

# A Review of Applying Spatial Modelling and GIS in Residential Water Use

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**Abstract:** Growing studies indicate that social geography characteristics and spatial interactions contribute to water sustainability management in residential water use. Recently, researches are being developed spatial decision support system by integrating spatial modelling with GIS, which clearly display the determined factors information of water consumption by the changing weights methods. Policy makers will use the tool to manipulate and evaluate the effective of water management strategies, and it is beneficial to analyse a range of alternative water conservation policies. Such studies and model applying are of great significance for reference in sustainable water management in China. Thus, this paper reviews the previous researches of spatial modelling and application in residential water use.

## 1. Introduction

More and more countries face the challenge of water security causing climate variability and rising populations. For alleviating water resource deficits, governments are developing policies and strategies of urban water sustainable management. [1, 2] Besides, many water suppliers have carried out water saving programs, such as water efficiency of residential programs, leak management programs, and seasonal water charge. [3] However, much water saving programs aim at water suppliers and are implemented at urban water provide scale, but neglecting the heterogeneity of spatial and temporal applying in residential scale. [4] Because of the wide difference in water use patterns between residential and urban water systems, it may influence the effectiveness of water conservation policy in residential water use. Thus, for achieving good results in the water conservation plan, we need to know the influencing factors, water patterns over space and time in residential water use, [5] and the application study in family water saving programs should be noted. Moreover, studying and analyzing the scalar dynamics within cities are of great significance for decision makers to develop relevant water management strategies. [6]

Sustainable urban water management requires accurate estimates in water consumption and the influencing factors based on a lot surveys. [7] Several studies have been carried out in different countries in order to determine the influencing factors in residential water consumption. However, most studies have been based on samples in America and Australia, it is critical to study in developing countries, especially in China. Thus, this paper reviews the literature of the spatial modeling and applied in



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residential water management, it is of great significance to promote the water management and conservation in residential in China.

## 2. Spatial Modelling and Influencing Factors in Residential Water Use

Exploring residential modeling and factors influencing water use have been conducted in various regions of the world. Prior researches indicate that higher water use is in line with lower water price, warmer climates, higher incomes, larger house sizes. [8-11] However, these studies limited to a small sample within a single community, and they only focus on weekly or monthly water demand rather than seasonal, [12] they do not quantify the interactions between influencing factors and not correlate static and dynamic analyses by composite analysis. The determined factors in residential water consumption may differ spatially as well as temporarily and resulting in different influence on water conservation policies. Hence, it is critical to know the dynamic process of water use as they relate to urban spatial structure and socioeconomic variables, [13-16] and examine the neighborhood effect on spatial aggregate scale. [17]

Previous researches have attached importance to the impact local spatial proximity in residential water use on the city scale, which indicate that water consumption patterns influenced by different neighborhood characteristics, such as the localized climate, socioeconomic, cultural, various water supply conditions in infrastructure and maintenance. Several studies have conducted spatial analysis on the census tract and census block group scales to explore controlling factors and spatial patterns of residential water use. [18] Table 1 summarizes spatial modeling and influencing of residential water use in the different area.

Table 1 Studies of spatial modeling and factors in urban residential water consumption

Study area	Factors (Impact on water)	Modeling
Phoenix [19, 20]	urban heat island effect (+); temperature (+); precipitation (-); the presence of garden and swimming pool (+)	Global Moran's I; Ordinary least squares regression (OSL); Spatial error regression
Portland [12, 21]	temperature (+); precipitation (-); building size (+); building density (+); building age (+)	Global Moran's I ;OSL; Spatial error regression
Austin and Salt Lake City [22]	Building age(-); Assessed value (+); percent impervious surface (-)	Global Moran's I ;OSL; Spatial error regression
Sydney [23]	Garden (+); land use (+); Water use behavior (+); demography (+)	Global Moran's I; spatial autocorrelation
Lincoln, Grand Island, and Sidney [24]	Housing units(+); Average household size(+); Building footprint(+); Housing density(+); Population density(+); Landscape area(+)	OLS; Pearson correlation coefficient; Global Moran's I; spatial correlation
Kelowna [25]	lots(+); building size (+); the presence of swimming pool (+); water use in bathrooms (+); water use in landscaping(+)	OLS; spatially autoregressive; spatially lagged regression

Researches show that different patterns in urban water consumption are attributed to socioeconomic, climate, space and time dynamics. [26] There is an urgent need for developing water demand studies because of climate change and environmental degradation, which can better predict and manage the residential water demand, water managers also receive benefit from being informed and empowered in the management task. Also the predictive accuracy of water management modelling will be improved apparently by integrating spatial indicators. [27] Spatial modelling is considered as the most important tool by presenting determine factors information that have been impacted water use. Besides, according to the improved spatial model, decision makers can also take action by adding extra infrastructure, developing saving water systems, taking seasonal and preventive maintenance. [28]

As state above, studies indicate that it is beneficial to maximize water conservation by taking advantage of the spatial effect. Taking full advantage of the spatial characteristic of residential water use, it can achieve more than three times water savings by the best spatial pattern of innovations than the worst. [29] Therefore, spatial models may be an effective tool for policy makers to strengthen sustainable water management by recognizing the city characteristics and bring the superiority of neighboring effects into full play.

### **3. Developing the Spatial Decision Support System for Residential Water Demand**

Many studies have been developed the spatial models in household water consumption, and the determinants are socio-economic and environmental factors. Spatial models are used for supporting policy decisions, but a majority of them are designed for the specifics study area and it rarely be applied in other locations. [30,31] Thus, these models are ineffective decision making tools for making optional policies and generally not adaptable in other regions. In view of these limitations, spatial support system based on GIS and spatial modeling becomes a practical tool for residential water management.

To assess the effect of urban development scale on water use patterns in Portland, Chang et al. [32] propose a differentiated methodological theory based on GIS and spatial analysis methods. Research explains the patterns of family water use in block groups, and explore the structural, environmental, and socio-economic characteristics differ across the regions. At the end of the research, for managing water and land resources effectively, they develop a water demand side framework by integrating the urban spatial factors with urban development policies.

Coping the water demand policy measures which are imposed by the Queensland government during the drought years, Shearer et al. [33] studied the main factors of single residential water use by using GIS. Based on spatial analysis and GIS, the research provides a map displaying the relative information of water use on urban spatial scales, and various characteristics such as socio-demographic and urban structural variables. Furthermore, they carried out a decision support framework for decision makers, which is capable assesses water demand more accurately by an objective aggregation method. [12]

The main need for decision makers is a fully integrated information system and deliver the immediate results, they can make policy according to the system and adjust the management strategies on the basis of the spatial and temporal differences. [25] GIS has been used for organizing and analyzing spatial data, it is suitable for investigating the effects on the performance of policy maker in spatial scale. [34] Taking account of all socioeconomic and environmental characteristics in a spatial model, we can observe the interaction effects between factors and water consumption. The spatial decision support system put the merits of GIS and spatial model into full use, it can identify determined factors by the changing weights methods and directly produce color maps displaying these factors information of water consumption. [35]

### **4. Future Perspective of Spatial Modelling in Residential Water Use in China**

Water resources are unevenly distributed in China, water allocation, use status and efficiency various in different regions. Water distribution is not in the same way as population, most of the water is in the south, whereas more than 40% of the population lives in the north. Furthermore, residential water use different apparently over the provinces in China, and the patterns of water consumption show spatial aggregation. Figure 1 shows the distribution of residential water use in China.

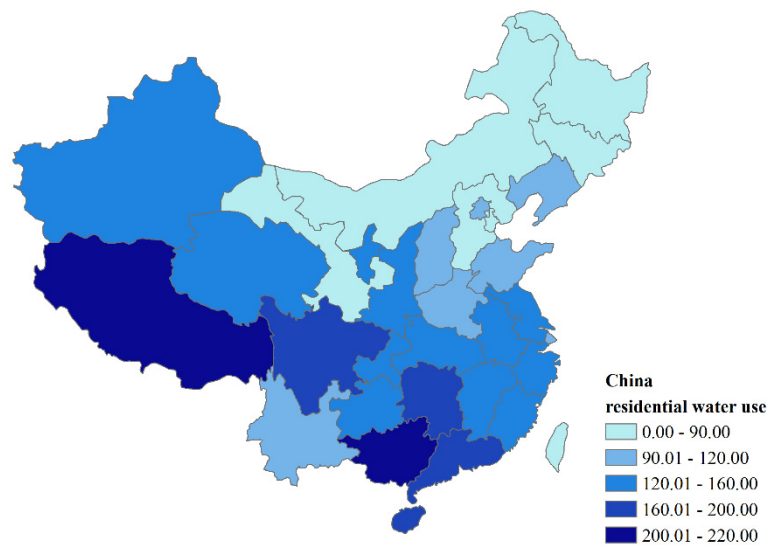


Figure 1. The distribution of urban residential water use in China (Due to lack of water consumption data in Taiwan, 0 L/ per·d shows in this figure)

In the eastern part of China, Heilongjiang province and the Inner Mongolia autonomous region have the lowest urban residential water consumption per capita, 68.45 L/ per ·d and 70.99 L/ per ·d, respectively. The water consumption in northeastern and northern of China is lower than 100.00 L/ per ·d, the highest of the regions is 99.68 L/per ·d in Beijing. Shandong province and Hunan province are the lowest and the highest residential water consumption in eastern and central China, which is 94.59 L/per ·d and 183.15 L/per ·d. Residential water consumption in three provinces in south China is distributed between 173.98 L/per ·d and 200.72 L/per ·d. In the western part of China, the distribution of household water consumption in the northwest and southwest regions is 87.55-139.67 L/per ·d, 111.26-207.32 L/per ·d, respectively. It is obvious that the residential water use has strong spatial characteristics according to the water use data in the year of 2016. However, what are the main factors of household water use in urban cities in China, how do factors vary in seasonal and spatially, how the neighboring effects influence water consumption and how can decision makers develop better policies according to the urban basic conditions, these questions need to be solved.

In recent years, increasing water resources demand has been needed to satisfy the rapid development of cities and population growth. The average daily water consumption per capita in China increased from 204.07 L/ per·d in 2005 to 285.83 L/ per·d in 2016. The proportion of residential water use in total urban water consumption is up to 45.00% in 2016, which is the most water use in urban water demand. Thus, it is obvious that saving water in residential will make a great contribution to the urban water conservation programs. To resolve the water crisis, better management plans and saving water strategies should be developed. Such studies and spatial models applying researches are of great significance for reference on the sustainable water management in China.

Spatial decision support systems for residential water use are developed in many studies by integrating the spatial modeling and GIS, which can output maps clearly displaying the different factors. The system also provides the flexibility in evaluating the changing determinants factors and offering benefits for local government to analyze feasibility policies. There is a large need for conducting spatial residential water use researches under the condition of changing global and local environments, which can provide water managers a more efficiently working tool and information support in residential water demand management in China.

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