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The Coupling Coordination Relationship Between Urbanization and the Eco-Environment in Resource-Based Cities, Loess Plateau, China

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Abstract: Resource-based cities face numerous sustainability challenges, making the coupled and coordinated relationship between urbanization and the eco-environment critical for sustainable development strategies. The Loess Plateau is an essential energy base and ecologically fragile area in China, holding unique and significant research value. This research employed the Remote Sensing Ecological Index (RSEI) and the Compound Night Light Index (CNLI), based on MODIS and night light data, to investigate the socio-economic development and eco-environmental changes across 25 resource-based cities on the Loess Plateau (LP) in China over the past 20 years. The Coupling Coordination Degree Model (CCDM) and Multi-Scale Geographically Weighted Regression (MGWR) were utilized to assess the relationship between urbanization and ecological factors. The average RSEI values for these cities ranged from 0.4524 to 0.4892 over the 20 years, reflecting an upward trend with a growth rate of 8.13%. Simultaneously, the average CNLI values ranged from 1.5700 to 6.0864, with a change of 4.5164. Over the past two decades, all cities in the study area experienced rapid urbanization and ecological development. The correlation between urbanization and ecological factors strengthened, alongside an increasing spatial heterogeneity. While the coupling coordination relationship in most cities showed improvement, many remained within the low to middle grades. These findings enhance the understanding of the intricate relationships between urbanization and ecology, offering valuable insights for policy-making aimed at creating sustainable and livable resource-based cities.

Keywords: resource-based cities; eco-environment; urbanization; RSEI; Loess Plateau; sustainability

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1. Introduction

Since the launch of China's reform and opening-up policies in 1978, the country's economy and society have rapidly developed alongside the urbanization process [1]. The latest data from the National Bureau of Statistics (2021) indicate that China's urbanization level reached 63.89% at the end of 2020. Furthermore, this trend of rapid increase is likely to continue in the coming years [2]. In process of urbanization, the land use and land cover change (LUCC) caused by human activities, as a complex and diverse risk source, has sharply modified the structure and morphology of cities, meanwhile facing a gradually increasing demand for environment [3]. The development of urbanization has resulted in an increase in urban population density, which, in turn, has led to the overconsumption of resources [4,5], moreover, actual and potential problems in the ecological environment such as atmospheric pollution, urban heat islands, and water and soil pollution [6–9]. In

addition, the degraded eco-environment acts as a hindrance to the continued expansion of urbanization [10]. This situation particularly occurs in resource-based cities, where dominant industries depend on natural resources such as minerals, gas, and oil [11].

The United Nations' 2030 Agenda introduced the Sustainable Development Goals (SDGs) in 2015, which have since provided a framework for both national institutions and international organizations to develop strategies for achieving sustainable development [12]. As sustainable development gains increasing attention, it becomes crucial to prioritize the coupling and coordination between urbanization and the eco-environment. This relationship is highly complicated, non-linear, and multifaceted [13]. Researchers have studied the correlation degree, coupling degree, and coordination degree of various regions, such as Chongqing, using CCD and GIS spatial methods [14]. Other scholars, like Zou et al., have explored the dynamic changes in and spatiotemporal heterogeneity of the coupling relationship between urbanization and the ecological environment in Shaanxi Province using CCDM, RDDM, and GTWR [15]. Fu et al. [16] used a comprehensive index system to quantitatively evaluate the evolution of the relationship between urbanization and the eco-environment development in Qingdao. Overall, there has been a growing scholarly interest in exploring the connection between urbanization and the eco-environment in recent years, indicating that relevant research remains a hot topic in urban ecology [17].

The concept of coupling, derived from physics, describes the interaction of two or more subsystems. Modeling the degree of coupled coordination evaluates the harmony between subsystems—a method widely used in resource and environmental studies. The coupling coordination degree is typically established through the evaluation of both the urbanization level and the eco-environmental quality, which has been accomplished in various studies through the use of different statistical indicators [18]. For instance, Yang et al. [19] characterized the ecological environment using ecological footprint, while Shi et al. [20] used primary productivity (NPP) and fractional vegetation cover (FVC) to evaluate the eco-environment. Zhang et al. [21] also employed different indicators to support indexes in cities. However, the subjectivity in constructing indicator systems and selecting specific indicators, as well as the challenge of obtaining and filtering large spatial- and temporal-scale data, pose difficulties in these studies. To address this situation, remote sensing can offer an efficient and convenient approach [22,23]. Traditional statistical data analysis reflects regional trends at the overall city level, but fails to capture changes in the internal spatial structure of cities. As a result, the consistency and reliability of long-term statistical data are often difficult to ensure. In contrast, remote sensing data objectively reflect regional changes without requiring weight parameters factitiously.

China boasts abundant mineral resources and relatively favorable natural conditions, making it the world's largest energy producer [24]. Resource-based cities in China play a critical role in supporting the improvement of people's standard of living and driving national economic development by providing a significant quantity of resources [25]. Nowadays, resource-based cities serve as crucial components of China's energy and resource security base, and the sustainability of these areas is essential for ensuring the stability of both the economy and the environment [26]. As urbanization continues to develop, it is crucial to prioritize environmental protection. Consequently, it becomes both urgent and necessary to transition resource-based cities from a focus on high-speed growth to a focus on high-quality development [27]. As a less developed inland region with both economic and ecological vulnerability [28], the Loess Plateau (LP) has 39 resource-based cities, accounting for 14.8% of China. The LP is characterized by a fragile local environment and a high concentration of resource-based cities, leading to an evident contradiction between the demand for economic development and ecological protection in the region [29]. As such, it presents a typical case for exploring the relationship between urbanization and the eco-environment, which could inform policies related to environment conservation and urban development. Therefore, as a class of important cities with special significance facing huge problems in sustainable development, to protect these resource-based cities, we urgently need to implement a sustainable development coupling analysis with SDGs as the basic guideline [30].

The LP is characterized by a fragile local environment and a high concentration of resource-based cities, leading to an evident contradiction between the demand for economic development and ecological protection in the region. Therefore, as a class of important cities with special significance facing huge problems in sustainable development in the LP, to protect these resource-based cities, we urgently need to implement a sustainable development coupling analysis with SDGs as the basic guideline. This study aimed to achieve the following three key objectives: (1) How have the eco-environments of resource-based cities located in the LP changed over the past two decades, and what were the underlying factors contributing to these changes? (2) What were the spatiotemporal patterns of the urbanization levels in the resource-based cities located in the LP over the past two decades, and how have they varied across different regions and time periods? (3) To what extent was there a coupling coordination between the eco-environment and urbanization levels in resource-based cities located in the LP, China, and how have the spatial relationships between urbanization and the environment varied across different regions and time periods? This research will provide more detailed and meaningful information about urbanization and the environment for both policy makers and scholars to achieve the sustainable development of resource-based cities.

2. Materials and Methods

2.1. Study Area

The LP has a total area of 6.487×10^5 km^2 and is rich in energy and mineral resources. Resource-based cities represent a critical component of both the national energy security base and ecological security barrier. According to the National Plan for Sustainable Development of Resource-Based Cities (2013–2020) issued by the State Council, there are 39 resource-based cities within this region, comprising 25 prefecture-level cities, 12 counties (cities), and 2 municipal districts. For data consistency and availability across administrative units, this study focuses on 25 resource-based cities within the LP (Figure 1). These cities, identified by the national development plan as resource-based, are distributed across the Loess Plateau, resulting in a non-continuous study area. Among these cities, growing and mature resource-based type cities account for a relatively high proportion; more than half of them are coal-based cities. In 2020, the GDP of all 25 resource-based cities in the Loess Plateau region was 4.2135×10^{12} RMB. The population is 7.148×10^7 people, including 4.086×10^7 people in urban areas.

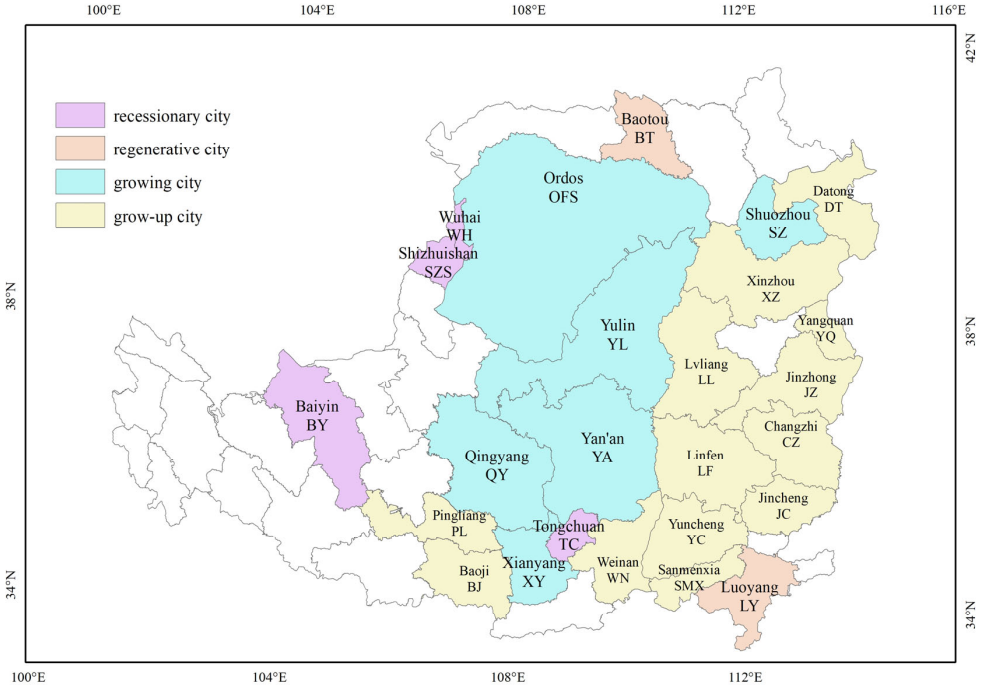


Figure 1. Development stage and location of resource-based cities in the Loess Plateau area.

2.2. Data Sources

This study primarily utilizes the following data: MODIS (Moderate-resolution Imaging Spectroradiometer) data, including the MOD09A1, MOD11A2, and MOD13A1 products from the GEE (https://earthengine.google.com/ (accessed on 30 September 2024)) dataset, which, respectively, provide terra surface spectral reflectance, land-surface temperature (LST), and Vegetation Index (VI). The satellite products collected in the years 2000, 2005, 2010, 2015, and 2020 were deemed suitable for the study, with a 20-year interval between each collection period; to enable better comparison across different years, image collection was limited to the period between June and September, while the population data were obtained from the WorldPop Global Project Population Data. Nighttime light data were obtained from NPP-VIIRS-like NTL Data from National Tibetan Plateau Data Center [31], generated via the NTLSTM network, and exhibit a high reliability with an RMSE of 0.73, R^2 of 0.95. Administrative and physical geographic boundary data were provided by Center of Resources and Environment Science, Chinese Academy of Sciences (https://www.resdc.cn/ (accessed on 1 October 2020)).

2.3. Data Methods

2.3.1. Calculation of the RSEI

RSEI is an aggregated index developed in recent years for the fast monitoring of ecological circumstances exclusively through remotely sensed data [32,33]. To represent the greenness index, which reflects vegetation growth and its distribution density in the study area, the Normalized Difference Vegetation Index (NDVI) was used [34]. Additionally, the Normalized Difference Impervious Surface Index (NDISI) was calculated using the Index-based Built-up Index (IBI) and Soil Index (SI), which reflects the spectral response of land desertification and urbanization, as reported by [35]. To obtain the Land Surface Temperature (LST) indicator of the study area, the MODIS LST product data were used, which can reflect the heat condition of the study area [36]. Lastly, the Water and Soil Erosion Index (WET) was calculated using the Tasseled Cap Transformation (TCT), a widely used method for analyzing remote sensing data, which was used to reflect the land degradation caused by the soil water content [37]. All of the aforementioned indexes were operationally processed on the Google Earth Engine platform. In this study, the RSEI was calculated using the following formulas.

$$\mathrm{NDVI} = (\rho_{\mathrm{NIR}} - \rho_{\mathrm{Red}})/(\rho_{\mathrm{NIR}} + \rho_{\mathrm{Red}}) \tag{1}$$

$$\mathrm{Wet} = 0.1147\mathrm{B}_1 + 0.2489\mathrm{B}_2 + 0.2408\mathrm{B}_3 + 0.3132\mathrm{B}_4 - 0.3122\mathrm{B}_5 - 0.6416\mathrm{B}_6 - 0.5087\mathrm{B}_7 \tag{2}$$

$$\mathrm{NDSI} = \tfrac{1}{2}(\rho_{\mathrm{Swir1}} + \rho_{\mathrm{Red}} - \rho_{\mathrm{Blue}} + \rho_{\mathrm{Nir}}) \times \left(\frac{\rho_{\mathrm{Swir1}}}{\rho_{\mathrm{Swir1}}+\rho_{\mathrm{Red}}+\rho_{\mathrm{Blue}}+\rho_{\mathrm{Nir}}} - \frac{\rho_{\mathrm{Nir}}}{2\rho_{\mathrm{Swir1}}+\rho_{\mathrm{Nir}}+\rho_{\mathrm{Red}}} + \frac{\rho_{\mathrm{Green}}}{\rho_{\mathrm{Green}}+\rho_{\mathrm{Swirl}}}\right) \tag{3}$$

$$\mathrm{RSEI}_0 = 1 - \{\mathrm{PC}_1[\mathrm{f}(\mathrm{Wet}, \mathrm{NDVI}, \mathrm{NDSI}, \mathrm{LST})]\} \tag{4}$$

$$\mathrm{NI}_i = \frac{\mathrm{I}_i - \mathrm{I}_{\min}}{\mathrm{I}_{\max} - \mathrm{I}_{\min}} \tag{5}$$

$$\mathrm{RSEI} = \frac{\mathrm{RSEI}_0 - \mathrm{RSEI}_{\min}}{\mathrm{RSEI}_{\max} - \mathrm{RSEI}_{\min}} \tag{6}$$

where ρ stands for the surface reflectance bands; ρ_{red}, ρ_{blue}, ρ_{green}, ρ_{nir1}, ρ_{nir2}, ρ_{swir1}, and ρ_{Swir2} are the surface reflectance of the MDOIS bands; PC_1 represents the first component of the spatial principal component analysis (SPCA); NI_i indicates the normalized result of each index; and RSEI means the normalized result of the $RSEI_0$.

2.3.2. Calculation of the Nighttime Light Index

The level of urbanization reflects a comprehensive integration of factors such as population, industrial structure, and regional spatial development, while the average intensity of night lighting represents the combined influence of these elements. Therefore, utilizing the average intensity of night lighting to analyze and evaluate urbanization levels

is both appropriate and effective. The Compound Night Light Index (CNLI) was developed as a means of using nighttime light data to gauge the level of regional urbanization, offering a greater accuracy compared to previous studies and aligning closely with results derived from population and land indicators [38]. Hence, the CNLI was employed to assess the overall level of urbanization in each city using the following formula [39]:

$$CNLI = LAP \times MLI = \frac{\sum_{i=T}^{DN_M}(DN_i \times n_i)}{N_L \times DN_M} \times \frac{Area_N}{Area} \quad (7)$$

where LAP represents the average night light brightness of all pixels in the region, while MLI represents the proportion of urban areas to the total area of the region. DN_i is the DN value of the ith gray level; n_i is the number of pixels at the ith gray level; DN_M is the maximum DN value; N_L is the number of pixels with a DN value between T and DN_M; N is the number of total pixels of the region; $Area_N$ is the area of city region in study area; and Area is the total area of the study area.

2.3.3. Coupling Coordination Degree Model

The degree of coupling coordination between urbanization and the eco-environment, denoted as C (U, E), was calculated using the following formula [40]:

$$C = 2 \times \frac{\sqrt{UE}}{U + E}, 0 \le C \le 1 \quad (8)$$

The coupling degree (C) between urbanization and eco-environment was calculated as the value of the relationship between the Compound Night Light Index (CNLI) and the Remote Sensing Ecological Index (RSEI), where U represents CNLI and E represents RSEI.

The level of effect between urbanization and eco-environment (T) was defined as follows:

$$D = \sqrt{C \times T}, T = \alpha U + \beta E \quad (9)$$

where D is the coupling coordination degree and α and β are contribution comprehensive weight coefficients. In this study, assuming that the eco-environment is as important as urbanization, hence $\alpha = \beta = 1/2$ [41]. When D is between 0 and 0.4, the urban ecosystem is characterized by a low coupling coordination; a value of D between 0.4 and 0.5 indicates a moderate coordination, while a value of D between 0.5 and 0.8 indicates a high coordination. If D is between 0.8 and 1, the urban ecosystem is considered to have an extremely high coordination [42]. The coupling coordination degree classification between urbanization (U) and eco-environment(E) is shown in Table 1.

Table 1. The classification levels of the CCD.

Composite Category	Coordination Level	Subcategory	Systematic Exponential Comparison	Type
Coordinated development	$0.7 < D \le 1$	High coordination	E-U > 0.1 U-E > 0.1 |E-U| < 0.1	Sluggish urbanization (IV-1) Ecological environment lag (IV-2) Coordinated development (IV-3)
Transformation development	$0.6 < D \le 0.7$	Moderate coordination	E-U > 0.1 U-E > 0.1 |E-U| < 0.1	Sluggish urbanization (III-1) Ecological environment lag (III-2) Coordinated development (III-3)
Uncoordinated development	$0.4 < D \le 0.6$	Reluctant coordination	E-U > 0.1 U-E > 0.1 |E-U| < 0.1	Sluggish urbanization (II-1) Ecological environment lag (II-2) Coordinated development (II-3)
	$0 < D \le 0.4$	Serious imbalance	E-U > 0.1 U-E > 0.1 |E-U| < 0.1	Sluggish urbanization (I-1) Ecological environment lag (I-2) Coordinated development (I-3)

2.3.4. MGWR

Compared with traditional geographically weighted regression (GWR), which can only choose the same bandwidth for all independent variables for regression, multi-scale geographically weighted regression (MGWR) uses the respective optimal bandwidth for each independent variable, solving the problem of different variable scales and bandwidths [43]. Hence, we applied the MGWR model to identity the spatially varying relationships in the cities. The general structure of the MGWR is as follows [44]:

$$y_i = \sum_{j=1}^{k} \beta_{bwj}(u_i, v_i)x_{ij} + \varepsilon_i \quad (10)$$

where X_{ij} is the jth predictor variable, (u_i, v_i) is the center-of-mass coordinate of each block i, and β_{bwj} represents the bandwidth of the regression coefficient of the jth variable.

3. Results

3.1. The Spatio-Temporal Pattern of the Eco-Environment and Urbanization

3.1.1. Changes in Comprehensive Ecological Environment

Principal component analysis results showed that the average contribution rate of the index exceeded 75% in the data for the fifth phase, indicating that PC1 explained over 75% of the variance in the ecological index on average. This suggests that the coupled RSEI effectively represented the ecological environment quality. The RSEI values in the LP were categorized into the following five classes: Very Bad (0–0.2), Bad (0.2–0.4), Medium (0.4–0.6), Good (0.6–0.8), and Very Good (0.8–1.0) (Figure 2). The results indicated a significant upward trend in the RSEI of resource-based cities in China's LP from 2000 to 2020. The average RSEI values of resource-based cities in China's LP in the five periods were 0.4524, 0.4282, 0.4609, 0.4491, and 0.4892, which revealed a fluctuating up trend with approximately 8.13% growth rates. In the past 20 years, significant changes have occurred in the ecological status of resource-based cities in China's LP. The proportion of the "Very Bad" ecological status was reduced by 79.4%, decreasing from 4.71% in 2000 to 0.97% in 2020. Moreover, the area with "Bad" ecological status decreased by 32.1% compared to 2000. In contrast, the areas with a "Medium", "Good", or "Very Good" ecological status all showed a significant increase, with growth rates of 23.4%, 48.4%, and 87.8%, respectively. In 2000, the proportion of "Medium" and "Bad" ecological conditions was relatively similar, at about 40%, while areas with a "Very Bad", "Good", or "Very Good" ecological status accounted for about 4.71%, 14.12%, and 0.58%, respectively. In 2020, the ecological conditions of "Bad", "Medium", and "Good" accounted for 27.5%, 49.4%, and 20.9% respectively, indicating a clear change compared to 2000. Overall, in the past 20 years, about 20–25% of the areas categorized below the "Medium" ecological status have shown improvement. Initially, the northern regions were heavily impacted, classified as "Very Bad" and "Bad". Over the years, substantial efforts or natural recovery processes have led to a significant reduction in degraded areas, with a corresponding increase in regions classified as "Good" and "Very Good". By 2020, the majority of the study area demonstrated an improved ecological quality, indicating successful ecological restoration and management efforts. The changes in the RSEI values indicated that the eco-environment in resource-based cities of China's LP has improved over the past two decades.

Cities of different development types showed different change trends (Figure 3). Most cities of the recessionary type showed a bad eco-environment such as BY, WH, and SZS. Regenerative cities, including LY and BT, showed opposite ecological conditions, which were medium. Growing cities saw a big difference, but maintained a medium status. Grown-up cities, overall, showed a stable and good eco-environment. While the overall ecological status of resource-based cities in China's LP has improved, it is important to note that there are still areas that have poor ecological conditions. This could be attributed to human activities and environmental factors. Furthermore, the ecological circumstances in southern cities were generally better than those in northern cities, including BY, SZS, YL,

and OFS, which are mainly characterized as recessionary and growing cities. In addition, no city with a very good degree of ecological quality appeared.

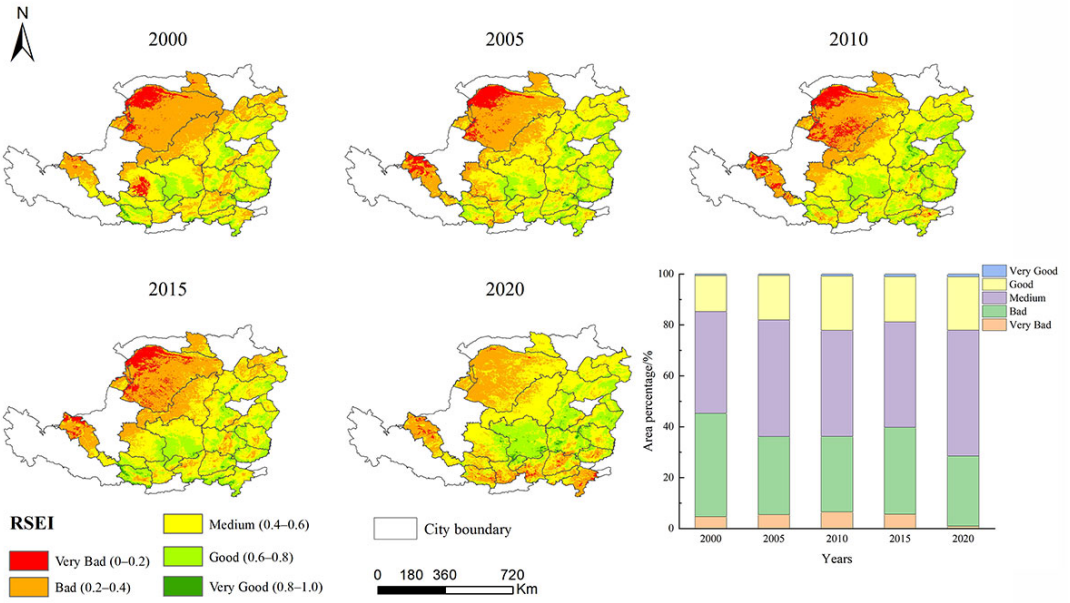


Figure 2. The RSEI map and area percentage in 2000, 2005, 2010, 2015, and 2020.

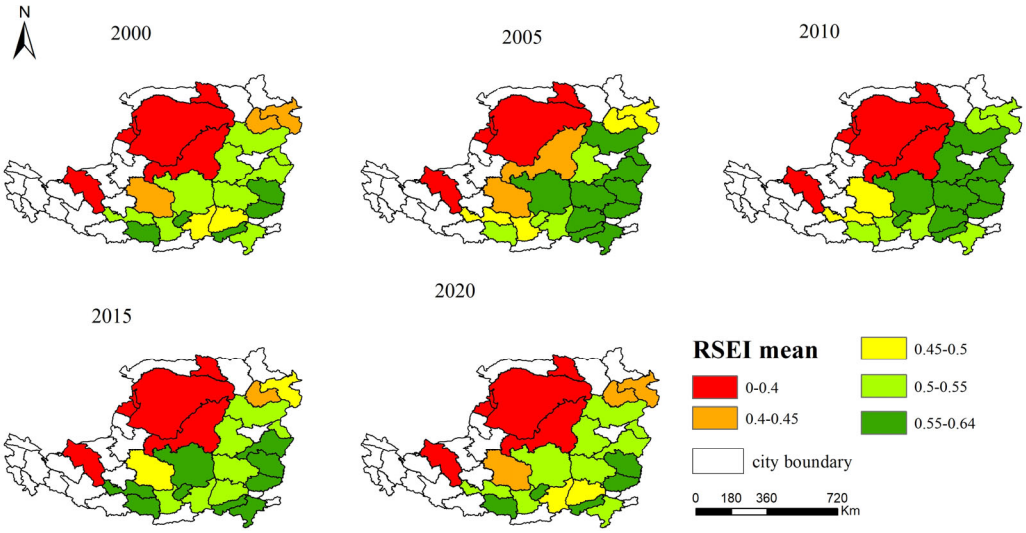


Figure 3. The RSEI mean value distribution between 2000 and 2020.

3.1.2. Changes in Comprehensive Urbanization Quality

Figure 4 depicts the nighttime light images of resource-based cities in China's Loess Plateau from 2000 to 2020, revealing a steady increase in both the lighting area and light pixels number. The MLI value, which was merely 0.033 in 2000, grew year by year and reached 0.065 in 2020, indicating a remarkable growth rate of about 96.6%. Moreover, the LAP increased from 23.5% in 2000 to 40.3% in 2020. Overall urbanization has been rapidly progressing since 2000, with southeastern cities showing better development than northwestern cities. While the urbanization rate in grown-up cities remained relatively stable, the other three city types underwent significant changes over the past 20 years. Despite this noticeable urbanization progress, the ecological conditions of resource-based cities in China's Loess Plateau still need improvement due to the impact of human activities on the environment. Additionally, southern cities generally exhibited better ecological

conditions than northern cities, including BY, SZS, YL, and OFS, which mainly belong to the recessionary and growing city categories.

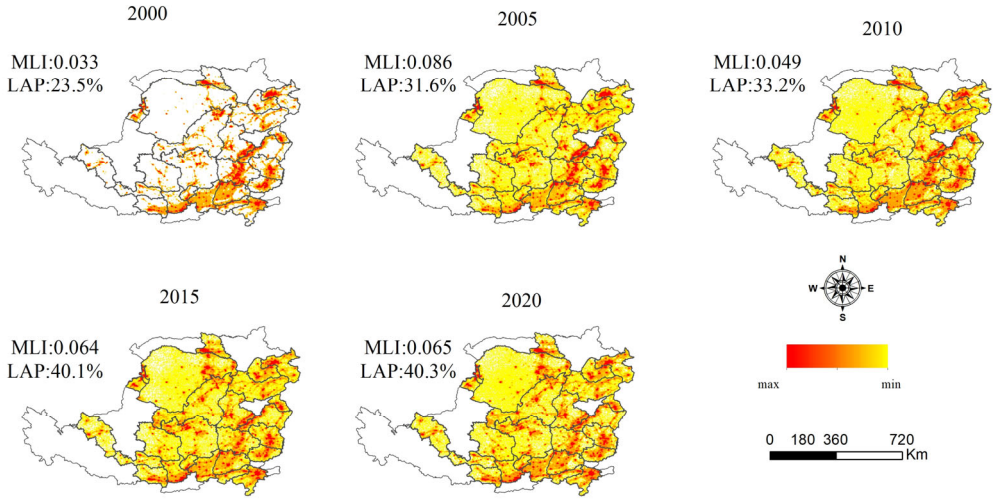


Figure 4. Resource-based cites in China's Loess Plateau light images and changes from 2000 to 2020.

The CNLI values and their changes were calculated for each city (Figure 5). The average CNLI values for all cities in the five periods were 1.5700, 4.4708, 4.6896, 5.8961, and 6.0864, with a change trend value of 4.5164. In 2020, the average CNLI value increased by 287.66% compared to 2000. The spatial distribution of CNLI was similar to the eco-environmental quality, and a high coupling coordination was mainly distributed in the southeastern region of the study area. The cities with the greatest improvement were WH, BJ, LY, BT, and SZ, which belong mainly to the growing and regenerative city categories, while LF, YZ, OFS, BY, and QY, which mainly belong to the growing city categories, saw less improvement. Despite the overall urbanization process of various resource-based cities having grown over the past 20 years, this development has been very uneven.

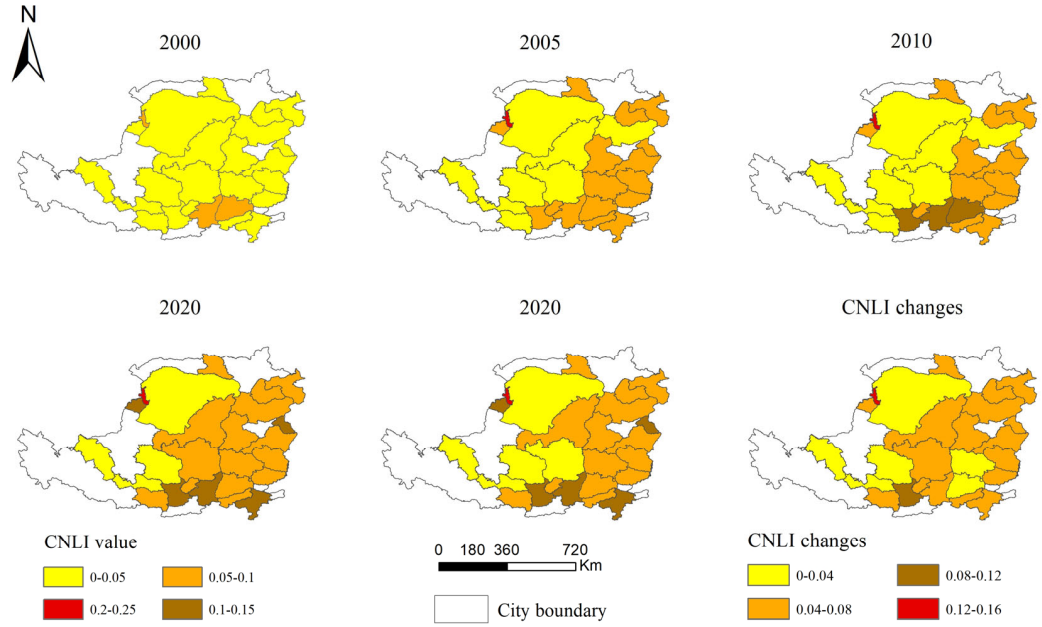


Figure 5. CNLI of resource-based cites in China's Loess Plateau and its changes.

3.2. The Spatio-Temporal Relationship Between Eco-Environment and Urbanization

The interaction between the eco-environment and urbanization was directly and effectively measured using MGWR in conjunction with mutual variables, taking into

account spatial and temporal differences. Table 2 shows the remaining parameters, with urbanization as the dependent variable. The standard deviation of the coefficients reflects the degree of variation in the relationship between the eco-environment and urbanization, with larger values observed in 2000 compared to other years. In terms of the absolute mean value of the coefficient, 2000 had the greatest impact on the overall quality of the eco-environment, while the other years did not differ much. The year with the greatest overall impact on the ecosystem, in terms of the absolute value of the median, was also 2000, followed by 2015, 2020, 2005, and 2010. These results suggest that urbanization had a greater and more volatile impact on the eco-environment in 2000, indicating a strong spatial heterogeneity.

Table 2. Statistics of regression results of MGWR model.

Year	Mean	STD	Min	Median	Max
2000	0.042	0.725	−1.684	0.348	0.661
2005	−0.001	0.003	−0.005	−0.001	0.004
2010	−0.001	0.002	−0.004	−0.001	0.002
2015	−0.001	0.004	−0.008	−0.001	0.005
2020	−0.002	0.002	−0.006	−0.001	0.003

The feedback of the eco-environment on urbanization in different regions is presented from 2004 to 2018 (Figure 6). The MGWR coefficient map demonstrates a spatial pattern with positive estimates stretching from the northwest to the southeast. Specifically, in 2000, the areas with positive MGWR coefficient values were mainly located in the southeast of the study area, including cities such as LY, SMX, YC, WN, CZ, JC, and BJ. In 2005, great changes occurred, with positive MGWR coefficient value areas transferring to northeast regions, such as BT, DT, SZ, XZ, and YQ. The range of significant coefficients was between −1.684 and 0.6612, which showed large fluctuations. In addition, the overall value decreased from southeast to northwest. Since 2005, over the next 15 years, this showed that similar spatial distribution. The range of significant coefficients was between −0.0040 and −0.0010, which showed small fluctuations. The overall value decreased from northeast to southwest. With the development of time, cities in northeast areas showed a large correlation between the eco-environment and urbanization incidence.

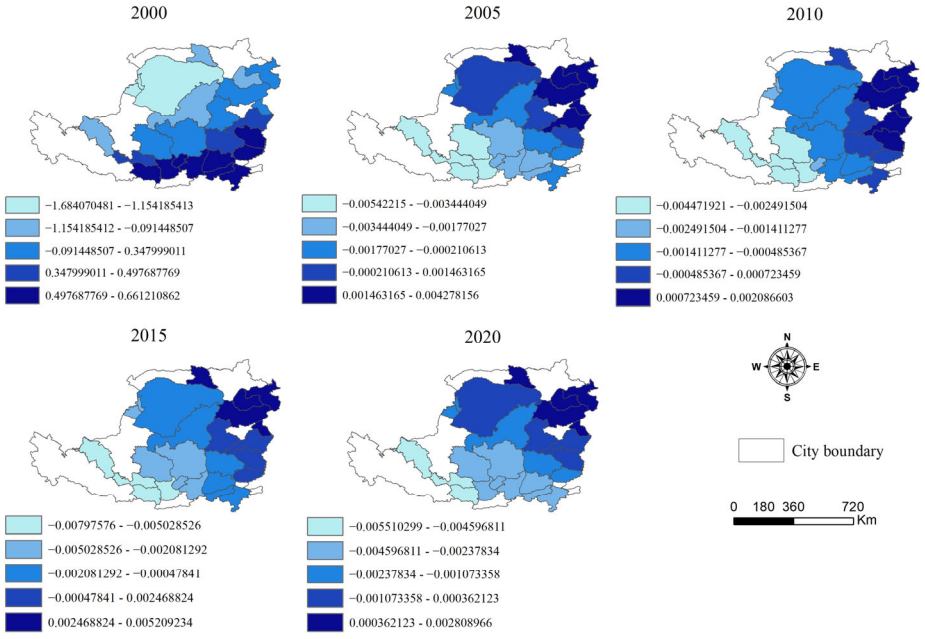


Figure 6. Spatial distribution of coefficients of multi-scale geographically weighted regression model.

3.3. Coupling Coordination Evaluation Results of Eco-Environment and Urbanization

The cluster maps (Figure 7) broadly illustrate the pattern of CCD spatial distribution. The results indicate that, in 2000, most resource-based cities in the LP were dominated by low and moderate coordination, and only a few cities such as Yuncheng and Weinan were at a moderate coordination level. All other cities had a low coupling coordination, of which Ordos was the lowest. In 2005 and 2010, the overall CCD of cities in the LP had the trend of a slow increase, a change compared with 2000, especially in cities in the southeast, where most were located in Shaanxi and Shanxi province. All cities had a low or medium coupling coordination. Additionally, more and more cities had an increasing coupling coordination degree at the same time. Many cities, about 72%, changed from a low coupling coordination to a medium coupling coordination, while only a few cities maintained a low coupling coordination. In 2015, the CCD continued to increase in most cities. In 2020, the CCD compared with 2010 changed to being better in general. Only six cities had a low coordination level, which were BY, OFS, YL, QY, PL, and BJ. There was no city with an extremely high coordination over the two decades.

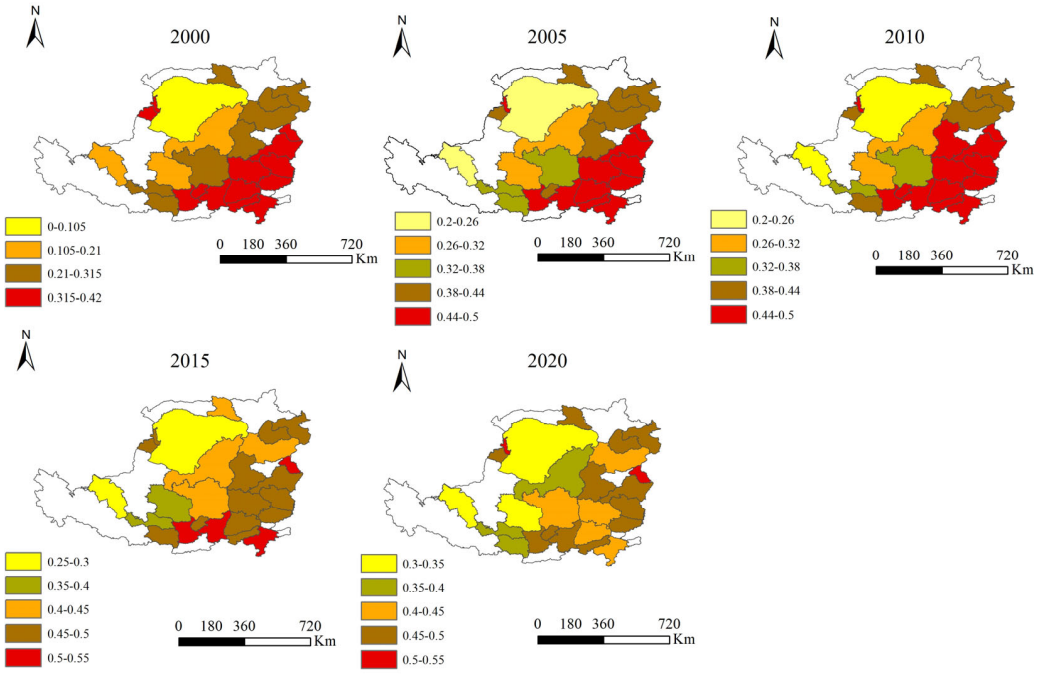


Figure 7. The coordination degree between eco-environment and urbanization in China's Loess Plateau.

From the perspective of temporal-scale changes (Figure 8), the CCD increased compared to 2000, regardless of the city type. The improvement of the coupling coordination degree can be attributed to many factors, including ecological restoration projects such as the Grain for Green Program, funding and policy protection, and active public participation in the LP. The cities saw CCD fluctuations of 36%. The CDD of the remaining cities increased persistently. The CCD of some cities continued to rise year by year, such as BY, Ordos, SZ, Yl, QY, and DT, which mostly belong to the recessionary and grown-up city categories. The CCD in the remaining cities remained stable or fluctuated after elevated development. In general, resource-based cities were more influenced by human activities, and economic development and ecological management have been deepening over the past 20 years.

Furthermore, the specific coupling coordination type assigned to each county highlighted the tension between urbanization and the state of the ecological environment (Table 3). The results showed that most resource-based cities on the LP experienced uncoordinated development, serious imbalances, and sluggish urbanization. In the later stages, some cities had transitioned to reluctant coordination, but continued to experience sluggish

urbanization. Except for Wuhai, where the eco-environment and urbanization were in coordinated development in 2005, 2010, and 2015, other cities experienced sluggish urbanization in their comparative relationship between urbanization and the eco-environment. Most cities experienced a serious imbalance at the beginning of the 20th century and have since developed into a state of reluctant coordination. Additionally, cities like Changzhi, Yuncheng, and Weinan have remained in a state of reluctant coordination for the past 20 years. In a few cities, such as Shuozhou and Baoji, there have been repeated shifts in the coupling coordination between reluctant coordination and a serious imbalance.

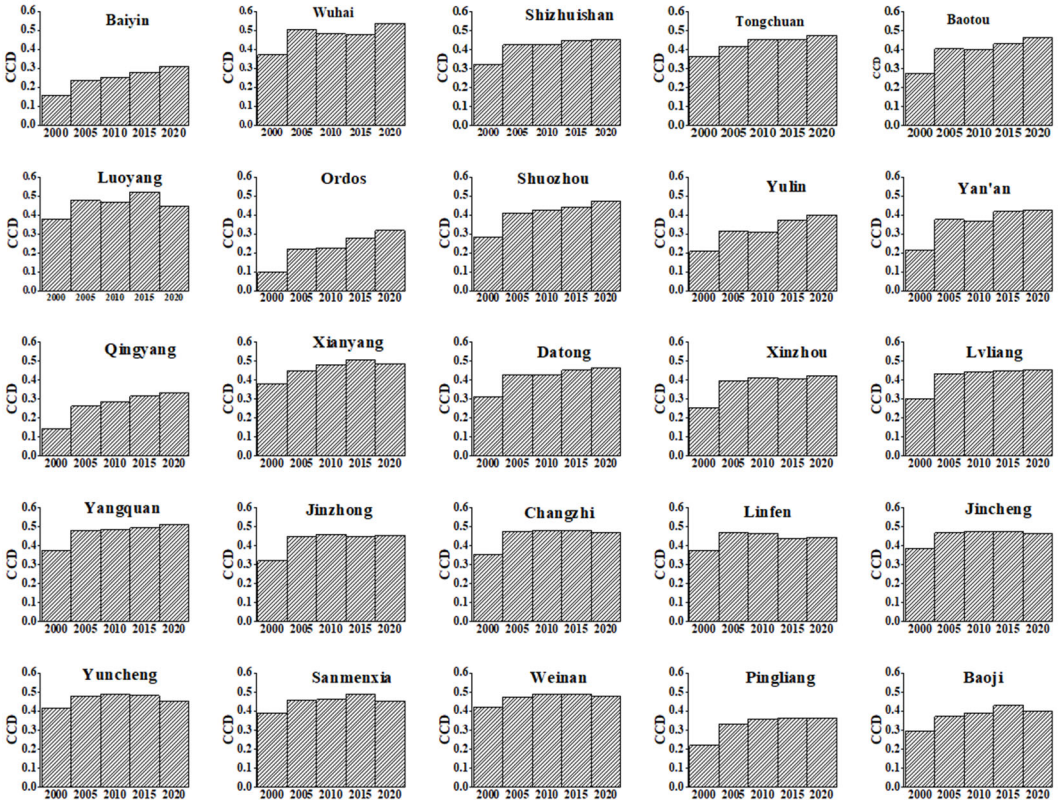


Figure 8. The temporal changes of the CCD between eco-environment and urbanization in China Loess Plateau about prefecture-level cities.

Table 3. Statistics of regression results of MGWR model.

City	Types	2000	2005	2010	2015	2020
Baiyin	Recessionary	I-1	I-1	I-1	I-1	I-1
Wuhai		I-1	II-3	II-3	II-3	II-1
Shizhuishan		I-1	II-1	II-1	II-1	II-1
Tongchuan		I-1	II-1	II-1	II-1	II-1
Baotou	Regenerative	I-1	II-1	I-1	II-1	II-1
Luoyang		I-1	II-1	II-1	II-1	II-1
Ordos	Growing	I-1	I-1	I-1	I-1	I-1
Shuozhou		I-1	II-1	II-1	II-1	II-1
Yulin		I-1	I-1	I-1	I-1	I-1
Yan'an		I-1	I-1	I-1	II-1	II-1
Qingyang		I-1	I-1	I-1	I-1	I-1
Xianyang		I-1	II-1	II-1	II-1	II-1
Datong	Grown-up	I-1	II-1	II-1	II-1	II-1
Xinzhou		I-1	I-1	II-1	II-1	II-1
Lvliang		I-1	II-1	II-1	II-1	II-1

Table 3. *Cont.*

City	Types	2000	2005	2010	2015	2020
Yangquan	Grown-up	I-1	II-1	II-1	II-1	II-1
Jinzhong		I-1	II-1	II-1	II-1	II-1
Changzhi		II-1	II-1	II-1	II-1	II-1
Linfen		I-1	II-1	II-1	II-1	II-1
Jincheng		I-1	II-1	II-1	II-1	II-1
Yuncheng		II-1	II-1	II-1	II-1	II-1
Sanmenxia		I-1	II-1	II-1	II-1	II-1
Weinan		II-1	II-1	II-1	II-1	II-1
Pingliang		I-1	I-1	I-1	I-1	I-1
Baoji		II-1	I-1	I-1	II-1	I-1

4. Discussion

4.1. Evolution and Relationship of Eco-Environment and Urbanization

Over the past two decades, urbanization has rapidly advanced in resource-based cities on the LP of China, resulting in significant changes in the eco-environment of these cities. Due to its natural background, the LP is predominantly covered with unique loess soil, leading to long-term soil erosion, low vegetation cover, and a poor ecological quality in most areas over the past century. Moreover, the local economic base of the region is weak, and the development of these cities relies on exploiting various resources to achieve rapid economic growth and significant socio-economic progress. This study utilized the Compound Night Light Index (CNLI) and Remote Sensing Ecological Index (RSEI) to estimate the urbanization and Eco-Environmental Quality (EEQ) of resource-based cities in the LP region to investigate the influence of urbanization on the eco-environment. The research findings revealed significant improvements in both the urbanization level and eco-environmental quality of these cities from 2000 to 2020.

Given the importance of resources for the success and sustainability of these cities, it is critical to address the prominent unsustainable problems they face. Conducting research is crucial to understanding the coupled and coordinated relationship between urbanization and the eco-environment in resource-based cities on the LP. Rapid urbanization in these cities has significantly impacted the eco-environment, but local ecological protection projects have been implemented to ensure stability. Recessionary resource-based cities, suffering from ecological degradation, declining urbanization rates, and limited economic diversification due to prolonged resource extraction, experience socio-economic stagnation. Priority should be given to economic diversification and environmental restoration, focusing on alternative industries like renewable energy and sustainable agriculture to rebuild the local economy. In contrast, regenerative cities are characterized by improving ecological conditions and moderate urbanization as restoration efforts progress. These cities should strengthen their green infrastructure and attract environmentally sustainable industries to reduce resource dependence, while advancing green technology. Growing cities, experiencing rapid urbanization, face challenges in balancing economic expansion with ecological preservation due to intensified environmental pressures. Lastly, grown-up cities represent a mature stage of urbanization with stable, diversified economies and a degree of ecological improvement. At the beginning of the 21st century, the coupling coordination in all cities of the study area was at a low to medium level. However, after implementing economic and ecological projects, the coupling coordination in most cities has continued to rise, although many cities still require improvement.

4.2. Implications and Suggestions for Resource-Based Cities Ecological Management and Sustainable Development

The findings of this study revealed that the coupling coordination degree between urbanization and the eco-environment in resource-based cities on the LP has been consistently low to medium over an extended period, with gradual improvement. These cities should aim

to create sustainable, regenerative systems that support human and environmental health. Policy makers should prioritize investments in renewable energy, sustainable and green industry. In addition, it still is necessary to balance urban development with environmental conservation, protecting natural resources while supporting economic growth.

To address the challenges of slow urbanization, sluggish coordinated development, and delayed urbanization in resource-based cities, three targeted strategies are recommended. First, to enhance urbanization processes, policies should focus on diversifying the local economy beyond resource dependency by attracting new industries and supporting entrepreneurship, which can increase employment opportunities and reduce economic reliance on a single sector. Second, for improving coordinated development, there is a need to strengthen infrastructure, particularly in transportation and public services, to foster connectivity and integration with surrounding areas. This would facilitate the flow of goods, services, and labor, enhancing regional development and supporting balanced growth across sectors. Third, to address the slow urbanization specific to these cities, it is crucial to promote sustainable resource utilization and environmental rehabilitation efforts. This involves implementing stricter regulations on resource extraction, encouraging green technologies, and initiating ecological restoration projects to improve environmental conditions and make these cities more attractive for sustainable investment and migration. Together, these strategies aim to revitalize resource-based cities by fostering balanced, resilient, and sustainable urban development.

4.3. Implications, Limitations and Further Research

In this paper, we delved into an analysis of the evolutionary characteristics of the eco-environment and urbanization, with particular focus on their coupling coordination over the past two decades. Nonetheless, certain limitations need to be discussed regarding this research. With the results of principal component analysis, we confirmed that the data used in this study were relatively reliable and the results obtained are accurate and effective. However, the natural background to LP has long been extremely complex. In quantifying the intensity of ecological quality, only four directly perceived and remotely sensed easily inverted ecological factors were considered, which may lead to an inaccurate and complete representation of ecological quality. The application of a comprehensive system with multi-index evaluation and comparative analysis of subsystem transformations is valuable for future reference and analysis [45]. More accurate methods for extracting urbanization are needed, rather than relying solely on nighttime light data, such as incorporating multi-source data correction [46]. Furthermore, it should be noted that the situation such as energy use, land use, and soil erosion were not considered in this study. A comprehensive examination of the diverse driving factors contributing to the phenomenon is necessary, as the current quantitative explanations are insufficient. This oversight may hinder the establishment of a solid foundation for future ecosystem management and policy-making. For resource-based cities, the research scale should be expanded beyond the LP, with diverse future studies conducted across China and globally [47].

The direction of our future research will be concentrated on the following three areas: (1) selecting more targeted indicators to more accurately quantify the eco-environment of the LP in China, including about terrain, atmosphere, and biodiversity; (2) high-resolution data and multi-source data such as Synthetic Aperture Radar (SAR), unmanned aerial vehicle (UAV), and so on will be used to enhance quantization results about urbanization; and (3) more models should be employed to explore and analyze the coupling relationship about the different ecological factors, ecological elements, and ecological systems. Future local urbanization and ecological environment trends need to be quantitatively predicted based on historical data. The coupling and coordination of urbanization and ecological environment development are crucial steps toward achieving sustainable urban development [48]. Overall, our future research will focus on improving our understanding of the eco-environment of resource-based cities in China, with the ultimate aim of achieving sustainable development goals in different regions.

5. Conclusions

In this study, the eco-environment and urbanization over the period of 2000–2020 were evaluated by RSEI and CNLI, based on the MODIS data and nighttime light data, for 25 resource-based cities in the LP of China. This was based on the RSEI and CNLI, with data derived from MODIS and nighttime light sources. The main conclusions are as follows:

(1) The investigation of the relationship between the eco-environment and urbanization was conducted using a coupling coordination degree model and MGWR. Over the period from 2000 to 2020, the urbanization level and the eco-environmental quality of all cities in study area exhibited a steady increase. In addition, coupling coordination of all cities also rose at the same time. The development of different types of cities was very uneven, although there were continuous improvements in development over 20 years. Over those 20 years, CNLI values ranged from 1.57 to 6.08, while the RSEI values ranged from 0.46 to 0.48. The regression coefficient of economic urbanization in resource-based cities on the ecological environment across different regions was mainly negative, indicating that the ecological environment in these cities is considered to be seriously threatened. The CCD ranged from 0.30 to 0.43, indicating that all cities remained in uncoordinated development for the last 20 years.

(2) Based on an analysis of the four types of resource-based cities—recessionary, regenerative, growing, and grown-up—the coordination between urbanization and ecological environment status varied significantly. Recessionary cities showed a consistent trend of sluggish urbanization and environmental lag, indicating ongoing ecological challenges and limited urban expansion. In contrast, regenerative and growing cities demonstrated a moderate to high coordination, with a developing balance between urban development and ecological health.

(3) The grown-up cities exhibited signs of improved alignment between urbanization and ecological conditions. So, it is necessary to get rid of the industrial structure dependent on resources as soon as possible, continue to develop the economy and maintain the ecological balance, and constantly improve the degree of coupling and coordination. The findings of this study provide valuable insights into the internal mechanisms and fundamental conditions of the interaction and coupling between resource-based cities in the LP region. The findings of this study hold practical significance for promoting sustainable regional development and optimizing decision making related to eco-environmental issues. The profound interaction between spatial urbanization and the ecological environment suggests that limiting urbanization should not be viewed as the sole method of preventing ecological degradation. Therefore, with regard to the different coordination types of cities, there is still a requirement for specific suggestions and effective measures to be formulated in order to facilitate regional sustainable development.

Therefore, it is of paramount importance for policy makers and planners to acquire an in-depth comprehension of the coupled and coordinated development relationship between resource-based urban expansion and ecological environment. Such understanding serves as a scientific reference basis for making informed decisions. The present study generated spatially for understanding patterns of eco-environment and urbanization, along with their evolution trends and relationships. The findings of this study can raise public and governmental awareness of environmental protection and ecological security management. Moreover, the spatially varying impacts of urbanization can offer location-specific guidance for resource-based cities on urban landscape planning and effective ecological management in the future.

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References

1. Ji, J.; Tang, Z.; Zhang, W.; Liu, W.; Jin, B.; Xi, X.; Wang, F.; Zhang, R.; Guo, B.; Xu, Z.; et al. Spatiotemporal and Multiscale Analysis of the Coupling Coordination Degree between Economic Development Equality and Eco-Environmental Quality in China from 2001 to 2020. *Remote Sens.* **2022**, *14*, 737. [CrossRef]
2. Cai, J.; Li, X.; Liu, L.; Chen, Y.; Wang, X.; Lu, S. Coupling and Coordinated Development of New Urbanization and Agro-ecological Environment in China. *Sci. Total Environ.* **2021**, *776*, 145837. [CrossRef] [PubMed]
3. Sun, Y.; Liu, S.; Dong, Y.; An, Y.; Shi, F.; Dong, S.; Liu, G. Spatio-Temporal Evolution Scenarios and the Coupling Analysis of Ecosystem Services with Land Use Change in China. *Sci. Total Environ.* **2019**, *681*, 211–225. [CrossRef] [PubMed]
4. Guan, X.; Wei, H.; Lu, S.; Dai, Q.; Su, H. Assessment on the Urbanization Strategy in China: Achievements, Challenges and Reflections. *Habitat Int.* **2018**, *71*, 97–109. [CrossRef]
5. Wu, H.; Guo, B.; Fan, J.; Yang, F.; Han, B.; Wei, C.; Lu, Y.; Zang, W.; Zhen, X.; Meng, C. A Novel Remote Sensing Ecological Vulnerability Index on Large Scale: A Case Study of the China-Pakistan Economic Corridor Region. *Ecol. Indic.* **2021**, *129*, 107955. [CrossRef]
6. Fan, H.; Zhao, C.; Yang, Y. A Comprehensive Analysis of the Spatio-Temporal Variation of Urban Air Pollution in China during 2014–2018. *Atmosphere* **2020**, *220*, 117066. [CrossRef]
7. Guo, A.; Yang, J.; Xiao, X.; Xia, J.; Jin, C.; Li, X. Influences of Urban Spatial Form on Urban Heat Island Effects at the Community Level in China. *Sustain. Cities Soc.* **2020**, *53*, 101972. [CrossRef]
8. Zevenbergen, C.; Fu, D.; Pathirana, A. Transitioning to Sponge Cities: Challenges and Opportunities to Address Urban Water Problems in China. *Water* **2018**, *10*, 1230. [CrossRef]
9. Yu, H.; Liu, Y.; Shu, X.; Ma, L.; Pan, Y. Assessment of the Spatial Distribution of Organochlorine Pesticides (OCPs) and Polychlorinated Biphenyls (PCBs) in Urban Soil of China. *Chemosphere* **2020**, *243*, 125392. [CrossRef]
10. Han, Z.; Jiao, S.; Zhang, X.; Xie, F.; Ran, J.; Jin, R.; Xu, S. Seeking Sustainable Development Policies at the Municipal Level Based on the Triad of City, Economy, and Environment: Evidence from Hunan Province, China. *J. Environ. Manag.* **2021**, *290*, 112554. [CrossRef]
11. Yu, J.; Li, J.; Zhang, W. Identification and Classification of Resource-Based Cities in China. *J. Geogr. Sci.* **2019**, *29*, 1300–1314. [CrossRef]
12. Sachs, J.D.; Schmidt-Traub, G.; Mazzucato, M.; Messner, D.; Nakicenovic, N.; Rockström, J. Six Transformations to Achieve the Sustainable Development Goals. *Nat. Sustain.* **2019**, *2*, 805–814. [CrossRef]
13. Sun, Q.; Zhang, X.; Zhang, H.; Niu, H. Coordinated Development of a Coupled Social Economy and Resource Environment System: A Case Study in Henan Province, China. *Environ. Dev. Sustain.* **2018**, *20*, 1385–1404. [CrossRef]
14. Yang, C.; Zeng, W.; Yang, X. Coupling Coordination Evaluation and Sustainable Development Pattern of Geo-Ecological Environment and Urbanization in Chongqing Municipality, China. *Sustain. Cities Soc.* **2020**, *61*, 102271. [CrossRef]
15. Zou, C.; Zhu, J.; Lou, K.; Yang, L. Coupling Coordination and Spatiotemporal Heterogeneity between Urbanization and Ecological Environment in Shaanxi Province, China. *Ecol. Indic.* **2022**, *141*, 109152. [CrossRef]
16. Fu, S.; Zhuo, H.; Song, H.; Wang, J.; Ren, L. Examination of a Coupling Coordination Relationship between Urbanization and the Eco-Environment: A Case Study in Qingdao, China. *Environ. Sci. Pollut. Res.* **2020**, *27*, 23981–23993. [CrossRef]
17. Sui, Y.; Hu, J.; Zhang, N.; Ma, F. Exploring the dynamic equilibrium relationship between urbanization and ecological environment—A case study of Shandong Province, China. *Ecol. Indic.* **2024**, *158*, 111456. [CrossRef]
18. Xing, L.; Xue, M.; Hu, M. Dynamic Simulation and Assessment of the Coupling Coordination Degree of the Economy–Resource–Environment System: Case of Wuhan City in China. *J. Environ. Manag.* **2019**, *230*, 474–487. [CrossRef]
19. Yang, Y.; Wang, L.; Yang, F.; Hu, N.; Liang, L. Evaluation of the Coordination between Eco-Environment and Socioeconomy under the "Ecological County Strategy" in Western China: A Case Study of Meixian. *Ecol. Indic.* **2021**, *125*, 107585. [CrossRef]
20. Shi, F.; Liu, M.; Qiu, J.; Zhang, Y.; Su, H.; Mao, X.; Li, X.; Fan, J.; Chen, J.; Lv, Y.; et al. Assessing Land Cover and Ecological Quality Changes in the Forest-Steppe Ecotone of the Greater Khingan Mountains, Northeast China, from Landsat and MODIS Observations from 2000 to 2018. *Remote Sens.* **2022**, *14*, 725. [CrossRef]
21. Zhang, F.; Wang, Y.; Ma, X.; Wang, Y.; Yang, G.; Zhu, L. Evaluation of Resources and Environmental Carrying Capacity of 36 Large Cities in China Based on a Support-Pressure Coupling Mechanism. *Sci. Total Environ.* **2019**, *688*, 838–854. [CrossRef] [PubMed]
22. Yuan, Q.; Shen, H.; Li, T.; Li, Z.; Li, S.; Jiang, Y.; Xu, H.; Tan, W.; Yang, Q.; Wang, J.; et al. Deep Learning in Environmental Remote Sensing: Achievements and Challenges. *Remote Sens. Environ.* **2020**, *241*, 111716. [CrossRef]

23. Yu, J.; Li, X.; Guan, X.; Shen, H. A remote sensing assessment index for urban ecological livability and its application. *Geo-Spat. Inf. Sci.* **2024**, *27*, 289–310. [CrossRef]
24. Wang, D.; Shi, Y.; Wan, K. Integrated Evaluation of the Carrying Capacities of Mineral Resource-Based Cities Considering Synergy between Subsystems. *Ecol. Indic.* **2020**, *108*, 105701. [CrossRef]
25. Ruan, F.; Yan, L.; Wang, D. The Complexity for the Resource-Based Cities in China on Creating Sustainable Development. *Cities* **2020**, *97*, 102571. [CrossRef]
26. Fan, F.; Zhang, X. Transformation Effect of Resource-Based Cities Based on PSM-DID Model: An Empirical Analysis from China. *Environ. Impact Assess.* **2021**, *91*, 106648. [CrossRef]
27. Li, Q.; Liu, S.; Yang, M.; Xu, F. The Effects of China's Sustainable Development Policy for Resource-Based Cities on Local Industrial Transformation. *Resour. Policy* **2021**, *71*, 101940. [CrossRef]
28. Song, Y.; Xue, D.; Dai, L.; Wang, P.; Huang, X.; Xia, S. Land Cover Change and Eco-Environmental Quality Response of Different Geomorphic Units on the Chinese Loess Plateau. *J. Arid Land* **2020**, *12*, 29–43. [CrossRef]
29. Zhang, Y.; Chen, Y. Research Trends and Areas of Focus on the Chinese Loess Plateau: A Bibliometric Analysis during 1991–2018. *Catena* **2020**, *194*, 104798. [CrossRef]
30. Zhang, H.; Sun, X.; Ahmad, M.; Lu, Y.; Xue, C. A Step Towards a Green Future: Does Sustainable Development Policy Reduce Energy Consumption in Resource-Based Cities of China? *Front. Environ. Sci.* **2022**, *10*, 901721. [CrossRef]
31. Li, S.; Cao, X.; Zhao, C.; Jie, N.; Liu, L.; Chen, X.; Cui, X. Developing a pixel-scale corrected nighttime light dataset (PCNL, 1992–2021) combining DMSP-OLS and NPP-VIIRS. *Remote Sens.* **2023**, *15*, 3925. [CrossRef]
32. Xu, H.; Wang, Y.; Guan, H.; Shi, T.; Hu, X. Detecting Ecological Changes with a Remote Sensing Based Ecological Index (RSEI) Produced Time Series and Change Vector Analysis. *Remote Sens.* **2019**, *11*, 2345. [CrossRef]
33. Xu, H.; Li, C.; Shi, T. Is the z-score standardized RSEI suitable for time-series ecological change detection? Comment on Zheng et al. (2022). *Sci. Total Environ.* **2022**, *853*, 158582. [CrossRef]
34. Xu, Y.; Yang, Y.; Chen, X.; Liu, Y. Bibliometric Analysis of Global NDVI Research Trends from 1985 to 2021. *Remote Sens.* **2022**, *14*, 3967. [CrossRef]
35. Li, H.; Hong, L. Spatio-Temporal Land Use/Land Cover Dynamics and Its Driving Forces in the Mekong Basin Using Landsat Imageries from 1988 to 2017. *Geocarto Int.* **2022**, *37*, 14676–14698. [CrossRef]
36. Ermida, S.L.; Soares, P.; Mantas, V.; Göttsche, F.M.; Trigo, I.F. Google Earth Engine Open-Source Code for Land Surface Temperature Estimation from the Landsat Series. *Remote Sens.* **2020**, *12*, 1471. [CrossRef]
37. Tollerud, H.J.; Brown, J.F.; Loveland, T.R. Investigating the Effects of Land Use and Land Cover on the Relationship between Moisture and Reflectance Using Landsat Time Series. *Remote Sens.* **2020**, *12*, 1919. [CrossRef]
38. Gao, B.; Huang, Q.; He, C.; Ma, Q. Dynamics of Urbanization Levels in China from 1992 to 2012: Perspective from DMSP/OLS Nighttime Light Data. *Remote Sens.* **2015**, *7*, 1721–1735. [CrossRef]
39. Fu, H.; Shao, Z.; Fu, P.; Cheng, Q. The Dynamic Analysis between Urban Nighttime Economy and Urbanization Using the DMSP/OLS Nighttime Light Data in China from 1992 to 2012. *Remote Sens.* **2017**, *9*, 416. [CrossRef]
40. Liu, N.; Liu, C.; Xia, Y.; Da, B. Examining the coordination between urbanization and eco-environment using coupling and spatial analyses: A case study in China. *Ecol. Indic.* **2018**, *93*, 1163–1175. [CrossRef]
41. Li, P.; Liu, C.; Liu, L.; Wang, W. Dynamic analysis of supply and demand coupling of ecosystem services in Loess Hilly Region: A case study of Lanzhou, China. *Chin. Geog. Sci.* **2021**, *31*, 276–296. [CrossRef]
42. Pan, Z.; Gao, G.; Fu, B.; Liu, S.; Wang, J.; He, J.; Liu, D. Exploring the historical and future spatial interaction relationship between urbanization and ecosystem services in the Yangtze River Basin, China. *J. Clean. Prod.* **2023**, *428*, 139401. [CrossRef]
43. Oshan, T.M.; Li, Z.; Kang, W.; Wolf, L.J.; Fotheringham, A.S. mgwr: A Python Implementation of Multiscale Geographically Weighted Regression for Investigating Process Spatial Heterogeneity and Scale. *ISPRS Int. J. Geo-Inf.* **2019**, *8*, 269. [CrossRef]
44. Hu, J.; Zhang, J.; Li, Y. Exploring the Spatial and Temporal Driving Mechanisms of Landscape Patterns on Habitat Quality in a City Undergoing Rapid Urbanization Based on GTWR and MGWR: The Case of Nanjing, China. *Ecol. Indic.* **2022**, *143*, 109333. [CrossRef]
45. Feng, Y.; Li, G. Interaction between urbanization and eco-environment in the Tibetan Plateau. *J. Geogr. Sci.* **2021**, *31*, 298–324. [CrossRef]
46. Hou, Y.; Huang, Q.; Ren, Q.; Gu, T.; Zhou, Y.; Wu, P.; Fan, Y.; Zhu, G. Spatiotemporal dynamics of urban sprawl in China from 2000 to 2020. *GISci. Remote Sens.* **2024**, *61*, 2351262. [CrossRef]
47. Liu, X.; Guo, P.; Yue, X.; Zhong, S.; Cao, X. Urban transition in China: Examining the coordination between urbanization and the eco-environment using a multi-model evaluation method. *Ecol. Indic.* **2021**, *130*, 108056. [CrossRef]
48. Zhang, X.; Fan, H.; Liu, F.; Lv, T.; Sun, L.; Li, Z.; Shang, W.; Xu, G. Coupling coordination between the ecological environment and urbanization in the middle reaches of the Yangtze River urban agglomeration. *Urban Clim.* **2023**, *52*, 101698. [CrossRef]

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