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Drag Effect of Water Consumption on Urbanization—A Case Study of the Yangtze River Economic Belt from 2000 to 2015

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Abstract: Urbanization is an engine of economic development, but this process is often constrained by increasingly scarce water resources. A model predicting the drag effect of water consumption on urbanization would be useful for future planning for sustainable water resource utilization and economic growth. Using panel data from 11 provinces in China's Yangtze River economic belt (YREB) from 2000 to 2015, we apply Romer's growth drag theory with spatial econometric models to quantitatively analyze the drag effect of water consumption on urbanization. The results show the following. (1) The drag effect of water consumption on urbanization has significant spatial correlation; the spatial Durbin model is the best model to calculate this spatial connection. (2) The spatial coefficient is 0.39 and the drag that is caused by water consumption on urbanization in the YREB is 0.574, which means that when spatial influences are considered, urbanization speed slows by 0.574% due to water consumption constraints. (3) Each region in the YREB has different water consumption patterns and structure; we further calculate each region's water consumption drag on urbanization. We find that areas with high urbanization levels, like Shanghai (average 84.7%), have a lower water consumption drag effect (0.227), and they can avoid the "resource curse" of water resource constraints. However, some low-level urbanization provinces, like Anhui (average 39.3%), have a higher water consumption drag effect (1.352). (4) Our results indicate that the water drag effect is even greater than the drag effect of coal and land. Therefore, policies to increase urbanization should carefully consider the way that water constraints may limit growth. Likewise, our spatial model indicates that policy makers should work with neighboring provinces and construct an effective regional water cooperation mechanism.

Keywords: water consumption; urbanization; spatial spillover effective; drag

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1. Introduction

As an engine of economic growth, urbanization is the predominant pattern of socio-economic development throughout the world. In 2016, 54.5% or more of the 3.95 billion of the world's population lived in cities, and by 2050 70% of the world's population is expected to live in cities [1]. Thus, urbanization is one of the most significant global trends in the 21st century [2–4]. Typically, once countries have an urbanization rate of 30%, the rate of urbanization accelerates, until reaching around

70%, which is considered to be urbanized [5]. However, most developing countries, such as China and India, which occupy more than one-third of the world's population, are only now at the stage of rapid urbanization [6]. Rapid urbanization has brought vast profits for key stakeholders in these areas. However, a number of problems are associated with rapid urbanization, including resource scarcity [7,8]. The global water crisis is another of these anticipated problems [9].

Water is recognized as a most critical resource in the world [10]. In recent years, due to the rising population and the increasing water demand for all sectors' needs, the demand for water has been increasing at an alarming rate [11,12]. Today, four billion people (two-thirds of the global population) face severe water scarcity at least one month a year and half a billion people in the world face severe water scarcity all year round [13]. Many them are centralized in developing countries, like China, India, and Africa. These countries are facing rapid urbanization and are trying hard to develop their economies. At the same time, limited water and the increasing fresh water scarcity has a huge impact on socio-economic and environment conservation, presenting a serious challenge for the urbanization process [14–17].

There is a complicated relationship between water consumption and urbanization [18]. Some researchers believe that with rapid urbanization, the urban water shortage is aggravated [19–21]. While another opinion is that urbanization could improve water use efficiency through agglomeration effects, and thereby have a positive impact on water consumption [22]. Others have studied what influences water consumption efficiency during urbanization and developed a framework for sustainable urban water resource management [16,19,23]. However, these studies are mainly about urbanization's influence on water, water pressure, or water sustainability for urbanization. There is limited research on the water consumption constraint on urbanization.

With increasingly severe water limitations, water scarcity is a prominent trend. Against this backdrop, quantifying the constraints of water resources on urbanization could help to better coordinate water use and urbanization. Many studies have concentrated on the resource constraint effect on optimal economic growth. Nordhaus [24] first called the resource constraint on economic growth a "growth drag". Following this concept, Bruvoll [25] measured environmental drag in Norway using the Computable General Equilibrium (CGE) model. Noel [26] calculated energy's influence on American economic growth. These studies introduce resource and environmental elements into an endogenous growth model and reveal that technological advances could overcome the constraints of resources. Once Romer [27] proposed a growth drag theory, researchers began to use it in the study of water and land [28] and coal consumption [29]. Following this idea, we study the drag effect of water consumption on urbanization.

As a natural flowing resource, regions sharing water will inevitably have spatial connections in the process of water resource utilization [30]. Now, increasingly, researchers realize this situation and propose integrated water resource management [31,32]. With the proposal of virtual water [33], inter-regional water resource deployment [34], and water rights [35], the influence is not only upstream to downstream, but also the fact that downstream could change the upstream water consumption. It is important to demonstrate and quantify spatial spillover effects because these can act as counter-balance measures for the uneven distribution of water resources [36]. However, studies using thresholds of section data [17] or multi-objectives and multi-hierarchy methods [37] ignore the spatial spillover effect.

To fill this research gap, we quantify the constraints of water resources on urbanization while considering the spatial spillover effects. Our research leads to useful suggestions that can help policy makers to relieve regional water supply and demand pressures and promote the sustainable development of water resources and the urbanization process.

2. Materials and Methods

2.1. Study Area

The Yangtze River economic belt (YREB) includes nine provinces and two municipalities (Chongqing and Shanghai) and has a surface area of two million square kilometers (21.27% of the total China area). As it comprises over 40% of China's GDP, population, and urban citizens [38], it has been officially marked as one of China's key strategic development regions since 2014. Furthermore, as part of the One Belt and One Road initiative, which is one of the most important international cooperative endeavors, the YREB connects "the Silk Road Economic Belt" from the west and the "21st Century Maritime Silk Road" from the east [39].

There are three reasons for choosing this study area. First, as one of the fastest growing urban agglomerations in the world, the YREB's urbanization process is accelerating. In 2015, the urbanization level of the YREB was 55.5% [5]. As a primary pioneering region in China's urbanization, a study of the comprehensive condition of the YREB will not only help China achieve urbanization success, but it will also offer some useful suggestions for the urbanization process. Second, the YREB's development cannot be sustained without water resources from the Yangtze River. The water consumption in this area has increased from 2224.1 (10^8 cubic meter) in 2000 to 2622.7 (10^8 cubic meter) in 2015, a net increase of 398.6 (10^8 cubic meter), almost 10 times the annual water consumption of Beijing. While at the same time, YREB water consumption per capital in 2000 was 400.69 (m^3/(person·year)) and changed to 446.28 (m^3/(person·year)) in 2015, showing an increased trend. Together with the fast rate of industrialization and urbanization in the YREB, water consumption is expected to continue to increase. As the water resources are limited, this will become a huge obstacle to the urbanization of the YREB. This situation makes this area an ideal case to study the drag effect of water constraints on urbanization. Third, as shown in Figure 1, the YREB connects the southwest border to the seacoast along the Yangtze River and it promotes the coordination and interaction among east, central, and west China. Thus, the water consumption in each region will influence the other regions.

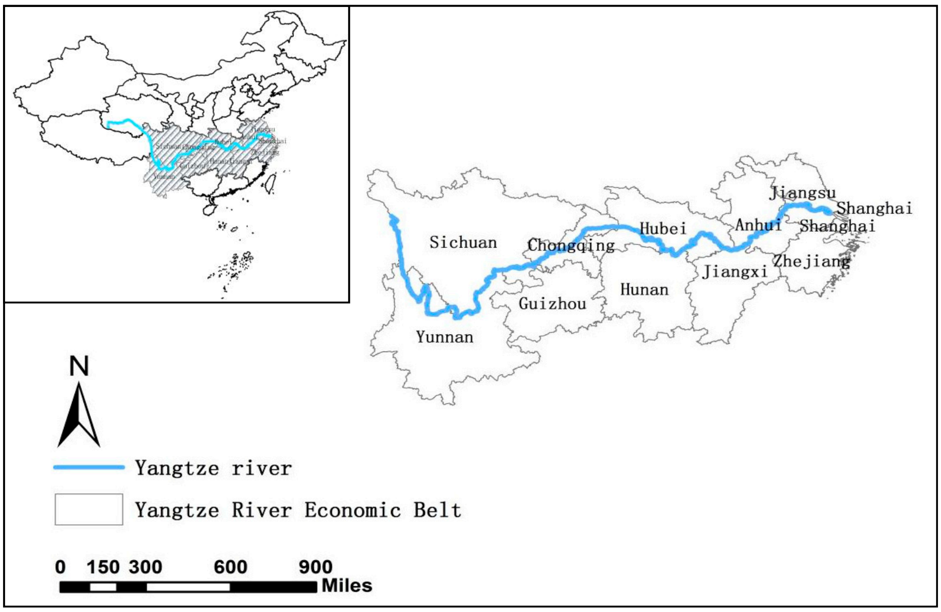
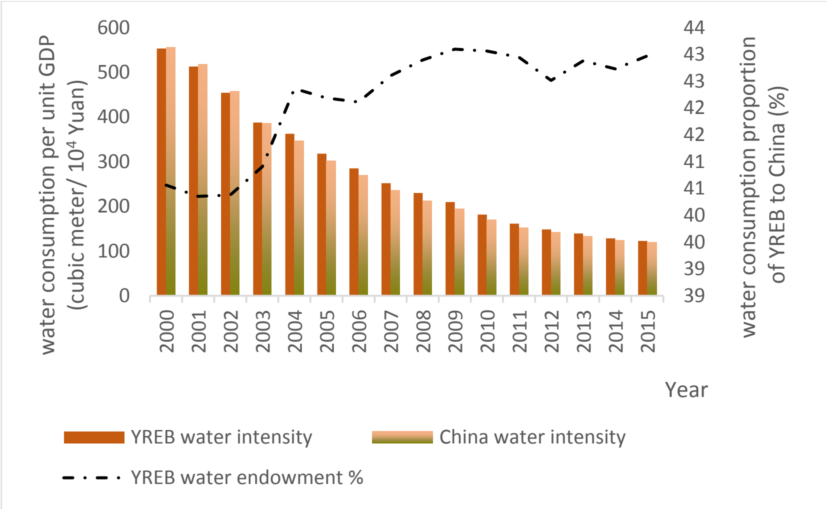
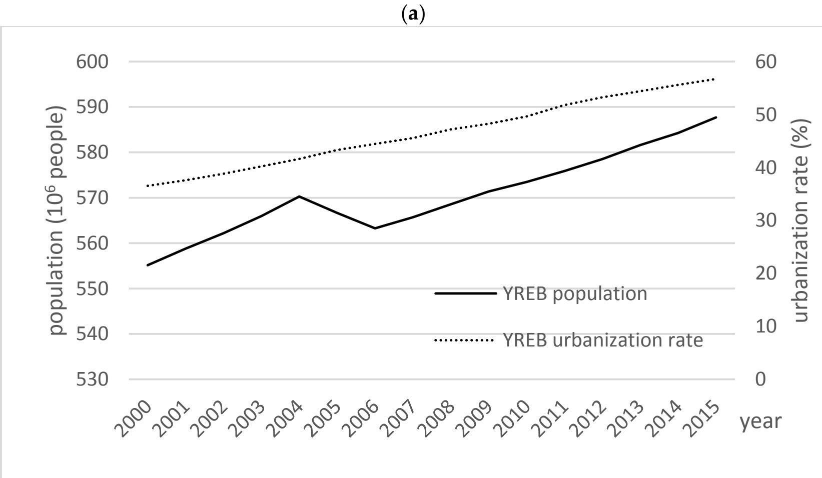


Figure 1. Yangtze River Economic Belt (YREB).

To better understand the situation of YREB, the water consumption and urbanization feature in YREB are shown in Figure 2a,b.



(**a**)



(**b**)

Figure 2. (**a**) The YREB water consumption characteristics from 2000–2015 (water intensity means water consumption per unit GDP, water endowment is the water consumption proportion of YREB to China). (**b**) The YREB demographic characteristics from 2000–2015.

From Figure 2a, we can see that the YREB has superiority in water endowment (water consumption proportion of the YREB to China); its perennial total water consumption proportion is more than 40% of all of China's water consumption, while its water intensity (water consumption per 10 thousand GDP) is bigger than China's average water intensity. This indicates that the YREB has inefficient water utilization. In Figure 2b, with the rapid growth of the total population in the YREB, the level of urbanization continues to increase and a large number of people have poured into cities in the YREB in a short amount of time producing more water pollution emissions. In our proposed model, we will deeply analyse the drag effect of water consumption in this water rich place on urbanization and give some useful suggestions for policy makers to have a more sustainable urbanization.

2.2. Data Source

The sample size of 16 years in the Yangtze River economic belt and its 11 provincial administrative regions was chosen as the research object. The data include the following: water consumption ($\times 10^8$ cubic meter), economic growth as indicated by GDP ($\times 10^4$ yuan), labor ($\times 10^4$ people) and capital stock ($\times 10^8$ yuan), urbanization level (%), and total population ($\times 10^4$ people). Specifically, capital stock is calculated using the method of Shan [40] as follows: $K_t = (1 - \delta)K_{t-1} + I_t$, where K_t is the t th year of capital stock ($\times 10^8$ yuan), I_t is investment in fixed assets normalized to base year 2000 prices to eliminate the impact of inflation, and δ is the rate of depreciation. The urbanization rate (%) is defined as the proportion of the urban population out of the total population.

In order to avoid the problem of non-linear modeling and heteroscedasticity, economic growth (GDP), water consumption (W), and labor (L) are converted to the natural log form as LNY (Y means GDP), LNW, and LNL, respectively.

The GDP and water consumption data are obtained from the China Statistic Yearbook and the China Water Resources Bulletin (2000–2015) [41]; urbanization level and labor data are directly or indirectly obtained from the China Statistic Yearbook (2000–2015) [42]. For all economic data, according to the growth rates when compared to the prior year, we converted these to the constant price in 2000.

2.3. Methods

Our methods are as follows. First, we apply Romer's [27] growth drag theory and establish the constraint model of water consumption on economic growth. Second, using spatial econometric methods [16,43], we evaluate the connection between regions. Third, according to the correlation between urbanization and economic growth, we calculate the drag effect of water on urbanization. Fourth, we compare the drag effect of water consumption on the urbanization across different areas.

2.3.1. Basic model for the relationship between economic output and water consumption

Water consumption is introduced into the Cobb-Douglas production function [44] and the expanded economic growth model can be expressed, as follows:

$$Y(t) = K(t)^{\alpha} W(t)^{\beta} [A(t)L(t)]^{\gamma} \tag{1}$$

where Y represents economic output, K is capital stock, denotes water consumption, A is "technological advances" or "labor effectiveness", L is labor, and $A(t)L(t)$ represents working labor. $\alpha > 0$, $\beta > 0$, and $\gamma > 0$ denote the corresponding elastic constants for K, W, A, and L.

The logarithmic transformation of Equation (1) to construct the general panel data model is as follows.

$$\ln Y_{it} = \alpha \ln K_{it} + \beta \ln W_{it} + \gamma [\ln A_{it} + \ln L_{it}] + c_i + a_t + e_{it} \tag{2}$$

where, c_i and a_t are the intercept terms in region i and period t, respectively, and e_{it} is the error term, $e_{it} \sim N(u, \sigma^2)$.

2.3.2. Spatial Autocorrelation Analysis Model and Test Procedure

When considering the spatial spillover effect, spatial autocorrelation analysis can help to describe whether the variables have spatial dependence and spatial heterogeneity. The spatial models include a spatial lag model (SLM), a spatial error model (SEM), and a spatial Durbin model (SDM) [45,46]. The three kinds of models [47,48] are expressed in Equations (3)–(5).

$$\ln Y_{it} = \delta \sum_{j=1}^{n} w_{ij} \ln Y_{it} + \alpha \ln K_{it} + \beta \ln W_{it} + \gamma [\ln A_{it} + \ln L_{it}] + c_i + a_t + e_{it} \tag{3}$$

The spatial lag model in Equation (3) mainly reflects the interaction effect of the explained variable in neighboring units on the explained variable in a specific unit.

$$\ln Y_{it} = \alpha \ln K_{it} + \beta \ln W_{it} + \gamma [\ln A_{it} + \ln L_{it}] + c_i + a_t + u_{it}, u_{it} = \rho \sum_{j=1}^{n} w_{ij} u_{it} + e_{it} \tag{4}$$

The spatial error model in Equation (4) indicates the interaction effect of the explanatory variables in the neighboring units on the explained variable in a specific unit.

$$\begin{aligned}\ln Y_{it} &= \delta \sum_{j=1}^{n} w_{ij} \ln Y_{it} + \alpha \ln K_{it} + \beta \ln W_{it} + \gamma[\ln A_{it} + \ln L_{it}] + \theta w_{ij} \ln K_{it} \\ &\quad + \theta w_{ij} \ln W_{it} + \theta w_{ij}[\ln A_{it} + \ln L_{it}] + c_i + a_t + e_{it}\end{aligned} \tag{5}$$

The spatial Durbin model in Equation (5) contains both the explained variable and the explanatory variables' effect.

In the equation, δ is the spatial regression coefficient, ρ is the spatial error coefficient, u_{it} is the spatial autocorrelation error term, σ is the spatial lag term coefficient of the explanatory variable, and w_{ij} is the spatial weights matrix. In the spatial (or time) random effects model, c_i, a_t and e_{it} are independent.

w_{ij} is the spatial weights matrix of region i and region j in period t.

$$w_{ij} = \begin{cases} 1, & if\ i\ th\ j\ th\ spatial\ units\ are\ neighboring \\ 0, & if\ i\ th\ j\ th\ spatial\ units\ are\ not\ neighboring \end{cases} \tag{6}$$

To choose the best estimate model from the above three, as Elhorst [49] did, we summarize their model test procedure, as shown in Figure 3.

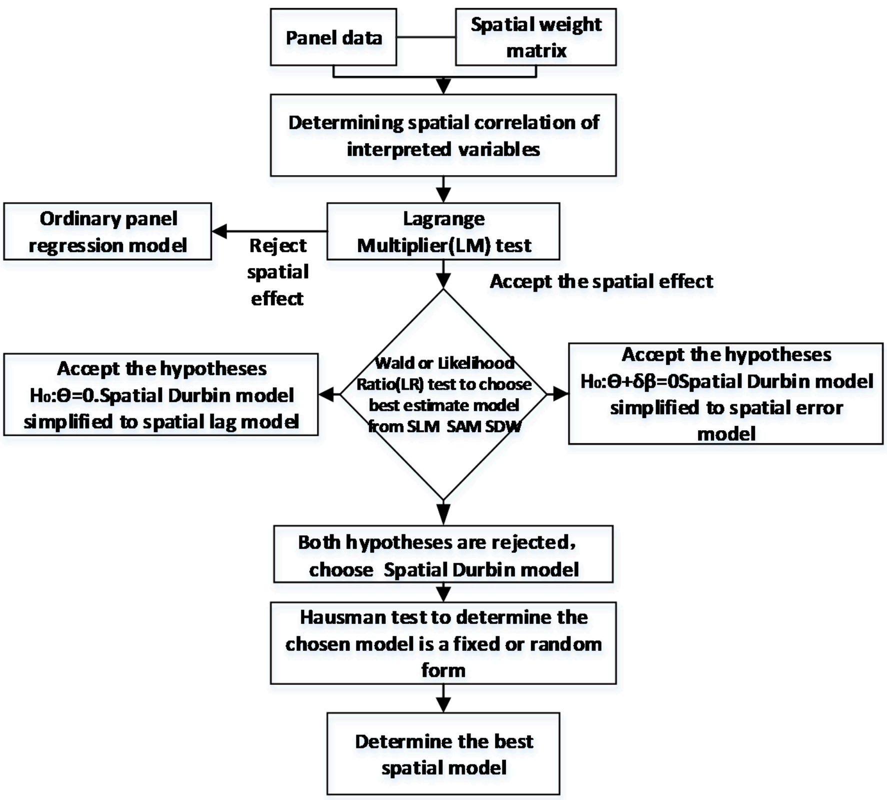


Figure 3. The process of spatial model determination.

2.3.3. Drag Effect of Water Consumption on Urbanization in Connected Regions

To calculate water consumption's drag effect on economic growth, following Xu and Zhou [29], we use Romer's [27] expanded classical Solow model to emphasize the correlation between urbanization and water consumption. According to this method, to calculate the drag effect of water on economic growth, we first look at the optimal growth path to deduce the water constraint. Since the water resources of our study region are nearly constant at least in the short term [50], water resource reserves have been dramatically decreasing under constant exploitation and consumption. When in a water resource constrained situation, $\dot{W}(t) = -mW(t)$, where $m > 0$ is the rate of water consumption. When there is no water restriction, $\dot{W}(t) = nW(t)$, where the water consumption growth rate is synchronous with the labor growth rate n. The drag effect of water consumption on economic growth will be as follows (the detail proof can be found in Appendix A).

$$Drag_W^Y = g_{Y/L}^{\widetilde{bgp}} - g_{Y/L}^{bgp} = \frac{\beta(n+m)}{1-\alpha} \tag{7}$$

In order to find the drag effect of water on urbanization, we establish a quantitative relationship between urbanization and economic growth. Many scholars agree that their relationship can be expressed as follows in a logarithmic curve [46,47,51,52].

$$U = a + b\ln y + \varepsilon(a > 0, b < 0\ ) \tag{8}$$

where U represents the urbanization level, y is the per capital economic output, and ε denotes the random error.

By simplifying the transformation (the process can be found in Appendix B), we get the following.

$$\frac{dU}{dt} = \frac{1}{\pi}\frac{dy}{dt} \tag{9}$$

Here, $\frac{dU}{dt}$ represents the urbanization growth rate, $\frac{dy}{dt}$ is the per capital output growth rate, and π denotes urbanization's elastic constant for per capital output. According to Equation (7) and (9), the drag effect of water consumption on urbanization can be calculated by Equation (10).

$$Drag_W^U = \frac{\beta(n+m\ )}{1-\alpha} \times \frac{1}{\pi} \tag{10}$$

We see that the drag effect of water consumption on urbanization is determined by the depletion rate of water consumption, labor growth rate, capital stock, and water consumption's elasticity coefficient, and urbanization's elastic constant for per capital output.

2.3.4. Each Region's Drag Effect

Each region has different water use patterns and structures in the urbanization process. We further measure the drag effect of water consumption on urbanization in each region. To reduce the adverse effects of multicollinearity that may exist between variables, we use the ridge regression estimation method, as Hoerl et.al. [53] did. With ridge regression estimation, we estimate each region's capital stock and water consumption elasticity coefficient and then calculate the drag effect.

3. Results

3.1. Basic Model Result for the Relationship of Economic Growth and Water Consumption

We use the unit root test (the result can be found in Appendix C Table A1) to check the stationarity of the panel data series. The result shows that all the indicators are stationary after being expressed in natural logs. Then, for the variables of economic growth (LnY) and water consumption (LnW), the Granger causality test result (Appendix C Table A2) showing that in our model water consumption is the Granger cause of economic growth. Moreover, the cointegration test (see in Appendix C Table A3) shows that these variables have cointegration. Through a model type contrast, we use the random effects form in the general panel data regression model. The results are shown in Table 1.

Table 1. Results of general panel data regression model in the YREB.

Variables	Regression Coefficient	*t*
lnK	0.809	68.45 ***
lnW	0.25	4.06 ***
lnL	−0.125	−1.67 **

Note: ***, ** denote level of significance at 1%, 5%, and 10%, respectively.

3.2. *Spatial Model Result for Relationship of Economic Growth and Water Consumption*

Per the process in Figure 1, the LM test (the results are presented in Appendix C Table A4) shows that there is a spatial effect. With the Wald test (also called LR test and results shown in Appendix C Table A5), we find that it cannot be simplified to a spatial lag or a spatial error model. Therefore, the Spatial Dubin model with spatial and time fixed effects best describes the data. Using this estimator, we calculate the regression coefficients in a spatial model. The results are shown in Table 2.

Table 2. Results of spatial Dubin model with spatial and time fixed effects.

Variables	Regression Coefficient		Lag term Coefficient			
	Coefficient	***t***	**Coefficient**	***t***	**R^2**	**0.995**
LnK	0.272	9.89 ***	0.225	4.1 ***	Log-likelihood	299.078
LnW	0.112	2.75 ***	0.443	5.75 ***		
LnL	−0.44	8.37 ***	0.397	4.87 ***		
Spatial regression coefficient δ			0.343	4.72 ***		
Decomposition	**Direct Effects**		**Indirect Effect**		**Total Effect**	
Variables	**Coefficient**	***t***	**Coefficient**	***t***	**Coefficient**	***t***
LnK	0.312	12.74 ***	0.4436	15.49 ***	0.756	44.28 ***
LnW	0.07	4.17 ***	0.177	6.35 ***	0.247	6.6 ***
LnL	−0.405	8.01 ***	0.351	3.13 ***	−0.054	−0.4

Note: *** denote level of significance at 1%, 5%, and 10%, respectively.

The spatial regression coefficient δ is positive and statistically significant. It indicates that economic output that is produced by water consumption has positive spatial spillover effects in the YREB. If water consumption in neighboring provinces increases 1%, economic output of the local province increases 0.34%. From the direct and indirect effect coefficients, water consumption the indirect effect (0.177) is larger than in terms of the direct effect (0.07), and water consumption in each region influences other provinces' economic output. Using the total effect coefficients of LnK (0.756) and LnW (0.247), we can calculate the drag effect of water consumption on urbanization and compare this drag effect with the general panel data model result.

3.3. *Drag Effect Result for Water Consumption on Urbanization in the YREB*

On average for the YREB, water consumption has a drag effect on urbanization, as shown in Table 3. The drag is 0.574, which means that water consumption constraints will slow the urbanization level rate by 0.574% each year. This is nearly a quarter of the average speed of urbanization in the YREB. The general panel model's drag is 0.743, thus, bigger than when considering the spatial effect. This means that missing spatial variables will overestimate water consumption's restriction on urbanization. Furthermore, in Table 3, m is the annual average water consumption growth rate and we can see that the YREB's development is significantly dependent on water consumption. The YREB water consumption has a large drag effect on urbanization.

Table 3. The YREB'S drag effect of water consumption on urbanization.

Methods	Capital Production Elasticity Coefficient α	Water Consumption Production Elasticity Coefficient β	Reciprocal of π (1/π)	Labor Growth Rate n (%)	Water Consumption Growth Rate m (%)	Drag Value of Water Consumption to Urbanization
Considering the spatial effect	0.756 ***	0.247 ***	0.288	0.94	1.03	0.574
General panel data	0.809 ***	0.25 ***	0.288	0.94	1.03	0.743

Note: *** denotes level of significance at 1%, π denotes urbanization's elastic constant for per capital output.

3.4. Comparing the Water Consumption Drag Effect on Urbanization in Each Region

In order to compare each region's water consumption and the drag effect, we use the ridge regression to recalculate α and β in each region, which allows for us to calculate the output elasticity of LnK and LnW, respectively. Using Equation (10), we calculate each region's water consumption drag effect on urbanization. The results are shown in Table 4.

Table 4. Each region's drag effect of water consumption on urbanization.

Regions	Capital Production Elasticity Coefficient α	Water Consumption Production Elasticity Coefficient β	Reciprocal of π (1/π)	Labor Growth Rate n (%)	Water Consumption Growth Rate m (%)	Drag value of Water Consumption to Urbanization
shanghai	0.312 ***	0.3 ***	0.167	3.16	−0.047	0.227
Jiangsu	0.36 ***	0.28 ***	0.273	0.47	1.69	0.258
Zhejiang	0.35 ***	0.25 ***	0.2	1.99	−0.49	0.115
Anhui	0.3 ***	0.64 ***	0.34	1.45	2.9	1.352
Jiangxi	0.32 ***	0.78 ***	0.356	1.5	0.7	0.898
Hubei	0.304 ***	0.307 ***	0.192	0.49	1.07	0.132
Hunan	0.31 ***	0.28 ***	0.305	0.67	0.17	0.104
Chongqing	0.31 ***	0.28 ***	0.291	0.17	2.74	0.344
Sichuan	0.31 ***	0.28 ***	0.297	0.25	1.33	0.190
Guizhou	0.31 ***	0.29 ***	0.269	0.27	0.49	0.086
Yunnan	0.31 ***	0.3 ***	0.428	1.56	0.25	0.337

Note: *** denotes level of significance at 1%.

From Table 4, the biggest drag effect is in the Anhui province and the smallest is in Guizhou. In order to compare the water consumption drag effect on urbanization, each region's urbanization and water consumption in the YREB are shown in Figures 4 and 5. Using the urbanization value of 0.328, 0.459, and 0.577 as demarcation points, the 11 regions are divided into four urbanization level and the results are shown in Figure 4. Although Figure 4 shows that the urbanization levels are high in Shanghai and Zhejiang, Figure 5 shows that their drags are relatively low. According to the different drag in each region, while using the drug value of 0.15 and 0.26 as the demarcation points, respectively, the 11 regions are divided into low, moderate, and significant constraints. These classifications are shown in Figure 5. We can see that Hubei, Hunan, Guizhou, and Zhejiang belong in the low constraint group, Shanghai, Jiangsu, and Sichuan are in the moderate constraint group, while Anhui, Jiangxi, Chongqing, and Yunnan are in the significant constraint group.

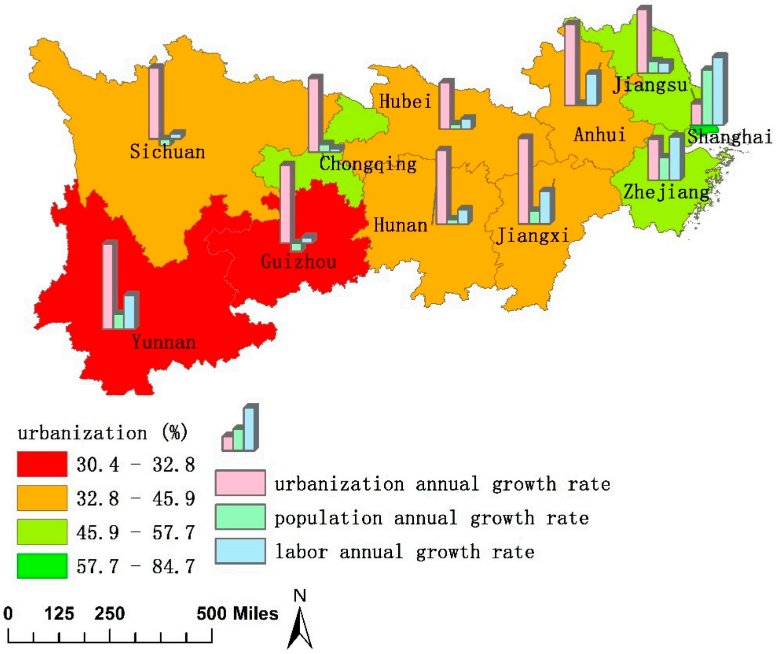


Figure 4. YREB each region's demographic characteristics and urbanization level.

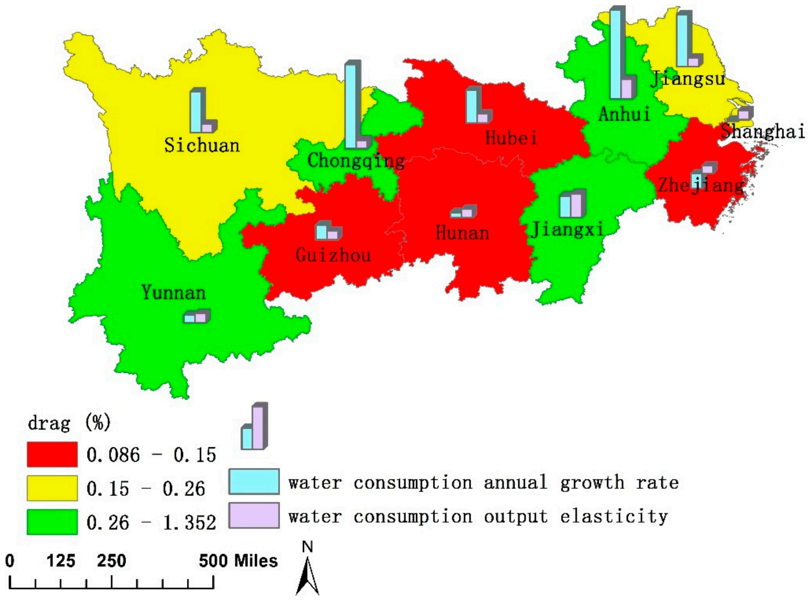


Figure 5. YREB each region's water characteristics and drag.

When comparing each region's urbanization rate (%, in Figure 4) and drag effect (Figure 5) in YREB, we find that Jiangsu, Zhejiang, and Chongqing are at the same urbanization rate but have totally different drag effect levels (in Figure 5 Zhejiang, Jiangsu, and Chongqing are in the low, moderate, and significant constraint grouping, respectively). Shanghai, with the highest urbanization level, far exceeds the other regions in the YREB, while its drag is not that high. Anhui and Jiangxi's water consumption also causes a big drag effect with relatively low levels of urbanization. Although Hubei, Hunan, and Guizhou do not have high urbanization levels or that big a drag.

In terms of the factors that influence the water consumption drag effect on urbanization, the capital production elasticity coefficient almost had no difference in each region of YREB (Table 4). While the population and labor annual growth showed large difference. As shown in Figure 4, the central and eastern regions were much higher than western regions. Most regions' water consumption output elasticity in YREB were similar, except Anhui and Jiangxi (Table 4 and Figure 5). For water consumption annual growth rate, Anhui, Chongqing, and Jiangsu had a relative high growth rate when compared to other regions (Figure 5).

Since we choose Jiangsu, Zhejiang, and Chongqing as the typical example, the urbanization and water characteristics are shown in Figure 6. Among these three regions, Jiangsu and Chongqing's urbanization rate increases faster than Zhejiang. Water consumption per unit GDP in Jiangsu was decreasing fastest, but when compared with Zhejiang and Chongqing, it still had the highest level. Zhejiang has the lowest water consumption per unit GDP value.

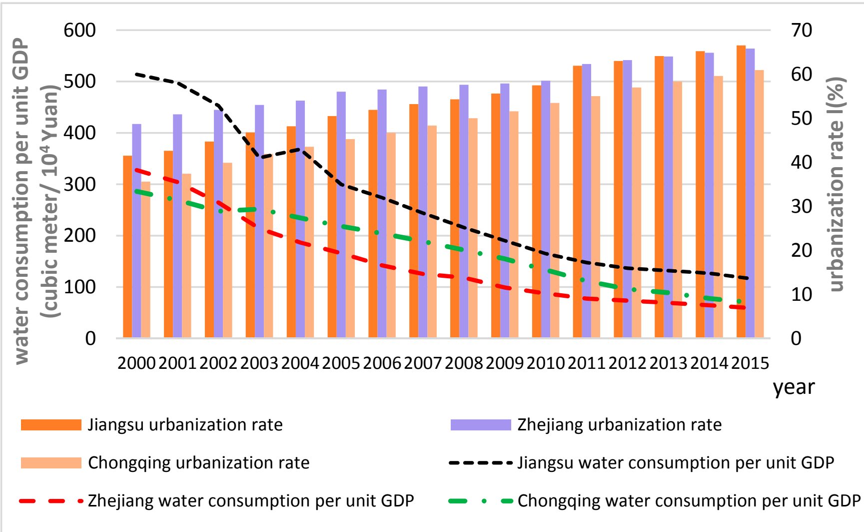


Figure 6. Jiangsu-Zhejiang-Chongqing urbanization and water characteristics.

4. Discussion

Urbanization is a global trend that will continue to place demands on water resources. While much research has looked at how water resources are stretched thin due to urbanization, there is little research on how water constraints might slow the urbanization process. Here, while using spatial econometric techniques, we estimated the water drag effect on urbanization to show how constrained water resources may slow urban development in China. Using the panel data, we found that capital stock and water consumption regression coefficients of the general panel model, which are used to calculate drag, are all statistically significant. Therefore, we conclude that water consumption in the YREB does have an impact on economic growth. This is the basis for our further research on water consumption drag effect on urbanization.

When we consider the spatial spillover effect, the spatial regression coefficient also passes the significance test, indicating that we should not ignore water consumption's impact on economic output. Per our calculation, ignoring the spatial spillover effect will overestimate water consumption's restriction. Since 2005, the provinces along the YREB have emphasized strengthening cooperation and the "YREB Cooperation Agreement" has eased conflicts surrounding shipping and economic division. There is also a reform called "Customs Clearance" in the YREB, which has further strengthened inter-regional trade development since 2014. Recently, the One Belt-One Road initiative and the "Outline YREB Development Plan" that rely on the Yangtze River continue to improve regional transportation efficiency and could overcome administrative limitations and trade barriers, enhance inter-regional trade capacity significantly, and guide the reasonable flow of the population and economic factors among the YREB regions. Moreover, these programs can help achieve coordinated development among regions, enhance resource carrying capacity, and alleviate the adverse effects of water consumption shortages. However, even with coordinated regional development, the water consumption drag effect in the YREB my still hinder urbanization. In the future, regional cooperation on water consumption and economic output should be further strengthened in order to reduce water consumption's drag effect on the process of urbanization.

The drag effect of water consumption on urbanization in the YREB using the general panel regression and the spatial Dubin model regression are, respectively, 0.743% and 0.574%. This is larger than water resource constraint intensity on urbanization in the arid area of northwest China at 0.525% [17]. When compared with Liu and Yaobin [27] and Xu and Jing's [28] calculation of water, arable land, and coal consumption's drag effect on China's urbanization, water consumption's drag effect on urbanization in the YREB is larger than the water and arable land drag effect on China's urbanization, and even equal to coal consumption's drag effect. Due to constraints on water consumption, the speed of urbanization in YREB has significantly slowed. Compared to other resources, like arable land and coal consumption, the scarcity of water consumption has brought increasingly obvious restrictions to the process of urbanization. Because every aspect of a resident's life and social production is inseparable from water, the irreplaceability and importance of water make the constraining effect on urbanization that is caused by its shortage more significant.

Although the YREB has significant water endowment, it is difficult to escape the shadow of the "resource curse" in the process of urbanization. The superiority of water endowment makes water resources easily accessible in this area and causes people to have little water saving awareness, which leads to low water-use efficiency (as YREB water consumption per capital in 2000 was 400.69 (m^3/(person·year)) and 446.28 (m^3/(person·year)) in 2015). Rapid population aggregation in the YREB has produced increased water pollution emissions and severely weakened water resources [54,55]. What is more, YREB economic development shows dependency on water consumption. Water consumption in the YREB will push against limits to supply for water during the rapid urbanization process. This will lead to a significant water consumption drag effect in future YREB development.

The drag effect of water consumption on urbanization is heterogenous across regions. Chongqing shows a large water consumption constraint. Located in southwestern China, from 2000 to 2015, the average annual growth rate of urbanization in Chongqing was 3.42%. However, since the total population remained almost unchanged, the urban population increased by more than 80% during this period in Chongqing. This explosion of urban population growth and extreme disorderly expansion of urbanization caused a 54% surge in water consumption. Urbanization, while still rapid, was constrained by limited water resources. Furthermore, as showing in Figure 6, water consumption per unit GDP declined slowly when compared with Jiangsu and Zhejiang, the large number of water-intensive industries in Chongqing was one of the reasons [56]. It will be difficult for Chongqing to avoid water-intensive industry-led economic growth in recent years. As time goes on, limited water consumption will not be able to sustain Chongqing's urbanization process. We expect the provinces of Anhui and Jiangxi to face similar challenges.

Jiangsu's water consumption drag effect is in the middle when compared with Chongqing and Zhejiang. From Figure 6, we found that even though Zhejiang and Jiangsu's water use efficiency are decreasing year over year, Jiangsu still has lower water use efficiency compare to Zhejiang. Likewise, the proportion of heavy industry in Jiangsu exceeds 70% and is dominated by high water-consuming industries. These negative factors have been mitigated, however, by a stable urban population increase. Combined, these factors have led to a moderate drag on urbanization.

Zhejiang is a good example of sustainable water use during urbanization. First, Zhejiang has focused on the adjustment of its industrial structure in the process of urbanization. Today, the service sector has become its leading industry, while others are developing into high-tech and emerging resource-friendly industries [57]. Since 2008, Zhejiang's water use efficiency has continuously improved and achieved a strong development trend with less water consumption year over year [58]. Second, Zhejiang's urbanization population increase has been small, and its development is relatively stable

(Figure 6). Above all, Zhejiang has been able to avoid the adverse effects of water shortages in the process of urbanization and its experience is worthy of study. Shanghai is also a good example. The urbanization level in Shanghai reached 87.6% in 2015, which is a mature stage [5]. Since 2011, water consumption in Shanghai has decreased every year. Extremely high human capital and water use efficiency have effectively relieved the drag effect of water consumption on the process of urbanization. These two provinces' good experience on water consumption could guide Hubei, Hunan, and Guizhou, which do not have a high drag and they show a mid-urbanization level.

Our proposed framework could be modified and improved for future research. First, there may be other important predictors of water use like climate condition that could be integrated into a model. This might be especially important if interested in predicting future urbanization rates under climate change. Second, the drag effect on urbanization could be disaggregated by different types of water consumption (agricultural, industrial, or domestic water consumption). Third, it may be interesting to text whether the water consumption drag on urbanization will change if one considers an urbanization quality index (household equipment, industrial production, and types, and so on).

5. Conclusions

Urbanization is the main driving factor for developing countries in the future. But, its developing process facing a great threat from water consumption. By constructing a spatial econometric model to capture the spatial effect during the process of urbanization, we take the Yangtze River Economic Belt as the research object and analyze the characteristics of water consumption constraints in the process of urbanization. The main conclusions are as follows. (1) Water consumption has obvious spatial spillover effects on the constraint of urbanization and policy maker should take into account when formulating water consumption policies. (2) Urbanization is constrained by water consumption, even in water endowment, like YREB. So, government should be vigilant and take effects to prevent the constrain effect of water consumption on urbanization. (3) The reason each regional water consumption constraints in the process of urbanization vary from place to place. Common but differentiated water consumption policy should be formulated.

Above all, wise water consumption policies could help solve the dilemma of water consumption constraints on the process of urbanization. First, all regions need to raise the degree of cooperation, guide the rational flow of resource elements among regions, and realize the coordinated development upstream, mid-stream, and downstream. Second, the government need to construct an effective regional unified water cooperation mechanism and appropriately distribute the pressures of water demand across local areas. This should consider each region's urbanization process and water consumption, while formulating mutually complementary water consumption strategic plans and an urbanization development strategy. Third, policy makers should determine the appropriate rate of urbanization based on the water resource carrying capacity and avoid explosive urban population growth and disorderly urban expansion. Last, residents should apply innovative water-saving technology, improve water management, and improve water use efficiency to realize water conservation in the process of urbanization.

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Appendix A

The proving process of water consumption's drag effect to economic growth base on Romer's (2001) expanded Solow model.

From the Cobb-Douglas production function expanded economic growth model, the relationship between water consumption and economic output could expressed as follows:

$$Y(t) \ = K(t)^{\alpha} W(t)^{\beta} [A(t)L(t)]^{\gamma} \tag{A1}$$

where Y means economic output, K is capital stock, W denotes water consumption, A is "technological advances" or "labor effectiveness", L is labor, $A(t)L(t)$ working labor. The $\alpha > 0$ $\beta > 0$ $\gamma > 0$, denote the corresponding elastic constant for K, W, A and L.

Consistent with Solow model, the temporal dynamic change of K, L and A can be described as follows:

$$\begin{aligned} \dot{K}(t) \ &= sY(t) - \delta K(t) \\ \dot{L}(t) &= nL(t) \\ \dot{A}(t) &= gA(t) \end{aligned} \tag{A2}$$

Above s is the saving ratio, t is time, n means the labor growth rate, δ is the depreciation rate. Since the water resources endowment of a country or region is basically constant, water resource reserves have been dramatically decreasing under constant exploitation and consumption. When under water resources constrained situation, we can write:

$$\dot{W}(t) \ = -mW(t) \tag{A3}$$

Here $m > 0$ is the rate of water consumption. As in the paper, in a logarithmic form,

$$\ln Y_t = \alpha \ln K_t + \beta \ln W_t + \gamma [\ln A_t + \ln L_t] \tag{A4}$$

The growth rate can be defined as the logarithm of the time derivative of the variables as follow:

$$g_Y(t) \ = \alpha g_K(t) + \beta g_W(t) + \gamma [g_A(t) + g_L(t)] \tag{A5}$$

In classical assumptions $g_{\bullet}(t)$ means correspond variable's constant growth rate .while the capital stock $\dot{K}(t) = sY(t) - \delta K(t)$ can be converted to $\dot{K}(t)/K(t) = sY(t)/K(t) - \delta$. If the growth rate for K is fixed, means the growth rate of Y and K equal. Then the above forum could be write as:

$$g_Y^{bgp} \ = \frac{\gamma(g+n) - \beta m}{1-\alpha} \tag{A6}$$

Above g_Y^{bgp} is the equilibrium path growth rate. Because water consumption limitation, there is a drag effect on economic growth. In this case, the growth rate for output per worker can be expressed as

$$g_{Y/L}^{bgp} = g_Y^{bgp} - g_L^{bgp} = \frac{r(g+n) - \beta m}{1-\alpha} - n = \frac{r(g+n) - \beta m - n - n\alpha}{1-\alpha} \tag{A7}$$

If there is no water consumption restrain, the consumption rate of water is n instead of m, the same procedure as above adopted to compute the growth rate of unit labor input on the balanced growth path:

$$g_Y^{\widetilde{bgp}} = \frac{rg + rn + \alpha n + \beta m - n}{1-\alpha} \tag{A8}$$

The drag effect of water consumption on economic growth will be the difference between no water consumption restrain and equilibrium path growth rate:

$$Drag_W^Y = g_{Y/L}^{\widetilde{bgp}} - g_{Y/L}^{bgp} = \frac{\beta(n+m)}{1-\alpha} \tag{A9}$$

Appendix B

The relationship between urbanization and economic growth can be express as a logarithmic curve, the forum as follows

$$U = a + b \ln y + \varepsilon (a > 0, b < 0) \tag{A10}$$

U means urbanization level, y is per capital output, in order to connect with the growth rate of per capital output, let $a = -\frac{\ln f}{\pi}$, $b = \frac{1}{\pi}(f > 0, \pi > 0)$ then could get

$$U = -\frac{\ln f}{\pi} + \frac{1}{\pi} \ln y + \varepsilon \tag{A11}$$

Deformation the above forum

$$U - \varepsilon = \frac{\ln(y/f)}{\pi} \tag{A12}$$

Then $\pi(U - \varepsilon) = \ln(y/f)$,

$$\begin{gathered} y = f e^{\pi U} e^{-\pi\varepsilon} (f > 0, \pi > 0) \\ \pi \frac{dU}{dt} = \frac{dy}{dt}, \frac{dU}{dt} = \frac{1}{\pi} \times \frac{dy}{dt} \end{gathered} \tag{A13}$$

$\frac{dU}{dt}$ means urbanization growth rate, $\frac{dy}{dt}$ is per capital output growth rate, π denotes urbanization's elastic constant for per capital output.

Appendix C

Table A1. Unit root test of panel data.

Variables	LLC Test (t-Value)	Handri Test (Z-stat)	Result
lnY	−6.92 ***	7.69 ***	stationary
lnK	−6.719 ***	8.22 ***	stationary
lnW	−1.89 **	7.019 ***	stationary
lnL	−5.36 ***	7.883 ***	stationary

Note: ***, ** denote level of significance at 1% and 5% respectively.

Table A2. Result of Granger causality test.

Null Hypothesis	Obs.	F-Statistic	Prob.
LnY does not Granger Cause LnW	165	1.0598	0.3048
LnW does not Granger Cause LnY	165	6.19889	0.0138

Note: Obs. means observation, If Prob. (probability) <0.05, means reject the null hypothesis.

Table A3. Johansen Cointegration Test of panel data.

Hypothesized No. of CE (s)	Fisher Statistics (from Trace Test)	Fisher Statistics (from Max-Eigen Test)
None	438.8	358.8
At most1	186.2	125.8
At most2	97.63	68.76
At most3	73.97	73.97

Table A4. Results of LM test with spatial effects in YREB.

Result	Spatial Lag Effect LM Test	Spatial Lag Effect Robustnesss LM Test	Spatial Error Effect LM Test	Spatial Error Effect Robustnesss LM Test
Statistic	20.259	20.625	4.13	5.366
P-value	0.000 ***	0.000 ***	0.044 **	0.024 **

Note: ***, ** denote level of significance at 1% and 5% respectively.

Table A5. Likelihood test (LR test) Result in YREB.

Name of Test	Result
Likelihood-ratio test	LR chi2(3) = 89.29
Assumption: sar nested in sdm	Prob. > chi2 = 0.0000
Likelihood-ratio test	LR chi2(3) = 232.88
Assumption: sem nested in sdm	Prob. > chi2 = 0.0000

Note: Prob. means probability, sdm is Spatial Durbin model, sar means Spatial lag model, sem presents Spatial error model.

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