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A study on spatio-temporal coordination and driving forces of urban land and water resources utilization efficiency in the Yangtze River Economic Belt

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ABSTRACT

Using panel data from 11 provinces from 2003 to 2017 in the Yangtze River Economic Belt, the study explores the spatio-temporal differentiation characteristics and driving forces of coupling coordination of urban land and water resource utilization efficiency by constructing the coupling coordination model and the spatial econometric model. The results show that (1) in terms of time, the situation of inefficient utilization of urban land and water resources was severe. Spatially, the distribution of utilization efficiency of two resources was consistent with the pattern of regional economic development; (2) the coupling coordination degree of urban land and water resources utilization efficiency was mainly of mild disorder type and transitional type, and was in a gradient decreasing spatial distribution from downstream to midstream to the upstream region; (3) the coupling coordination degree of urban land and water resources utilization efficiency presented significantly positive spatial auto-correlation, but the agglomeration trend was weakening; (4) per capita GDP, employment labor force and fixed assets investment were important driving forces for the coordination development of urban land and water resources, while the role of government and the total population had a negative impact on it, and the driving role of the industrial structure had not yet been played.

Key words: coupling coordination, driving forces, land resources utilization efficiency, spatial correlation, water resources utilization efficiency, Yangtze River Economic Belt

HIGHLIGHTS

- This study analyzes the spatio-temporal differentiation characteristics of urban land and water resources utilization efficiency.
- This study explores the driving forces of coupling coordination degree of urban land and water resources.
- This study makes it possible to point out the weak factors, so as to improve the related strategies to help build a harmonious relationship between urban land and water resources.

The Yangtze River Economic Belt covers 11 provinces and cities, including Anhui Province, Jiangxi Province, Yunnan Province, Guizhou Province, Hubei Province, Hunan Province, Chongqing City, Sichuan Province, Shanghai City, Jiangsu Province, and Zhejiang Province, covering an area of about 2.05 million km^2 and spanning China's eastern, western, and central regions (Figure 1). The Yangtze River Economic Belt is an important growth pole of China's economic development, and the new urbanization importantly promotes the coordinated development of it. In 2019, the average urbanization rate of 11 provinces in the Yangtze River Economic Belt was 61.7%, exceeding the national average of 60.6%. As the rapid urbanization and the agglomeration of population and industry, the contradiction between the supply of urban land and water resources and the need for economic development is increasingly prominent in the Yangtze River Economic Belt. Therefore, the study comprehensively measures the urban land and water resources utilization efficiency, reveals the spatio-temporal coordination situation of the two resources utilization efficiency and its driving factors, and puts forward some suggestions on optimizing the rational allocation of land and water resources, which is of great practical significance for promoting the sustainable development in the Yangtze River Economic Belt.

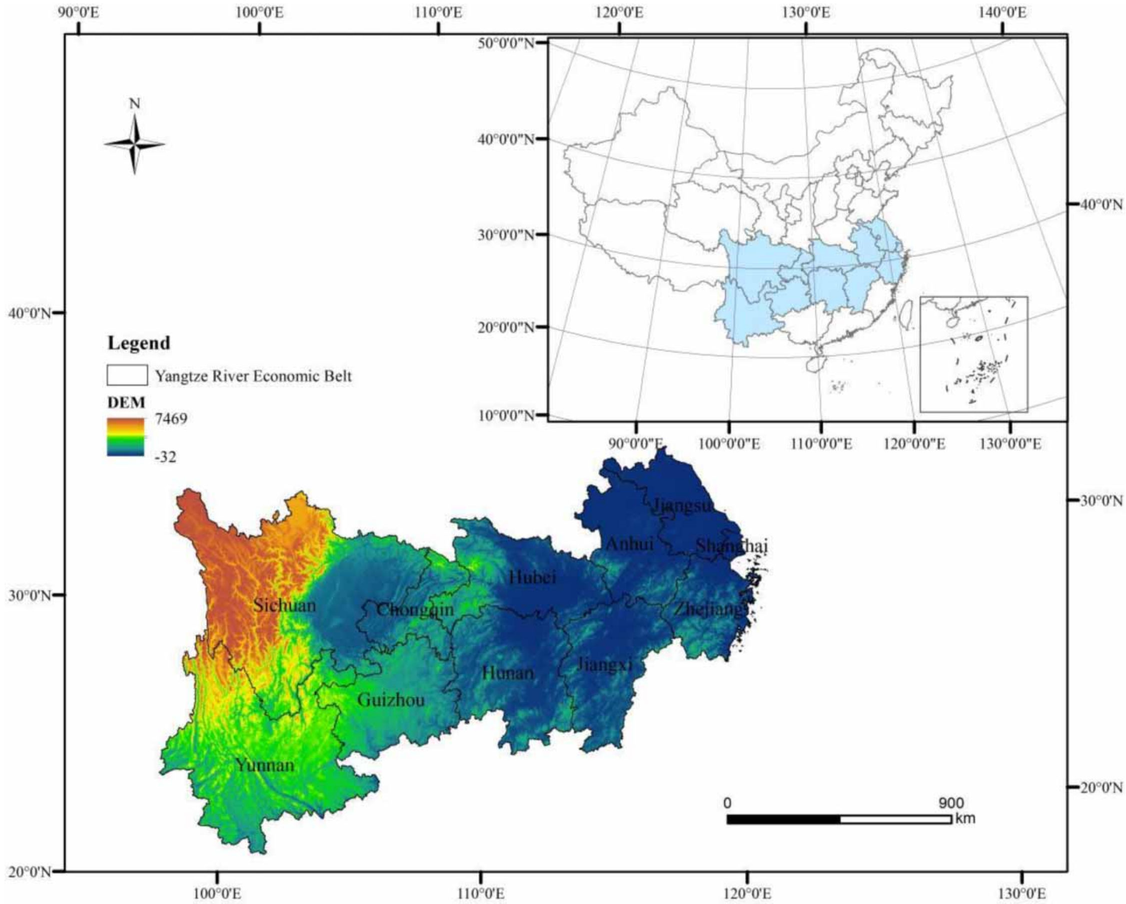

Figure 1 | Administrative map of the study area.

1. RESEARCH DEVELOPMENT AND MECHANISM ANALYSIS

1.1. Research development

Land and water resources are two important subsystems to maintain urban social and economic development. Some scholars had explored the influencing factors of urban land utilization efficiency from the perspectives of intensive use and sustainable urban development (Esbah 2007), optimization of urban land structure (Benabdallah & Wright 1991), and regional economic growth (Kim 2011). In the studies of measuring urban land utilization efficiency, Ke *et al.* (2014) analyzed the regional differences in urban construction land utilization efficiency and put forward suggestions for optimizing the allocation of construction land. Chen *et al.* (2017) pointed out that the overall evolutionary dynamics of urban land utilization efficiency in China was fluctuating with an upward trend in the eastern and the western region and a downward trend in the central region. Jin *et al.* (2018) proposed that there were regional differences in the spatial distribution and the evolutionary path of urban land utilization efficiency in the Yangtze River Economic Belt. In the studies method of land utilization efficiency, Bao *et al.* (2009) constructed an index system from the three objectives of economic, social, and environmental benefits, and studied urban land utilization efficiency by using a multi-attribute comprehensive evaluation method. Zhang *et al.* (2017) measured urban construction land utilization efficiency in 31 provinces and cities of China from 2009 to 2013 by constructing DEA model from input and output and the results showed that only a few inter-provincial urban construction land utilization efficiency reached the optimal DEA efficiency.

Regarding the studies on water resources utilization efficiency, Zhao *et al.* (2013) and Han *et al.* (2018) theorized the connotation of water utilization efficiency from two dimensions of water input and output, measuring the national and different provincial water utilization efficiency, respectively, by using the DEA method, and pointing out that most cities in China had poor water utilization efficiency. Sun *et al.* (2014) devised a spatial Tobit model to explore the influencing factors of water utilization efficiency in Chinese provinces and pointed out that transportation infrastructure had a positive impact on water utilization efficiency, while FDI had a negative impact. Ma *et al.* (2012) analyzed the factors influencing water utilization efficiency in different regions of China, in which economic level and water price had a positive effect on total factor water utilization efficiency, and industrial structure and government influence had a significant negative effect. In addition, China's total factor water resources utilization efficiency showed a decreasing trend from the eastern to the central to the western region.

In summary, scholars had focused on the measurement of the utilization efficiency of a single land or water resource system and the analysis of its influencing factors. However, as the two fundamental resources supporting urban economic development, the coupling coordination relationship between land resources utilization efficiency and water resources utilization efficiency was still relatively little studied. Especially on a spatial scale, scholars mainly explored the coordination relationship between land and water resource utilization efficiency at the national or provincial level, but only a few analyzed the coupling coordination dynamics of two resources utilization efficiency and the driving factors in the Yangtze River Economic Belt. Therefore, this study takes 11 provinces in the Yangtze River Economic Belt as the research object, statistically measures the utilization efficiency of urban land and water resources, and adopts the coupling coordination degree model to explore the spatial and temporal evolution of two resource coupling coordination degrees and its driving factors. The importance and the originality of this study are that it provides a scientific basis for reference to improve land and water resources utilization efficiency and realize rational utilization of resources.

1.2. Analysis of mechanism of coupling coordination of urban land and water resources utilization

As the support and important guarantee of regional economic development, whether urban land and water resources can achieve benign coupling coordination development will directly affect the sustainability of the regional economy. The connotation of coupling coordination of urban land and water resources refers to the phenomenon and process of interpenetration and dynamic integration in the utilization of land and water resources, by breaking through the original single element field to improve the utilization efficiency of each resource and finally to promote the resource structure adjustment and coordinated development of the whole urban ecosystem.

The land system and water system are not only components of an integral urban system, but mutually dependent and interact subsystems from the perspective of coupling coordination mechanism. The land system has both productive and load-bearing functions and can be classified into ecological land, productive land, and living land according to different land use patterns (Zhao *et al.* 2016). The water system covers a series of complete water cycle processes such as water storage, water production, water transmission, water transfer, water treatment, and secondary use, and can be divided into ecological water, production water, and domestic water according to the type of demand. They are inseparably intertwined through human socio-economic activities and together constitute land and water resources system. On the one hand, the land resources system provides land conditions and bearing places for the storage, processing, transportation, and irrigation of the water resources system. The type and intensity of land development utilization, industrial activities, and the protection of the ecosystem will significantly affect the changes in urban hydrological situation. In addition, the discharge of production wastewater and domestic sewage will increase with the expansion of urban construction land, thus affecting the health of water resources system. On the other hand, the water resources system guarantees the supply of basic raw materials such as ecological, living, and production of water for the land resources system. The water storage projects, the total distribution of water resources, and the availability of water quality conditions will also restrict the utilization and spatial distribution of urban land resources.

2. RESEARCH METHODOLOGY AND DATA

2.1. Research methodology

The following graphical abstract (Figure 2) is used to explain the research content and research methodology of this paper.

2.1.1. Entropy method

In this study, the entropy method is used to measure the utilization efficiency of urban land and water resources in the Yangtze River Economic Belt (Ma *et al.* 2015).

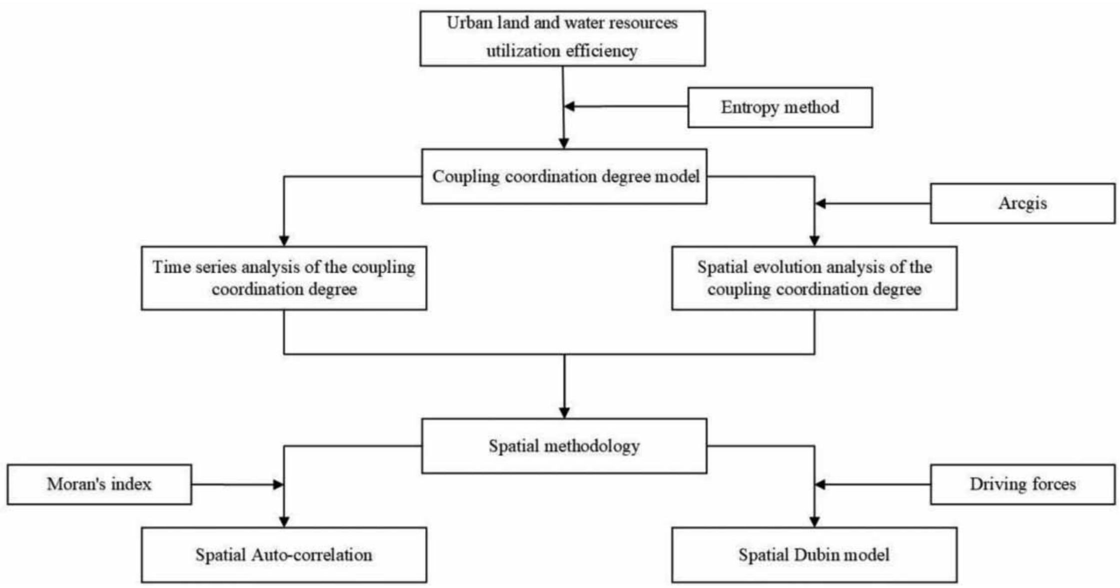

Figure 2 | Graphical abstract of research content and methods.

To standardize the index data, the processed data are all dimensionless values, so as to solve the problem of inconvenient calculation caused by different orders of magnitude and dimensions of data. The calculation formula is as follows:

$$\text{Positive indicators} \quad \mu_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \tag{1}$$

$$\text{Negative indicators} \quad \mu_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} \tag{2}$$

where X_{ij} is the original value of indicator data, X_{max} and X_{min} are the maximum and minimum values of indicator data in the system i, respectively. μ_{ij} is the value of the indicator j in the system i.

$$P_{ij} = \frac{\mu_{ij} + 0.001}{\sum_{i=1}^{m} (\mu_{ij} + 0.001)} \tag{3}$$

$$e_j = -\frac{1}{LN\, m}\left(\sum_{i=1}^{m} P_{ij} \times LN\, P_{ij}\right) \tag{4}$$

$$\theta_j = 1 - e_j \tag{5}$$

$$W_j = \frac{\theta_j}{\sum_{j=1}^{n} \theta_j} \tag{6}$$

where m represents the number of provinces and cities studied, n is the number of evaluation indicators, e_j is the information entropy of the indicator, θ_j is the redundancy of indicators, W_j is the indicator weight.

2.1.2. Coupling coordination degree model

The coupling coordination degree model is used to analyze the coupling coordination relationship between urban land resources utilization efficiency and water resources utilization efficiency (Wen *et al.* 2017). The coupling coordination degree is based on the coupling degree to more accurately quantify the degree of matching between the land resources and the water resources system. The specific formula for the coupling coordination degree is shown in Equations (7)–(9).

$$D = \sqrt{C \times T} \tag{7}$$

$$C = \sqrt{\frac{U \times V}{(U + V)^2}} \tag{8}$$

$$T = \alpha U + \beta V \tag{9}$$

where the coupling coordination degree $D \in [0, 1]$, the coupling degree $C \in [0, 1]$. T is the comprehensive evaluation index of land resources utilization efficiency and water resources utilization efficiency. The larger the C value is, the better the coupling correlation between water and land resource utilization is. U is the utilization efficiency of land resources and V is the utilization efficiency of water resources. a and β are parameters indicating the importance of land resources and water resources for socio-economic development. Considering that land resources and water resources are of equal importance to the provinces in the Yangtze River Economic Belt, the values of the two parameters are set to 0.5 in this study.

According to the variation of coupling coordination degree values, this study draws on the classification criteria of the related literature (Zhao *et al.* 2016) to classify the coupling coordination levels into three types, i.e. dysfunctional type, transitional type, and coordinated type (as shown in Table 1).

2.1.3. Moran's index

There is a spatial relationship between urban land resource utilization efficiency and water resource utilization efficiency. Because the coupling coordination degree model can not identify the spatial interaction and distribution characteristics of the coupling coordination degree of urban land and water resources utilization efficiency. This study uses the Moran's I and ArcGIS 10.5 software to analyze the spatial correlation and aggregation characteristics of the coupling coordination degree of two resources utilization efficiency. The Moran's I include global spatial auto-correlation analysis (Global Moran's I) and local spatial auto-correlation analysis (Local Moran's I).

The Global Moran's I formula is as follows:

$$I = \frac{\left[(N/S_0) \times \left(\sum_{i=1}^{n} \sum_{j \neq 1}^{n} W_{ij}(X_i - \bar{X})(X_j - \bar{X})\right)\right]}{\sum_{i=1}^{n} (X_i - \bar{X})^2} \tag{10}$$

where N is the observation unit; X_i and X_j are the observed values in regions i and j, respectively; S_0 is the normalized element whose value is equal to the weight matrix element; W_{ij} is the spatial weight matrix, using spatial adjacency as to define W_{ij} (1 means adjacent, 0 means non-adjacent).

The Local Moran's I formula is as follows:

$$I_i = Z_i \sum_{j \neq 1}^{n} W_{ij} Z_j \tag{11}$$

where Z_i and Z_j are the standardized forms of the observations in the region i and region j. Local spatial correlation can be divided into four quadrants: H–H means high level of self and surrounding; L–L means low level of self and surrounding; H–L means high level of self and surrounded by low level area; L–H indicates a low level of self surrounded by a high level area.

2.1.4. Spatial methodology

In view of the numerous factors affecting the coordination of urban land and water resources utilization efficiency and the existence of certain spatial correlations. This study selects an econometric model that can consider spatial factors to further identify the driving factors of the coupling coordination degree of two resource utilization efficiency in the Yangtze River Economic Belt.

Table 1 | Classification criteria of coupling coordination level of urban land and water resources utilization efficiency

	Coupling coordination level								
Type	**Dysfunctional type**			**Transitional type**			**Coordinated type**		
Numerical range of coupling coordination degree	[0,0.1]	[0.1,0.2]	[0.2,0.3]	[0.3,0.4]	[0.4,0.5]	[0.5,0.6]	[0.6,0.7]]	[0.7,0.8]	[0.8,0.9]
Coupling coordination status	Severe disorder	Moderate disorder	Mild disorder	Borderline disorder	Grudging coordination	Primary coordination	Intermediate coordination	Good coordination	Quality coordination

2.2. Data sources

The data can be collected from *the China Statistical Yearbook* (2004–2018), the statistical yearbooks of provinces in the Yangtze River Economic Belt (2004–2018), *the China Urban Construction Statistical Yearbook* (2004–2018), and the *Yangtze River Economic Belt Big Data Platform*.

2.3. Indicator system construction

To accurately measure the comprehensive development level of urban land and water resources and coordination degree status, this study divides 10 specific indicators from the input and output dimensions respectively to construct an evaluation index system of land and water resources utilization efficiency (Fang *et al.* 2014; Zhu *et al.* 2021). The input indicators of water resources utilization efficiency and land resources utilization efficiency are characterized by physical input, capital input, and labor input, and the output indicators are characterized by economic benefits and environmental benefits. The basic indicators are set out in Table 2.

3. ANALYSIS OF RESULTS

3.1. Urban land and water resources utilization efficiency values and evolutionary analysis

The results of the evaluation indices of urban land resources utilization efficiency and water resource utilization efficiency of 11 provinces from 2003 to 2017 in the Yangtze River Economic Belt are measured separately according to the entropy method, and evolutionary characteristics are analyzed from a spatial and temporal perspective, respectively.

The urban land resources and water resources utilization efficiency values from 2003 to 2017 were in an inefficient state, and the situation of inefficient utilization was rather serious from the perspective of time series (as shown in Figure 3). In terms of the development trend of land and water resources utilization efficiency, the efficiency of land resources utilization was on a fluctuating downward trend. Also, the efficiency of water resources utilization experienced a phase of first rising, then falling in 2008, and resumed rising in 2012. Which indicated that the economic development of the provinces after 2008 in the Yangtze River Economic Belt was at the expense of water pollution. Since the Chinese government emphasized the implementation of the three red lines of water resources management in 2012, the efficiency of water resource utilization everywhere has started to pick up. In particular, there is a tendency for land resource utilization efficiency to lag behind water resources utilization efficiency after 2008.

The Yangtze River Economic Belt, as the main site of national urbanization, has a significantly lower carrying threshold of water and land resources than the threshold of economic development and is facing a more serious problem of imbalance between land supply and demand, low utilization rate, and large demand for new construction land. Although the government has introduced numerous policies and plans to control the limited scale of land use in recent years due to the concept of protecting the ecological environment, the development of urban industrialization and urbanization still needs

Table 2 | The evaluation index system of urban land and water resources utilization efficiency

	Classification of indicators	Indicator composition	Unit	Nature of indicators	Weights
Land resources utilization efficiency	Input indicators	Urban construction land area	km^2	-	0.160
		Urban fixed asset investment	billion yuan	+	0.288
		Number of urban employees	10,000 people	-	0.136
	Output indicators	Urban gross regional product	billion yuan	+	0.269
		Greening coverage of built-up areas	%	+	0.147
Water resources utilization efficiency	Input indicators	Total urban water population	10,000 people	-	0.155
		Town fixed asset investment	billion yuan	+	0.226
		Water consumption	m^3/person	-	0.060
	Output indicators	Urban gross regional product	billion yuan	+	0.246
		Sewage treatment rate	%	-	0.313

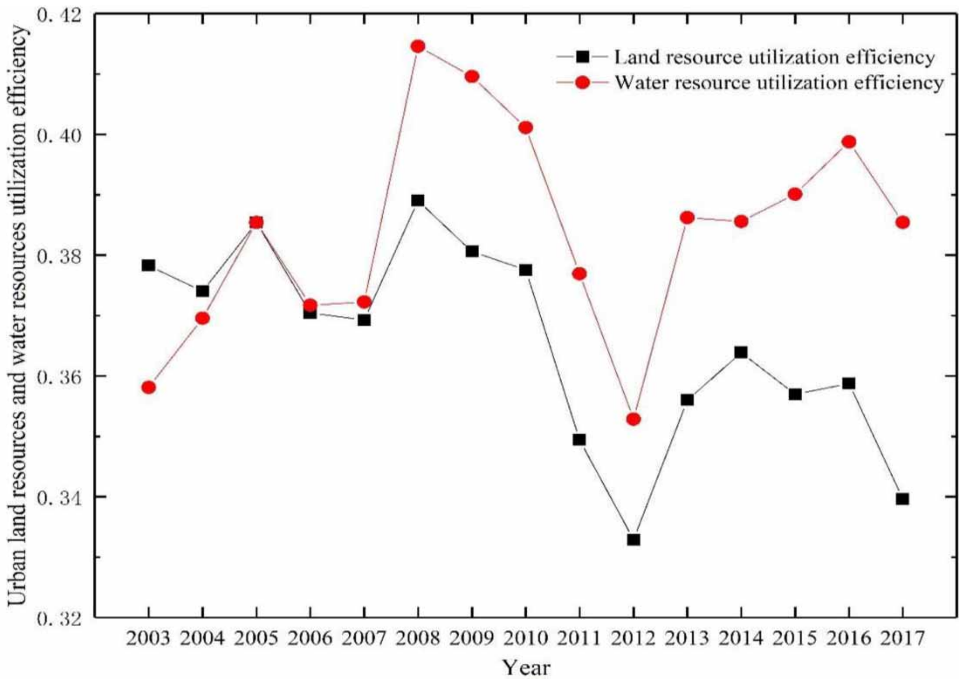

Figure 3 | Values of urban land resources utilization efficiency and water resources utilization efficiency from 2003 to 2017 in the Yangtze River Economic Belt.

to be supported by urban land resource allocation, and the contradiction between human and land remains prominent, resulting in the improvement of land use efficiency, but the overall trend is still declining.

Although water resources also serve as an important support to promote the process of high-speed urbanization, in recent years, China has vigorously promoted the construction of a water-saving society and water-saving cities, comprehensively implemented the strictest water resources management and various water conservation system measures, and the concept of water conservation is deeply rooted in people's hearts while relying on the rigid water resources constraint system, the level of intensive and economical use of water resources has been continuously improved.

From the perspective of space (as shown in Table 3), the distribution of urban land resources utilization efficiency and water resources utilization efficiency was consistent with the pattern of economic development in the Yangtze River Economic Belt, with a decreasing distribution trend from downstream to midstream to upstream region. Specifically, the average values of urban land resources utilization efficiency in the upstream, midstream, and downstream regions were 0.17, 0.33, and 0.58, and the average values of water resources utilization efficiency were 0.23, 0.31, and 0.61, respectively. As the unique location advantage and superior economic development level, the average values of urban land resources utilization efficiency and water resource utilization efficiency in the downstream region had exceeded the level of all regions; the average value of land and water resources utilization efficiency in the midstream region basically matched the level of all the regions. But the upstream region had the worst land and water resources utilization situation among the three regions, which meant the upstream region failed to give full play to the advantages of water and land resources. The upstream region of the Yangtze River Economic Belt was constrained by objective geographical conditions. The industrial structure was poorly laid out, urban buildable land was scarcer compared to the midstream region and downstream region, and economic development was slower compared to other regions. Which were the main reason for the low level of efficiency in the region as a whole. To achieve sustainability in the upstream region, it is necessary to manage the Yangtze River basin as a whole in an integrated manner. Based on the principle of joint development of economic benefits and ecological benefits, dynamically supervise changes about the resources and ecological environment in the basin, and gradually establish and improve the evaluation and assessment system for the efficiency of water and land resource use in the upstream region.

Table 3 | Utilization efficiency values of urban land and water resources from 2003 to 2017 in the Yangtze River Economic Belt

Indicators	Region	Year 2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average value
Land resources utilization efficiency	Upstream	0.15	0.15	0.15	0.15	0.14	0.17	0.19	0.2	0.18	0.17	0.18	0.19	0.18	0.19	0.18	0.17
	Midstream	0.3	0.33	0.32	0.32	0.33	0.34	0.35	0.36	0.33	0.3	0.33	0.35	0.34	0.34	0.34	0.33
	Downstream	0.66	0.63	0.63	0.63	0.62	0.65	0.6	0.57	0.53	0.52	0.55	0.55	0.55	0.53	0.5	0.58
	All	0.37	0.37	0.37	0.37	0.37	0.38	0.38	0.38	0.35	0.33	0.35	0.36	0.36	0.36	0.34	0.36
Water resources utilization efficiency	Upstream	0.17	0.15	0.19	0.18	0.22	0.23	0.24	0.29	0.24	0.23	0.26	0.24	0.25	0.25	0.22	0.23
	Midstream	0.28	0.28	0.27	0.27	0.27	0.31	0.33	0.3	0.32	0.26	0.32	0.33	0.33	0.35	0.36	0.31
	Downstream	0.66	0.63	0.64	0.64	0.66	0.68	0.64	0.59	0.56	0.55	0.56	0.57	0.57	0.58	0.56	0.61
	All	0.37	0.35	0.37	0.36	0.38	0.41	0.4	0.39	0.37	0.34	0.38	0.38	0.39	0.39	0.38	0.38

3.2. Analysis of the spatial and temporal evolutionary dynamics of the coupling coordination degree of urban land and water resources utilization efficiency

3.2.1. Time series analysis of the coupling coordination degree of urban land and water resources utilization efficiency

Figure 4 illustrated the development trend of coupling coordination degree of urban land and water resources utilization efficiency.

Combined with the classification of coupling coordination level as shown in Table 1, the graph revealed the downstream region had the optimal coupling coordination level of urban land and water resources utilization efficiency from 2003 to 2017, and overall was in the primary coordination state, but the coupling coordination level was slowly decreasing. The possible reason is that the relative scarcity of land resources and water resources leads to a decrease in the coupling coordination degree of two resource utilization efficiency.

The coupling coordination level of urban land and water resources utilization efficiency in the midstream region was lower than that in the downstream region from 2003 to 2017, close to the average level of the whole Yangtze River Economic Belt, and was a steady improvement. Coupling coordination status reached a grudging coordination level except for 2017 and was at the borderline disorder level for a long time. The midstream region had abundant land resources and water resources, but the resources utilization lacked efficiency and had not fully converted the resource endowment into advantages for promoting sustainable urban development.

The coupling coordination level of urban land and water resources utilization efficiency in the upstream region slowly improved from 2003 to 2017, and the level of coordinating development lagged behind that of the midstream and downstream regions, which had been in a mild disorder level for a long time. On one hand, the industries in the upstream region were limited by the location conditions and the low industrial agglomeration level; on the other hand, the slow construction of infrastructure and the backward technical level restricted the coordinating development of urban land and water resources utilization efficiency.

3.2.2. Spatial evolution analysis of the coupling coordination degree of urban land and water resources utilization efficiency

To intuitively reflect the spatial distribution of the coupling coordination level of urban land and water resources utilization efficiency, this study used ArcGIS 10.5 software to plot the spatial evolution trend of the coupling coordination degree of land and water resources utilization efficiency in 2003, 2008, 2012, and 2017 in 11 provinces in the Yangtze River Economic Belt, as shown in Figure 5.

Where the coupling coordination level of urban land and water resources utilization efficiency was characterized by significant spatial divergence, and the inter-provincial differences in the coordination degree of land resources and water resources had been narrowing over time, but still showed a decreasing gradient distribution pattern from downstream to midstream to upstream region. The coordinated type region was mostly concentrated in the downstream region of Jiangsu, Zhejiang, and

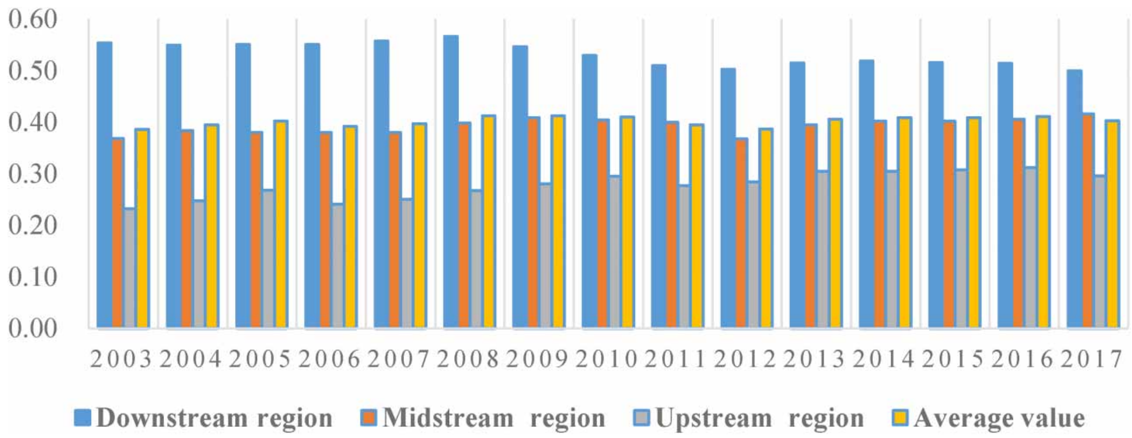

Figure 4 | Development trend of coupling coordination degree of urban land and water resources utilization efficiency from 2003 to 2017 in the Yangtze River Economic Belt.

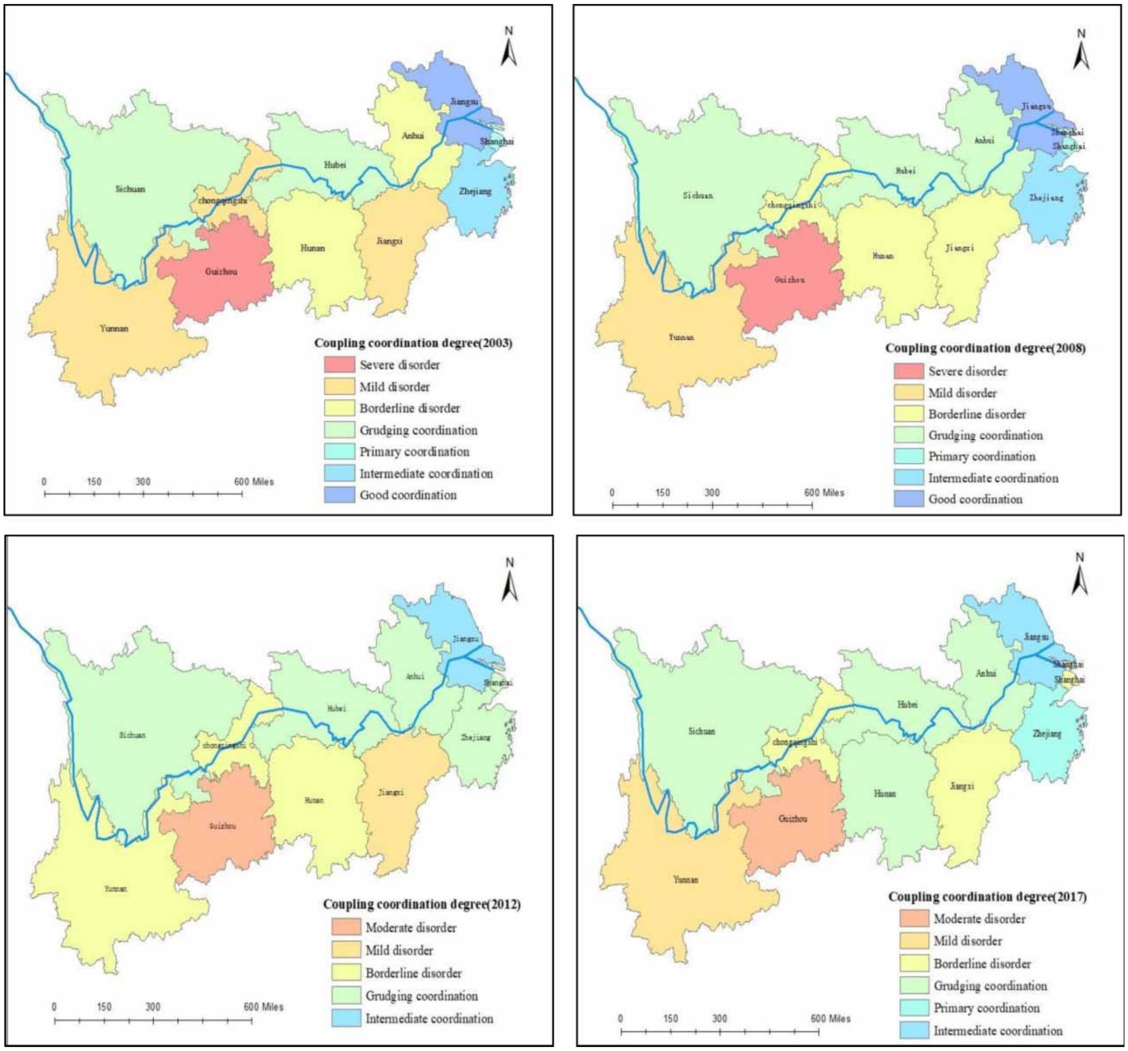

Figure 5 | Spatial pattern evolution of coupling coordination level of urban land and water resources utilization efficiency from 2003 to 2017 in the Yangtze River Economic Belt.

Shanghai, which had abundant resource advantages and vibrant economy. But the differentiation of the coupling coordination degree between provinces in the downstream region was obvious, and the coordination situation of urban land and water resources needs to be further optimized. The transitional type region was mainly located in the midstream region, where the coupling coordination degree of land and water resources utilization efficiency was developing slowly and the spatial pattern had not changed significantly. The dysfunctional type region was mainly the upstream region represented by Guizhou, Yunnan, and Chongqing. Compared with the utilization of resources in the midstream region and downstream region, the utilization efficiency of land resources and water resources was lower, which led to the slow growth of the coupling coordination degree of urban land resources and water resources utilization efficiency.

3.3. Spatial auto-correlation analysis of coupling coordination degree of urban land and water resources utilization efficiency

From the above-mentioned spatial distribution pattern of the coupling coordination degree level of urban land and water resources utilization efficiency, there was a certain spatial correlation between the coordination status of land resources and water resources. To further reveal the spatial interaction between them, this study used the Moran's index to analyze the spatial correlation of the coupling coordination degree of water resources and land resources and the spatial clustering effect.

3.3.1. Global spatial auto-correlation analysis of coupling coordination degree

Based on the measured coupling coordination degree, as shown in Table 4, the Global Moran's *I* was calculated by using Stata14.0 and Geoda software to analyze spatial correlation and spatial clustering characteristics. The Global Moran's *I* of coupling coordination degree of urban land and water resources utilization efficiency from 2003 to 2017 was positive and passed the significance test, indicating that the coupling coordination degree of urban land and water resources utilization efficiency in the Yangtze River Economic Belt was positively auto-correlation and showed a spatial clustering distribution in the overall. The inter-provincial differences in the coordination degree of land resources and water resources in the Yangtze River Economic Belt had been narrowing over time, so the spatial correlation was on a decreasing trend.

3.3.2. Local spatial auto-correlation analysis of coupling coordination degree

To further investigate the coupling coordination relationship of urban land and water resources utilization efficiency between neighboring provinces in the Yangtze River Economic Belt, this study selected the local spatial auto-correlation analysis to explore the spatial clustering effect between the coupling coordination degree of land and water resources utilization efficiency of a province with the surrounding provinces. This study used Stata14.0 software to draw Moran scatter plots for local spatial auto-correlation analysis in 2003, 2008, 2012, and 2017, and divided the plane region into four quadrants of H–H (high value–high value), H–L (high value–low value), L–H (low value–high value), and L–L (low value–low value), as shown in Figure 6.

From the diagram, the local Moran's indexes were positive in 2003, 2008, 2012, and 2017, indicating that there was a positive spatial correlation between the coupling coordination degree of urban land and water resources utilization efficiency of neighboring provinces in the Yangtze River Economic Belt. The more similar the coupling coordination degree was, the more likely it was to cluster in space. But Moran's index kept decreasing, showing that the spatial clustering trend kept weakening.

The H–H agglomeration region included provinces in the downstream region with the most spillover benefits, such as Shanghai, Zhejiang, and Jiangsu. Anhui had been in the region since 2008. This agglomeration region was the province with a higher coupling coordination degree of land and water resources utilization efficiency, and had a greater aggregation effect and radiation effect on the surrounding provinces through regional resource cooperation and technology exchange, thus forming an H–H region for the integration of the Yangtze River Delta. The H–L agglomeration region mainly included Hubei and Sichuan, where their coupling coordination degree developed better, forming an H–L region with neighboring low-coordinated provinces. Hunan had been in the region since 2017 but had not played a good role in the radiation

Table 4 | Global Moran's Index of the coupling coordination degree of urban land and water resource utilization efficiency from 2003 to 2017 in the Yangtze River Economic Belt

Year	Moran's *I*	*Z*-value	*P*-value
2003	0.296	2.179	0.015
2004	0.279	2.060	0.020
2005	0.314	2.244	0.012
2006	0.293	2.188	0.014
2007	0.305	2.369	0.009
2008	0.288	2.320	0.010
2009	0.237	2.154	0.016
2010	0.227	2.140	0.016
2011	0.174	1.737	0.041
2012	0.212	1.915	0.028
2013	0.183	1.663	0.048
2014	0.169	1.557	0.060
2015	0.180	1.648	0.050
2016	0.146	1.421	0.078
2017	0.118	1.261	0.104

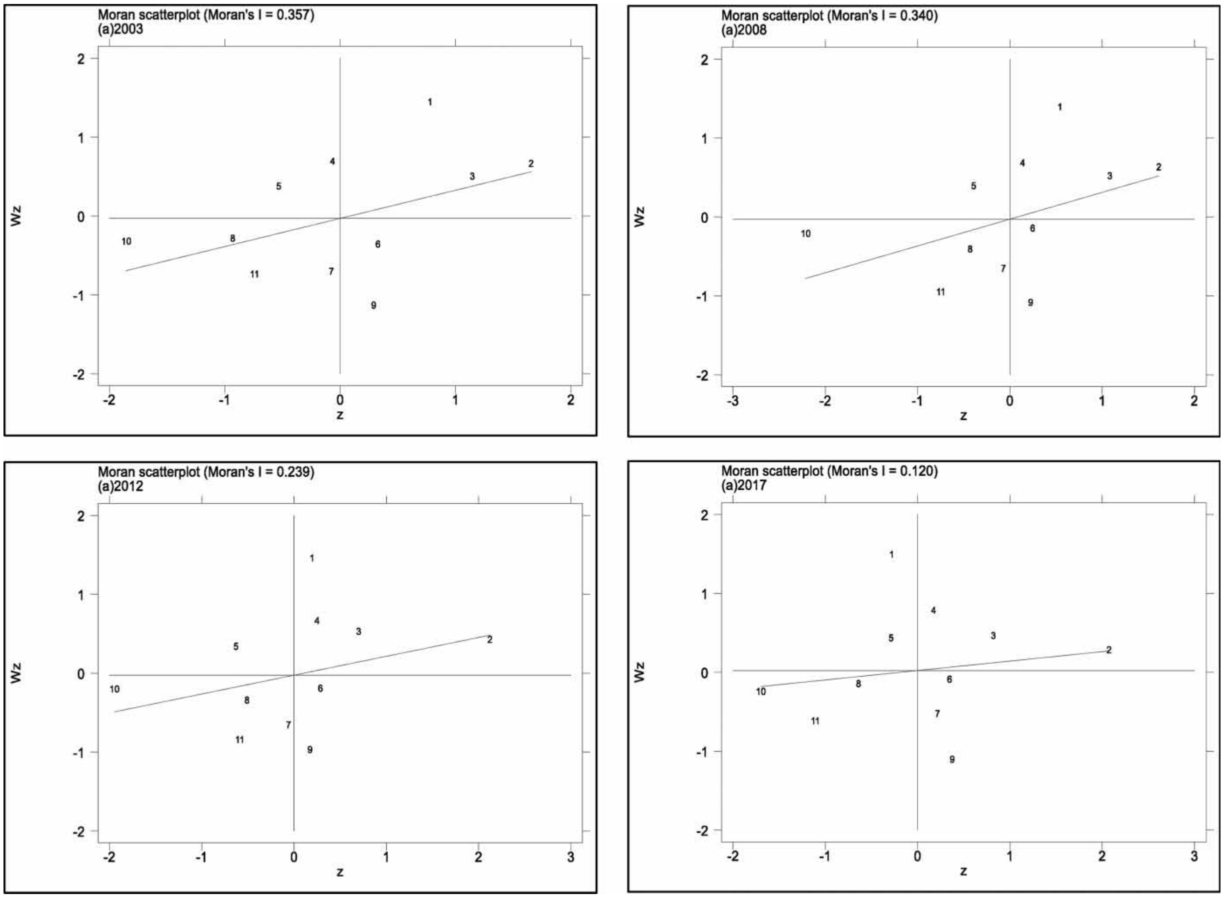

Figure 6 | Moran's index diagram of coupling coordination degree of urban land and water resources utilization efficiency from 2003 to 2017 in the Yangtze River Economic Belt. (1) Shanghai city, (2) Jiangsu province, (3) Zhejiang province, (4) Anhui province, (5) Jiangxi province, (6) Hubei province, (7) Hunan province, (8) Chongqing city, (9) Sichuan province, (10) Guizhou province, and (11) Yunnan province

drive of the high-value region. The L–H agglomeration region was in a geographically transitional region, and Jiangxi was located in this region. Shanghai had been in the region since 2017. High-coordinated provinces and geographically adjacent low-coordinated provinces formed an L–H region, but the low-value region failed to absorb the positive radiation effect from the high-value region well. The L–L agglomeration region included provinces with low coupling coordination degree of land and water resources utilization efficiency such as Guizhou, Chongqing, and Yunnan in the upstream region. These provinces had weak inter-provincial coordination radiation and spillover effects due to low matching of intensive land utilization and water resources development.

3.4. Analysis of the driving forces of the coupling coordination degree of urban land and water resources utilization efficiency

3.4.1. Dynamic driving factor analysis of the coupling coordination development of urban land and water resources utilization efficiency

The factors affecting urban land and water resource utilization efficiency were complex and diverse. The existing research (He & Wang 2021; Wang & Tian 2022) showed that economic development, industrial structure, government regulation, total population, employment, and social development would affect the allocation of factors, thus affecting the coupling coordinated utilization of urban land and water resources. Figure 7 presented six main dynamic factors, i.e. original force (economic development), supporting force (industrial structure), regulating force (government restriction), stimulating force (population density), potential force (employed labor force), and promoting force (social development), and described exploringly the dynamic mechanism of the coupling coordination development of urban land and water resources utilization efficiency.

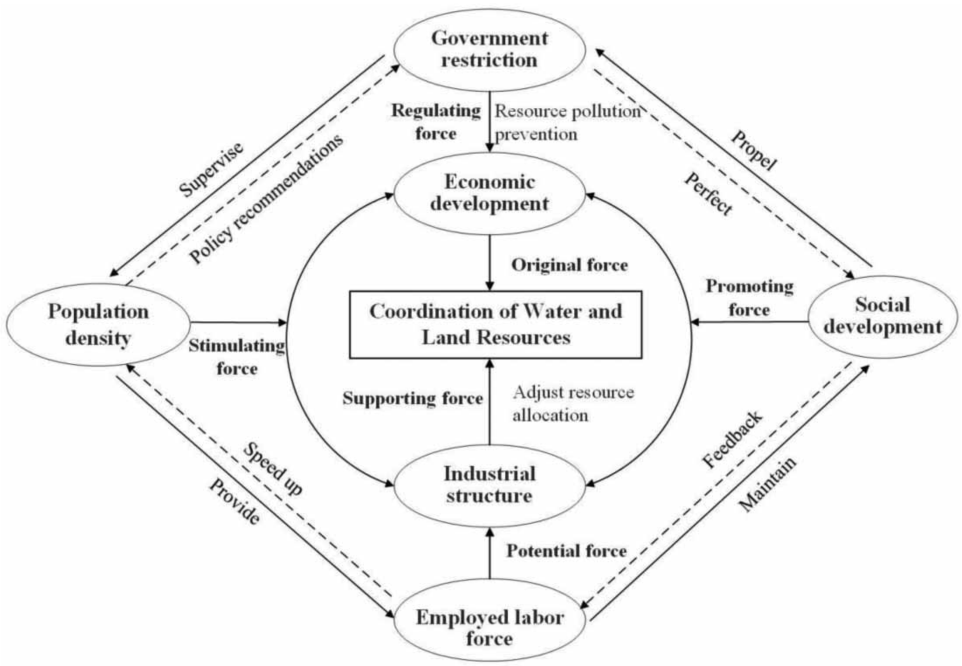

Figure 7 | Structure diagram of the driving forces system for the coupling coordination development of urban land and water resources utilization efficiency.

3.4.2. Variable selection and model construction

To further identify the coordinated development mechanism of urban land and water resources utilization efficiency in the Yangtze River Economic Belt, this study takes the coupling coordination degree of urban land and water utilization efficiency as the dependent variable and selected six factors, namely, economic development, industrial structure, government control, total population, employed labor force, and social development, as independent variables (Zhu & Ning 2021). The statistical description of each variable is shown in Table 5.

To solve the problems that the traditional panel regression model does not consider spatial heterogeneity and the fitting regression accuracy is low, a spatial econometric model is established based on the panel regression model. The conventional spatial econometric models include spatial lag model (SAR), spatial error model (SEM), and spatial Durbin model (SDM). Compared with the ordinary panel model, the SAR increases the spatial lag factor of dependent variables and the SEM increases the spatial lag factor of error terms. Compared with the SAR, the SDM increases the spatial lag term of independent variables, and takes into account the spatial spillover effect of independent variables and dependent variables, so as to avoid the bias of results caused by missing variables. Through inspection and comparison, it is found that the SDM model cannot degenerate into SAR and SEM models. Therefore, the SDM with general significance, relatively wide coverage, and the

Table 5 | Driving factors of the coupling coordination degree of urban land and water resources utilization efficiency from 2003 to 2017 in the Yangtze River Economic Belt

Independent variables	Symbols	Indicator descriptions	Unit
Economic development	*gdp*	Gross regional product/total population	Yuan/person
Industry structure	*is*	Secondary and tertiary gross domestic product/regional gross domestic product	%
Government control	*gov*	Government fiscal expenditure/*GDP*	%
Total population	*pop*	Total population/total area of the municipality	Person/km^2
Employed labor force	*ep*	Number of city employees	10,000 people
Social development	*fai*	Fixed assets investment amount	Billion

highest goodness of fit is selected, and the data are logarithmized to reduce heteroscedasticity. The spatial econometric model constructed in this paper is shown as follows:

$$\begin{aligned}\ln cod_{it} =& c + \rho \times W \ln cod_{it} + \beta_1 \ln gdp_{it} + \beta_2 \ln is_{it} + \beta_3 \ln gov_{it} + \beta_4 \ln pop_{it} + \beta_5 \ln ep_{it} + \beta_6 \ln fai_{it} \\ &+ \theta_1 \times W \ln gdp_{it} + \theta_2 \times W \ln is_{it} + \theta_3 \times W \ln gov_{it} + \theta_4 \times W \ln pop_{it} + \theta_5 \times W \ln ep_{it} + \theta_6 \times W \ln fai_{it} + \varepsilon_{it}\end{aligned} \tag{12}$$

where cod_{it}, gdp_{it}, is_{it}, gov_{it}, pop_{it}, ep_{it}, and fai_{it}, respectively, represent the coupling coordination degree of urban land and water resources utilization efficiency, economic development, industrial structure, government regulation, total population, employed labor force and social development, i and t denote city and year; W represents the spatial weight matrix, β_1–β_6 is the regression coefficient of explanatory variables, θ_1–θ_6 is the spatial lag coefficient of independent variables, ρ is the spatial regression coefficient, and ε_{it} represents the random disturbance term.

3.4.3. Empirical analysis of the drivers of coupling coordination degree

The influencing factors of coupling coordination degree of urban land and water resources utilization efficiency in the Yangtze River Economic Belt from 2003 to 2017 were analyzed by the spatial Dubin model under time-fixed effects, and the results of the correlational analysis are summarized in Table 6.

In the regression significance of each variable in Table 6, other variables passed the significance test at the 1% level except for the industrial structure, indicating that *GDP* per capita, government role, total population, employed labor force, and fixed asset investment all had a strong correlation with the coupling coordination degree of urban land and water resources utilization efficiency. But the role of industrial structure on the coupling coordination degree of urban land and water resources utilization efficiency was not significant, which might be related to the existence of a certain time lag in industrial structure adjustment.

Among the regression coefficients of each variable, the coefficients of *GDP* per capita, employed labor force, and fixed asset investment were 1.329, 1.077, and 0.558 in order, and the signs of the regression coefficients were positive, indicating that the above factors had positive effects on the coupling coordination degree of urban land and water resources utilization efficiency. Obviously, the factors of *GDP* per capita and employment labor played a stronger contribution, which showed that the level of economic development was conducive to improving the coupling coordination degree of land and water resources utilization efficiency, and reflected the importance of the government to expand employment.

In addition, the coefficients of industrial structure, governmental role, and total population factors were −0.463, −0.998, and −0.856, respectively, indicating they had a negative effect on the coupling coordination degree of urban land and water resources utilization efficiency. The possible reason was that the government's intervention in the land market affected the efficiency of land utilization to a certain extent, which was not conducive to the coupling coordination development of urban land and water resources utilization efficiency. Industrial restructuring had not yet played a role in promoting the coupling coordination development of urban land and water resources utilization efficiency due to the time lag.

Table 6 | Estimate results of SDM

Independent variables	Coefficient	Standard error	*Z*-value	*P* > *Z*
ln*gdp*	1.329	0.171	7.77	0
ln*is*	− 0.463	0.484	− 0.96	0.34
ln*gov*	− 0.998	0.254	− 3.93	0
ln*pop*	− 0.856	0.124	− 6.89	0
ln*ep*	1.077	0.147	7.34	0
ln*fai*	0.558	0.201	2.78	0.01

4. CONCLUSIONS AND POLICY RECOMMENDATIONS

4.1. Conclusions

The conclusions of this study are as follows: (1) In terms of time, the overall efficiency of urban land and water resources utilization from 2003 to 2017 in the Yangtze River Economic Belt was in an inefficient state, and the land resources utilization efficiency was lagging behind the water resources utilization efficiency. Spatially, the distribution of urban land and water resources utilization efficiency was consistent with the economic development pattern of Yangtze River Economic Belt. (2) The coupling coordination degree of urban land and water resources utilization efficiency in the Yangtze River Economic Belt as a whole was on the rise, but the spatial and temporal patterns differed significantly, with the most downstream region in the coordination type, and the midstream region and upstream region were in the transition type and dysfunctional type respectively, showing a spatial gradient decreasing distribution pattern from downstream to midstream to upstream region. (3) The coupling coordination degree of urban land and water resources utilization efficiency in the Yangtze River Economic Belt showed a significant spatial agglomeration effect, but the spatial agglomeration trend was weakening. The H–H agglomeration region was mainly distributed in the Yangtze River Delta with the most spillover benefits. The L–H agglomeration region was geographically transitional, indicating the positive radiation effect of the periphery on this region was not obvious. (4) The estimation results of the models showed that GDP per capita, employment labor, and fixed asset investment were the main driving factors of the coupling coordination degree of urban land and water resource utilization efficiency. But the government role and total population factor had a negative influence on it, and the driving role of the industrial structure had not yet been played.

4.2. Policy recommendations

Based on the above findings, this study proposes the following recommendations.

Innovating the institutional arrangement to enhance the urban land and water resources utilization efficiency. Provinces in the Yangtze River Economic Belt, based on the strict implementation of the current regulatory system related to the development and utilization of land resources and water resources, should innovate institutions conducive to the optimal allocation and efficient utilization of land resources and water resources, with the aim of using the institutions to force the improvement of land and water resources utilization efficiency. In particular, the government should establish and improve incentive and compensation policies conducive to the efficient utilization of land resources and water resources, and increase support for the midstream and upstream regions to narrow the gap with the downstream region.

Breaking through administrative barriers to strengthen regional cooperation in the efficient use of land and water resources. In the coordinated region and downstream region with H–H concentration, the provinces should aim to establish a more advanced industrial system, further exert the spatial spillover effect of land and water resources, and promote the efficient flow and optimal allocation of land and water resources among provinces. In the transitional region and L–L concentration of the midstream region, on the basis of taking over the industrial transfer of the downstream region, we should innovate the level of science and technology to drive the optimization of industrial structure, and replace the land elements with technology and capital, reducing the cost of water environment treatment for industrial development. In the upstream region of the dysfunctional type, it should take the initiative to absorb the experience and technology of neighboring provinces in land intensification and water resource utilization to strengthen the synergistic development and management of land resources and water resources.

Promoting economic growth to solidify the material basis for efficient utilization of land and water resources. The provinces in the Yangtze River Economic Belt should increase the scale of investment in fixed assets, actively expand employment, and accelerate the adjustment of industrial structures to enhance the role of driving factors.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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