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The Coupling Coordinated Relationship Between New-type Urbanization, Eco-Environment and its Driving Mechanism: A Case of Guanzhong, China

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As an important platform for participating in international competition and cooperation, supporting economic growth and promoting coordinated regional development, urban agglomeration plays an important role in China's economic, social and urbanization development. At this time, the Guanzhong Plain urban agglomeration (GZPUA), as the second largest urban agglomeration in western China, has a moderate population density. The high demand and high input of resources for population growth make the regional ecological destruction and environmental pollution more prominent. Therefore, it is of great practical significance to study the coordinated development of urbanization and ecological environment in GZPUA. By using the panel data of the GZPUA of China between 2008 and 2017, this study constructed evaluation index system of new-type urbanization and ecological environment quality and calculated the weights of the indices within the evaluation system via the improved entropy weight method, finally determined the new-type urbanization and ecological environment quality of each city. Then the coupling coordination degree model was used to analyze the coupling coordination relationship between two systems of GZPUA and their coupling stages and levels. In addition, the driving mechanism of their coordination degree was explored by using geographic detector method. The results show that: 1) The GZPUA new-type urbanization quality is characterized by both slow growth except Xi'an by a rapid increase. The ecological environment quality is characterized by both slow growth and fluctuations, except Qingyang by a decrease. There are spatial differences between the quality of new-type urbanization and the quality of ecological environment. 2) The 11 cities can be divided into high-high type (Xi'an), high-low type (Xianyang, Yuncheng, Linfen), low-low type (Pingliang, Weinan), and low-high type (Shangluo, Tianshui, Qingyang), different types should take different development paths. 3) The coordination degree between urbanization and ecological environment quality in GZPUA showed an upward trend, and formed a spatial distribution pattern with Xi'an as the core and decreasing to the outer circle cities, with regional differences. 4) The coordinated development of new-type urbanization and ecological environment is a process in which various driving factors
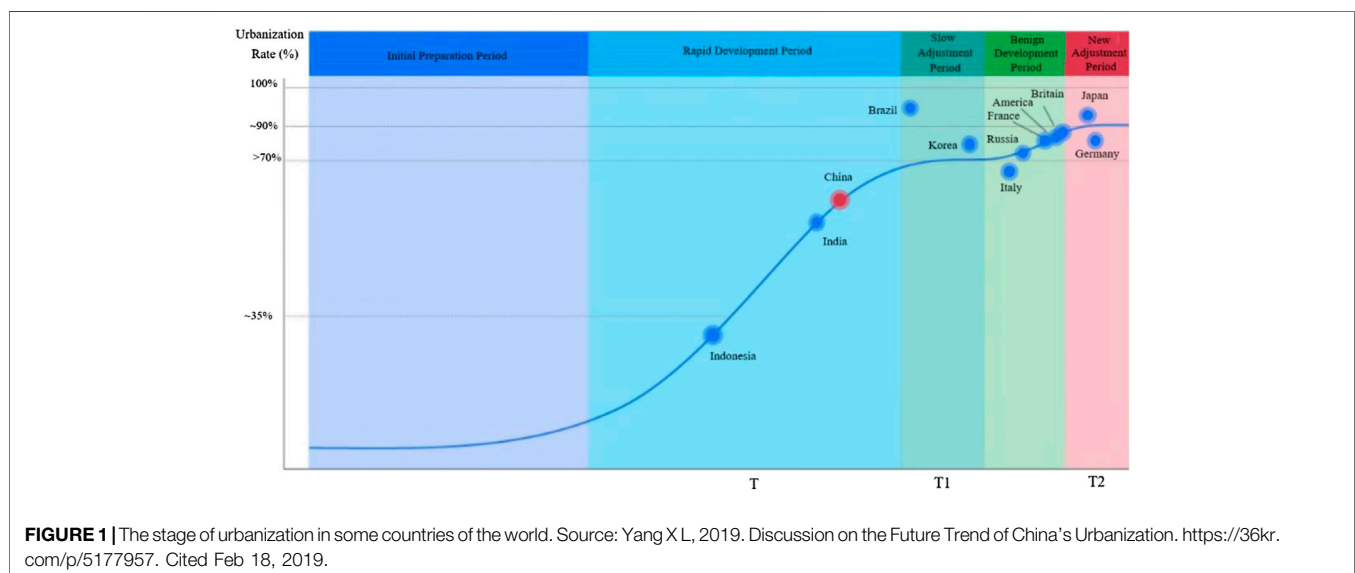
act on different driving forces. These driving forces can be summarized as market driving force, endogenous driving force, outward driving force and administrative driving force. Based on the current situation of coordinated development of new-type urbanization and ecological environment in the GZPUA, it is recommended to promote the coordinated development of urbanization and ecological environment according to local conditions, strengthen the urbanization market mechanism, and optimize the industrial layout. Further, guide the flow of various factors across regions, strengthen technological innovation on the basis of breaking regional divisions, narrow the gap between urban and rural areas, establish the concept of coordinated development, and give play to the government's "visible hand" role.

INTRODUCTION

Since the industrial revolution in the middle of the 18th century, fundamental changes have taken place in cities. Human beings have made brilliant achievements in transforming nature and developing the economy, but global urbanization has also exerted tremendous pressure on the ecological environment. A report by the Population Division of the United Nations Department of Economic and Social Affairs shows that about 55% of the world's population currently lives in cities or urban areas, and this number will rise to 68% in the coming decades (Fang et al., 2016). Under such a background, the contradictions of various elements in the human-land system have become increasingly prominent, and various negative feedback effects have begun to appear. Therefore, how to achieve the coordinated development of urbanization and ecological environment has become one of the hot issues of global attention. Since reform and opening up, China has experienced the largest and fastest urbanization in world history. According to the data released by the National Bureau of statistics, the urbanization rate in 2019 is 60.60%

(National Bureau of Statistics, 2020). **Figure 1** shows that China's urbanization is in the second half of the period of rapid development, and there is still room for 10–20% growth in the future. According to the forecast of Evergrande Research Institute, about 80% of the new urban population by 2030 will be distributed in 19 urban agglomerations (Zhang and Liu, 2019). In 2019, China's urban agglomerations created 88% of the country's GDP with 25% of the land. The urbanization of urban agglomerations is the new engine of China's development, and the traditional development model of long-term dependence on resource consumption to promote industrialization to drive urbanization, while promoting economic development, also poses a huge threat to the resources and environment. In some areas, there are environmental problems such as low resource utilization efficiency, air pollution, water pollution, and land pollution. (Pan and Feng, 2017; Duan et al., 2018; Sun et al., 2019). Especially in the process of urban agglomeration development, it presents the characteristics of high-density agglomeration, high speed expansion and high intensity pollution. The environmental problems brought about by its


FIGURE 1 | The stage of urbanization in some countries of the world. Source: Yang X L, 2019. Discussion on the Future Trend of China's Urbanization. https://36kr.com/p/5177957. Cited Feb 18, 2019.

FIGURE 2 | Planning scope of Guanzhong Plain urban agglomeration. Source: Guanzhong Plains Urban Agglomeration Development Plan.

development are also more significant and worsened. How urbanization can achieve reasonable, effective and high-quality development within the carrying capacity of the ecological environment, and how the ecological environment can better provide a good space and basic carrier for the development of urbanization, has become a key issue for regional sustainable development. Therefore, how to coordinate the relationship between urbanization development and environmental protection in urban agglomeration and realize the sustainable development of urbanization has become an urgent problem to be studied and solved, which has been taken as the basic strategy of China's development.

Guanzhong Plain is an important birthplace of Chinese civilization and the starting point of the ancient Silk Road, bearing the historical glory and profound memory of the Chinese nation. The Guanzhong Plain urban agglomeration (GZPUA) is located in the inland center of China and has a unique strategic position in the overall national modernization construction and all-round opening pattern. As the engine of northwest development, the GZPUA spans the three provinces of Shaanxi, Gansu, and Shanxi, with 11 prefecture-level cities and 90 counties (districts) under its jurisdiction. Specifically, including Xi'an, Baoji, Xianyang, Tongchuan, Weinan, Yangling Agricultural High-tech Industry Demonstration Zone, Shangluo, Yuncheng, Linfen, Tianshui, Pingliang, and Qingyang, the land area is 107,100 square kilometers (**Figure 2**). Its comprehensive economic strength is strong, as of 2018, the total GDP reached 2.08 trillion yuan (Zhou et al., 2019). In 2018, the urbanization rate of Xi'an reached 74.01%, and Tongchuan, Yangling, Baoji, Xianyang, Baoji, Linfen, and Qingyang all exceeded 50%. Rapid urbanization has put tremendous pressure on regional population capacity, resource

carrying capacity, and environmental carrying capacity. The rapid development of traditional resource industries has brought certain challenges to the ecological environment. The coordinated development of urbanization and ecological environment has attracted more and more attention. The China National Development and Reform Commission and Ministry of Housing and Urban-Rural Development also proposed the Guanzhong Plain Urban Agglomeration Development Plan in January 2018 (Ministry of Housing and Urban-Rural Development, 2018), which made detailed plans for the development of the GZPUA in 2017–2035, and proposed the concept of ecological civilization was integrated into the entire process of urban agglomeration construction. The ecological environment protection of the GZPUA is imminent. The coordinated development of urbanization and the ecological environment is of great significance to the sustainable development of China's urbanization, the development of the western region, and the construction of "One Belt and One Road."

There is a relationship between urbanization development and ecological environment in urban agglomerations in China. On the one hand, economic urbanization destroys the ecological environment through industrial agglomeration effect, and protects the ecological environment through industrial upgrading effect, scale economy effect and comparative advantage effect. Population urbanization protects ecological environment through population scale effect, resident quality effect and environmental self-purification effect, and destroys ecological environment through population agglomeration effect. Green urbanization protects ecological environment through ecological construction effect, and social urbanization

FIGURE 3 | Coupling mechanism diagram of new-type urbanization and ecological environment.
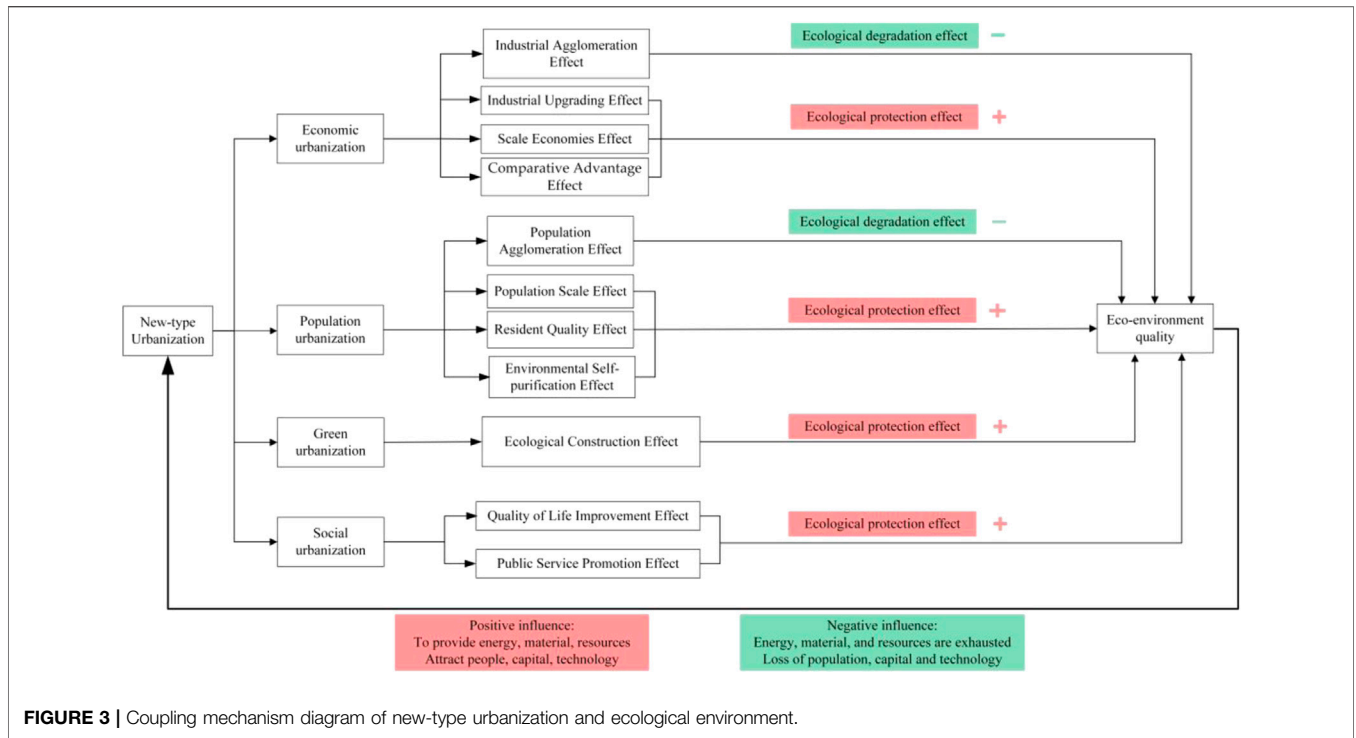
protects ecological environment through quality of life improvement and public service promotion effect (Yu, 2021). Specifically, with the continuous expansion of the urban system, the adjustment of industrial structure, the increase of population, residents' life and energy consumption will undoubtedly directly lead to changes in water, land, energy, ecology, climate, and environment. In particular, due to the rapid increase in carbon emissions, greenhouse gases act on climate change, causing global warming. Although the cities within the GZPUA are all inland cities, the probability of disasters such as typhoons, hurricanes, and tsunamis is extremely small, but it is worth noting that global warming has increased the probability of extreme weather (Ren and Zhou, 2014; Lin et al., 2020). The natural disaster crisis caused by climate change has become a part of the urban crisis, which has greatly affected the development of urban economy, society and culture. On the other hand, Wang Rusong, a Chinese ecologist, believes that there are feedback and restriction mechanisms between urbanization and ecological environment by using the law of positive and negative feedback and limiting factor in the principle of ecological coordination (Wang, 1988). A good ecological environment can improve the quality of urbanization, provide resources, energy, material, and other carriers for urbanization development, enhance the core competitiveness of cities and towns, attract more people to employment and tourism, and facilitate the inflow of capital, technology and talent. However, if urbanization develops too fast and exceeds the carrying capacity of the ecological environment, the ecological environment of cities and towns will deteriorate, the urbanization process will be limited, and urbanization will eventually lose the support of the ecological environment. The coupling mechanism between the two is shown in **Figure 3**:

According to the report of the United Nations World Urbanization Outlook 2018, it is estimated that China's urban population will increase by 255 million by 2050 (People's Daily Online, 2018). The urban population flow will break the east-west gradient pattern and develop toward the direction of regional multi-center (Yang, 2019). It is estimated that about 20% of the increase in urban population is in western cities. As the second largest urban agglomeration in the western region, the GZPUA is bound to attract more and more people to flow in. In recent years, the implementation of the new household registration policy and the "recruitment of talents" project has resulted in sufficient human resources in the GZPUA. However, the industrial development model of high energy consumption, high pollution, high emissions, and low returns has not been fundamentally changed. The high demand and high input of resources for population growth make the regional ecological destruction and environmental pollution more prominent. Lack of water resources, unreasonable land use, reduced vegetation area, abnormal climate change, excessive energy consumption, and severe environmental pollution have become important factors restricting the healthy development of the GZPUA (Wang et al., 2014; Li and Zhou, 2016; Gerten et al., 2019; Wei et al., 2019).

The GZPUA is one of the 19 urban agglomerations that China is focusing on cultivating, and it is the core engine leading the opening up and development of the Northwest China. In order to promote the transformation of GZPUA from "pollution agglomeration area" to "sustainable development area", it is

necessary to accelerate the urbanization process while improving the quality of the ecological environment, thereby promoting the benign coupling and coordinated development between the urbanization and ecological environment. This paper constructed a new-type urbanization and eco-environmental quality index system, combined the coupling coordination degree model to quantitatively analyze the coupling process, temporal and spatial distribution characteristics, state judgment and phases of urbanization quality and eco-environmental quality. The driving mechanism is analyzed by using the geo-detector mechanism to objectively reflect the focal point of efficient and coordinated development of new-type urbanization and ecological environment quality in GZPUA.

This not only reveals the inherent law of coordinated development between urbanization and ecological environment in GZPUA, provides decision-making basis for new-type urbanization construction and ecological environment protection in GZPUA, but also provides reference for coordinated development between urbanization and ecological environment in other similar urban agglomeration. Furthermore, promoting the healthy and green development of urban agglomerations and the high-quality development of regional economy, and driving the further improvement of the national urbanization level and ecological level, has certain theoretical and practical significance for enriching the sustainable development research of urban agglomerations. Therefore, it is urgent to study the synergistic effects of urbanization and ecological environment systems in urban agglomerations, so that people can have a clearer understanding of the law of coordinated development between urbanization and eco-environmental system, and the main factors influencing the coordinated development of the system can be determined.

In view of this, this paper, the research is carried out according to the research idea of "establishment of indicator system -- verification of coupling relationship -- judgment of grade type -- analysis of space-time evolution -- analysis of driving mechanism". Firstly, the evaluation index system of new-type urbanization quality and ecological environment quality is constructed. Then, the entropy weight method and coupling coordination degree model were used to calculate the evaluation value and coupling coordination degree of new-type urbanization quality and ecological environment quality of cities in GZPUA from 2008 to 2017. Furthermore, we analyzed the quality of new-type urbanization and the quality of ecological environment in each city over the past 10 years, and evaluated the coupling stage and level between the two system. Eventually, the driving mechanism affecting the coupling and coordination degree of new-type urbanization and ecological environment is analyzed by using geodetector, which can provide decision-making basis for sustainable development of GZPUA.

The remainder of the paper is structured as follows. The "*Literature Review*" section provides a brief literature review. The data sources, the comprehensive index system and research method in "*Materials and methods*" section. In the "*Analysis on the Coupling Coordination Degree of New-Type Urbanization and*

Ecological Environment in GZPUA" section, we analyze the coupling coordination degree of urbanization and ecological environment in GZPUA. The "*The Driving Mechanism of Coupling Coordination Degree Between New-Type Urbanization and Ecological Environment in GZPUA*" section studies the driving mechanism of coupling coordination degree between urbanization and ecological environment in GZPUA. Lastly, the "*Conclusion and Policy Implications*" offers conclusion and policy implications.

LITERATURE REVIEW

This section reviews the literature on the coupling of urbanization and ecological environment. We review scholars' research on the coupling between urbanization and ecological environment from three aspects: research content, research method and research area.

From the perspective of research content, some scholars have studied the coupling relationship between urbanization and various factors in the ecological environment system. On the coupling relationship between urbanization and water resources. Urbanization has caused shortages of water resources, water pollution and damage to groundwater. Srinivasan et al. (2013) studied the relationship between urbanization and water vulnerability in a rapidly developing city in Chennai, India, using a coupled human-environment system (CHES) modeling method. The results show that water resource vulnerability is dynamic, spatially and scale dependent. Moreover, similar researches focusing on China, such as Bao and Zou (2017), Shen et al. (2019). Furthermore, Ma et al. (2016) introduced a dynamic coupling model and triple exponential smoothing method to analyze and predict the coupling degree between urbanization and water resource utilization. On the coupling relationship between urbanization and land use. An important feature of China's urbanization is land-centred (Lin et al., 2017). Some scholars use Chinese prefecture-level cities as research objects, such as Wang et al. (2016) and Bai et al. (2019) evaluated the coupling stage of land use efficiency and new-type urbanization. Also, Wang et al. (2017) and Cao (2018) evaluated the coupling stage of land use efficiency and new-type urbanization at the provincial level and further explored its spatial-temporal differentiation. On the coupling relationship between urbanization and atmosphere. Ding et al. (2015) believes that rapid urbanization causes air pollution problems. By establishing the comprehensive index system of urbanization and air environment in Wuhan, the relationship between urbanization and the atmospheric environment is discussed from the perspective of coupling and coordination theory. The results show that the degree of coordination and coupling between urbanization and air environment is an s-shaped curve. Liu et al. (2018) used the same research approach to study the coupling relationship between jinan's urbanization and atmospheric environment security, and found that the coupling degree of the two systems was constantly increasing. Furthermore, Fan et al. (2020) used the method of global

principal component analysis, the harmony degree model, the coupling coordination degree model and GIS to explore the coupling coordination degree and spatial pattern between urbanization and various air pollutants. On the coupling relationship between urbanization and climate. With the continuous advancement of the global urbanization process, its impact on climate change is increasing and significant, such as urban heat island effect, extreme heat, heavy rainfall and urban waterlogging. Meanwhile, the feedback of climate to urbanization has a series of effects on urban residents (Luo and Chen, 2019). Lu et al. (2017) used entropy weight method, coupled coordination degree model and method of GIS technology to show that the urbanization pattern of Wanjiang urban belt is consistent with the distribution of climate bearing capacity. Morris et al. (2016) used the NCAR weather and research forecast (WRF) model, combined with the surface and urban canopy model (NOAH LSM/UCM), to investigate the local urban climate change during the decade of urbanization (1999–2011). The results showed that the Urbanization of Putrajaya has induced a daily prevailing urban heat island intensity of ~2.1°C. On the coupling relationship between urbanization and energy. Li et al. (2016) believe that urbanization is closely coupled with energy consumption and carbon emissions. Wang et al. (2019) studied the coupling relationship between energy and environmental efficiency and urbanization in Guangdong province. The results show that the coupling relationship between the two systems changes from the low coupling stage to the middle coupling stage. Guan and Zhou (2019) found that urbanization and energy consumption are in the antagonistic stage, and urbanization development has caused great pressure on energy consumption.

On the coupling relationship between urbanization and ecosystems. He et al. (2017) established a coupling coordination degree model between urbanization and ecological environment in Shanghai, and found that the coupling coordination between urbanization and ecological environment formed an s-shaped curve. Additionally, Yao et al. (2019) studied the coupling coordination degree of China's new-type urbanization and ecological environment pressure, and determined the spatial and temporal pattern of the coupling coordination degree of the two systems. The results showed that the coupling coordination degree of the developed regions in the east coast and the central region was generally higher than that of the less developed regions in the west. Zhao et al. (2020) calculated the spatial and temporal pattern of coupling coordination between new-type urbanization and ecological environment in the Yellow River basin and its influencing factors. The results show that, the level of economic development, the level of government capability and the level of science and technology investment have positive effects on the degree of coupling coordination.

From the perspective of research methods, remote sensing (Zhang et al., 2017; Ariken et al., 2020), coupling degree function (Sun et al., 2017; Liao et al., 2019; Wang et al., 2019a), structural equation model (Feng and Liu, 2016), exploratory spatial analysis method (Wang, 2017), GIS (Fan et al., 2020), dynamic coupling model (Bai et al., 2019), system dynamics model (Liu et al., 2005; Liu and Lin, 2015), spatial Markov chain (Liu et al., 2018a) and triple exponential smoothing method (Ma and Li, 2017) are mostly used to measure, evaluate and predict the coupling degree between urbanization and various natural element systems of ecological environment. Additionally, the random effects panel Tobit model is used to determine the factors that affect the coupling between systems (Zhao et al., 2020).

From the perspective of research area, it covers countries (Tian, 2015; Ariken et al., 2021), provinces (municipalities directly under the central government) (Zhang et al., 2016; Gai and Zhang., 2018; Wang et al., 2020; Yang et al., 2020a), prefecture-level cities and county cities (Ai et al., 2015; Fan et al., 2019; Zhu et al., 2020; Yang et al., 2020b). In recent years, there has been an increasing research on urban agglomerations, especially the urban agglomeration as a research area to study the coupling relationship between urbanization and ecological environment, but most of them are distributed in economically developed areas, such as the Beijing-Tianjin-Hebei urban agglomeration, Yangtze River Delta agglomeration, Area of Hangzhou Bay (Fang and Ren, 2017; Chen et al., 2018; Cui et al., 2019; Han et al., 2019; Lu and Xiang, 2020; Xiao et al., 2020). However, few studies have focused on the less developed areas in the west.

In summary, the existing research on the coupling of urbanization and ecological environment is mostly about the coupling relationship between urbanization and a single environmental element, and there are few quantitative methods to analyze the coupling mechanism. In order to make up for the deficiencies of existing research, this paper establishes an evaluation index system with multiple comprehensive perspectives. Taking regional natural elements (water, land, energy, ecology, climate, environment) and humanistic elements (population, economy, society, infrastructure, innovation, globalization, etc.) as the starting point, it is systematic and scientific. There are 19 urban agglomerations in China. Due to different historical development, resource endowment, industrial base, economic structure and other conditions, the urbanization development level of each urban agglomeration is quite different, and the ecological environment conditions and ecological problems are more complex and diverse, leading to different coupling characteristics of the two. Therefore, in combination with the characteristics of GZPUA, this paper comprehensively uses a variety of empirical analysis methods, including improved entropy weight method, coupling coordination degree model, and geographic detector method, and covers management, economics, geographic economics and other multi-disciplines to study it.

Based on the above analysis, this research innovates from the following three aspects. 1) Taking the Guanzhong Plain urban agglomeration (GZPUA) as the research object, it enriches the research on the less developed areas in western China. 2) We build an ecological environment quality index system starting from the natural elements of urban agglomerations. 3) An empirical study is made on the driving mechanism of the coordinated development of urbanization and the ecological environment.

MATERIALS AND METHODS

Source of Data

The study area selected the main cities of the GZPUA. Due to the lack of data in Yangling Agricultural High-tech Industry Demonstration Zone, it was not included in the study. In addition, according to the contents of the Guangzhong Plain Urban Agglomeration Development Plan approved by the State Council in January 2018, some counties in Yuncheng, Linfen, Tianshui and Pingliang do not fall into the planning scope. Considering the difficulty of data acquisition, we included the districts and counties not included in these areas into the research scope, which means that the data we obtained is city-level data. This study selects 2008–2017 as the sample period for the following reasons. 1) According to the United Nations, global city has a population of more than 2008 rural population, the world really into the world of urbanization. In 2008, China's urbanization rate stood at 45.7%, marking an important turning point and the beginning of a decade of rapid growth. 2) In January 2018, the State Council officially approved the development plan of GZPUA. The construction of this urban agglomeration is still in the exploratory stage. In order to avoid the influence of policy factors on the research results, the research period was ended in 2018. The data sources mainly include three aspects: 1) Statistical yearbooks, statistical bulletins, China Urban Statistical Yearbook (2009–2018) and China Regional Economic Statistical Yearbook (2009–2014) of the GZPUA. 2) Some of the data were obtained through public applications to Shaanxi provincial bureau of statistics, Shanxi provincial bureau of statistics, Xianyang municipal bureau of statistics, Yuncheng municipal bureau of statistics and Linfen municipal bureau of statistics. 3) we use the mean value method, interpolation method and analogy method to calculate the missing data.

Construct the Comprehensive Index System

Based on the actual situation of the GZPUA, this paper deeply grasps the composition and connotation of new-type urbanization and ecological environment on the basis of related theories and literature research (Fang and Yang, 2006; Dong et al., 2017; Wang et al., 2018; Wang and Yu, 2019). To ensure the accuracy and feasibility of the evaluation index system, we follow the steps below to construct an indicator system on the basis of scientific, clear, systematic, representative and practical. 1) Primary selection of indicator system: Appropriate indicators are selected according to the four major areas in the new-type urbanization indicators, including economy, population, ecology and society, and the six major areas in the ecological environment quality assessment indicators, including water, land, energy, ecology, climate, and environment. Economic urbanization mainly reflects the degree of regional economic development, population urbanization mainly reflects the quantity and quality of urbanization population, green urbanization mainly reflects

the construction and governance of urban ecology, and social urbanization mainly reflects the level of medical care, public facilities and urban-rural gap. Ecological environment quality mainly refers to the status quo of water resources, land resources, energy, ecology, climate and environment. On the basis of conforming to the former principle, the indexes with more frequent occurrence in each indicator system are selected in priority by referring to relevant literatures (Li and Zhang, 2008; Yang, 2013; A et al., 2016; Lan et al., 2017; Liu et al., 2018b; Deng et al., 2019; Liu et al., 2020). Based on the suggestions of relevant experts, this paper has completed the preliminary selection of the indicator system. 2) Optimization of index system: We used collinearity test, conditional index test and variance inflation factor test to screen the evaluation indicators of the primary election, and completed the optimization of the indicators. 3) Construction of the index system: Determine the evaluation index system. The final evaluation index system is shown in **Table 1**.

Based on the establishment of the above index system, the interactive coercing relationship of the key elements between new-type urbanization and eco-environment in urban agglomerations the is expressed in **Figure 4**.

Research Methods

Evaluation of the Indicators' Weight

This paper refers to previous studies (Yang and Sun, 2015), by adding time variables to make the analysis results more rational. The entropy method evaluation model as follows:

Step 1: Standardization of indicators:

$$x'_{\theta ij} = \frac{x_{\theta ij}}{x_{\max}}, \quad x_{\theta ij} \text{ is a positive indicator.} \tag{1}$$

$$x'_{\theta ij} = \frac{x_{\min}}{x_{\theta ij}}, \quad x_{\theta ij} \text{ is a negative indicator.} \tag{2}$$

Step 2: Calculate indicator weights:

$$y_{\theta ij} = \frac{x'_{\theta ij}}{\sum_{\theta} \sum_{i} x'_{\theta ij}}, \tag{3}$$

Step 3: Calculate the entropy of the jth indicator:

$$e_j = -k \sum_{\theta} \sum_{i} y_{\theta ij} \ln\left(y_{\theta ij}\right), \tag{4}$$

Step 4: Calculate the information utility value for the jth indicator:

$$g_j = 1 - e_j, \tag{5}$$

Step 5: Calculate the weight of each indicator:

$$w_j = \frac{g_j}{\sum_j g_j}, \tag{6}$$

Step 6: Calculate the comprehensive scores of urbanization level and eco-environment quality of each city:

$$H_{\theta i} = \sum_j \left(w_j x'_{\theta ij}\right), \tag{7}$$

TABLE 1 | The evaluation indicators system of new-type urbanization and eco-environment quality.

	First grade indicators	Basic grade indicators	Weight
Index system of the new-type urbanization	Economic urbanization	Per capita GDP (yuan)	0.135
		Second, third industry account for the proportion of GDP (%)	0.002
		Total export-import volume/GDP (%)	0.689
		The proportion of scientific expenditure to fiscal expenditure (%)	0.174
	Population urbanization	Urbanization rate of permanent residents (%)	0.039
		Resident population/Regional area (person/km2)	0.205
		Urban registered unemployment rate (%)	0.021
		Number of college students per 100,000 people	0.735
	Green urbanization	Coverage rate of green area in built-up area (%)	0.091
		Urban park green space per 10,000 people (hectare)	0.443
		Comprehensive utilization rate of industrial solid waste (%)	0.325
		Urban domestic sewage treatment rate (%)	0.141
	Social urbanization	Number of beds in medical institutions per 1,000 people	0.051
		Urban employee pension insurance coverage rate (%)	0.121
		Urban basic medical insurance coverage rate (%)	0.074
		Number of public vehicles per 10,000 people	0.215
		Per capita water supply (tons)	0.323
		Per capita area of roads (m^2)	0.073
		Ratio of urban and rural per capita disposable income	0.033
		Ratio of urban and rural per capita consumption	0.110
Index system of the eco-environment quality	Water resources element	Water resources per capita (m^3)	0.103
		Water consumption per 10,000 GDP (m^3/10,000 yuan)	0.031
	Land resource element	Per capita construction land area (square kilometers)	0.031
		Crop planting area (1,000 ha)	0.021
	Energy element	Total energy consumption (tons of standard coal)	0.082
		The unit GDP energy consumption (tons of standard coal/10,000 yuan)	0.033
	Ecological element	Afforestation area completed in that year (hectare)	0.040
	Climatic element	Annual average temperature (°C)	0.003
		Average annual precipitation (mm)	0.005
	Environmental element	Generation of general industrial solid waste (10,000 tons)	0.347
		Total discharge of industrial wastewater (10,000 tons)	0.180
		Emissions of industrial smoke and dust (tons)	0.124
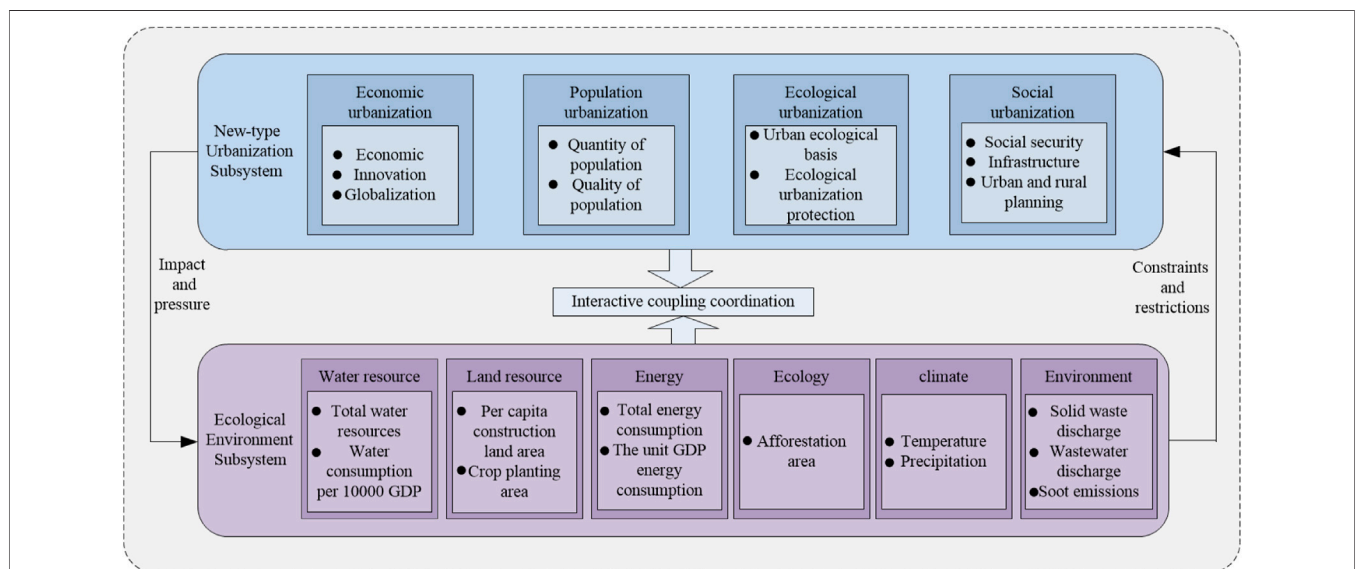
FIGURE 4 | Interactive coercing relationship of the key elements between new-type urbanization and eco-environment in urban agglomerations.

TABLE 2 | The classification of the coupling coordination degree of urbanization and eco-environment systems.

Coordination degree	$0 < D \leq 0.2$	$0.2 < D \leq 0.4$	$0.4 < D \leq 0.6$	$0.6 < D \leq 0.8$	$0.8 < D \leq 1$
Category	Severe imbalance (I)	Moderate imbalance (II)	Low coordination (III)	Moderate coordination (IV)	Advanced coordination (V)

where r is the number of years, n is the number of cities, m is the number of indicators, $x_{\theta ij}$ is the jth index value of the city i of the θ year, k > 0, k = 1/ln (rn). The final weights are shown in **Table 1**.

The Coupling Coordination Degree Model

Coupling comes from physics. Coupling degree refers to the phenomenon that two (or more) systems affect each other through various interactions between themselves and the outside world. In this paper, the capacity coupling coefficient model in physics is used to analyze the coupling degree of urbanization and ecological environment. The coupling degree model of the two systems is as follows:

$$C = \left[\frac{U_1 \times U_2}{\left(\frac{U_1 + U_2}{2} \right)^2} \right]^{1/2}, \tag{8}$$

In this formula, C is the coupling degree and the value range is $0 \leq C \leq 1$. U_1 is the value of the new-type urbanization quality, U_2 is the value of the ecological environment quality. When $C = 1$, the coupling degree is the largest, and the systems reach a benign resonance coupling with each other; when $C = 0$, the coupling degree is the smallest, and the elements between the systems are in an irrelevant state.

The degree of coupling can reflect the degree of interaction between new-type urbanization and the ecological environment, but it cannot fully reflect the degree of coordination between them. Therefore, further establishing a model of coupling and coordination degree can better judge the degree of coordinated development of new-type urbanization and ecological environment, calculated as follows:

$$T = \alpha U_1 + \beta U_2, \tag{9}$$
$$D = \sqrt{C \cdot T}, \tag{10}$$

In this formula, T is the coupling coordination index of new-type urbanization and ecological environment. D is the degree of coupling coordination, the value range of D is [0, 1], and α, β are respectively the contributions of new-type urbanization and ecological environment to urban development. We believe that they are equally important, therefore $\alpha = \beta = 0.5$.

According to the degree of coupling coordination (D), the coordination types of new-type urbanization and ecological environment can be divided into five categories (**Table 2**). Specifically, we subdivide the types of coupling coordination degree by comparing the values of urbanization quality (U_1) and ecological environment quality (U_2), when $U_2 - U_1 > 0.1$, it is the urbanization lag type (type 1); when $|U_2 - U_1| \leq 0.1$, it is the balanced development type (type 2); when $U_2 - U_1 < -0.1$, it is the ecological environment lag type (type 3) (Li et al., 2012; Wang et al., 2019b).

Geo-Detector Analysis

The coupling relationship between new-type urbanization and ecological environment is deeply affected by many factors, such as population, economy, society, resources and environment. Traditional methods to study such problems need to meet many assumptions. Geographical detector is widely applied to reveal the driving factors behind the spatial distribution of things due to its advantages of no linear hypothesis and clear physical meaning. Its model is as follows:

$$P_{D,U} = 1 - \frac{1}{n\sigma_U^2} \sum_{i=1}^{m} n_{D,i} \sigma_{U_{D,i}}^2. \tag{11}$$

In this formula, $P_{D,U}$ is the detection force value of the detection factor ; $n_{D,i}$ is the number of samples in the second-lever region ; n is the number of samples in the whole region ; m is the number of sub-regions ; σ_U^2 is the variance of the coupling coordination degree between new-type urbanization and ecological environment of the whole region ; $\sigma_{U_{D,i}}^2$ is the variance of the sub-regions. The value interval of $P_{D,U}$ is [0,1]. The larger the value of $P_{D,U}$, the greater the influence of the detection factor on the degree of coupling coordination.

ANALYSIS ON THE COUPLING COORDINATION DEGREE OF NEW-TYPE URBANIZATION AND ECOLOGICAL ENVIRONMENT IN GUANZHONG PLAIN URBAN AGGLOMERATION

Time Series Trends in New-type Urbanization and the Ecological Environment Quality in the Guanzhong Plain Urban Agglomeration

In this paper, the improved entropy method was applied to enable objective weighting of indicators, and calculates the values of new-type urbanization and ecological environment quality. In order to analyze time series trends of urbanization and ecological environment quality in different areas of GZPUA, we have drawn a trend chart, as shown in **Figure 5**.

(1)   From 2008 to 2017, 11 cities in the GZPUA were taken as the horizontal comparison unit. It was found that overall level of new-type urbanization quality in the GZPUA shows a slowly rising trend, except for Xi'an, which is a rapid rising trend, and the average comprehensive index increased from 0.235 in 2007 to 0.318 in 2017 (**Figure 5**). Comparing average values, Xi'an occupies the first
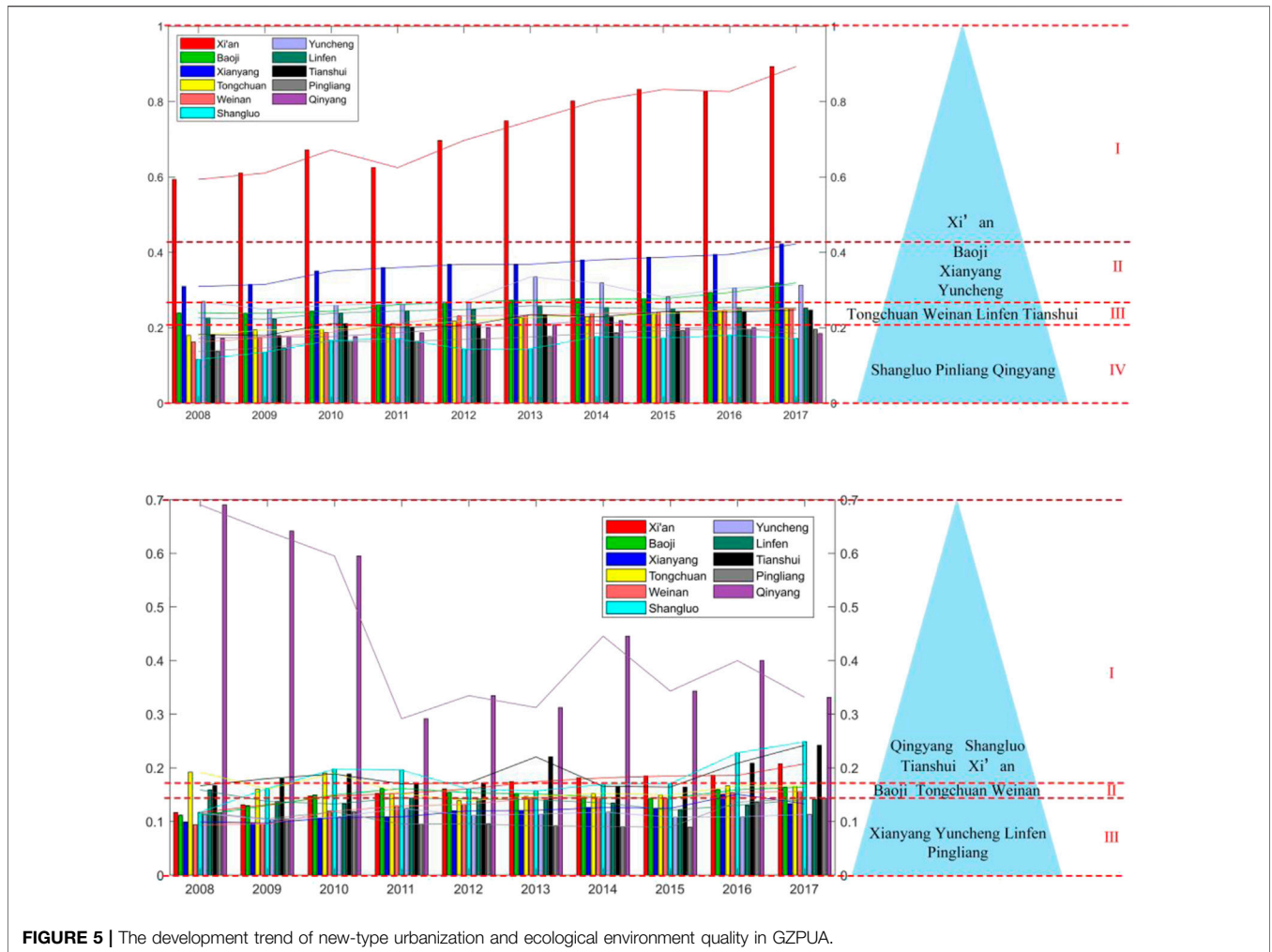
FIGURE 5 | The development trend of new-type urbanization and ecological environment quality in GZPUA.

echelon of urbanization in the region. It has obvious location advantage, and then absorbs the external superior resources. It is also clear that Baoji, Xianyang and Yuncheng comprise second echelon cities. Baoji is the second largest city in Shaanxi Province and an important hub for North-South transportation. Xi Xian New Area was established by the Shaanxi provincial government in 2010 and then approved by the State Council as a state-level new area in 2014. In this process, Xi Xian New Area is constantly developing urbanization and increasing the development of economic construction. With the development of Xi Xian New Area, Xianyang extended the urban framework to the northern bank of the Weihe River, which greatly promoted the development of urbanization in Xianyang. Yuncheng is an important part of Shanxi energy and heavy chemical industry base, and also an emerging industrial base of Shanxi. Industrialization is the foundation of urbanization. The improvement of industrialization has accelerated the agglomeration and flow of labor, capital and land, creating conditions for urbanization. The cities of Tongchuan, Weinan, Linfen,

and Tianshui are in the third echelon, and the data in some years are higher than the average. Shangluo, Pingliang, and Qingyang are the fourth echelon, and their development potential needs to be further tapped. In summary, the areas with medium and high levels of urbanization quality are in the form of a strip in spatial distribution, with Xi'an as the center and extending to Shanxi and Gansu. The low-level areas are relatively scattered in spatial distribution, mainly in the fringes of the GZPUA.

Through **Table 3**, the change trend of urbanization subsystem can be further analyzed. The annual average value is ecological urbanization, social urbanization, population urbanization, and economic urbanization in descending order. From 2008 to 2017, population urbanization surpassed economic urbanization, population growth entered a stage of rapid development, urban areas expanded, and large numbers of people poured into cities from rural areas, leading to a rapid increase in population urbanization rates. At the same time, economic growth began to shift from growth rate to growth quality, which led to a decline in economic growth rate, which initially

TABLE 3 | The dynamics comparison results of urbanization in 2008–2017.

Year	Average of economic urbanization index	Average of population urbanization index	Average of ecological urbanization index	Average of social urbanization index	Average of new-type urbanization index	Average of ecological environment quality
2008	0.375	0.384	0.513	0.461	0.425	0.180
2012	0.384	0.399	0.539	0.488	0.442	0.157
2017	0.414	0.428	0.572	0.525	0.477	0.186

changed the situation of relying on resource-based industries and heavy industry to drive economic growth for a long time, and slowed down the speed of economic growth in order to realize the reform of the economic growth pattern. The social urbanization subsystem also shows an upward trend, with the largest improvement rate among the four subsystems, indicating that the GZPUA has made great efforts to continuously improve the infrastructure and service functions of medical, health, culture, public transportation and so on, and narrow the urban-rural gap. The ecological urbanization subsystem contributes the most to the new urbanization. It shows that in the development process of new-type urbanization, the government's vigorous rectification of the ecological environment and the improvement of social public service level greatly promote the development of new-type urbanization.

(2)   The ecological environment quality of the GZPUA is characterized by slow growth and fluctuations, except for Qingyang showing a downward trend (**Figure 5**). The quality of the ecological environment in Xi'an, Shangluo, Tianshui and Qingyang constitutes the first echelon cities, all of which are much higher than the average level. As the capital of Shaanxi province, the central city of northwest China and an important node city of the Belt and Road Initiative, Xi'an has a strong sense of environmental protection due to strict laws and regulations. The Qinling mountains in the northwest of Shangluo serve as a natural barrier. Tianshui is a famous historical and cultural city in China as well as a famous tourist city. Data show that the ecological environment quality of Baoji, Tongchuan, and Weinan constitutes the second echelon cities. Obviously, the cities on the second echelon are all bordering by Xi'an, indicating that Xi'an has exerted certain radiation capacity and promoted environmental protection in the surrounding areas. The other cities constitute the third echelon of GZPUA. This is consistent with Wei's research. Although the Guanzhong Plain and Fenhe Valley have good economic and transportation conditions, some cities are affected by severe air pollution, and the ecological environment quality is lower than that of the surrounding mountainous areas. Plain cities such as Linfen and Yuncheng have many high-polluting metallurgical industries. The economic foundation is good, but the quality of the ecological environment is not high. To sum up, the natural and social environments of the cities in the GZPUA are

different, and the natural environment, water and land resource combination, and economic foundation of different cities and towns are different. There are spatial differences in the quality of the ecological environment, which is generally characterized by high in the central and western regions. From 2008 to 2017, the average ecological environment quality of the urban agglomeration in the Guanzhong Plain showed a U-shaped change curve trend (**Table 3**), which was in line with the environmental Kuznets curve. This indicates that the ecological environment of the GZPUA has been in a tense state but on the whole has been improving.

The Rank Quadrant Analysis of New-type Urbanization and Ecological Environmental Quality

The 11 cities in the GZPUA will be ranked according to the new-type urbanization quality and ecological environment quality in 2017, and according to the ranking by 1–11 a total of 11 numbers to sort. Taking the ranking number of new-type urbanization of cities as the x-coordinate and the ecological environment quality ranking number of cities as the y-coordinate, the point of coordinate (6,6) as the origin to construct the quadrant diagram, the 11 cities were divided into four quadrants and four types (**Figure 6**).

(1)   Area I is the high-high type. In area I, the quality of new-type urbanization and the quality of ecological environment are high. Cities in this region should play

FIGURE 6 | Comprehensive ranking diagram of new-type urbanization quality and ecological environment quality (2017).
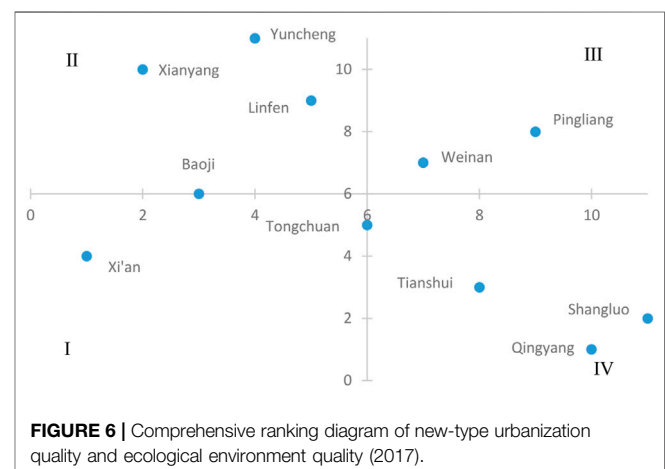
a leading role in the construction of urban agglomeration, and take the lead in taking a path that can lead to the sustainable development of urbanization in the GZPUA and even the whole country. In the GZPUA, only Xi'an belongs to this type. On the basis of existing foundations, Xi'an should accelerate industrial transformation and structural upgrading, and increase investment in environmental protection to enhance the quality of new-type urbanization and the quality of ecological environment. Eventually achieve high-quality development, which in turn will promote the common development of other cities in the urban agglomeration.

(2) Area II is high-low type. In area II, the quality of new-type urbanization is high, the quality of ecological environment is low. The urbanization development of these cities should follow the path of green urbanization and focus on the restoration of the damaged ecology. In the future development, more attention must be paid to ecological construction and environmental protection. Xianyang, Yuncheng and Linfen are in the area II. The geographical location of Linfen determines that its ecological environment is relatively fragile. It relies too much on resource-based industries and has poor environmental protection awareness, which leads to serious ecological environment problems. Therefore, the industrial structure should be adjusted, the backward production capacity should be eliminated, the development of emerging industries should be promoted, and new economic growth points should be found for the development of the city. These cities should develop new industries and high value-added manufacturing on the basis of sound urbanization development, so as to promote the development of urban agglomerations.

(3) Area III is the low-low type. In area III, the quality of new-type urbanization and ecological environment are low. We should learn from the advanced experience of other regions to reduce energy consumption and protect the environment while promoting urbanization. Pingliang and Weinan can speed up the transformation of production and life. In the premise of green environmental protection to achieve the integration of industry, city and people. The urbanization level of these cities is not high, and the task of economic development is still very heavy. The primary goal for a long period of time in the future is to promote economic and social development and improve the level of urbanization. The expansion of urban scale and the concentration of population will inevitably put pressure on the ecological environment. Therefore, in this process, we should change the traditional concept of development and take green development as the main purpose to improve the level of urbanization.

(4) Area IV is the low-high type. In area IV, the quality of new-type urbanization is low, the quality of ecological environment is high. These cities have a good ecological environment. However, we should avoid abandoning the development of urbanization to protect the ecological environment and ignoring the people's needs of pursuing economic development. Such ecological protection lacks economic foundation and the support of the masses, the achievements of ecological protection can hardly be maintained. Such as Shangluo, Tianshui, and Qingyang, these cities have resource-rich mountain areas, which can give full play to the advantages of large environmental bearing capacity and abundant resources to develop resource-based industries, such as tourism. Eventually drive the transformation and upgrading of other industries, and then promote the development of urbanization.

Spatiotemporal Differentiation of the Degree of Coordination Between New-type Urbanization and Ecological Environment

Degrees of coupling and coordination of new-type urbanization and the ecological environment within the GZPUA were calculated using **Eqs. 8–10**. Coupling degree is a measure of the degree of correlation between systems, which only reflects the degree of interaction between systems, but not the level of each system. The degree of coupling coordination can reflect whether each system has a good level, and it can also reflect the interaction relationship between the systems. Therefore, the degree of coordination was selected for analysis.

As shown in **Table 4**, the coordination degree category within the GZPUA is mainly low coordination, and there is no advanced coordination. **Figure 7** shows that the coupling coordination degree between the quality of new-type urbanization and the ecological environment of all cities in the GZPUA has been improved to varying degrees (the range of red line is larger than that of blue line). Data show that between 2008 and 2017, the degree of coordination between urbanization and the eco-environment within the GZPUA have generally increased over time, but the improvement rate is slow, some areas have also fallen back. Specifcally, Xi'an had reached moderate level of coordination. However, the coordination level of other cities is still low. This result is consistent with the current situation as the relationship between urbanization and ecological environment protection remains in a state of dislocation.

In order to compare the spatial differences in the coupling development of new-type urbanization and ecological environment quality in the GZPUA, this paper presents a spatial visualization of the coordination degree between new-type urbanization and ecological environment quality in 11 cities of GZPUA in 2008 and 2017. As can be seen from **Figure 8**, the coordination degree of the 11 cities in the GZPUA in 2008 is different in space, and the coordination degree is low. In 2017, the coordination degree of the 11 cities in the GZPUA has been improved to varying degrees. The region with high coordination degree presents "one point" distribution, only Xi'an has a moderate coordination degree. In conclusion, from 2008 to 2017, the coordination degree between urbanization and ecological environment quality in GZPUA showed an upward trend, and formed a spatial distribution pattern with Xi'an as the

TABLE 4 | Summary table of coordination index of new-type urbanization and ecological environment of the GZPUA 2008–2017.

| City	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Xi'an	0.513	0.532	0.561	0.555	0.579	0.601	0.618	0.626	0.626	0.656
Baoji	0.404	0.419	0.437	0.453	0.450	0.451	0.447	0.446	0.465	0.478
Xianyang	0.419	0.418	0.440	0.445	0.459	0.459	0.468	0.469	0.493	0.487
Tongchuan	0.431	0.420	0.439	0.420	0.417	0.428	0.433	0.434	0.450	0.452
Weinan	0.352	0.359	0.387	0.406	0.418	0.428	0.430	0.431	0.442	0.445
Shangluo	0.341	0.384	0.426	0.428	0.389	0.388	0.416	0.414	0.450	0.454
Yuncheng	0.420	0.401	0.409	0.425	0.416	0.442	0.440	0.418	0.427	0.434
Linfen	0.435	0.418	0.422	0.433	0.433	0.437	0.430	0.417	0.426	0.434
Tianshui	0.418	0.424	0.447	0.430	0.433	0.477	0.441	0.447	0.474	0.495
Pingliang	0.355	0.352	0.373	0.353	0.357	0.357	0.360	0.362	0.404	0.409
Qingyang	0.587	0.579	0.569	0.483	0.509	0.505	0.559	0.511	0.532	0.497
Average	0.425	0.428	0.446	0.439	0.442	0.452	0.458	0.452	0.472	0.476

core and decreasing to the outer circle cities, with regional differences. In conclusion, from 2008 to 2017, the coordination degree between urbanization and ecological environment quality in GZPUA showed an upward trend, and formed a spatial distribution pattern with Xi'an as the core and decreasing to the outer circle cities, with regional differences. Xi'an, as the core city of the GZPUA, the capital city of Shaanxi and an international metropolis, the quality of urbanization has maintained a high level of steady growth. Meanwhile, Xi'an is vigorously developing ecological economy, and people are paying more and more attention to the protection of ecological environment. Therefore, the degree of coupling coordination between urbanization and the ecological environment is at a high level.

According to the classification criteria of urbanization and ecological environment coordination proposed in this study (**Table 2**), the stages and types of variables in GZPUA from 2008 to 2017 were analyzed (**Table 5**). Specifically, the ecological environment quality of Xi'an, Baoji, Xianyang, Linfen and Yuncheng lags behind the new-type urbanization quality. This means that the improvement of ecological environment quality is

FIGURE 7 | Coupling coordination degree between urbanization development level and ecological environment quality of cities in GZPUA in 2008 and 2017.

imminent. Indeed, urbanization is developing too fast, but the ecological environment is relatively backward, that is to say, the protection measures of the latter have not kept pace with the development of the former.

In Qingyang, on the contrary, the quality of the ecological environment is higher than the quality of urbanization. In 2013, Qingyang took the lead in conducting a strategic environmental assessment study on environmental carrying capacity, earnestly implemented the planning of functional zones, and provided strong protection for many ecological areas such as arable land, nature reserves, water sources and vegetation coverage. The coordination degree of Tianshui and Tongchuan is low, but the synchronization of urbanization and ecological environment is good. The level of coordination in Pingliang, Weinan, and Shangluo has changed from a moderate imbalance to low coordination, in this process, urbanization and the ecological environment have always maintained a good synchronization. These small cities are characterized by slow urbanization and good ecological environment. They urgently need to accelerate the process of new-type urbanization while protecting the ecological environment. To sum up, the lagging ecological environment of core cities and the low urbanization level of small and medium-sized cities are the important reasons for the low coordination degree of urban agglomeration.

In summary, the relationship between urbanization and the ecological environment is a complex process of changes in the population, society, economy, and resource-environmental systems. It has also been a focus of attention by academic circles at home and abroad, especially in the northwestern region where the ecological environment is relatively fragile. It can be seen from the results of this study that the urbanization development of the GZPUA is polarized obviously, and the problem of uneven regional development is prominent. The absence of long-term spatial regulation measures makes Xi'an alone big. The low-level urban function is excessively concentrated, and the radiation effect of polarized regions is limited, which to some extent limits the play of the progressive driving role of urban agglomeration and the integration and balanced development of regional economy. The overall ecological environment quality of the central and western regions of the urban agglomeration is higher than that of the eastern region of the urban agglomeration. Shanxi, as the
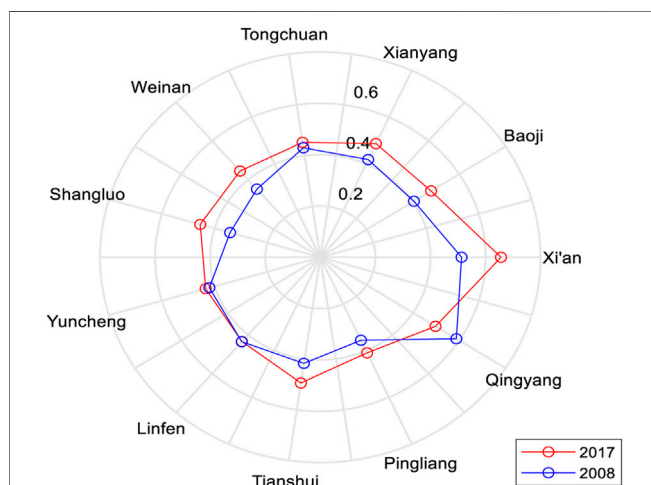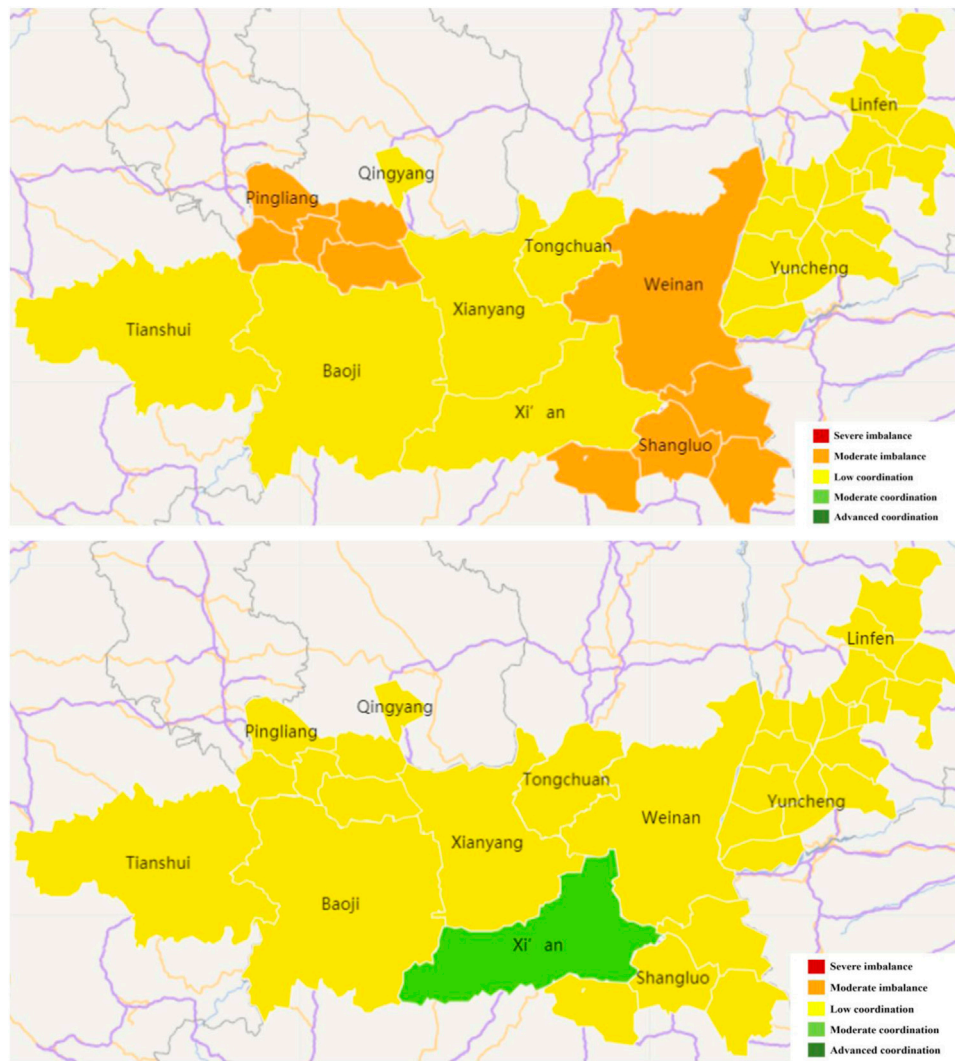
FIGURE 8 | Spatial pattern evolution of coordination degree of urbanization and ecological environment in GZPUA 2008 and 2017.

TABLE 5 | New-type urbanization and ecological environment coordination degree classification tables 2008–2017.

City	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Xi'an	III-3	III-3	III-3	III-3	III-3	III-3	IV-3	IV-3	IV-3	IV-3
Baoji	III-3	III-3	III-2	III-2	III-3	III-3	III-3	III-3	III-3	III-3
Xianyang	III-3	III-3	III-3	III-3	III-3	III-3	III-3	III-3	III-3	III-3
Tongchuan	III-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2
Weinan	II-2	II-2	II-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2
Shangluo	II-2	II-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2
Yuncheng	III-3	III-3	III-3	III-3	III-3	III-3	III-3	III-3	III-3	III-3
Linfen	III-2	III-2	III-3	III-3	III-3	III-3	III-3	III-3	III-3	III-3
Tianshui	III-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2	III-2
Pingliang	II-2	II-2	II-2	II-2	II-2	II-2	II-2	II-2	III-2	III-2
Qingyang	III-1	III-1	III-1	III-1	III-1	III-1	III-1	III-1	III-1	III-1

country's energy and heavy chemical industry base, has a relatively poor ecological environment. As the pace of urbanization in Northwestern China has accelerated in recent years, the population in some areas has grown rapidly, and the

development and use of various resources has increased. At the same time, the economic structure within the urban agglomeration is converging, the industrial level is low, and traditional industrial urbanization with high input, high

TABLE 6 | Impact of elements to coupling coordination degree between urbanization and eco-environment.

Year	Per capita GDP	The population density	The number of college students per 100,000 people	The unit GDP energy consumption	Ratio of urban and rural per capita disposable income	Per capita budgetary revenue
2008	0.3908	0.2814	0.5772	0.3064	0.2243	0.4678
2012	0.7962	0.8273	0.5053	0.3583	0.4648	0.8313
2017	0.4985	0.8909	0.9247	0.9636	0.8574	0.8491

consumption, and high emissions is the mainstay. In addition, the fragile background ecology in the northwest has increased the bearing pressure on resources and the environment, resulting in a relatively high proportion of low-coupling and coordination areas in the GZPUA. The unsustainability of this development model needs to be alleviated urgently. This is basically consistent with previous research conclusions in other regions (Pan and Feng, 2017; Yan et al., 2018; Bie et al., 2018; Cui et al., 2019).

THE DRIVING MECHANISM OF COUPLING COORDINATION DEGREE BETWEEN NEW-TYPE URBANIZATION AND ECOLOGICAL ENVIRONMENT IN GUANZHONG PLAIN URBAN AGGLOMERATION

The coordinated development of urbanization and ecological environment is comprehensively affected by various factors. This paper is based on the previous research results (Zhang et al., 2018), combined with the actual situation of the coordinated development of urbanization and ecological environment in GZPUA and the opinions of relevant experts. Finally, per capita GDP, population density, the number of college students per 100,000 people, the unit GDP energy consumption, ratio of urban and rural per capita disposable income and per capita budgetary revenue were selected as the detection factors. We use the geo-detector analysis method to conduct an empirical study on the driving mechanism of the coupling coordination degree between urbanization and ecological environment. In ArcGIS 10.1, the natural crack classification of each element is carried out, and the influence degree of each element on the coordination degree of urbanization and ecological environment is calculated by using **Eq. 11**, the results are shown in **Table 6**.

As can be seen from **Table 6**, per capita GDP, number of college students per 100,000 people and per capita budgetary revenue are all important factors influencing the coordinated development of urbanization and ecological environment in three years, while other factors have different impacts on the coordination degree in different years. In 2008, it was mainly affected by per capita GDP, the number of college students per 100,000 people and per capita budgetary revenue. In 2012, per capita budgetary revenue and population density played an

important role. In 2017, the number of college students per 100,000 people and the unit GDP energy consumption played an important role. In a word, the coordinated development of urbanization and ecological environment is the result of the interaction of various factors on various driving forces (**Figure 9**). It can be summarized as:

(1) Market driving force. According to the theory of sustainable economic development based on ecological capital (Ren, 2016), the level of economic development is the basis of the coordinated development of urbanization and ecological environment, and the efficiency of economic development is the direct driving force of the coordinated development of urbanization and ecological environment. As can be seen from **Table 6**, in the three years, the influence p-value of per capita GDP first increased and then decreased, while the influence p-value of unit GDP energy consumption first increased slowly and then increased rapidly. This is because in the early stage, the level of economic development needs to be improved. At this time, the increase in per capita GDP is particularly important. In the later stage, when the level of economic development reached a certain level, compared with the level of economic development, the efficiency of economic development become a more important goal of social development, so its p-value keeps increasing. Increasing the efficiency of economic development means technological progress, industrial structure transformation and upgrading, and a perfect market operation price mechanism. All these have improved the stability of the city's own economy and promoted the coordinated development of urbanization and ecological environment.

(2) Endogenous driving force. Population factor is the premise of coordinated development of urbanization and ecological environment, as well as its internal fundamental driving force. Population factors not only reflect the development of urbanization, but also reflect the pressure on the ecological environment. **Table 6** shows that the influence of population density is increasing year by year, indicating that the intensity of population agglomeration in GZPUA has a stronger influence on the coupling and coordinated development of urbanization and ecological environment. GZPUA is located in the undeveloped
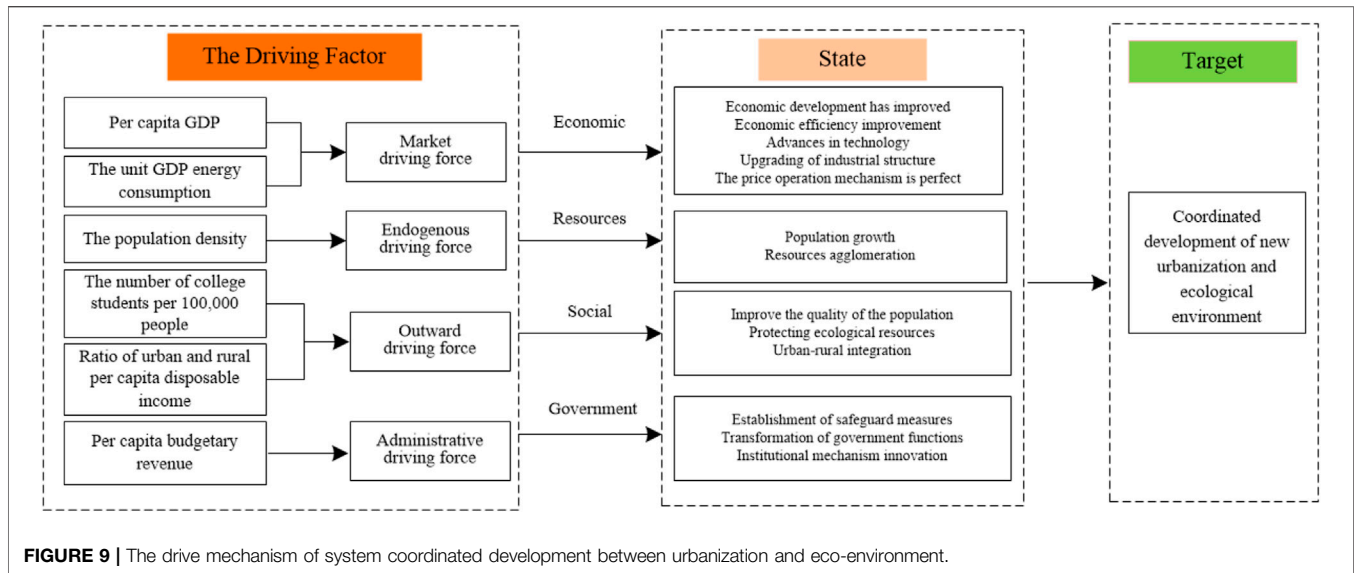
FIGURE 9 | The drive mechanism of system coordinated development between urbanization and eco-environment.

western region. With the promotion of policies in recent years, urbanization has brought about the effect of resource agglomeration, absorbed more rural surplus labor, and the effect of population agglomeration has gradually become prominent. The concentration of population resources further drives the concentration of other resources (Yu, 2012), providing a development basis for the coordinated development of urbanization and the ecological environment.

(3) Outward driving force. The degree of urban civilization and the urban and rural development have an important impact on the coordinated development of urbanization and ecological environment. **Table 6** shows that the P-value of the number of college students per 100,000 people and ratio of urban and rural per capita disposable income has been increasing. The degree of civilization is not only the core of urbanization development, but also the guarantee of ecological environment construction. Therefore, the P-value of the number of college students per 100,000 people is relatively large in three years. There are many national-level poverty-stricken counties in the GZPUA area. The local people lack funds, technology, etc., and their ideas and concepts are backward, which has caused great damage to the regional ecological environment (Wang et al., 2018). The improvement of population quality effectively promotes modern urban civilization, improves people's life style, and strengthens the public's concept of environmental protection, thus promoting the coordinated development of urbanization and ecological environment. In addition, some urban transportation location conditions and infrastructure construction levels in China are relatively weak, and the urban-rural gap is large. Especially in the western region, road construction, communication network construction, and aviation networks are relatively backward. The urban-rural integration of the GZPUA

has contributed greatly to the coordinated development of urbanization and ecological environment.

(4) Administrative driving force. Government action is the guarantee force for the coordinated development of urbanization and ecological environment. Cities can obtain more resources by virtue of their own political advantages. As a national central city, Xi'an is affected by the administrative level of the city, and the coordinated development of urban development and ecological environment is relatively high (Feng and Zhang, 2019). **Table 6** shows that the p-value of influence of per capita budgetary revenue has been increasing. Many issues involved in urbanization and ecological construction, such as spatial planning and layout, basic public services, social justice and ecological and environmental protection, make it difficult for the market to play an effective role. As the main body of responsibility, the government must play a good role in regulation, service and guidance through macro-control, supervision and coordination. Therefore, the government has played an important role in the coordinated development of urbanization and ecological environment.

CONCLUSION AND POLICY IMPLICATIONS

By constructing new-type urbanization and ecological environment evaluation index system, we evaluated the new-type urbanization and ecological environment quality development level of 11 cities in the GZPUA from 2008 to 2017. Further, the coupling coordination degree model is used to analyze the coupling coordination relationship between new-type urbanization and ecological environment quality. Finally, using geographic detector methods, an empirical study of the driving mechanism affecting the coupling and coordination

relationship between the two is conducted, and the following conclusions are drawn:

(1) From 2008 to 2017, the overall level of new-type urbanization quality in the GZPUA shows a slowly rising trend, except for Xi'an, which is a rapid rising trend. The ecological environment quality of the GZPUA is characterized by slow growth and fluctuations, except for Qingyang showing a downward trend. The areas with medium and high levels of urbanization development index are in the form of a strip in spatial distribution, with Xi'an as the center and extending to Shanxi and Gansu. The low-level areas are scattered in spatial distribution, mainly in the fringes of the GZPUA. There are spatial differences in the quality of ecological environment, which is generally higher in the central and western regions than in the eastern regions.

(2) The quadrant map of the new-type urbanization quality and ecological environment quality of each city in 2017 shows: only Xi'an belongs to the high-high type. Xianyang, Yuncheng, and Linfen belong to the high-low type. Pingliang and Weinan belong to the low-low type. Shangluo, Tianshui, and Qingyang belong to the low-high type. Different types should take different development paths.

(3) The overall level of coupling and coordinated development of new urbanization and ecological environment in GZPUA is low but rising. The coordination degree between new-type urbanization and ecological environment quality in GZPUA is between 0.341–0.656, with an average value of 0.490. The coordination degree category within the GZPUA is mainly low coordination and there is no advanced coordination. Moreover, the quality of the ecological environment generally lags behind the quality of urbanization. The coordination degree forms a spatial distribution pattern with Xi'an as the core and decreasing to the outer ring road, and there are regional differences.

(4) Through the analysis of geographic detector, it is found that the main influencing factors of coupling coordination degree include the per capita GDP, the population density, the number of college students per 100,000 people, the unit GDP energy consumption, ratio of urban and rural per capita disposable income and per capita budgetary revenue. In a word, the coordinated development of new-type urbanization and ecological environment is a process driven by various driving factors interacting with different types of driving forces, which can be summarized as the four-element driving mechanism of market driving force, endogenous driving force, outward driving force and administrative driving force.

In order to promote the coordinated development of urbanization and ecological environment, based on the above analysis and combined with the actual situation of GZPUA, several countermeasures and suggestions were proposed:

(1) The 11 cities need to adopt a different coupling and coordination path of urbanization and ecological environment according to their own urban development characteristics. The coordinated development of urbanization and ecological environment in the GZPUA should proceed from the reality of regional differentiation. Different types of cities should adopt different development paths. Cities in area I should consolidate existing achievements and expand new areas of development. Cities in area II should follow the path of green urbanization. Cities in area III should follow the path of development and governance at the same time. Cities in area IV should take the path of efficient utilization of advantageous resources.

(2) Xi'an, an economically developed city with a high degree of coordination, should play a leading role in surrounding areas by virtue of its core status as a national central city in the future, and strengthen regional cooperation in urbanization and ecological environment governance. For the cities with advanced urbanization in the low coordination type, including Baoji, Xianyang, Linfen, and Yuncheng, they are all in the development stage of running in and improving, and the ecological environment problems are relatively prominent. The level of urbanization in these cities is relatively high. Due to the constraints of the previous environmental damage, urban development pays more attention to the pursuit of ecological civilization. In the future, in the process of economic transformation, in addition to strengthening its own pollution source control, it is also necessary to focus on coordinated development and joint pollution prevention with large regions. For the cities with balanced development in the low coordination type, including Tianshui, Pingliang, Weinan, Tongchuan, and Shangluo, they are currently in the transition and running-in development stage, with relatively prominent economic backwardness and low pollution discharge pressure. In general, urbanization and the ecological environment are basically adapted and run-in. In the future, it is necessary to actively integrate into the GZPUA, economic circle and western economic uplift zone under the premise of strict implementation of environmental protection policies and focus on environmental protection construction to achieve rapid development of urbanization. For the cities with advanced ecological environment in the low coordination type, they have their own environmental advantages, and the speed and scale of regional urban spatial expansion should be appropriately guided and controlled. In particular, the scale of arable land occupation by development zone project construction should be strictly controlled to prevent extensive use of resources.

(3) In order to better promote the Guanzhong Plain urban agglomeration coordinated development between urbanization and ecological environment, first of all,

we need to change the pattern of urban economic growth, promote the upgrading of industrial structure, the road to explore green transformation of urbanization. Secondly, we should guide the cross-regional flow of various elements, especially the introduction of talents, and further strengthen scientific and technological innovation. In addition, we should establish a new concept of urbanization that is compatible with the construction of ecological civilization, strengthen the awareness of green, low-carbon and environmentally friendly development, and narrow the gap between urban and rural areas. Finally, relevant policies will be introduced to support energy conservation and emission reduction, strictly enforce environmental protection standards, and eliminate backward production capacity, so as to promote sustainable development of the Guanzhong Plain urban agglomeration.

It should be noted that there are some limitations in this study, we hope to conduct in-depth studies from the following three aspects in the future: 1) Explore the influencing factors of the coupling coordination degree between urbanization and ecological environment from the perspective of spatial heterogeneity, and further explore the internal mechanism of the spatial difference of coupling coordination degree between urbanization and ecological environment from multiple perspectives. 2) Research on the coupling and coordinated development trend of urbanization and ecological environment. The prediction model can be used to further explore the coupling and coordination development trend between the two in GZPUA. 3) Construct a sustainable development model through data products to form a scientific platform, make decisions and assessments on the sustainable development of urbanization, and find a path for the coupling and coordinated development of urbanization and ecological and environmental systems. This is the focus and challenge of future research.

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DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

LD proposed the main research idea, detailed literature review, analysis of results through the employed software's following conclusion and recommendations. JS acted in the supervisory role and reviewed the manuscript. RA contributed to the results, writing, editing, and revised the manuscript. RR contributed to the revised this manuscript. Lastly, thanks to anonymous reviewers whose useful suggestions added significant value in the document. All authors have read and agreed to the published version of the manuscript.

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