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# Urbanization and Water Efficiency in China: A Spatial Dubin Model Analysis

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**ABSTRACT**

This study investigates the impact of urbanization on water efficiency using panel data from 31 provinces and cities in China from 2011 to 2021. By employing the spatial Dubin model, we examine the spatial heterogeneity and spatial agglomeration effects in water usage per 10,000 yuan of GDP. The findings reveal that urbanization in China significantly supports the improvement of water efficiency and exhibits spatial spillover effects. Moreover, the decomposition of spatial effects indicates that the indirect effects play a dominant role. These findings contribute to our understanding of the relationship between urbanization and water efficiency, providing valuable insights for water resource management and sustainable urban development.

**Keywords:** Urbanization, water resource utilization efficiency, spatial econometrics

## 1. INTRODUCTION

Urbanization is an inevitable outcome of economic development through economies of scale. Ensuring the smooth progress of urbanization is an important prerequisite for promoting national and regional economic development and social progress. According to relevant data, the urbanization rate of China's permanent population has increased by an average of 1.39 percentage points per year over the past decade. Urbanization has gradually entered the middle and later stages of development, with the urban development system transitioning from a single center to multiple centers. Metropolitan areas and urban clusters will become important engines for China's future economic development.

It is worth noting that the rapid development of urbanization in China has accelerated industrial restructuring and economic growth, but it has also placed enormous pressure on resource supply and environmental protection. The advancement of urbanization and industrialization in China has fully demonstrated the significance of water resources as fundamental natural resources and strategic economic resources, with their demand increasing day by day. However, the contradiction between socioeconomic development and insufficient water resource carrying capacity is becoming increasingly prominent. If the carrying capacity of water resources is exceeded, it will lead to water scarcity, thereby hindering the sustainable development of urbanization and the economy and society as a whole. The key to addressing this contradiction lies in improving the efficiency of water resource utilization. Therefore, studying the impact and patterns of urbanization on urban water usage and achieving harmonious development of the economy, society, and environment is a significant problem that needs to be addressed.

## 2. LITERATURE REVIEW

Scholars in China have conducted extensive research on the relationship between urbanization and water efficiency. Li et al. (2008)[1] examined regional disparities in water resource utilization efficiency across China and highlighted regional economic development as a key determinant. Bao et al. (2014)[2] developed a comprehensive model to analyze the driving forces behind urbanization, economic growth, and water consumption. Their findings revealed that population and economic urbanization in China significantly reduced total water consumption and water

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consumption per unit of GDP. Ma et al. (2016)[3] focused on 15 prefecture-level cities in Xinjiang and employed a DEA model to assess water resource utilization efficiency. They observed that urbanization led to increased scale and efficiency of water resource utilization, with the agglomeration effect playing a major role in reducing water consumption. Pan et al. (2017)[4] conducted an analysis and prediction of water resource utilization in the context of urbanization in Chengdu. Their study indicated a significant negative correlation between urbanization and water resource utilization efficiency, while industrial and economic development levels had a positive impact on improving water resource utilization efficiency. Ma (2021)[5] investigated the relationship between urbanization, water resource utilization efficiency, and economic growth. The empirical results demonstrated a positive spatial correlation among the new type of urbanization, water resource utilization efficiency, and economic growth in China. These studies collectively signify notable progress in understanding the interplay between urbanization and water resources.

Building upon this existing body of research, our study adopts similar methodologies and takes into account factors such as the natural flow of water resources, inter-regional water allocation, water rights distribution, and the characteristics of virtual water trade between regions. From a spatial spillover perspective, we aim to explore the impact of urbanization on water resource utilization efficiency.

## 3. STUDY METHOD AND DESCRIPTION OF THE VARIABLES

### *3.1 Spatial econometric model construction*

Compared to traditional regression analysis, spatial econometric models allow for the measurement of spatial correlation among economic variables, thereby expanding the scope of traditional research. Regional economic phenomena are interrelated, and in the context of this study, the water efficiency of a particular region does not change in isolation. Due to the strong flow of water, water usage in one area can easily transmit to neighboring areas. Therefore, it is appropriate to employ spatial econometric models to measure the spatial spillover effects on water efficiency.

Commonly used spatial econometric models include spatial lag models, spatial error models, and spatial Dubin models. The spatial lag model introduces the spatial lag term of the dependent variable into a general panel data model, representing the influence of explanatory variables in neighboring spatial units on the current unit. The spatial error model incorporates spatially correlated error terms, indicating that the error term of one spatial unit is influenced by the error terms of neighboring spatial units. The spatial Dubin model combines the characteristics of spatial lag models and spatial error models.

In this study, panel data will be utilized, and the spatial Dubin model will be employed to examine the impact of urbanization on water efficiency. The panel data specification of the spatial Dubin model is as follows:

$$Y_{it} = \delta\sum_{j=1}^{N} W_{ij}Y_{jt} + X'_{it}\beta + \sigma\sum_{j=1}^{N} W_{ij}X'_{jt}\theta + \mu_i + \lambda_t + \varepsilon_{it}$$

On this basis, combined with the variable selection methods of existing studies, the spatial panel model is constructed as follows:

$$E_{it} = \delta\sum_{j=1}^{N} W_{ij}E_{jt} + \beta urban_{it} + \sigma\sum_{j=1}^{N} W_{ij}urban_{it} + \gamma X_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

In the above equations, $E_{it}$ represents the dependent variable of water efficiency in province i in year t, while $urban_{it}$ represents the water efficiency in province i in year t, which serves as the explanatory variable in this study. $X_{it}$ is the vector of control variables, including per capita GDP, the proportion of the secondary sector, the proportion of the tertiary sector, per capita water resources, urban population density, the proportion of agricultural water usage, the proportion of industrial water usage, and the ratio of research and development expenses of large-scale industrial enterprises to GDP. The parameters $\beta$ and $\sigma$ represent the coefficients to be estimated, where $\beta$ captures the direct impact of urbanization on water efficiency, and $\sigma$ captures the intensity of spatial spillover effects of urbanization on water efficiency. $\mu_i$ represents the regional effects, $\lambda_t$ denotes the time effects, and $\varepsilon_{it}$ represents the random disturbance term.

### *3.2 variable declaration*

(1) Dependent variable

Existing studies commonly measure water efficiency using statistical indicators or water input-output efficiency analysis. The former approach includes indicators such as the irrigation water use coefficient and the per unit water consumption in agricultural irrigation to assess water efficiency in agricultural production[1][6]. Indicators like the industrial water reuse rate and the water consumption per unit of industrial output value are used to measure water efficiency in industrial production. The per capita domestic water consumption is used to evaluate water efficiency in domestic usage, while the water consumption per unit of GDP represents comprehensive water usage in the production process[1].

The latter approach involves methods such as stochastic frontier analysis (SFA), data envelopment analysis (DEA), and the super-efficiency SBM-DEA model to calculate the efficiency of water resource utilization as a production factor input[5][7]. In order to simplify variables and minimize information loss during calculations, this study follows the approach of the "China Water Resources Bulletin" and adopts the indicator of water consumption per unit of GDP (E) to comprehensively represent regional water efficiency. A higher value of E indicates lower water efficiency in the respective region.

(2) Independent variable

In this study, the explanatory variable used to measure the level of urbanization in a region is the urbanization rate (urban). It is calculated as the ratio of the urban population at the end of the year to the total population at the end of the year.

(3) control variable

In order to make the research results realistic, this paper introduces a series of factors that may affect regional water resources from the aspects of economic development and structure, resources endowment, population size, water use structure and technological progress. The economic development level is measured by per capita GDP; the industrial structure is a key factor affecting the water use efficiency in different regions, and the water use efficiency is very different, so the proportion of the secondary industry and the tertiary industry is selected. There is often a negative relationship between the abundance of water resources and the efficiency of water use. The resource curse effect is not only reflected in the economic development, but also reflected in the efficiency of resource utilization, as measured by the amount of per capita water resources. On the one hand, the size of the population increases the pressure of water use, and on the other hand, expanding the scale of production, measured by urban population density (pop). Water use structure and technological progress will also affect the efficiency of water resources, measured by the proportion of agricultural water, industrial water and the ratio of R & D costs of industrial enterprises above designated size to GDP.

Table 1. variable declaration

| Category | Primary Indicator | Secondary Indicator | unit | Symbol |
|---|---|---|---|---|
| Dependent variable | Water Use Efficiency | Water Consumption per 10,000 yuan of GDP | $m^3$ /10,000 yuan | E |
| Independent variable | Urbanization Level | The ratio of the urban population at the end of the year to the total population at the end of the year | % | urban |
| Control variable | Economic Development and Structure | Per Capita GDP | yuan | perGDP |
| | | Share of Secondary Industry | % | Rsec |
| | | Share of Tertiary Industry | % | Rthird |
| | Resource Endowment | Per Capita Water Resources | $m^3$ /person | perW |
| | Population Size | Urban Population Density | person/ $km^2$ | pop |
| | Water Use Structure | Share of Agricultural Water Use | % | WRa |
| | | Share of Industrial Water Use | % | WRi |
| | Technological Progress | R&D Expenses of Large-scale Industrial Enterprises/ GDP | % | RD |

### *3.3 Data and statistical description*

Considering the availability of data, the research objects in this paper are 31 provinces and autonomous regions except Hong Kong, Macao and Taiwan, and all the original data are from the provincial annual data of the National Bureau of Statistics. Descriptive statistics for each variable are presented in Table 2 below.

Table 2. Descriptive statistics

| Variables | N | Mean | Std | Min | Max |
|---|---|---|---|---|---|
| E | 341 | 122.2 | 124.3 | 10.13 | 898.8 |
| urban | 341 | 58.62 | 13.05 | 22.81 | 89.60 |
| perGDP | 341 | 56147 | 28642 | 16024 | 184000 |
| Rsec | 341 | 42.50 | 8.684 | 15.80 | 59 |
| Rthird | 341 | 47.82 | 9.619 | 29.70 | 83.90 |
| perW | 341 | 6467 | 23662 | 51.89 | 145780 |
| pop | 341 | 2876 | 1146 | 515 | 5821 |
| WRa | 341 | 60.50 | 18.51 | 6.863 | 95.19 |
| WRi | 341 | 19.81 | 12.92 | 1.876 | 66.35 |
| RD | 341 | 1.113 | 0.880 | 0.0243 | 12.13 |

## 4. ANALYSIS OF THE STUDY RESULTS

### *4.1 Spatial correlation test*

4.1.1 Space global autocorrelation

With the help of stata 15, this paper calculates Moran's I of water use efficiency and urbanization based on the adjacent matrix, which are 0.266 and 0.460, respectively, and are significant at the 99% significance level. Therefore, it can be considered that under the level of 99% confidence, the provincial water use efficiency in China from 2011-2021 is not isolated and randomly distributed, and there is a positive spatial spillover effect. The results are illustrated in Table 3

Table 3. Global Moran's I test results

| Variables | I | E(I) | sd(I) | z | p-value* |
|---|---|---|---|---|---|
| E | 0.266 | -0.003 | 0.038 | 7.130 | 0.000 |
| urban | 0.460 | -0.003 | 0.038 | 12.065 | 0.000 |

4.1.2 Spatial local autocorrelation

The Moran scatter plot is drawn to further analyze the local dependence characteristics of water resources utilization efficiency in China. Figure 1 and Figure 2 depict the Moran scatter plots of China's water resources utilization efficiency in 2011 and 2021 respectively. The scatter positions in the figure are mainly concentrated in the first and third quadrant, showing significant characteristics of high-high agglomeration and low-low agglomeration. In addition, from the national perspective, there are large regional differences in the water consumption per 10,000 yuan of GDP. The high-high agglomeration is mainly in the economically underdeveloped areas such as Xinjiang and Tibet, while the low-low agglomeration is in the central and western regions. To sum up, considering the effect of urbanization on the utilization efficiency of water resources, the influence of geospatial factors cannot be ignored.

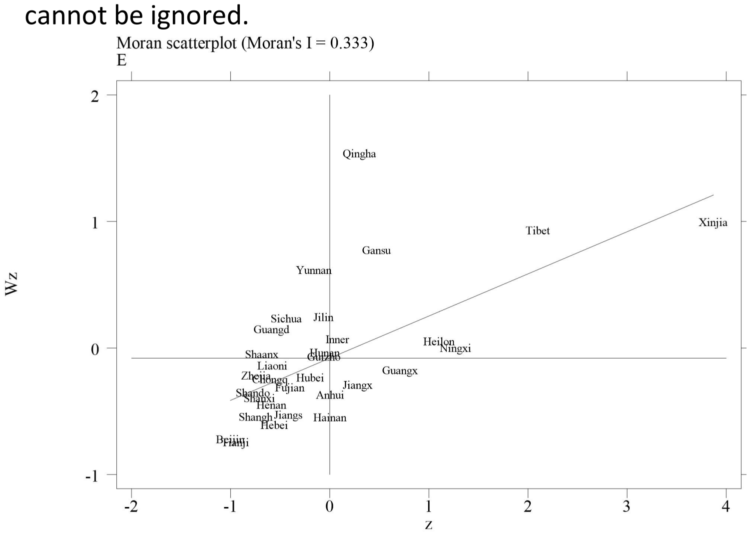


Fig. 1. Moran scatter plot of water consumption in 10,000 yuan of GDP in 2011

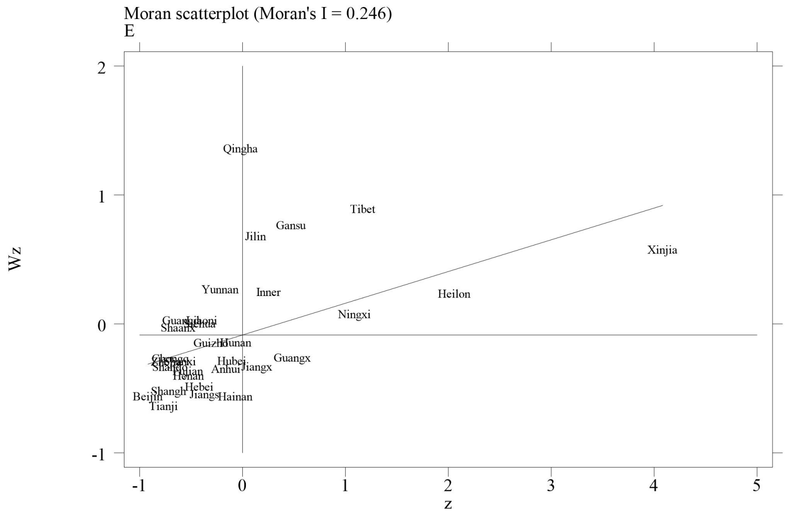


Fig. 2. Moran scatter plot of water consumption per 10,000 yuan of GDP in 2021

*4.2 Analysis of the empirical results*

For the specific setting form of the space panel model, the LM test shows that the spatial Dubin model should be selected (Table 4); the Hausman test results show that chi2 (19) =141.04 and P value =0.0000. Based on the practical significance of the sample selection method, the model finally selects the fixed effect mode.

Table 4. Summary of the results of the spatial correlation tests

| Test statistics (P-value) | result |
|---|---|
| space error:<br>LMERR=10.110(Prob=0.001)<br>R-LMERR=3.494(Prob=0.062) | the error terms have spatial correlations |
| Space lag:<br>LMLAG=19.595(Prob=0.000)<br>R-LMLAG=12.979(Prob=0.000) | the lag terms have spatial correlations |
| Hausman's test:<br>chi2(19)=141.04 Prob>=chi2=0.0000 | Accep the fixed-effect model |
| Wald Test for SAR:<br>chi2(9) = 15.84 Prob>=chi2 = 0.0702 | Rejecting SDM Degenerates to the SAR |
| Wald Test for SEM:<br>chi2(9) = 20.79 Prob>=chi2 = 0.0136 | Rejecting SDM Degenerates to the SEM |

Table 5 presents the regression results of both the Spatial Dubin Model (SDM) and Spatial Autoregressive Coefficient (SAC) models to examine the robustness of the coefficients. The results of the SDM model indicate a positive spatial autocorrelation coefficient (rho) at a significance level of 5%. This suggests that there is a positive spatial spillover effect in water use efficiency, implying that improving local water use efficiency can also have a positive impact on the water use efficiency in neighboring areas.

The findings from the Spatial Dubin Model show that the coefficient of urbanization is significantly negative at a 1% level of significance. This result is consistent with the regression results of the SAC model, confirming the robustness of the findings. Specifically, when the urbanization rate increases by one unit, the water consumption per 10,000 yuan of GDP is estimated to decrease by approximately 6 units. This can be attributed to the fact that higher urbanization rates correspond to a larger proportion of non-agricultural industries and a smaller proportion of agricultural water consumption. Consequently, the overall water consumption per unit of GDP decreases. Furthermore, urbanization facilitates industrial agglomeration, leading to economies of scale in water supply and higher economic output per unit of water resources.

Table 5. Spatial econometric regression results

| | SAC (1) | | SDM (2) | |
|---|---|---|---|---|
| Main urban | -8.516*** | (-7.16) | -5.918*** | (-2.61) |
| perGDP | -0.000 | (-1.44) | -0.000 | (-0.60) |
| Rsec | -0.664 | (-0.31) | -3.270 | (-1.34) |
| Rthird | 0.947 | (0.44) | -0.756 | (-0.32) |
| perW | 0.004*** | (2.64) | 0.003** | (1.99) |
| pop | 0.005 | (0.78) | 0.003 | (0.46) |
| WRa | -1.865** | (-2.19) | -0.907 | (-0.66) |
| WRi | -3.525*** | (-3.08) | -2.782** | (-2.07) |
| RD | 43.165*** | (10.01) | 43.745*** | (10.90) |
| Wx urban | | | -8.292*** | (-2.64) |
| perGDP | | | 0.000 | (0.11) |
| Rsec | | | 11.250*** | (2.65) |
| Rthird | | | 11.129*** | (2.62) |
| perW | | | 0.004 | (1.34) |
| pop | | | 0.005 | (0.33) |
| WRa | | | -1.988 | (-1.00) |
| WRi | | | -4.733* | (-1.86) |
| RD | | | -1.668 | (-0.23) |
| Spatial rho | 0.301*** | (2.76) | 0.166** | (2.08) |
| lambda | -0.134 | (-0.90) | | |
| Variance sigma2_e | 1899.098*** | (13.68) | 1686.216*** | (13.01) |
| N | 341 | | 341 | |
| Overall. $R^2$ | 0.2170 | | 0.3296 | |
| Within. $R^2$ | 0.4864 | | 0.5102 | |
| Between.$R^2$ | 0.2040 | | 0.3375 | |

Note: ***,** and *respectively indicate significance at the 1%, 5% and 10% level.

The coefficient of Wurban in the Spatial Dubin Model is estimated to be -8.292 with a significance level of 1%. This indicates that the urbanization development in a particular area contributes to a reduction in water consumption per 10,000 yuan of GDP in the surrounding areas, thereby improving the water use efficiency in those areas. The coefficient Wx in the model represents the influence of independent variables in one region on the dependent variables in the surrounding areas.

### *4.3 Analysis of the spatial effects*

On the basis of the spatial Dubin fixed effect model, this paper makes LR tests for the time fixed effect, spatial fixed effect and double fixed effect model, and the test results show that the double fixed effect model should be selected. Therefore, the spatial effect is further decomposed into direct effect, indirect effect and total effect to further study the spatial effect of urbanization on water resources utilization efficiency. Direct effect and indirect effect respectively indicate the role of the changes of various influencing factors in the utilization efficiency of water resources, and the total effect is the sum of direct effect and indirect effect.

The empirical results are presented in Table 6. It can be seen that at the confidence level of 99%, the overall support effect of urbanization on the improvement of water use efficiency is about 12.5, the direct effect is 4.8, and the indirect effect is about 7.6. The indirect effect exceeding the direct effect shows that the improvement of a certain level of urbanization, on the one hand, plays a positive role in the improvement of local water efficiency. For example, Li, S., Cheng, J., & Wu, Q. (2008)[1] prove that in areas with low level of urbanization, the proportion of agriculture is high, the tertiary industry is low, and the water efficiency is low. Moreover, the local infrastructure with low level of urbanization and water conservation are often insufficient, and the survival pressure of relying on water resources is much higher than the importance of sustainable utilization of water resources, so the water utilization is extensive and the efficiency is low. On the other hand, the improvement of local urbanization level will lead to changes in other conditions. For example, the spatial spillover effect of urbanization can promote the continuous improvement of production efficiency and living efficiency. While factor agglomeration brings economic growth[8], it also accelerates the improvement of water resources utilization efficiency through multiple channels.

Table 6. The spatial Dubin model effect decomposition

| variable | Direct effect | Indirect effect | Gross effect |
|---|---|---|---|
| urban | -4.835** (-2.14) | -7.674** (-2.16) | -12.509*** (-3.27) |
| perGDP | 0.000191 (0.46) | 0.0000255 (0.31) | 0.000217 (0.45) |
| Rsec | -2.802 (-1.14) | -0.453 (-0.78) | -3.254 (-1.13) |
| Rthird | -0.173 (-0.07) | -0.0385 (-0.09) | -0.212 (-0.08) |
| perW | 0.003* (1.72) | 0.000 (1.00) | 0.003* (1.69) |
| pop | 0.00635 (1.11) | 0.00100 (0.93) | 0.00735 (1.14) |
| WRa | -1.748* (-1.79) | -0.268 (-1.01) | -2.016* (-1.77) |
| WRi | -3.846*** (-3.66) | -0.604 (-1.30) | -4.450*** (-3.43) |
| RD | 41.82*** (10.38) | 6.579 (1.33) | 48.40*** (6.63) |

## 5. CONCLUSIONS

In conclusion, this study introduced spatial weighting and controlled for variables such as per capita GDP, the proportion of the secondary industry, the proportion of the tertiary industry, per capita water resources, urban population density, the proportion of agricultural water use, and the proportion of industrial water use. It constructed a spatial panel econometric model to examine the relationship between urbanization level and water consumption per 10,000 yuan of GDP. Spatial correlation tests were conducted on the water consumption per 10,000 yuan of GDP, yielding the following main findings: 1)Water consumption per 10,000 yuan of GDP exhibits spatial heterogeneity and spatial agglomeration effect. 2)The urbanization level in China has a significant supportive effect on improving water use efficiency, and it demonstrates spatial spillover effects. Further decomposition of the spatial effects of urbanization reveals that indirect effects play a major role.

These results underscore the significance of considering spatial effects and urbanization in formulating policies and strategies to enhance water use efficiency. Future research can delve deeper into the mechanisms through which urbanization influences water consumption and explore additional factors contributing to spatial heterogeneity and agglomeration effects in water use efficiency.

**DECLARATION OF INTEREST STATEMENT**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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