese civilization, an important ecological barrier and an important economic zone (Fig. 1). In 2020, the GDP of the basin was $25.5 \times 10^{12}$ RMB, accounting for 25% of the national GDP, and the population was 421 million, accounting for 30% of the total population (National Bureau of Statistics 1979–2021). Except for the per capita income of rural residents in Shandong, which was higher than the national average, the rest per capita income of residents is lower than the national average. The Yellow River Basin is also a multi-ethnic gathering area, with ethnic minorities accounting for about 10%. Promoting ecological protection and high-quality development in the Yellow River Basin is not only to meet the people’s growing needs for a better life, but also to promote social stability. Therefore, we selected the Yellow River Basin as the study area to explore the influencing factors of HULR and provide the valuable references for ecological protection and high-quality development.

Research methods

To explore the spatiotemporal differences of HULR, we established an evaluation system for HULR and used the
entropy method to calculate the $HULR$ values. To identify the influencing factors of $HULR$, we selected the spatial error model, contribution model, and geographically and temporally weighted regression model to make spatial empirical analysis.

**Evaluation system of $HULR$**

Based on the existing evaluation index system, we selected 11 indicators from three categories pressure, state, and response to establish $HULR$ evaluation system and calculated the $HULR$ value by the entropy method (Table 1) (Ustaoglu et al. 2016; Liu et al. 2021). The detailed steps are as follows:

1. **Standardization of indicators**
   
   Positive indicator: $Z_{ij} = \frac{X_{ij} - \min \{X_{ij}\}}{\max \{X_{ij}\} - \min \{X_{ij}\}}$  
   
   Negative indicator: $Z_{ij} = \frac{\max \{X_{ij}\} - X_{ij}}{\max \{X_{ij}\} - \min \{X_{ij}\}}$

   where $X_{ij}$ is the original value of the $j$th index of the $i$th evaluation unit and $\max(X_{ij})$ and $\min(X_{ij})$ are the maximum and minimum values of the $j$ index in all evaluation units.

2. **Entropy method:**

   Due to the large number of indicators and a wide range of research, we selected the entropy method to determine the weights of indicator for the $HULR$. Because compared with principal component analysis, factor analysis, and expert scoring, the entropy method has stronger operability. The formulas are as follows:

   $$Y_{ij} = \frac{Z_{iy}}{\sum_{i=1}^{m} Z_{ij}}$$  

   $$(4) e_j = -\frac{1}{Lnm} \sum_{i=1}^{m} Y_{ij} \ln Y_{ij}$$  

   $$(5) f_j = 1 - e_j$$  

   $$(6) w_j = \frac{f_j}{\sum_{j=1}^{n} f_j}$$

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Table 1 Indicator system used to evaluate HULR and results of the entropy method

| System Evaluation system of HULR | Target layer | Indicator                          | Calculation method | Attribute | Information entropy | Redundancy | Weight |
|---------------------------------|--------------|------------------------------------|--------------------|-----------|---------------------|------------|--------|
| Pressure                        | Pressure     | Population                         | Population density | -         | 0.9937              | 0.0063     | 0.0254 |
|                                 | Pressure     | Economic                           | Economic density   | +         | 0.9285              | 0.0715     | 0.2877 |
|                                 | Natural      | Per capita arable land             | Per capita total   | +         | 0.9666              | 0.0334     | 0.1344 |
|                                 | Ecological   | “three-waste” emissions            |                    | -         | 0.9996              | 0.0004     | 0.0016 |
|                                 | State        | Terrain                            | Altitude           | -         | 0.9930              | 0.0070     | 0.0281 |
|                                 | State        | Agricultural land production       | Per area grain output | +       | 0.9829              | 0.0171     | 0.0687 |
|                                 | State        | Forest cover                       | NDVI               | +         | 0.9804              | 0.0196     | 0.0788 |
|                                 | State        | Urban land                         | Proportion of      | +         | 0.9268              | 0.0732     | 0.2947 |
|                                 |             |                                    | construction land  |           |                     |            |        |
| Response                        | Treatment    | land pollutants                    | Proportion of      | +         | 0.9952              | 0.0048     | 0.0193 |
|                                 | Treatment    | land pollutants                    | consumption        |           |                     |            |        |
|                                 | Treatment    | land pollutants                    | wastes that are    |           |                     |            |        |
|                                 | Treatment    | land pollutants                    | treated           |           |                     |            |        |
|                                 | Treatment    | land pollutants                    | industrial         |           |                     |            |        |
|                                 | Treatment    | land pollutants                    | solid waste that   |           |                     |            |        |
|                                 | Treatment    | land pollutants                    | is recycled        |           |                     |            |        |
|                                 |             |                                    | is treated centrally | +       | 0.9943              | 0.0057     | 0.0228 |

\[ U_s = \sum_{j=1}^{n} W_j Z_{ij} \]  
(7)

where \( Z_{ij} \) is the standardized value of the \( j \)th index of the \( i \)th evaluation unit, \( Y_j \) is the information entropy of the \( j \)th index, \( e_j \) is the information entropy of the \( j \)th index, \( f_j \) is the redundancy of the information entropy, and \( w_j \) is the information entropy of each weight of the index, and \( U_s \) is the comprehensive evaluation index of the subsystem (\( s = 3 \)), which represents the comprehensive level value of the sustainable development of land resources.

Spatial empirical analysis

Indicator selection and processing Combined the mechanism and characteristics of China’s utilization process of land resource with the characteristics of the Yellow River Basin, we chose the HULR value as the dependent variable. For the independent variables, from the four aspects of economy, society, environment, and policy selects 9 indicators (these are strongly related to the utilization of land resource) to conduct empirical analysis (Chang et al. 2015; Qin et al. 2017; Liu et al. 2022a). The 9 indicators include industrialization (value added by secondary industries divided by regional GDP), industrial upgrading (value added by tertiary industries divided by regional GDP), technological innovation (number of granted patent divided by the total population), spatial connectivity (road mileage per regional area), social service (number of beds in medical institutions divided by the total population), education (number of students in school divided by the total population), fiscal decentralization (total financial expenditure divided by regional GDP), marketization (number of urban private and self-employed persons divided by the total population), and climate (annual average precipitation), respectively.

Empirical analysis As the spatial panel model could overcome the spatial correlation and spatial heterogeneity caused by geographical location factors and make the estimation results more effective, we chose the spatial panel model and conducted empirical analysis with the help of STATA14.0 software (Ren et al. 2014). Spatial panel models mainly include spatial autoregressive model (SAR), spatial error model (SEM), and spatial Durbin model (SDM). The SAR and SEM models are special situations of the SDM model. The formula for calculating SDM is as follows:

\[
\begin{align*}
Y_t &= \rho \sum_{i,j=1}^{n} W_{ij} Y_{jt} + \beta X_{it} + \theta \sum_{i,j=1}^{n} W_{ij} X_{jt} + \mu_t + \gamma + \epsilon_{it} \\
\epsilon_{it} &= \lambda \sum_{i,j=1}^{n} W_{ij} \epsilon_{jt} + \varphi; i = 1, \ldots, n; t = 1, \ldots, T
\end{align*}
\]  
(8)

where \( i \) and \( j \) represent different city indicators (59 cities), \( t \) is the research period (2008~2019), \( W \) is the spatial weight (Queen matrix), \( Y \) is the explained variable (HULR value), and \( X \) is the explanatory variable (9 factors), \( \rho \) is the spatial regression coefficient, \( \lambda \) is the spatial autocorrelation coefficient of the error, and \( \epsilon \) is the random error term. When \( \lambda = 0 \) and \( \theta = 0 \), it is the calculation formula of the SAR model.
and when $\rho = 0$ and $\theta = 0$, it is the calculation formula of the SEM model.

In the modeling process, we first performed the OLS model and obtained the spatial dependence diagnosis (LM) results, which is an important step in selecting a suitable spatial model. Secondly, if it is determined in the LM test that the SDM model needs to be selected, the LR test needs to be carried out first, and based on the LR test results, it is judged whether the SDM model can be degraded into the SEM and SAR models; otherwise, this step is not performed. Third, based on the results of the Hausman test, it is determined whether fixed effects or random effects are needed in the model. Finally, the joint significance test is used to judge which of the individual effects, time effects, or dual effects is the best for the model, so as to select the most suitable and more reliable spatial regression model for this study (Anselin and Rey 1991). The test results showed that the SEM model with time fixed effects is an effective analytical model for exploring the influencing factors of $HULR$ in the Yellow River Basin (Table 2).

The contribution model is used to calculate the contribution of different influencing factors to $HULR$, so as to formulate more effective policy recommendations according to the contribution of each factor (Cai et al. 2021). The formula is as follows:

$$Con_K = \frac{AC_K}{\sum_{K=1}^{9} AC_K} \times 100\%$$

(9)

where $Con_K$ is the contribution of variable $k$ to the dependent variable ($Y$) and $AC_k$ is the absolute value of the coefficient $\beta_k$.

To further explore the spatial effects of different factors in different regions, we used the geographically and temporally weighted regression (GTWR) model to fit $HULR$ value and its influencing factors from 2008 to 2019 by using version 10.8 of the ArcGIS software (https://developers.arcgis.com/) (Wang et al. 2022). The formula is as follows:

$$y_i = \beta_0(\mu_i, v_i, t_i) + \sum_{j=1}^{n} \beta_j(\mu_i, v_i, t_i)x_{ij} + e_i$$

(10)

### Table 2 Statistical significance and contributions to $HULR$ in the Yellow River Basin for the 9 significant dimensions from 2008 to 2019

| Variable                | OLS          | SEM          |
|-------------------------|--------------|--------------|
| Industrialization       | $\beta_1 = 0.269^{**}$ (5.52) | $\beta_1 = 0.279^{**}$ (5.91) |
|                         | Con$_1$ = 13.41 | Con$_1$ = 13.09 |
| Industrial upgrading    | $\beta_1 = 0.179^{**}$ (3.80) | $\beta_1 = 0.219^{**}$ (4.72) |
|                         | Con$_1$ = 8.92 | Con$_1$ = 10.28 |
| Technological innovation| $\beta_1 = 0.345^{**}$ (15.02) | $\beta_1 = 0.348^{**}$ (15.14) |
|                         | Con$_1$ = 17.20 | Con$_1$ = 16.33 |
| Spatial connectivity    | $\beta_1 = 0.591^{**}$ (22.05) | $\beta_1 = 0.617^{**}$ (22.61) |
|                         | Con$_1$ = 29.46 | Con$_1$ = 28.95 |
| Social service          | $\beta_1 = 0.127^{**}$ (5.28) | $\beta_1 = 0.149^{**}$ (5.90) |
|                         | Con$_1$ = 6.33 | Con$_1$ = 6.99 |
| Education               | $\beta_1 = 0.074^{**}$ (3.74) | $\beta_1 = 0.044^{*}$ (2.02) |
|                         | Con$_1$ = 3.69 | Con$_1$ = 2.06 |
| Fiscal decentralization | $\beta_1 = 0.154^{**}$ (5.31) | $\beta_1 = 0.172^{**}$ (5.52) |
|                         | Con$_1$ = 7.68 | Con$_1$ = 8.07 |
| Marketization           | $\beta_1 = 0.188^{**}$ (7.46) | $\beta_1 = 0.213^{**}$ (8.53) |
|                         | Con$_1$ = 9.37 | Con$_1$ = 10.00 |
| Climate                 | $\beta_1 = 0.079^{**}$ (3.20) | $\beta_1 = 0.090^{**}$ (3.71) |
|                         | Con$_1$ = 3.94 | Con$_1$ = 4.22 |

| Test        | LM          |        | LM          |        |
|-------------|-------------|--------|-------------|--------|
| Moran’s I   | Mor (error) | 1      | 1.981*      |
| LM (error)  | 1           | 17.386**|
| LM (lag)    | 1           | 60.933**| R-LM (lag)  |
| R-LM (error)| 1           | 1      | 1.934 ns    |
|             | R-LM (error)| 1      | 45.481**    |
| Hausman     | Chi$^2$ (21) = 52.15, Prob$\geq$ chi$^2$ = 0.000 |
| Joint sig.  | R$^2$       | Log-L  | -482.460    |
| Individual  | 0.68        | 120.495|
| Both fixed  | 0.38        | 167.631|

Significance: $+, p < 0.1$; $*, p < 0.05$; **, $p < 0.01$; ns, not significant

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Environmental Science and Pollution Research (2022) 29:89438–89448

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where $\beta_0$ is the assumed constant, $\beta_j$ is the regression parameter for variable $j$ in region $i$, $(\mu_i, \nu_i, t_i)$ are the spatiotemporal coordinates of sample $i$, and $\varepsilon_i$ is normally distributed.

**Results**

The results showed that the $HULR$ value of the Yellow River Basin changed from 0.22 to 0.28, showing a clear upward trend from 2008 to 2019 (Fig. 2). The value was the highest in the downstream region, followed by the midstream region, and the lowest in the downstream region. The average values were 0.34, 0.24, and 0.21, respectively, showing obvious regional differences in general. From the perspective of spatial distribution pattern, the evolution trend of $HULR$ value generally showed high-level areas are mainly concentrated in the downstream, low-level cities are mainly concentrated in the upstream, the number of low-level cities gradually decreases, and the number of high-level cities gradually increases.

The results of spatial empirical analysis showed that indicators all have a positive influence on $HULR$ and pass the significance test, and different indicators have different degrees of influence on $HULP$ (Table 2). Specifically, the spatial connectivity (with a contribution of 29.0%) and technological innovation (with a contribution of 16.3%) were main factors affecting $HULR$, followed by the industrialization (13.1%), industrial upgrading (10.3%), and marketization (10.0%) had a contribution greater than 10%. The climate and education had less influence, with a contribution of less than 5%.

The influence of each factor on $HULR$ had the time lag effect (Table 3). Industrialization, social services, and fiscal decentralization contributed the most to $HULR$ in the first...
year, reaching 12.3%, 7.8%, and 7.9%, respectively. Technological innovation (19.2%), marketization (10.7%), and climate (4.8%) contributed the most to $HULR$ in the second year. Industrial upgrading, space connectivity, and education had the strongest time lag effects (in the third year), with contributions of 9.9%, 27.9%, and 3.3%, respectively. This indicated that the time lag effect is an unavoidable and common phenomenon, and the positive effect of time lag should be fully exerted in the process of promoting $HULR$.

The results of GTWR showed that the effects of different factors on $HULR$ in different regions had significant spatial differences (Fig. 3). The influence of industrialization, industrial upgrading, and technological innovation on $HULR$ showed a trend of increasing from western to eastern and from northern to southern, while marketization and fiscal decentralization showed the opposite trend. The influence of social services and education on $HULR$ showed a gradient effect that gradually weakened from downstream to upstream, and the influence of climate showed a “concentric circle” effect that gradually weakened from Shaanxi Province to the surrounding areas. The effect of spatial connectivity on $HULR$ showed a “W-shaped” change trend, and the areas with high-impact intensity were mainly concentrated in Gansu, Shaanxi, and Shandong provinces.

**Discussion**

The Yellow River Basin is one of the birthplaces of Chinese culture, with a long history of land use. In the early stage of land use, natural factors played a decisive role. With the progress in science and technology, influenced by industrialization and urbanization, human factors have become the decisive factors influencing the land use. However, the excessive use of land resources has brought serious ecological and environmental problems, and the sustainable use of land has become an important direction of land use. From our findings, the $HULR$ value of the Yellow River Basin showed an upward trend, but there are still significant regional differences, which are formed by a combination of reasons.

Rivers gave birth to early human civilization (Feng et al. 2019). The fertile land and sufficient water source in the basin provided important conditions for the development of traditional agriculture. The agriculture provided raw materials for the industry, and the abundant water resources and convenient transportation in the basin area further promote the industrialization (Wang et al. 2015). The development of industry has changed the original land use, promoted the intensive use, and realized the agglomeration effect of land use (Yin et al. 2020). However, the pollutants brought by industrialization have destroyed the ecological environment of the river basin, which is not conducive to the sustainable utilization of land resources (Guo et al. 2022). The pressure of solving pollution problems and pursuing higher benefits has prompted human to promote scientific progress through technological innovation to realize industrial upgrading, thereby promoting the green and efficient use of land resources. Therefore, industrialization, technological innovation, and industrial upgrading are important factors affecting utilization of land resources, and there are differences in different stages and regions. At the same time, there is a

| Variables               | Lag (1)                  | Lag (2)                  | Lag (3)                  |
|-------------------------|--------------------------|--------------------------|--------------------------|
|                         | $\beta_k$ | Con$_k$(%) | $\beta_k$ | Con$_k$(%) | $\beta_k$ | Con$_k$(%) |
| Industrialization       | 0.279**    | (5.49)      | 0.263**    | (4.92)      | 0.272**    | (4.53)      |
| Industrial upgrading     | 0.212**    | (4.22)      | 0.205**    | (3.84)      | 0.239**    | (3.98)      |
| Technological innovation | 0.369**    | (12.88)     | 0.444**    | (12.67)     | 0.447**    | (10.39)     |
| Spatial connectivity     | 0.632**    | (21.33)     | 0.640**    | (20.28)     | 0.669**    | (18.47)     |
| Social service           | 0.178**    | (6.49)      | 0.165**    | (5.59)      | 0.173**    | (5.13)      |
| Education                | 0.067**    | (2.84)      | 0.064*     | (2.53)      | 0.079**    | (2.73)      |
| Fiscal decentralization  | 0.179**    | (5.47)      | 0.175**    | (5.11)      | 0.172**    | (4.38)      |
| Marketization            | 0.240**    | (8.70)      | 0.249**    | (8.18)      | 0.243**    | (6.88)      |
| Climate                  | 0.112**    | (4.25)      | 0.112**    | (4.00)      | 0.100**    | (3.13)      |

Significance: +, $p < 0.1$; *, $p < 0.05$; **, $p < 0.01$; ns, not significant
time lag in the impact of technological innovation. It takes a time to convert innovative achievements into productivity. Therefore, technological innovation needs to be continuously promoted, so as to achieve continuous high-quality utilization of land resources.

Industrialization has promoted the movement of people between different regions. Population migration can provide plenty labor force, so as to make full use of land resources and promote economic development (Vermeulen and Ommeren 2009). However, a large number of populations have brought challenges to the carrying capacity of land resources and threatened the contradiction between human and land (Sun et al. 2020). Therefore, how to achieve a reasonable flow of population has become the key to sustainable use of land resources. Firstly, perfect traffic facilities can improve the transportation connectivity and promote the efficient flow of population. Secondly, social public services determine people’s sense of belonging and happiness and are also an important factor affecting population migration. Finally, education, as an important way to realize knowledge reproduction, is an important basis for scientific progress.

On the other hand, education can enhance residents’ awareness of sustainable development and their willingness to participate in the sustainable utilization of land resources. It is worth noting that the impact of education also has a significant time lag, so we should not only pay attention to short-term benefits, but also long-term benefits.

Marketization and fiscal decentralization are key systems for China’s economic and social development, as well as important factors that affect the sustainable use of land resources. Since the reform and opening-up, China has abandoned the centralized planned economy and implemented market-oriented economic reform, giving full play to the role of the market in allocating resources to arouse the enthusiasm of various subjects and promote the efficient use of land resources (Cheng et al. 2022). Second, fiscal decentralization gives local governments autonomy to formulate precise strategies based on the unique regional conditions. However, the spontaneity, blindness, and lag of market regulation may over-exploit land resources and destroy land ecosystems, causing irreversible damage to the ecological environment (Wu and Neerink 2016). In addition, the excessive autonomy

Fig. 3 Spatial distributions of the coefficients of GTWR model for the HULT of the 9 development indicators in the Yellow River Basin from 2008 to 2019
of local governments threatens the integrity of land use planning, resulting in disorderly use and vicious competition of land resources, which is not conducive to the sustainable use of land resources. Therefore, it is necessary to ensure the integrity of land utilization planning through macro-control policies and strengthen the assessment and supervision during the utilization process, so as to ensure the high-quality utilization and sustainable development of land resources.

The Yellow River Basin has a large area, and the conditions and stages of development vary widely among regions, which makes the influence degree of different factors have obvious spatial differences. The downstream area is located in the plain area of eastern China, with a high level of economy and urbanization, a high degree of land utilization, and a high population density. Social public services and education have a high degree of influence on the utilization of land resources in this area. However, the upstream area is located in the central and western regions of China, which was affected by the reform and opening-up policy late. Marketization and fiscal decentralization have a high degree of influence on the utilization of land resources in this area. Therefore, the utilization of land resources should be adapted to local conditions.

What’s more, as an important ecosystem in China, the Yellow River basin is characterized by poor ecological background, serious soil erosion, and weak carrying capacity of ecological environment. The utilization of land resources must consider both ecological thresholds (the ecological environment carrying capacity) and economic thresholds (the needs of different socioeconomic development), so as to realize the coordination and balance between natural resources and socioeconomic resources.

**Conclusion**

High-quality utilization of land resources (HULR) is related to security of land ecosystem and sustainable development of socio-economy. We analyzed the temporal and spatial differences and influencing factors of HULR to provide policy makers with effective policy recommendations to promote sustainable use of land resources.

Based on our findings, the HULR values of the Yellow River Basin were 0.22 to 0.28 from 2008 to 2019, showing obvious regional differences. The evolution trend of HULR value showed high-level areas are mainly concentrated in the downstream; low-level cities are mainly concentrated in the upstream. What’s more, the spatial connectivity, technological innovation, industrialization, industrial upgrading, and marketization are important factors influencing HULR, and different factors have different spatial effects in different regions. Therefore, the utilization of land resources should be implemented according to the actual conditions of different regions and in combination with important factors with a high degree of influence. As the Yellow River Basin is an important ecological barrier in China, the utilization of land resources must consider both ecological thresholds and economic thresholds to pursue the coordinated development of human and land. What’s more, the subjective perception of land utilization from residents is also an important factor affecting HULR in the Yellow River Basin, which needs to be gradually improved in future research.

As the Yellow River is the second largest river in China, it covers different utilization stages of land resources that will provide the reference for other countries to explore the main factors affecting HULR and achieve sustainable utilization of land resources.

**Acknowledgements** We thank Geoffrey Hart (Montréal, Canada) for editing an early version of this paper. We are also grateful for the comments and criticisms of the journal’s anonymous reviewers and our colleagues.

**Author contribution** Z. C. designed the research; W. L. and Z. C. performed the data analysis and wrote the main manuscript text. All authors have reviewed the manuscript and approved it for submission.

**Funding** This work was supported by the National Key Technology R&D Program (No. 2016YFC0501002).

**Data availability** The data presented in this study are available on request from the corresponding author.

**Declarations**

**Ethics approval** The work does not involve any hazards, such as the use of animal or human subjects’ issue.

**Consent to participate** All authors of the paper have participated in certain substantive aspects of this study, and they are acknowledged or listed as contributors.

**Consent for publication** The paper has not been and will not be submitted simultaneously to other journals. We consent to publish.

**Competing interests** The authors declare no competing interests.

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