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Spatiotemporal Patterns and Spillover Effects of Water Footprint Economic Benefits in the Poyang Lake City Group, Jiangxi

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Research

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ABSTRACT

The evolution of spatiotemporal patterns of water footprint economic benefits (WFEB) in the 32 counties (cities and districts) of the Poyang Lake City Group in Jiangxi Province was evaluated based on panel data. Where after, the spatial spillover effects of the regional WFEB in the Poyang Lake City Group were investigated using the spatial Durbin model (SDM). The results showed a rising trend in the total water footprint (WF) and WFEB of the Poyang Lake City Group from 2010 to 2013, and the number of cities at the levels of high efficiency in the Poyang Lake City Group increased steadily. Clear local spatial autocorrelations were found in WFEB, the degree of spatial clustering of WFEB gradually strengthened during 2010–2013, and the spatial agglomeration of WFEB in the Poyang Lake City Group mainly showed Low-High and Low-Low types of trends, which accounted for 9.4% and 12.5%, respectively, of the four types of trends. Our SDM analysis further confirmed significant spatial dependence of WFEB in the Poyang Lake City Group in Jiangxi Province.

***Keywords*: water footprint economic benefits; spatiotemporal pattern; spillover effects; Poyang Lake City Group**

1. INTRODUCTION

Water is a basic natural resource for human and environmental development[1], but it varies greatly across countries and global regions, and the shortage of water resources is become increasingly prominent with the rapid increase of economic development, urbanization, and industrialization. The basic way to solve the problem of a shortage of water resources is to improve their efficient utilization. However, the traditional method for evaluating the efficient utilization of water resources only involves direct water consumption in agriculture, industry, and residential life, which does not reflect the real consumption of water resources by human beings. Therefore, the concept of a water footprint was introduced, which has provided a new perspective for research on the efficient utilization of water resources and become a research hotspot in academia.

Water footprint (WF) is defined as the total volume of fresh water consumed and polluted directly or indirectly by producers or consumers of a country or region within a certain period of time [2]. WF has (1) made it possible to evaluate the direct use of the water resources system by human beings from the perspective of consumption, (2) established the relationship between the utilization of water resources and patterns of human consumption, (3) shown that WF is the best indicator to measure the environmental impact of human activities on the environmental system of water resources, and (4) extended the water consumption problem to socio-economic fields. Many recent studies have explored the WF across different levels of scale, including nations [1, 3, 4], river basins [5-7], provinces [8-10], regional cities [11], and sectoral categories [12-14]. Research has also found considerable diversity in the WF of various provincial regions in China [15]. For example, the WF in the Northeastern area of Leshan City was found to be greater than that of the Southwestern area in 1992–2012 [11], and fast developing areas with larger economic scales have been found to have the largest WF [16], whereas less economically developed provinces have a lower WF [17]. Sun et al. [18] found the decrease in the amount or intensity of the WF was uneven among the 31 provinces (regions), with the regions located in western China generally having larger decreases than the regions located in eastern China. WF intensity differs greatly among the cities of Liaoning Province and there is a significant spatial effect of WF intensity [19]. The above studies on WF have promoted the development of WF theory and provide a basis for better management of water resources. Few, however, have focused on the economic benefits of the WF in areas of urban agglomeration. Therefore, the current study measured the water footprint economic benefits (WFEB) of the 32 counties (cities or districts) of the Poyang Lake City Group in Jiangxi Province according to WF theory, and analyzed the existing spatial correlations and spatiotemporal transitions in WFEB using spatial econometric methods. The aims of the study were: (a) to analyze trends in spatiotemporal patterns in the evolution of WFEB for the Poyang Lake City Group of Jiangxi Province, (b) to identify the regions with the greatest changes in WFEB in a certain temporal range, and (c) ultimately to promote the utilization and management of regional water resources. We applied the Spatial Durbin econometric model to study the spatial spillovers of the inter-regional WFEB in order for decision-makers to develop countermeasures and to implement strategic plans to mitigate pressure on water resources in the Poyang Lake City Group of Jiangxi.

2. STUDY AREA

The Poyang Lake City Group, which is located in the northern part of Jiangxi Province in southeast China (113°34′36″ – 118°28′58″ east longitude and 26°14′48″ – 30°04′41″ north latitude), has China's largest fresh water lake — Poyang Lake is the core — and enjoys a subtropical humid monsoon climate. It contains of 32 counties (cities or districts), including Nanchang City, Jingdezhen City, Yingtan City, Jiujiang City, Xinyu City, Fuzhou City, Yichun City, Shangrao City, and a part of the county (city or district) in Ji’an City (Fig. 1). Its total area is 92,300 km^2, which accounts for 56.38% of the total area of Jiangxi Province, and it has a population of 33.53 million, which accounts for 86.57% of the total population of Jiangxi Province. The region's Gross Domestic Product (GDP) has reached 1,638.937 billion-yuan, accounting for 88.07% of Jiangxi's GDP. The average consumption level of residents has reached 17,707.40 yuan, and urbanization rate exceeds 50.00% [20].

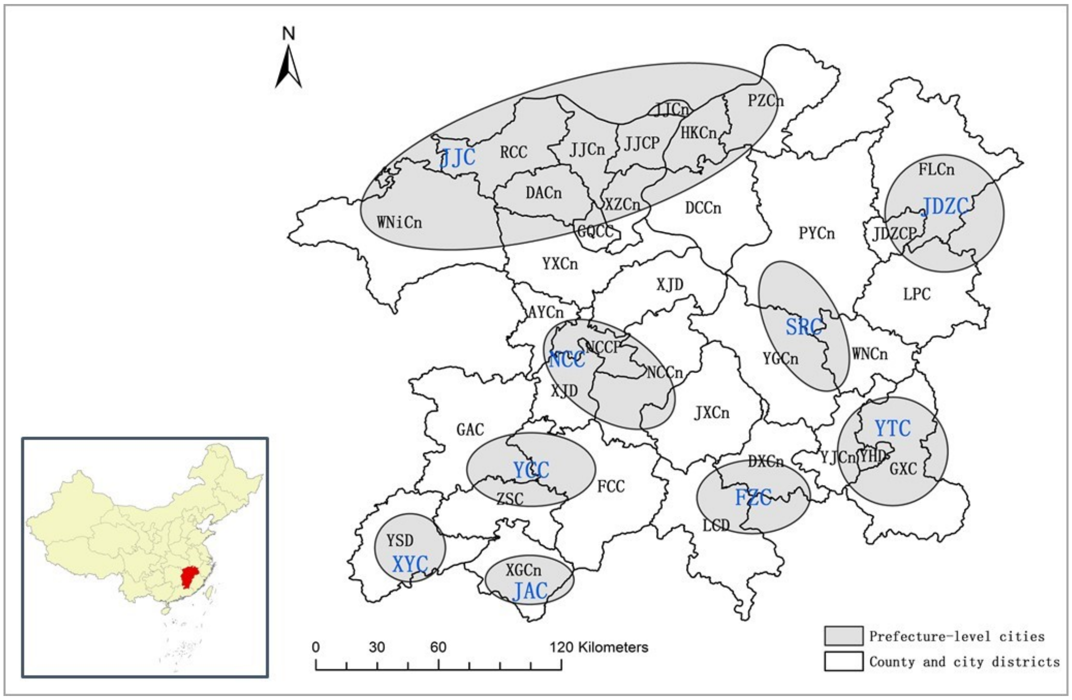

Fig. 1. The geographical location and composition of the Poyang Lake City Group in Jiangxi, China.

NCCP: Nanchang City Proper, including Donghu District, Xihu District, Qingshanhu District, Qingyunpu District, and Wanli District; NCCn: Nanchang County; XJCn: XinJian County; JXCn: Jinxian County; AYCn: Anyi County; JJCP: Jiujiang City Proper, including Xunyang District and Lushan District; JJCn: Jiujiang County; WNiCn: Wuning County; YXCn: Yongxiu County; GQCC: Gongqingcheng City; DACn: De'an County; XZCn: Xingzi County; HKCn: Hukou County; DCCn: Douchang County; PZCn: Pengze County; RCC: Ruichang City; YGCn: Yugan County; PYCn: Poyang County; WNCn: Wannian County; FCC: Fengcheng City; ZSC: Zhangshu City; GAC: Gao'an City; JDZCP: Jingdezhen City Proper, including Changjiang District (CJD) and Zhushan District (ZSD); FLCn: Fuliang County; LPC: Leping City; YTCP: Yingtan City Proper, namely Yuehu District (YHD); YJCn: Yujiang County; GXC: Guixi City; XYCP: Xinyu City Proper, namely Yushui District (YSD); WZCP: Fuzhou City Proper, namely Linchuan District (LCD); DXCn: Dongxiang County; JAC: Ji'an City; XGCn: Xingan County. The same abbreviations apply to Fig. 3 and 4.

The Poyang Lake City Group is the economic core of Jiangxi province, and a key development area for the Triangle of Central China (along with the Wuhan City Group and the Changzhutan City Group), and it is a pilot area in which China strives to build a modern urban agglomeration with green urbanization. Although the Poyang Lake City Group is in the early stage of rapid development and the overall level of development is still relatively low. The inter-city accessibility and inter-city coordination mechanisms are not high.

3. MATERIALS AND METHODS

3.1 Methodology

3.1.1 Water Footprint Measurement

The present study used a bottom-up approach. Due to the lack of data about water pollution, water consumption, and import-export product trade in the Poyang Lake City Group, the calculation of the WF included six types of WF, including a crop products WF (CWF), an animal products WF (AWF), a gray WF (GWF), an industrial production WF (IWF), a residential consumption WF (RWF), and an ecological environment WF (EWF). Based on the above-mentioned analysis, the equation used to calculate the total WF in each region of the Poyang Lake City Group was:

$$WF = CWF + AWF + GWF + IWF + RWF + EWF \tag{1}$$

The following computational formulas were used to process the original data of crop production and animal production WFs:

$$CWF = \sum_{j=1}^{n} VCWC \times Pc \tag{2}$$

$$AWF = \sum_{j=1}^{n} VAWC \times Pa \tag{3}$$

In equations (2) and (3), *n* represents the number of product categories; *VCWC* and *VAWC* represents the virtual water content of crop products and animal products of category *j* per unit mass, respectively; P_c and P_a represents the output of category *j crop* products and animal products, respectively.

Crop (Animal) products require more information, but part of the data in this study area were missing. Based on the available data, crop products in this study mainly included grain, oil, vegetables, tea, and fruits, and animal products mainly included meat, aquatic products, milk products, and poultry and eggs. These data are from the Statistical Yearbook of Jiangxi Province and the Statistical Yearbook of Poyang Lake Ecological Economic Zone. Currently, the virtual water content of agricultural products per unit mass in China's WF research is based on the results of some Chinese products in a study by Chapagain et al. [21]. However, studies by An and Xiao [22] and Zhao [23] have obtained data from specific study areas in China. Research indicates the virtual water content of crop products (or animal products) per unit mass (m^3/kg) is 1.10 for grain, 2.10 for oil, 0.1 for vegetables, 6.99 for tea, 0.83 for fruit, 6.7 for meat, 5.00 for aquatic products, 1.00 milk products, and 3.55 for poultry and eggs.

Gray WF can be defined as water resource levels of pollutants beyond the water bearing capacity from the products consumed and service emissions by a given population [18]. Since there are many causes of water pollution, this study calculated the pollution footprint of chemical oxygen demand (COD) and ammonia nitrogen (AN) from industrial wastewater and domestic wastewater, and then took the larger of the two values. The GWF calculation formula of Sun *et al.* (2013) was used in this study:

$$GWF = \max\left(\frac{P_{COD}}{ACC_{COD}}, \frac{P_{AN}}{ACC_{AN}}\right) \tag{4}$$

where the P_{COD} and P_{AN} were, respectively, the discharge amount of COD and AN, ACC_{COD} and ACC_{AN}, respectively, refer to the average bearing capacity of water to COD and AN. The average bearing capacity of COD and AN used China's national standards (GB) of Secondary Sewage Emission (GB 8978—1996), and the target-achieved concentration of COD and AN were, respectively, 120 mg /L and 25 mg /L. Because of the lack of established uniform methods of calculation and standards for IWF, RWF and EWF, and the actual water consumption of industrial production, residential living, and the ecological environment in the Jiangxi water resources bulletin were used as the basis for calculations in this study.

3.1.2 Water Footprint Economic Benefits

Water Footprint Economic Benefits (WFEB) refer to the coordination between regional economic development and water resource utilization, and its mathematical expression reflects the ratio of the total regional GDP to regional WF, which is expressed as [24]:

$$WFEB = \frac{GDP}{WF} * 100\% \tag{5}$$

where *WFEB* is the value of water footprint economic benefits, *GDP* is the gross domestic product of the region, and *WF* is the regional water footprint. This indicator reflects the impact of WF consumption on regional economic development and shows the level of economic benefits generated in the process of regional utilization of water resources. Larger WFEB values indicate that the economic benefit of the regional WF is greater and the level of regional economic development is affected more by the development and utilization of water resources, and that the degree and benefit of water resource utilization is higher.

3.1.3 Exploratory Spatial Data Analysis

Exploratory Spatial Data Analysis (ESDA) is a kind of spatial data analysis (SDA) technology and a space analysis method that includes a series of techniques and tools, including spatial autocorrelation coefficients and spatial statistics [25]. Spatial autocorrelation can measure the degree of spatial agglomeration [26], which can be divided into global spatial autocorrelation and local spatial autocorrelation, according to the analyzed space scale [27].

Global spatial autocorrelation describes the spatial characteristics of a certain geographical phenomenon or a particular attribute across the region, and summarizes the degree of spatial dependence of these geographic phenomena or attribute values, to determine the state distribution (agglomeration distribution, discrete distribution, or random distribution) of these spatial data [28]. The Global Moran's I (index) is defined as [29]:

$$I\left(d\right) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \tag{6}$$

In equation (6): *I* (*d*) is the global Moran's *I, which* ranges between -1 and +1 [30]. When 0 < *I* (*d*) ≤ 1, this indicates that the attribute value in each region has a positive spatial correlation; that is, the spatial entities show an agglomeration distribution pattern; When *I* (*d*) approaches or is equal to 0, this indicates there is no spatial autocorrelation between region attribute values; that is, the spatial entities show a random distribution pattern; when -1 ≤ *I* (*d*) < 0, this indicates there is a spatial negative correlation between region attribute values; that is, the spatial entities show a discrete distribution pattern. Moreover, the smaller the *I* (*d*) value is, the stronger the spatial differentiation is; *n* is the number of research units; X_i and X_j are the observed values of the *i*th and *j*th geographic units, respectively; `*X* is the mean value of the observed values of all geographical units; S^2 is the variance of the observed variable; and w_{ij} is a spatial weight matrix, which involves the spatial layout of the observed variables between different regions. We established the spatial weight matrix in the Poyang Lake City Group in this study based on a spatial adjacency relationship; namely that w_{ij} was equal to 1 if region *i* and region *j* were adjacent to each other; otherwise, w_{ij} was equal to 0. The *Z-statistic was used to test the significance level* of the global and local Moran's *I* in this study [31].

Local spatial autocorrelation can decompose the global Moran's *I* into each geographic unit, and is used to evaluate spatial agglomeration, spatial heterogeneity, or spatial regimes among regions [29]. It can be analyzed by a Moran scatter plot, G statistics, and Local Indicators of Spatial Association (LISA). The local Moran's *I*, which is computed at location *i*, is often called LISA [32], which is used to analyze local agglomeration between regions *i* and *j,* the local Moran's *I* is expressed as [29]:

$$I_i = \frac{\left(X_i - \bar{X}\right)}{S^2}\sum_{j=1}^{n} w_{ij}\left(X_j - \bar{X}\right) \quad (i \neq j) \tag{7}$$

where x_i, x_j, *n*, w_{ij}, and S^2 are the same as those used to calculate the global Moran's *I*. At a given significance level, 0 < I_i indicates positive local spatial autocorrelation, which shows that the similar value of geographical unit presents the agglomeration distribution law; I_i < 0 indicates negative local spatial autocorrelation, which shows that the similar value of geographical unit presents the discrete distribution law; $I_i = 0$ indicates that the local space is uncorrelated.

3.1.4 Spatial Durbin Econometric Model

Spatial effects are the essential reason for the existence of a separate field of spatial econometrics [33]. The spatial effects demonstrated by spatial correlation can be characterized by the Spatial Lag Model (SLM), the Spatial Error Model (SEM), and the Spatial Durbin Model (SDM). However, according to LeSage and Pace [34], the SDM model has several advantages over the SEM and SAR models. The SDM model produces unbiased estimates even when the true data-generating process is simply a spatial lag or a spatial error process, and it does not impose any prior restrictions on the magnitude of spillover effects [35]. Therefore, in order to test the spatial spillover effects of WFEB in the Poyang Lake City Group, the spatial panel data Durbin econometric model in this study was specified as [18]:

$$Y = X\beta + \rho Wy + WX\theta + \varepsilon \tag{8}$$

where *Y*, *W*, *X*, *WX,* and *ε* denote WFEB, the spatial weight matrix, factors influencing WFEB, the spatial lag term of the factors influencing WFEB, and the random disturbance term independent of region and period, respectively. W_y captures the spatial interdependence of the dependent variable in the model [33]. The spatial econometric model has a non-linear structure due to the introduction of the spatial weight matrix, so that the regression coefficients no longer reflect the effect of independent variables on dependent variables. LeSage and Pace [34] provided explanations of the parameters of SDM in the form of a partial derivative matrix, and proposed the definitions of total effects, direct (feedback) effects, and indirect (spillover) effects. Taking these into account, equation (8) can be expressed as:

$$\left(I_n - \rho W\right)Y = X\beta + WX\theta + \varepsilon \tag{9}$$

Multiply both sides of equation (9) by $(I_n\text{-}\rho W)^{-1}$, and denoted by:

$$Y = \sum_{r=1}^{k} S_r\left(W\right)x_r + V(W)\varepsilon \tag{10}$$

where $S_r(W) = V(W)(I_n\beta_r + W\theta_r)$, $V(W) = (I_n\text{-}\rho W)^{-1}$. By expanding equation (10), one can obtain the following:

$$\begin{pmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_n \end{pmatrix} = \sum_{r=1}^{k} \begin{pmatrix} S_r(W)_{11} & S_r(W)_{12} & \cdot\cdot\cdot & S_r(W)_{1n} \\ S_r(W)_{21} & S_r(W)_{22} & \cdot\cdot\cdot & S_r(W)_{2n} \\ \cdot & \cdot & \cdot\cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot\cdot & \cdot \\ S_r(W)_{n1} & S_r(W)_{n2} & \cdot\cdot\cdot & S_r(W)_{nn} \end{pmatrix} \begin{pmatrix} x_{1r} \\ x_{2r} \\ \cdot \\ \cdot \\ \cdot \\ x_{nr} \end{pmatrix} + V(W)\varepsilon \tag{11}$$

The total effects, direct (feedback) effects, and indirect (spillover) effects can be deduced from equation (11) as:

$$\overline{M}\left(r\right)_{total} = n^{-1} I_n^{-1} S_r(W) I_n \tag{12}$$

$$\overline{M}\left(r\right)_{direct} = n^{-1} tr(S_r(W)) \tag{13}$$

$$\overline{M}\left(r\right)_{indirect} = \overline{M}\left(r\right)_{total} - \overline{M}\left(r\right)_{direct} \tag{14}$$

The total effects are the average of all the derivatives of y_i with respect to x_{jr} for any i and j. The direct (feedback) effects is the average of all “own” derivatives. The average of all derivatives (total effects) less than the average “own” derivative (direct effects) equals the average cross derivative (indirect effects). I_n denotes the identity matrix, and the view expressed in equation (14) relates to how changes in a single observation j influence all the observations [34].

3.2. DATA RESOURCES

Our study used panel data from 32 counties (cities or districts) in the Poyang Lake City Group during 2010 -2013. All the original economic data were taken from the Statistical Yearbook of Jiangxi Province and the Statistical Yearbook of Poyang Lake Ecological Economic Zone. The data on the actual water consumption of industrial production, residential living, and the ecological environment in this study were from the Jiangxi water resources bulletin. The average bearing capacity of COD and AN uses China’s national standards (GB) of Secondary Sewage Emission (GB 8978-1996).

4. RESULTS

4.1 Water Footprint Measurement in the Poyang Lake City Group

Table 1 shows that the total WF, CWF, AWF, and RWF in the Poyang Lake City Group have risen steadily from 2010 to 2013, and by 2013 they had increased, respectively, by 12.16%, 11.07%, 10.07%, and 13.66% since 2010. The GWF and IWF increased in 2011, and then decreased, but they were higher in 2013 than they were in 2010. The EWF initially decreased and then stabilized.

As can be seen in Table 1, the AWF in the Poyang Lake City Group increased the most from 2010 to 2013, reaching 44.08%, followed by the CWF, IWF, GWF, and RWF; the EWF, which did not increase, was the lowest. Moreover, the AWF was the largest type of WF, which is because the Poyang Lake City Group is a new ecological urban agglomeration and has China's largest freshwater lake, with the Poyang Lake as the core. The basin area of its water system reaches 16.22 million hm^2, and has an annual output of more than 210 million tons of aquatic products [22]. In 2010, the food crops in the Poyang Lake eco-economic region accounted for 44.6% of the total of Jiangxi province (oil crops = 59.35%, cotton = 94.7%, pork = 47.2%, egg products = 56.7%, and aquatic products = 61.1% [36]), and it is an important region of agricultural and animal husbandry production in Jiangxi province.

Table 1. Changes in the water footprint (10^8 m^3) in the Poyang Lake City Group from 2010 to 2013

Years	CWF	AWF	GWF	IWF	RWF	EWF	Total WF
2010	141.04	164.37	15.20	37.93	11.35	3.00	372.89
2011	147.32	169.15	30.63	41.07	11.97	1.15	401.28
2012	153.71	176.79	27.27	38.67	12.61	1.14	410.19
2013	156.66	180.93	26.89	39.66	12.90	1.18	418.22

Notes: CWF: crop products water footprint; AWF: animal products water footprint; GWF: gray water footprint; IWF: industrial production water footprint; RWF: residents' living consumption water footprint; EWF: ecological environment water footprint.

4.2 Spatiotemporal Patterns and Spatial Heterogeneity Analysis of WFEB in the Poyang Lake City Group

4.2.1 Spatiotemporal Pattern Analysis

As can be seen in Fig. 2, the WFEB of the Poyang Lake City Group increased from 15.24 yuan/ m^3 in 2010 to 22.39 yuan/ m^3 in 2013 (the mean was 18.92 yuan/ m^3), which is an increase of 46.92% since 2010. This indicates that the increase in WFEB value was associated with the economic development level of the Poyang Lake City Group; i.e., greater development and utilization of water resources was accompanied by higher economic benefits.

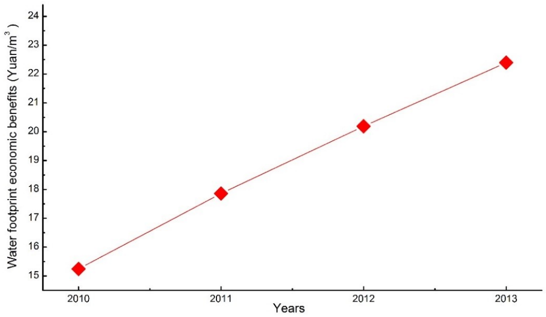

Fig. 2. Temporal change of water footprint economic benefits in the Poyang Lake City Group.

In order to identify the evolution of the spatial pattern of WFEB in the Poyang Lake City Group from 2010 to 2013 and understand its spatial distribution, the WFEB of the Poyang Lake City Group was divided by the *natural break point* method using ArcGIS 10.1 Spatial Analysis metering software (Fig. 3). As seen in Fig.3, the number of cities in the Poyang Lake City Group at the levels of high efficiency (>100) and sub-high efficiency ([75, 100)) increased steadily from 2010 to 2013. The following changes in WFEB occurred from 2010 to 2013: Gongqingcheng City changed from low efficiency ([0, 25)) to sub-medium efficiency ([25, 50)); Jiujiang City proper and the Yushui district changed from sub-medium efficiency ([25, 50)) to medium efficiency ([50, 75)); the Yuehu district changed from medium efficiency ([50, 75)) to sub-high efficiency ([75, 100)); and Nanchang City proper changed from sub-high efficiency ([75, 100)) to high efficiency (>100). This indicates that with the improvement of the national economy, the water resources of the above cities were effectively utilized and produced greater economic benefits.

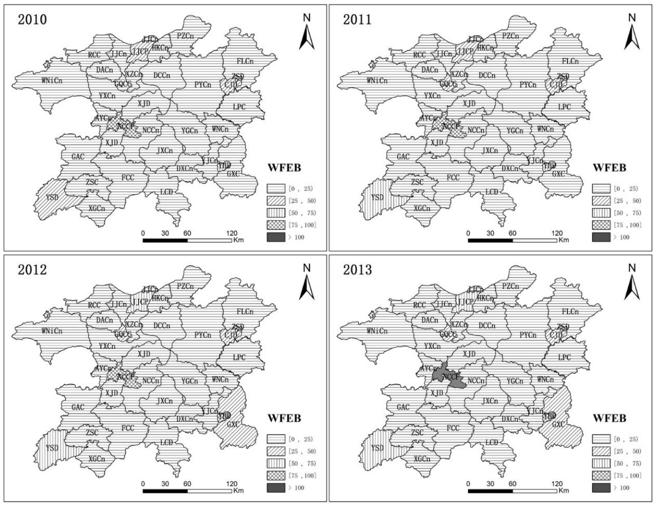

Fig. 3. Evolution of spatial patterns of water footprint economic benefits in the Poyang Lake City Group

4.2.2 Spatial Heterogeneity Analysis

Table 2 shows the Moran's *I* of global autocorrelation of the WFEB for the Poyang Lake City Group from 2010 to 2013. Moran's *I* for the WFEB was statistically significant for all years, indicating there was a significant positive correlation across years (Table 2). This means that the spatial distribution of the WFEB in the Poyang Lake City Group was not completely random but showed spatial agglomeration between similar regional values; that is, the higher value regions were clustered together. Therefore, when studying the WFEB of the Poyang Lake City Group, the econometric aspect of geographical spatial distribution cannot be ignored. Moreover, the two properties that should be considered in the context of spatial econometric analysis are spatial dependence and spatial heterogeneity. As seen in Table 2, the value of Moran's *I* index showed an upward trend with the annual change varying from 0.1024 to 0.1654. This means that with the continuous development and growth of city economies, cities were becoming more closely connected, the spatial correlation of the WFEB was becoming higher and higher, and the agglomeration of spatial distribution was gradually strengthening.

Table 2. Global spatial autocorrelations of water footprint economic benefits in the Poyang Lake City Group

Index	**2010**	**2011**	**2012**	**2013**
Moran's *I*	0.1024	0.1245	0.1337	0.1675
Z (*I*)	3.8455	4.4713	4.7487	5.6428
P value	0.0001	0.0000	0.0000	0.0000

Since the global spatial autocorrelation assumes that the space is homogeneous (that is, only one trend exists in an entire large region), and the global Moran's *I* is the overall autocorrelation statistic, it cannot reflect the characteristic strength of local spatial agglomeration. In contrast, the local spatial autocorrelation takes every local unit as the target item and can reveal the similarity and correlation among a local unit and its adjacent ones. It can also identify spatial agglomeration and spatial isolation and detect spatial heterogeneity. Thus, the next step was to use the local Moran's *I* to discover whether local agglomeration existed in the WFEB of the Poyang Lake City Group. Local spatial autocorrelation analysis was performed using common LISA tools supported by GeoDa, and the results are shown in Fig. 4. The four categories in Fig. 4 show the trend between one region with its neighboring regions, in which High-High and Low-Low indicate similar trends that result in positive spatial correlation, whereas High-Low or Low-High indicate inverse trends that result in negative spatial correlations.

In 2010, 2011, and 2013 (see Fig. 4), Nanchang City proper (NCCP) and the Changjiang District (CJD) belonged to the High-High type. However, in 2012, only Nanchang City proper (NCCP) belonged to the High-High type. From 2010 to 2013, no cities belonged to the High-Low type, while Xinzi County (XZCn) and Yongxiu County (YXCn) belonged to the Low-Low type. Zhangshu City (ZSC) and Xingan County (XGCn) belonged to the Low-Low type in 2010 and 2013, and Xingan County (XGCn) belonged to the Low-Low type in 2011. From 2010 to 2013, Pengze County (PZCn) and Hukou County (HKCn) belonged to the Low-High type. In 2013, Fuliang County (FLCn) belonged to the Low-High type. To summarize, the WFEB of the Poyang Lake City Group not only showed a trend in the utilization of water resources of some cities, but this reflected whether the levels of economic development between a city and its adjacent cities were correlated.

As Fig. 4 shows, the evolution of the trend for FLCn was the most pronounced trend among the 33 cities, and it increased from *no obvious agglomeration* in 2010, 2011, or 2012 to the Low-High" type surrounded by cities with a higher degree of water resource utilization. This may be because during the period of the Twelfth Five-Year Plan, FLCn was the city with the fastest development of water conservancy, the most investment in water conservancy, and the most remarkable achievements in water conservancy construction in the Poyang Lake City Group. Moreover, it won first place in the province with high marks in 2013 for provincial water conservancy reform and development assessment.

In a word, local spatial autocorrelation analysis and comparisons of the above four types found that the spatial agglomeration in the Poyang Lake City Group was mainly Low-High and Low-Low types, which accounted for 9.4% and 12.5% of the four types, respectively. As shown in Tables 1 and 2, the WFEB among adjacent cities had an obvious spatial correlation. Therefore, spatial econometric analysis was conducted to investigate the impacts of different variables on WFEB.

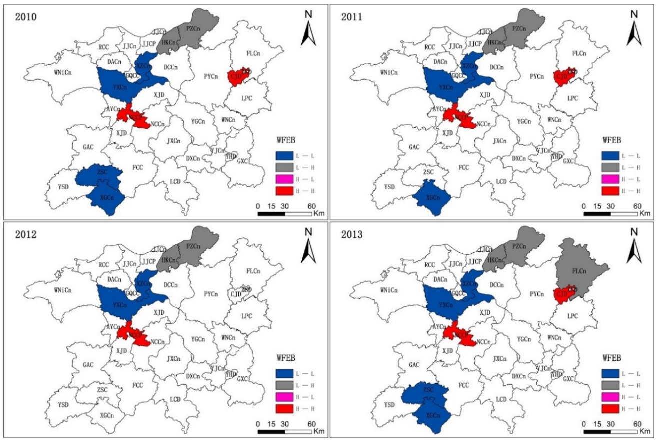

Fig. 4. LISA cluster map of the water footprint economic benefits in the Poyang Lake City Group

4.3 Spatial Spillover Effect of WFEB in the Poyang Lake City Group

The results of the above spatial correlation analysis quantitatively demonstrated: (a) a spatial effect of WFEB in the Poyang Lake City Group, (b) that a region’s WFEB was associated with its economic development, (c) that a region’s WFEB was also associated with the WFEB of the adjacent regions, and (d) that this autocorrelation identified the spatial dependence or spatial spillover effects of WFEB. Therefore, these spatial effects were deterministically analyzed using the spatial Durbin econometric model.

After considering the existing empirical studies and data accessibility, eight socio-economic variables were selected for analysis: WF waste rate (WFWR), per capita WF occupancy (PWFO), WF land density (WFLD), industrial structure (IS), foreign trade dependence degree (FTD), per capita water consumption (PWC), Total Retail Sales of Consumer Goods (TRS), and fixed-asset investment (FAI, million yuan RMB). Details about these variables are described below.

Water footprint waste rate (WFWR) is calculated as the ratio between urban wastewater quantity and water footprint, which reflects the effective utilization of water resources in the region. The lower this index is, the stronger the ability of the region to use water resources cleanly.

Per capita water footprint occupancy (PWFO; %) refers to the ratio of the total population in the region to the regional WF, which reflects the per capita WF in the region: the larger this value is, the more regional per capita WF there is; the larger the number of people supported and satisfied by the WF is; and the higher the WF of the region is, the greater the role and benefit of water resources utilization is.

Water footprint land density (WFLD; million tons/ km^2) is the ratio of the region’s WF to the region’s area, which reflects the amount of water resources consumed by a regional city in space. The higher this index is, the greater the water resource consumption is per unit area.

Industrial structure (IS) is closely related to water resource consumption structure, and its upgrade and adjustment will cause a change in the water resource consumption structure. It is expressed in this study as the proportion of total output of secondary industry in the regional gross domestic product (GDP).

Foreign trade dependence (FTD) refers to the proportion of the region's total foreign trade volume to the regional gross domestic product (GDP), reflecting the close ties between the region's economy and the international economy, which is one of the macro indicators for measuring the developmental level of a region’s open economy.

Water consumption per capita (WCP; tons/person) is an important indicator that comprehensively reflects the level of a region’s socioeconomic development and the development and utilization of water resources. It is closely related to regional water resources endowment conditions and its development and utilization, levels of social economic, scientific, and technological development, and water-saving level.

Total retail sales of consumer goods (TRS; billion yuan RMB) is the quantitative embodiment of social consumption, which reflects the change of people’s material and cultural living standards in a certain period of time and the degree of realization of social commodity purchasing power.

Fixed-asset investment (FAI; million-yuan RMB) is a measure that better reflects the extent of capital investment.

Table 3 presents the regression results of the dynamic SDM. The results showed the variables that significantly predicted WFEB were: WF land density, industrial structure, total retail sales of consumer goods, fixed-asset investment, and their spatial lagged factors. The regression model results were very good in terms of the R^2 and likelihood ratio.

Table 3. Regressions results of the dynamic spatial Durbin model

Variable	Coefficient	*Z* value	*p* value
Ln WFWR	-0.081***	-4.76	0.000
Ln PWFO	0.069*	1.88	0.061
Ln WFLD	0.062***	3.46	0.001
Ln *IS*	0.058***	2.60	0.009
Ln FTD	-0.018*	-1.94	0.053
Ln *WCP*	-0.022	-0.85	0.393
Ln TRS	-0.081***	-3.82	0.000
Ln *FAI*	0.097***	6.24	0.000
W * *Ln* WFWR	0.011	0.26	0.795
W **Ln* PWFO	0.518***	7.42	0.000
W **Ln* WFLD	0.058*	1.65	0.100
W **Ln* *IS*	0.252***	4.57	0.000
W **Ln* FTD	-0.052***	-2.58	0.010
W **Ln* *WCP*	0.242***	4.39	0.000
W **Ln* TRS	-5.254***	-29.84	0.000
W **Ln* *FAI*	3.010***	22.21	0.000
Y_{t-1}	1.084***	52.89	0.000
δ	0.128***	2.63	0.008
$R^2 = 0.990$ $N = 96$			

Notes: ***, **, * refers to significant at 1%, 5%, and 10% level, respectively. WFWR: Water footprint waste rate; PWFO: Per capita water footprint occupancy; WFLD: Water footprint land density; IS: Industrial structure; FTD: Foreign trade dependence degree; WCP: Water consumption per capita; TRS: Total Retail Sales of Consumer Goods; FAI: Fixed-asset investment.

However, the regression coefficients of the explanatory variables for the spatial Durbin econometric model cannot be considered marginal effects because of the existence of spatial autocorrelations, and the coefficients of their spatial lags cannot guarantee the existence of a spatial spillover effect. Therefore, the total, direct, and indirect effects that were calculated based on regression coefficients of the SDM, were used to quantify the effects of selected variables on WFEB and their spatial spillover effects. Direct effects (or local effects) represent the net effects of an explanatory variable in region *i* on the dependent variable in the same region. Indirect effects (or spillover effects) represent the net effects an explanatory variable in region *j* on the dependent variable in region *i*. Total effects are the sum of the direct and indirect effects. Table 4 shows the results of the direct, indirect, and total effects calculated based on Eqs. (12) –

Table 4. Total effects, direct effects, and indirect effects of the explanatory variables for water footprint economic benefits

	Direct effect		Indirect effect		Total effect	
	Coefficient	*Z* value	Coefficient	*Z* value	Coefficient	*Z* value
Ln WFWR	-0.082*	-4.74	0.018	0.49	-0.064*	-1.85
Ln PWFO	0.057	1.63	0.471***	8.11	0.528***	7.5
Ln WFLD	0.060***	3.46	0.048	1.58	0.108***	2.64
Ln IS	0.052**	2.44	0.224***	4.9	0.276***	5.39
Ln FTD	-0.016*	-1.8	-0.045**	-2.42	-0.061***	-2.97
Ln WCP	-0.028	-1.07	0.226***	4.39	0.198***	3.49
Ln TRS	0.174***	3.15	-1.406***	-33.6	-1.232***	-21.11
Ln FAI	-0.040	-1.26	0.758***	21.8	0.717***	18.07

Notes: ***, **, * refers to significant at 1%, 5%, and 10% level, respectively. WFWR: Water footprint waste rate; PWFO: Per capita water footprint occupancy; WFLD: Water footprint land density; IS: Industrial structure; FTD: Foreign trade dependence degree; WCP: Water consumption per capita; TRS: Total Retail Sales of Consumer Goods; FAI: Fixed-asset investment.

The total effects include the variables that had positive or negative associations with WFEB (see Table 4). The variables that had significant positive associations with WFEB were per capita WF occupancy, WF land density, industrial structure, water consumption per capita, and fixed-asset investment. The variables that had significant negative associations with WFEB were WF waste rate, foreign trade dependence degree, and total retail sales of consumer goods. Thus, it can be seen that increasing and decreasing these variables cam promote not only improvements in the WFEB of these cities, it can also promote improvements in the WFEB of other cities.

The variables that had direct positive effects on WFEB that were significant were WF land density, industrial structure, and total retail sales of consumer goods, whereas the variables that had direct negative effects on WFEB that were significant were WF waste rate and degree of foreign trade dependence (Table 4). Per capita WF occupancy, water consumption per capita, and fixed-asset investment were not significantly related to WFEB. The results suggest that controlling these variables for each city of the Poyang Lake City Group can promote improvements in the WFEB of those cities, but it cannot promote improvement in the WFEB of other cities.

Finally, Table 4 also shows the variables that had indirect effects on WFEB. Four variables had positive indirect effects on WFEB that were significant, including per capita WF occupancy, industrial structure, water consumption per capita, and fixed-asset investment. Two variables had negative indirect effects on WFEB that were significant: degree of foreign trade dependence and total retail sales of consumer goods. The indirect effects of WF waste rate and WF land density on WFEB were not significant. Thus, these results suggest that controlling these variables for each city of the Poyang Lake City Group can promote the improvement of WFEB of other cities, except their own city, but it cannot promote the improvement of the WFEB of local cities.

5. CONCLUSIONS

Based on the WF theory, this study employed ESDA analysis and the SDM model to investigate the evolution of spatiotemporal patterns of WFEB and its spatial spillovers in the 32 counties (cities or districts) of the Poyang Lake City Group in Jiangxi Province from 2010 to 2013. Several conclusions can be drawn from the findings.

First, from 2010 to 2013, crop products WF, animal products WF, and the residential living consumption WF in the Poyang Lake City Group showed a rising trend, and the animal products WF accounted for 43.13% of the total WF.

Second, from 2010 to 2013 the WFEB of the Poyang Lake City Group exhibited an increasing trend, and the number of cities in the Poyang Lake City Group that had high efficiency (>100) and sub-high efficiency ([75, 100]) increased steadily.

Third, the spatial distribution of the WFEB in the Poyang Lake City Group was not completely random; it exhibited spatial agglomeration between regions with similar values; that is, the higher value regions were clustered together. In addition, the spatial agglomeration in the Poyang Lake City Group was mainly Low-High and Low-Low types, which accounted for 9.4% and 12.5% of the four types, respectively.

Fourth, the WFEB in the Poyang Lake City Group showed spatial autocorrelation and convergence. Spatial spillover effects can help improve overall efficiencies across regions. Some variables can help augment spatial spillover effects, such as per capita WF occupancy, industrial structure, water consumption per capita, and fixed-asset investment. This, in turn, can help reduce the gap between efficiencies across regions, thereby improving the overall WFEB in the 32 counties (cities or districts).

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