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Abstract
This paper aims at estimating a residential water demand function for the city of Fortaleza, Brazil, considering the potential impact of spatial effects on water consumption. The empirical evidence is a micro dataset obtained by means of a household survey of water consumption in 2006. We estimated three econometric models, which had as explanatory variables the average price, the difference, income, number of residents and the number of rooms, under different spatial specifications: the spatial error model (SEM), the spatial autoregressive model (SAR), and finally, the spatial model autoregressive moving average (SARMA). The results show that spatial autocorrelation exists in two forms (error and lag), indicating that the SARMA specification is the "best"as shown by a series of tests. Such results are in contrast to that suggested by Chang et al. (2010), House-Peters et al. (2010), Franczyk and Chang (2008), Ramachandran and Johnston (2011), who favored the use of the SEM model. Our results point out to the necessity of considering spatial effects in the estimation of residential water demand, since the absence of spatial effects is a key misspecification error, underestimating the effect of important variables such as average price and number of residents, while overestimating the effect of other variables such as income and number of rooms.

Key words: Spatial Effects, Spatial Regression, Water Demand, Natural Resources
JEL Code: C21, Q21, Q25

1. INTRODUCTION

Even though water is one of the most important natural good for maintenance of life in earth, the way man have been dealing with this resource is far from optimal. Some researches point out that the instability between supply and demand of water (with supply lower than demand) will be one of the greatest problem faced by humanity in a not so far future (Glenn, Gordon, and Florescu, 2009; FAO, 2011). It is estimated that in 2025, around 3 billion people will not have access to fresh water. That will represent approximately 60% of the world population, according to Glenn, Gordon, and Florescu (2009).

In the past, classical economists considered water as a renewable natural good. Thus, water was considered a common good. In another words, everyone could use it as much as they wanted with no costs. However, this point of view prompted the use of water in a non rational way. In fact, it led to a waste of such precious good. Water may be a renewable resource, but disrespecting its natural cycle may turn water into a scarce resource. In this sense, water becomes an economic good with monetary value.

The warning regarding water scarcity raised the need for policies that could fight against a potential lack of water in the world. These policies could follow two ways: the first one would be by means of water supply management, and the second one would be by water demand control.

Until the mid-1950, the policies to fight against water scarcity focused in the supply side (see, Arbués, García-Valiñas, and Espiñeira (2003)). Such policies aimed at the creation and enlargement of reservoirs in order to boost fresh water supply. However, with the increasing expansion of water demand caused by population and economic growth, society realized that the best way to tackle water scarcity would be by controlling water demand. However, this new perspective over water management demands a deeper knowledge of household behavior [1].

From that perspective, Gottlieb (1963) and Howe and Linaweaver (1967) tried to explain the main determinants for water consumption. As a main result, the price of water got an important role to control its consumption. Since then, a wide literature regarding residential water demand estimation has been developed indicating the main variables that influence water consumption and the techniques of estimation to be employed.

A line of research that has not been explored in the literature yet is how spatial effects might influence water demand. Franczyk and Chang (2008) point that "the standard of water consumption cannot be explained by economic and population growth only, but also by biophysical and socioeconomic factors that usually have spatial dependence". Following the same line House-Peters, Pratt, and Chang (2010) suggest that "residential water consumption is not affected by socioeconomic, climate and physical variables only. But it is also affected by geographical location and its interaction with nearby regions."

Therefore, incorporating spatial effects into the analysis of residential water demand could provide a wider and more accurate explanation about water consumption variations. Papers like House-Peters, Pratt, and Chang (2010), Guhathakurta and Gober (2007), Chang, Parandvash, and Shandas (2010), Wentz and Gober (2007), Franczyk and Chang (2008), Ramachandran and Johnston (2011)

[1] According to Gonçalves (2006) and Cohim, Garcia, and Kiperstok (2009) "the consumption featuring inside a household is important ... for rational use of water. In another words, the more detailed is the knowledge about consumption the more efficient is demand management".

have recently aggregated spatial effects in their studies, increasing the significance of their models, compared to other models that do not use such effects. Based on that series of papers, we believe that our endeavor has its own merits. First, because estimation of water micro demand models with spatial effects is quite new in the international literature and absent in the national literature. Second, by aggregating new methodological procedures we can comprehend better the factors that influence residential water demand. Therefore, this paper aims to analyze water demand using spatial econometric techniques, although, in an exploratory way.

We have at our disposal information from a study field in the city of Fortaleza, Brazil (It is the state capital of Ceará, located in Northeastern Brazil. The city has a population close to 2.5 million and it is the 5th largest city in Brazil with an area of 313 square kilometers and one of the highest demographic densities in the country (8,001 per km^2), see the localization in Figure 1., page 6). The database houses information from a research project carried out by a group of researchers from UECE and UFC (State University of Ceara and Federal University of Ceara, respectively) for CAGECE (Water and Sewage Company of Ceara) (see, UECE, CAEN, and NPTEC (2006)). It applied more than 3,000 questionnaires containing socioeconomic and physical characteristics information from the household. Plus, CAGECE provided information about the monthly water consumption.

From a series of test procedures and econometric exercises, we confirm the importance of considering spatial effects, since the exclusion of those effects overestimates the impact of income and total of rooms over water demand while it underestimates the impact of average price and the total of residents. Although our results are of an exploratory nature, we believe they will open the way for a better understanding of how space matters for water micro demand estimation.

Besides this introduction and a section discussing final considerations, this paper has four more sections. Section 2 gives a brief explanation on how water is seen as an economic good, as well as a brief literature review on residential water micro demand estimation. Section 3 presents the database used in this work and the results of an exploratory spatial data analysis. Section 4 sets up the demand function to be estimated with a non-linear tax structure. Also, we present the econometric models used in this paper, such as the Spatial Error Model (SEM), the Spatial Autoregressive model (SAR) and the Spatial Autoregressive Moving Average model (SARMA), together with the tests used to (mis)specification analysis. Finally, Section 5 presents the results from the econometric model estimation.

2. RESIDENTIAL WATER DEMAND

Over the last years, the perspective of water scarcity has become a pressing problem faced by humanity. The lack of such important natural resource produces a devastating effect on humanity. According to Europarl (2009), the spread of diseases by contaminated water represents 80% of the total of ill people and death in developing countries. Moreover, a lack of water to be used in agriculture could lead to absence of food, causing a scene of food insecurity in the planet (FAO, 2011). Among the causes that could lead the world into this dark picture of scarcity, we may quote the population growth, the changes in weather, the lack of good management practice of water resources and, overall, the pollution of water sources and the waste of it.

Over decades and still today, a lot of people see water as an inexhaustible natural resource. This point of view makes them use water in a non rational way, wasting such important resource for

Figura 1: City of Fortaleza

maintenance of life in the planet. A report published by ISA (2007) (Socio Environmental Institute), estimated that in Brazil, in 2004, for every 100 liters of water taken from the sources that feed Brazilian capitals, 45 liters were lost in the distribution system. This value is extremely high if compared with countries like USA and France. In these countries the volume of wasted water reaches only 12 and 9 liters, respectively (Miranda and Koide, 2003).

But the waste of water does not occur in the distribution system only. It also occurs by the irrational and inefficient use by people in their households. While the per capita average consumption recommended by ONU is 110 liters of water per day, in Brazil the per capita average consumption is 150 liters per day, reaching 220 liters per day in capitals like Rio de Janeiro, Vitoria and Sao Paulo (ISA, 2007).

Compounding the problem of water scarcity, both population and economic growth over the last years has increased water demand. Therefore, a interaction between a contracted supply and an expanded demand increases the scarcity of such important resource. If no decision is taken, the trend in the long run would one of water scarcity for the majority of the global population. That is why it came out the need to create policies that aims fighting against the potential lack of water in the planet.

Until mid-1950, the policies to fight against a possible water scarcity focused in the supply side (Arbués, García-Valiñas, and Espiñeira, 2003). Such policies aimed the creation and enlargement of reservoirs, keeping the demand away from the main issue. From the beginning of the 1960s, and after the works of Gottlieb (1963) and Howe and Linaweaver (1967), it was realized that the best way to tackle water scarcity would be by controlling water demand. This process would avoid waste of water and would use it in a more effective way.

According to Milutinovic (2006) there are three ways to control water demand. The first one would be via price of water. The more people pay for water consumption the better they would use it in a rational way. The second way would be via public policies such as awareness of population, restrictions to water use etc. Finally, the last way would be by changes in technologies, developing new procedures that increase the efficiency of water use and decrease the consumption of it. In this work we will focus in control via price of water.

In the past, water did not have a price. It was regarded as a common good and it was available to the use of all. In classical economics, not only water but all the natural resources were regarded as determinants factors for production. In neoclassical economics, the natural resources were no longer seen as an obstacle to growth economic. For the neoclassical economists, the growing incorporation of technology in productive processes would solve the problem of natural resources scarcity so that economic growth would be continuous and not constrained. Besides that, they considered that natural resources were abundant and immutable, never facing scarcity. Therefore, natural resources were considered common goods with no economic value and available for everyone to use it in the amount they wanted. So, natural resources, including water, were subject to the tragedy of common. This represents a situation in which a resource is overused (wasted) causing inefficiency and, consequently, a lack of the good.

From the mid-twenty century, when people realized the problem of scarcity, water began to be seen as an economic good and, thus it came to be valued. As Araújo (2007, p. 1) quoted, "the economic value of water is due to its scarcity". Therefore, the pricing of water is seen as a form of conservation and protection of such natural resource, as explained by the Dublin Statement (1992, apud ARAÚJO, 2007, p.1):

> "Water has economic value in all of its uses and it must be recognized as an economic good ... . In the past, the not recognizing of water with economic value led to its waste and environmental damage resulting from its use. The management of water as an economic good is an important way to reach efficiency and equity in its use, and to promote its conservation and protection".

In Brazil, Federal law N^{o} 9433/97 establishes a national policy for water resources. In this law it is determined that "water is a limited natural resource with economic value". Also, it determines that charging water use must reach three goals: recognize water as an economic good and give to water user an indication of its real value; encourage rational use of water; and obtain funds to finance policies and intervention contemplated in water resources plans (Araújo, 2007). Therefore, Brazil also recognizes that charging water use is an important economic instrument of environmental policy when it leads to rationalization consumption by charging a fee.

To understand how charging water use affects its consumption, it is necessary to know the factors that determine water demand. As quoted by Gonçalves (2006) and Cohim, Garcia, and Kiperstok (2009), "the characterization of residential consumption is fundamental in determination of priority actions in the search for water rational use. In another words, the more detailed is the knowledge of consumption the more efficient is the demand management". In this sense, several studies have sought to characterize water consumption all around the world in order to provide a technical work that could be used as a support to implement policies aiming a more efficient water demand. Of course, for our purpose, the literature about econometric estimation of water micro demand embodies our way of characterizing the “structure” of water consumption under investigation. Next, we present a brief literature review on water demand estimation by econometric models.

3. RECENT LITERATURE ON WATER MICRO DEMAND ESTIMATION

3.1 Traditional Models

Since the studies of Gottlieb (1963) and Howe and Linaweaver (1967), several researchers in many countries have carried out studies to estimate a residential water demand function for its regions in order to provide technical work as a support to implement policies aimed at controlling water demand and promoting its rational use and conservation.

Agthe, Billings, and Dobra (1986) in a study for Tucson, Arizona (USA) proposed a model where water demand was a function of marginal price, of difference, of family income, and of climate variable defined as evapotranspiration less precipitation in inches. To solve the problem of endogeneity, Agthe, Billings, and Dobra (1986) used an instrumental variable approach. The authors found that, except for family income, all the variables were statistically significant. Regarding the price elasticity of demand they found an estimated value of -0,624 indicating that water is a good with inelastic demand. Moreover, they found that water presents price elasticity of demand greater in the long run than in the short run, as most of commodities.

In a study carried out in Indonesia, Rietveld, Rowendal, and Zwart (1997) used Burtless and Hausman methods, by means of a maximum likelihood estimation. They used this technique to estimate a residential water demand function for the city of Salatiga in Indonesia. They used as independent variables: marginal price, number of residents, virtual income, a dummy that indicates if the residence has access to alternative source of water, and a variable defined as the output of virtual income and marginal price that aims to turn price elasticity into a changeable variable. Also, the authors showed that the only variable not statistically significant was the virtual income. Also, they found that the water demand in Salatiga is extremely sensitive to its price since the estimated mean value of price elasticity of water demand is -1.176, indicating that water demand in that region is elastic.

Binet, Durand, Paul, and Carlevaro (2005) estimated a residential water demand function for the tropical island La Réunion. Such island belongs to France. To explain the water consumption pattern from those who live in the island, they proposed that the factors determining water consumption were marginal price, difference, a proxy variable to income, a climate variable measured by the total of raining days in a year, the residents age, the total of people that had a job, and if the house had a yard. They used the instrumental variable method. Interesting, although Binet, Durand, Paul, and Carlevaro (2005) affirm that the price structure has an important role in demand control, this must be done in an indirect way, by the income effect.

Finally, in Asia, Miyawaki, Omori, and Hibiki (2011) estimated the residential water demand in Japan. More specifically, in Tokyo and Chiba. They used as dependent variables: marginal price, virtual income, total of people living in the same house, total of rooms in the household, and the residence size. They used a maximum likelihood model. Miyawaki, Omori, and Hibiki (2011) pointed out that both the total of people living in the same house and the total of rooms presented a positive correlation with water demand. The residence size did not present any effect on water demand. As to the price elasticity of demand, the authors found an estimated value of -1.09, which means that in Japan water seems to be a good with elastic demand.

In Brazil, the literature about residential water demand estimation is still new. One of the first papers that had such approach was Andrade, Brandão, Lobão, and Silva (1995). They estimated a function of residential water demand for the state of Parana. In order to determine which factors affect water demand, the authors used the following variables: marginal price, difference, income and total of people living in the househould. Since Sanepar (Sanitation Company of Parana) adopted a tax structure in rising block, the authors faced a problem with endogeneity. To solve this problem they used McFadden method. This method creates a proxy variable to marginal price, not correlated to random error. Andrade, Brandão, Lobão, and Silva (1995) found that the marginal price elasticity of demand is inelastic. The estimated price elasticity is -0.24 indicating that a reduction in water consumption occurs in a lower proportion than a price increasing. As to the difference elasticity, the authors found an estimated elasticity of 0.05. The positive value indicates an embedded subsidy for families who consumed from 10 m^3 and up. In other words, for those families who consumed from the second block of consumption and on. Regarding the income and the total of people in the same house, the authors found that income does not have a significant effect on water consumption. The explanation for such result would be the lack of variability in family size presented in the sample.

Estimating a residential water demand for the city of Piracicaba, São Paulo, Mattos (1998) proposed that the variables determining residential water demand in that city would be the marginal price, difference, total of residents, familiar income, temperature and precipitation. Mattos (1998) used the OLS model, the instrumental variable, the McFadden method and the 2SLS model. Mattos (1998) found that only the marginal price and the difference were significant, explaining 71% of water consumption variation. They found an estimated value of -0.21 for the price elasticity of demand. This value is very close to the one found by Andrade, Brandão, Lobão, and Silva (1995).

Using data from “Banco do Nordeste” (BNB), Melo and Neto (2007) estimated a function of residential water demand for Northeast of Brazil. The variables explaining water demand were be average price, marginal price, income, how long the residents were living in the same place, total of room, and the average age of the head of household. To solve the problem of endogeneity due the rising blocks tax, Melo and Neto (2007) used Burtless and Hausman method. Such methods aggregate the information about the entire consumer’s budget constraints, modify the problem of maximization, turn the budget constraints into non linear function, and remove the bias caused by traditional methods (Melo and Neto, 2007).

Finally, Brasil (2009) estimates a residential water demand throughout the state of Ceara. From a database collected in a survey carried out by CAGECE in 2006, Brasil (2009) proposed to estimate a demand model where the variables that could explain water consumption would be average price, difference, family income, total of people living in the same residence, total of rooms, monthly average temperature, assessment from consumer about the quality of consumed water, assessment from consumer about the regularity of water supply, plus an assessment from consumer regarding quantity of consumed water. To solve the problem with endogeneity, Brasil (2009) estimated the proposed model via clustered OLS using first differences. She showed that an increase of $1 real in both average price and difference is responsible for a decrease of water consumption of 0.56 m^3 and 0.23 m^3, respectively.

3.2 Models that Incorporate Spatial Effects

When we handle data that deals with location, it comes out two types of problem that, if ignored, it may cause serious problems to the estimative obtained by traditional econometric techniques. Such problems are: spatial dependence and spatial heterogeneity. For spatial dependence we mean a situation where an observation of a given variable at place i depends on the observations in other location $j \neq i$. According to LeSage (1999), there are two reasons why such spatial dependence exists in a sample. The first one would be measurement error. In a sample created from observations associated to spatial units, such as municipalities, states, census divisions and so on, the administrative boundaries may not reflect, in an accurate way, the nature of the process that is being analyzed. Now, according to Anselin (1988), the second factor that causes spatial dependence in a sample "is the most fundamental and comes from the importance of space as an element in the construction of explanation on human behaviour". Still according to him, "the essence of regional science and human geography is that both location and distance are important, and the result is variety of interdependence in space and time". Thus, it is expected that there is spatial dependence in situations where both sociodemographic and economic characteristics, plus the regional activity, are an important aspect for modeling the problem.

Spatial heterogeneity refers to a situation where the relation among variables varies in space. In other words, there is a different relation in each point of space (LeSage, 1999). Anselin (1988) says that besides this lack of stability in relations through space, the region heterogeneity - that in general has different socioeconomic characteristics - is measured by error, what may cause heterocedasticity.

Thereby, we need a new theoretical approach to model problems where spatial issue has an important role to explain the phenomenon studied. In this sense, spatial econometrics has been used to explain several socioeconomic problems - such as problems related to regional development, criminality, contagion and, of course, residential water demand. However, in the specific case of water demand there are few studies in international literature and none in the national one.

In the case of residential water demand, according to House-Peters, Pratt, and Chang (2010), residential water consumption is not affected by residential socioeconomic, climate and physical variables only but also by region geographic location and its interaction with nearby regions. As consequence, nearby residences tend to present similar water consumption. So, it is expected that water consumption present a spatial dependence. Spatial dependence on water consumption is associated with the fact that the variables determining water consumption, such as infrastructure, socioeconomic and climate variables, tend to present a spatial distribution pattern. These variables end up affecting water consumption not only by its direct effect, but also by an indirect way through the effect of spatial association patterns, which is the spatial correlation of errors.

Aware over this problem, some authors started to include spatial effect in their analysis and sought to explain the spatial association pattern for water consumption. Wentz and Gober (2007) used GWR model (Geographic Weighted Regression) in a study for Phoenix, USA to verify if there was any additional contribution of spatial effect over the results obtained by OLS model (Ordinary Least Square). The authors verified, by means of the GWR model, that the importance of spatial effects reduces to two variables that determine water demand. The variables are: residence size and if there was a swimming pool in the residence. In another words, since there is a spatial pattern of residential distribution that has those characteristics, these variables represent similar water consumption. They found that any policy that aims decreasing water consumption by controlling the construction of swimming pools, the residence land size, or the type of vegetation in garden's house, will have different effects on different parts of the city. This conclusion was possible due to the fact that GWR model estimates a different coefficient for each region in the city.

For the state of Oregon (USA), Franczyk and Chang (2008) realized that water demand was not explained by both population and economic growth only, but also by other biophysical and socioeconomic factors that in general present spatial dependence. The authors used Spatial Erros Model (SEM), besides the OLS model, to include spatial autocorrelation effects into the problem. They used Moran-I statistics and showed that there is spatial dependence of errors. Also, they found that the inclusion of such effect increases the significance of factors that determine water demand.

For the city of Portland (Oregon, USA) Chang, Parandvash, and Shandas (2010) identified a spatial association pattern for water demand. They identified that the areas where water consumption was higher coincided with the areas which the residence size was big and with the areas where both building density and age of buildings were low. Besides the OLS and SEM models, the authors used the Piecewise Linear Regression model (PWLR), dividing both the residence size and the building density into two ranges. As in the Franczyk and Chang (2008)'s work, the model that better explained water consumption variability was the SEM model.

House-Peters, Pratt, and Chang (2010), in a study for the city of Hillsboro (Oregon, USA), analyzed the climate effects on water demand. Using spatial analysis techniques, the authors found that, although water demand in that area was not sensitive to dry conditions at all, specific areas presented higher water consumption under such conditions. Also, the authors showed that in areas where water demand is more sensitive to weather, these areas presented higher concentration of new and big residences, with high value and with residents with higher education level.

Ramachandran and Johnston (2011) analyzed if spatial effect influenced residential water demand for external use in the city of Ipswich (Massachusetts, USA) while a restricted use of water policy was in effect. The authors said that decisions about house landscape and the use of water to keep the landscape depended of both economic and social factors. In the first case, if the landscape influenced house's price sale, and in the last case for imitation, since people tend to copy the format and vegetation used in gardens close to their house. As a result the authors found that during the time the restriction was imposed spatial effect did not affect water use. This fact indicated that people made a special effort not to mimic the neighbor's water consumption pattern. However, during the time that the restriction was not imposed, the spatial effect was statically significant to explain water consumption pattern.

In Brazil, the literature about spatial effects on water demand econometric estimation does not exist. In this sense, this work aims to fill this gap aggregating such effects in the analysis of residential water demand in Fortaleza. Next section will present the database used in this work. Also, it will be carried out an exploratory analysis over the data.

4. DATA SET

4.1 The Sample

A total, 5,444 interviews were conducted in 56 municipalities of Ceara in February, 2007. Also, CAGECE tracked water consumption during 10 months (from August, 2006 to May, 2007) in the residences that participated in the survey (Brasil, 2009). Since our main goal was to estimate residential the water demand for the city of Fortaleza, we collected only information over consumers from that city. Thus, the final sample for the city of Fortaleza has 3,020 observations, as shown in Table 1.

Tabela 1: Descriptive Statistics of Variables

Variable	Obs	Mean	Median	Stand. Desv.	Min	Max
Water consumption (m^3)	3020	16.98	14.0	13.54	1	294
Property feature (Class)	3020	2.6983	3.0	0.5604	1	4
Residents ($N^{\underline{o}}$)	3020	3.8403	4	1.6222	1	9
Residents' age (Years)	3020	36.0887	33.63	14.0125	0	90
Family income (Class)	2940	2.3574	2.0	0.9717	1	4
Eduaction (Class)	3016	2.5145	3.0	0.9950	1	4
Living rooms ($N^{\underline{o}}$)	3020	1.2195	1.0	0.5203	0	4
Kitchens ($N^{\underline{o}}$)	3020	1.0043	1.0	0.1754	0	3
Bedrooms ($N^{\underline{o}}$)	3020	2.2754	2.0	1.1098	0	10
Bathrooms ($N^{\underline{o}}$)	3020	1.5473	1.0	0.8747	0	8
Gardens ($N^{\underline{o}}$)	3020	0.2476	0	0.4482	0	3
Rooms ($N^{\underline{o}}$)	3020	6.4387	6	2.3625	0	23

Source: Elaborated by authors

The data presented shows that residential water consumption in February 2007 for the city of Fortaleza was 16.98 m^3, on average. The median of 14 m^3 indicates that half of residences in Fortaleza are in CAGECE's second consumption block[2] (10 m^3 to 15 m^3). This might be not good for CAGECE if the tax structure is poorly designed.

As to socioeconomic characteristics, on average, each household has 4 residents and these residents are 36 years old. The families have an average monthly income of 2.35, which indicates that these families are between the class that earns more than a minimum wage and up to 2 minimum wage, and the class that earns 2 minimum wage and up to 5 minimum wage. For education, the respondents' average education was 2.51, something between the class that has fundamental education and the class that has completed high school.

As to the physical characteristics of households, the residences have, on average, 6.5 rooms, distributed in the following (on average): 1.21 living rooms, 1 kitchen, 2.27 bedrooms, 1.54 bathrooms and 0.24 gardens. The average rating of property feature is 2.69, indicating that the residences are classified between medium and regular categories.

[2] Tariff Structure on 13

Turning into the issue of prices, CAGECE applies an increasing tariff system in consumption blocks, as shown in Table 2. The tariff structure applied by the company looks for the following: i) allow all citizens access to services; ii) encourage rational water use; iii) finance the continued delivery of services; iv) allow investments to expand services; and v) maintain the economic and financial stability.

Tabela 2: Values of Tariff Structure by Consumption Group - February, 2007

Water consumption (m^3)	Price by m^3
[0 , 10]	R$ 0.98
(10 , 15]	R$ 1.56
(15 , 20]	R$ 1.65
(20 , 50]	R$ 2.80
(50 , ∞)	R$ 4.95

Source: Elaborated by authors

In this charging mechanism, the price paid by consumer is calculated in a "cascade way"; in another words, the total amount consumed is divided into consumption blocks where each part is charged by the rate established to that block as shown in the Equation 1.

$$P = \begin{cases} 0,98.10, \text{if } q \in [0,10] \\ 0,98.10 + 1,56.(q-10), \text{if } q \in (10,15] \\ 0,98.10 + 1,56.5 + 1,65.(q-15), \text{if } q \in (15,20] \\ 0,98.10 + 1,56.5 + 1,65.5 + 2,80.(q-20), \text{if } q \in (20,50] \\ 0,98.10 + 1,56.5 + 1,65.5 + 2,80.30 + 4,95.(q-50), \text{if } q \in (51,\infty) \end{cases} \quad (1)$$

Finally, since our focus is the spatial effect on water demand, Figure 2 presents the sample's spatial distribution over the city of Fortaleza. We can see a relatively well distributed pattern. However, some neighborhoods (*bairros*) are highlighted, such as: Centro, Praia de Iracema, Benfica, bairro de Fátima, Itaperi, Serrinha and Messejana.

There are two possible criticisms that may arise regarding the use of this database: the first one is that the sample was not developed for the city of Fortaleza; the second one is the presence of clusters. To justify the first problem, due to technical impossibility to georeference all address in inner cities of Ceara, we preferred to use data for the city of Fortaleza only. Regarding the presence of clusters in the sample, we are aware that this problem may affect the coefficient estimatives. However, we will ignore such possibility, since we do not have a specific sample set up for a spatial analysis. Now that the database and its spatial distribution were presented, an exploratory analysis over the data will follow.

4.2 Spatial Exploratory Data Analysis

In order to check the hypothesis that spatial effects have an important role to explain residential water demand, we will verify if water consumption presents any pattern of spatial association. The most well known spatial correlation index is the Moran-I statistic, that ranges from -1 to 1. It provides a general measure of spatial association that exists in a data set. Hence, we stick to the literature and use the Moran-I statistic to test for global spatial association, and the local Moran-I statistic to test for local spatial association, besides the significance's and clusters' maps.

Figura 2: Sample Spatial Distribution by *Bairros*

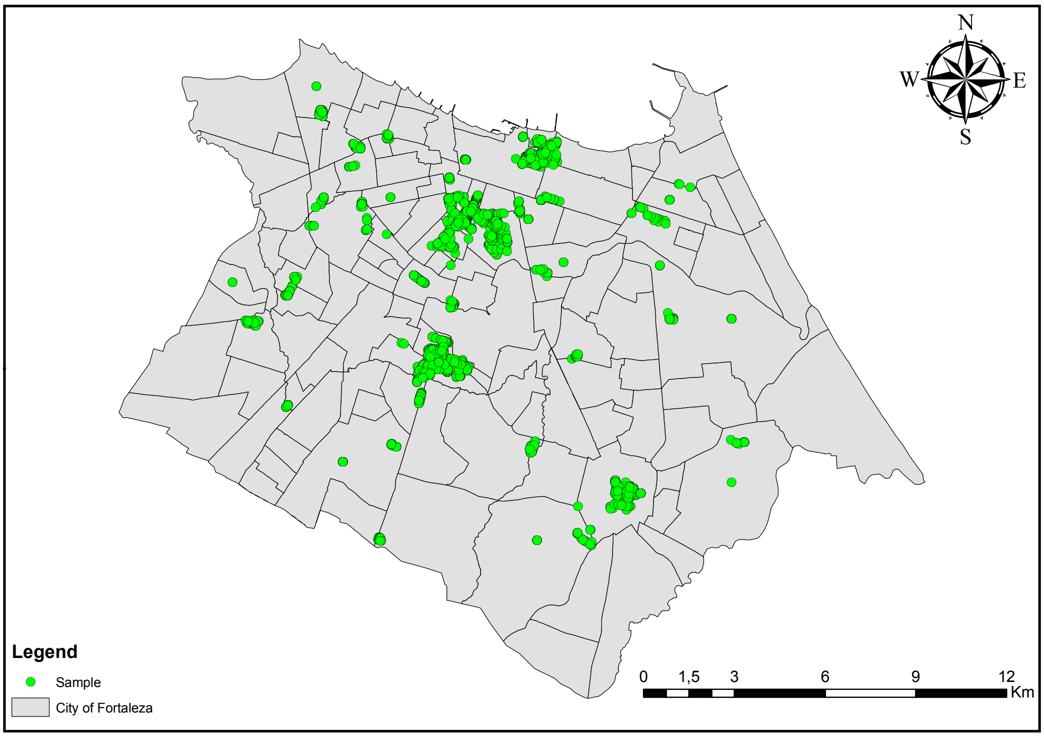


Tabela 3: Moran-I Statistic for Water Consumption

Moran-I statistic	Mean	Variance	p-value
0,039365	-3.31e-04	6.0e-07	$<$ 2.2e-16

Source: Elaborated by authors
Nota: empirical p-value based on randomization method

The results presented in Table 3 show that Moran-I is 0.03, a value that exceeds the statistical average, but it is very close to zero, which indicates that there is no spatial autocorrelation in water consumption. However, although this value is close to zero, it is statistically different from zero, once the pseudo p-value is extremely low and indicates that there is a positive spatial autocorrelation, even in a very reduced magnitude.

However, not always the global pattern of spatial association reflects the local pattern of spatial association. Anselin (1995) asserts that global statistics of spatial association are not able to identify the occurrence of local autocorrelation, since the global statistics may hide local association patterns through indication of global autocorrelation absence, or may mask the association patterns as clusters or spatial outliers through indication of a strong global autocorrelation. In this sense, the LISA index (Local Indicator Spatial Association) is used to overcome this obstacle and capture local patterns of linear association.

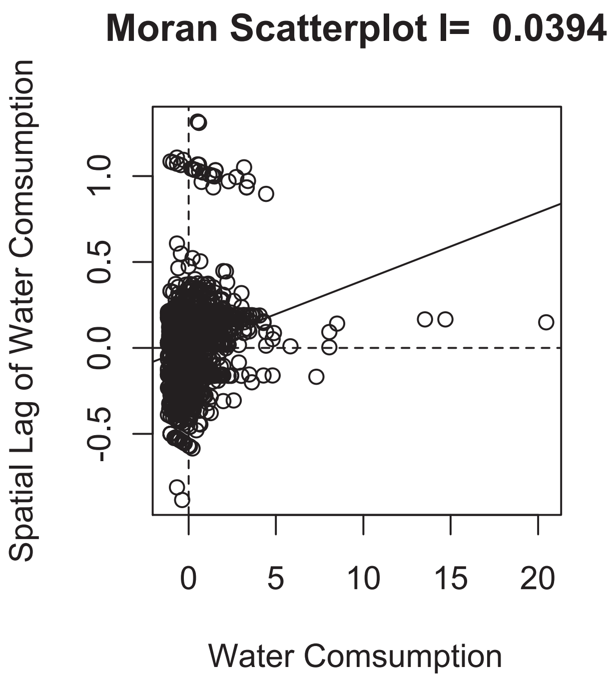
The most well known LISA statistic, the local Moran-I, is derived from a global indicator of autocorrelation that decomposes the local contribution of each observation into four categories. Each category corresponds to one quadrant in the Moran dispersion diagram. According to Anselin (1995), we may represent the local Moran-I in the following way:

$$I_i = \frac{(y_i - \overline{y}) \sum_j w_{ij}(y_j - \overline{y})}{\sum_i (y_i - \overline{y})^2 / n} \qquad (2)$$

Where:
n = number of observations
y_i = observation for the studied variable in region i
y_j = observation for the studied variable in region j
$\overline{y}$ = mean for the studied variable
w_{ij} = matrix element W that corresponds to distance between i and j regions.

According to Almeida (2004), "the intuitive interpretation is that the local Moran-I provides an indication of the clustering degree of similar values around a specific observation, identifying spatial clusters statistically significant". In order to analyze the local Moran-I, we used the Moran dispersion diagram and both the Moran dispersion (clusters) and the significance maps, which are presented next. The diagram is a way to interpret the Moran-I statistic. The Moran-I is the angular coefficient of a regression between the variable under analysis and its spatially lagged values[3].

Figura 3: Moran Dispersion Diagram



The results presented in the dispersion diagram (see, Figure 3) show that there is a tendency of positive autocorrelation with the observations distributed in the first and third quadrants. As to the significance map, Figure 4(a), on page 17, shows some clusters that are not significant, being represented in white, while the significant clusters are presented in green.

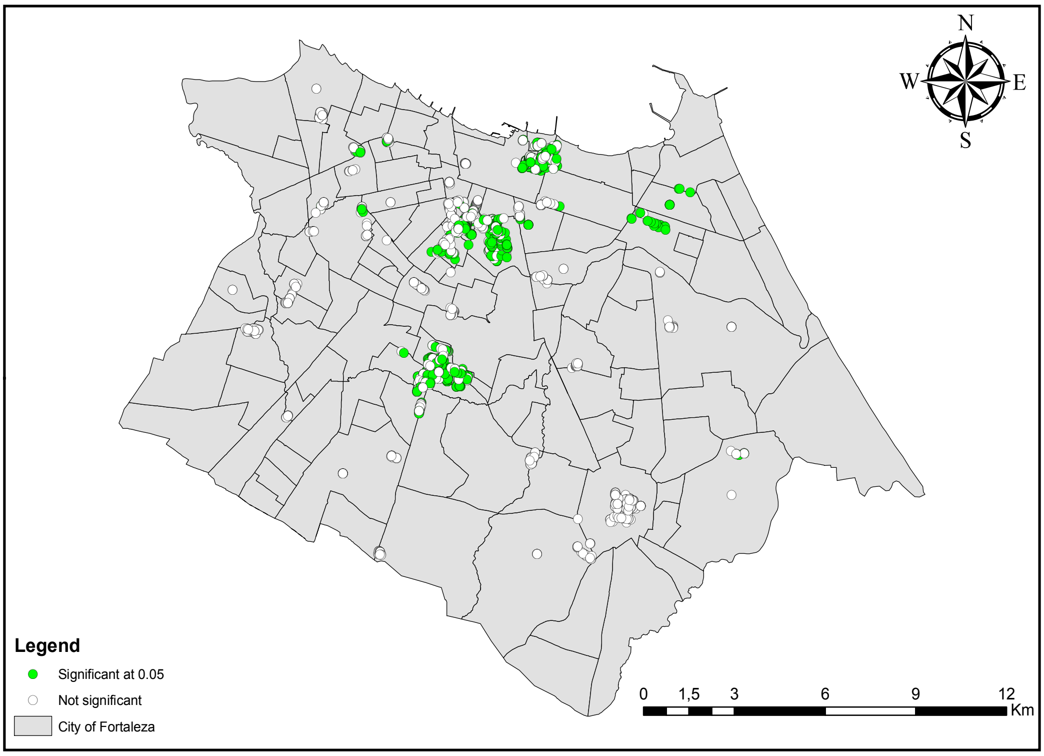
We move to the dispersion map. The results presented in the dispersion map (see figure

[3]Although these are two important instruments to detect local association patterns, both instruments exhibit clusters either statistically significant or not. In this sense, there is no point to exclude from the analysis the not significant clusters. Thus, the significance map comes out as an alternative, since it maps all Moran-I statistics

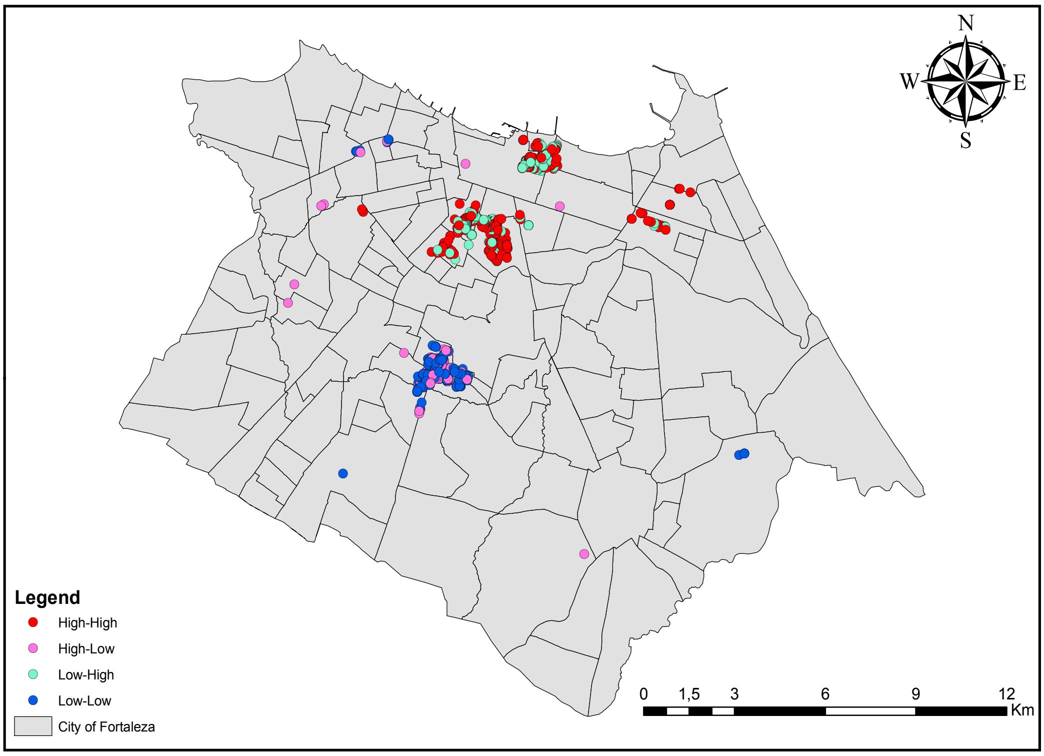
4(b), on page 17) show that there is a high concentration of water consumption at the top center in the city of Fortaleza, represented by the red dots that covers downtown area and the richest neighborhoods in capital. However there are low consumption clusters that are represented by blue dots in suburbs areas. Although almost imperceptible, there is a set up of low-high clusters at the top center, where is located the high-high cluster indicating that there are residences that have low water consumption, although these residences are located in rich areas. Also there is a set up of high-low clusters in suburbs, where there are residences that have high consumption in region where there is low consumption. A possible explanation for the configuration of such clusters is that the income distribution in the city of Fortaleza is unequal. In some popular neighborhoods there are some residents with a very high income level comparing to those who live in the same area. The same pattern takes place in the rich areas, where there are very poor residents living in such rich neighborhoods.

In this sense we can see that there is a local spatial autocorrelation pattern. Thus, it is expected that such spatial autocorrelation might be important to explain residential water consumption in the city of Fortaleza. Next section deals with the demand function model specification and estimation.

Figura 4: Significance and Dispersion Maps



(a) Significance Map



(b) Dispersion Map

5. ECONOMETRIC MODEL

In a set up with non linear prices, the consumer's budget restriction will be non linear as well. For example, suppose a consumer that consumes only two goods: water and a numerie good, which the last one represents all other goods. Suppose also that the tax structure in increasing blocks presents K blocks, with price and superior edge of each block being represented by P_k and $\overline{Y}_k$, respectively. Consider also $\overline{C}$ as the fixed cost of water consumption. Plus, being M the given amount consumed for other goods, and R the consumer's income. Then the utility maximization problem with budget restriction is given as:

$$\overline{C} + P_k(Y - \overline{Y}_{k-1}) + \sum_{j=1}^{k-1} P_j(\overline{Y}_j - \overline{Y}_{j-1}) + M \leq R \tag{3}$$

Now consider a consumer that has a well behaved utility function that depends on the amount of water consumed (Y) and on the amount of other consumed goods (M). Then, the consumer's utility maximization problem is given by:

$$V = \max_{Y,M} U(Y, M) \qquad \text{subject to} \qquad c(Y) + M \leq R \tag{4}$$

$$\text{where} \qquad c(Y) = \overline{C} + P_k(Y - \overline{Y}_{k-1}) + \sum_{j=1}^{k-1} P_j(\overline{Y}_j - \overline{Y}_{j-1}) \tag{5}$$

Before solving the problem of maximization and, consequently, finding the demand function, Moffitt (1986) says that we must define K problems of conditional utility maximization. Then, we have:

$$V = \max_{Y,M} U(Y, M) \qquad \text{subject to} \qquad P_kY + M \leq Q_k \tag{6}$$

$$\text{where} \qquad Q_k = R - \overline{C} - \sum_{j=1}^{k-1} (P_j - P_{j+1})\overline{Y}_j \tag{7}$$

Considering CAGECE's tax structure presented in previous section, we may write the conditional demand function to be chosen by segment in the following way:

$$A = \begin{cases} f(P_1, R_1), \text{if } A \leq 10; \\ f(P_2, R_2), \text{if } 10 < A \leq 15; R_2 = R_1 + 10.(P_2 - P_1); \\ f(P_3, R_3), \text{if } 15 < A \leq 20; R_3 = R_2 + 15.(P_3 - P_2); \\ f(P_4, R_4), \text{if } 20 < A \leq 50; R_4 = R_3 + 20.(P_4 - P_3); \\ f(P_5, R_5), \text{if } A > 50; R_5 = R_4 + 50.(P_5 - P_4); \end{cases} \tag{8}$$

As there is a demand function for each price level, the total demand will be a demand composition in every price level and, in this way, we will have a non linear demand function that it is represented as:

$$A = D_1 f(P_1, R_1) + D_2 f(P_2, R_2) + D_3 f(P_3, R_3) + D_4 f(P_4, R_4) + D_5 f(P_5, R_5)$$
$$D_1 = 1, \text{if } 10 - f(P_1, R_1) \geq 0, D_1 = 0, \text{otherwise;}$$
$$D_2 = 1, \text{if } 15 - f(P_2, R_2) \geq 0, D_2 = 0, \text{otherwise;}$$
$$D_3 = 1, \text{if } 20 - f(P_3, R_3) \geq 0, D_3 = 0, \text{otherwise;}$$
$$D_4 = 1, \text{if } 50 - f(P_4, R_4) \geq 0, D_4 = 0, \text{otherwise;}$$
$$D_5 = 1, \text{if } 50 - f(P_5, R_5) > 0, D_5 = 0, \text{otherwise;} \quad (9)$$

However, the residential water demand is not a function of water price and consumer's income only. So, it was aggregated other variables besides price water, which has been used to explain residential water demand, as the following equation:

$$ln(QC_i) = \beta_1 + \beta_2 ln(PME_i) + \beta_3 DIF_i + \beta_4 R_i + \beta_5 NR_i + \beta_6 NC_i + \varepsilon_i \quad (10)$$

where,

- $ln(QC)$ = Natural Logarithm for amount of consumed water in February, 2007
- PME = Natural Logarithm for average price in February, 2007
- DIF = Difference variable
- R = Familiar Income
- NR = Total of residents in the household
- NC = Total of rooms in the household
- ε = Error term

To choose a measure for price, we decided to use the average price, since the value for water bill is so low compared to income that consumers will not look either to structure or to intramarginal changes (Bachrach and Vaughan, 1994). Looking to the difference variable , we based our choice on the specification from Taylor (1975) and Nordin (1976). The authors say that using two variables for price is the best way to measure the impact of price over demand for goods, where it is applied the tax in increasing blocks of consumption. The choice of socioeconomic variables and residence's physical characteristics followed the main studies carried out over water demand estimation, such as Arbués, García-Valiñas, and Espiñeira (2003).

We expect that family income, total of residents and total of rooms, present a positive effect over water demand, since an increase in these variables will increase water demand. Regarding average price and difference price, it is expected that water reacts as a normal good. This means that an increase in price reduces water demand.

It is known that the estimation of a demand function in a non linear tax context creates, a priori, a problem of endogeneity, once the amount consumed determines the price to be paid. To confirm the endogeneity hypothesis, we need to run the Hausman test. However, it will not be possible to run this test, once in our database there is no valid instrument for the variable price. We are aware of the potential deleterious impacts of endogeneity on our estimates, however we will ignore it, since the focus of this paper is on analyzing the impact of spatial effects over residential water consumption.

To verify if the inclusion of spatial effects affect residential water demand we used three models: SEM (Spatial Error Model), which is used when we believe that spatial dependence is caused by autocorrelation in error terms; mixed SAR (Spatial Autoregressive), that aggregates the explicative variables and it is used when the spatial dependence is contained in the dependent variable; and finally, the SARMA model (Spatial Autoregressive and Moving Average), that is used when we believe that spatial dependence is contained both in error terms and in the dependent variable, so the values for the dependent variable in a region i are affected both by error terms and by values for the dependent variable in other j regions, with $j \neq i$. Next, it will be presented the SARMA model, which is the general case.

$$Y = \rho W_1 Y + X\beta + \varepsilon \tag{11}$$

$$\varepsilon = \lambda W_2 \varepsilon + u \tag{12}$$

Or,

$$Y = (I - \rho W_1)^{-1} X\beta + (I - \rho W_1)^{-1}(I - \lambda W_2)^{-1} u \tag{13}$$

In the SARMA model presented above, Y is a $n \times 1$ vector that contains observations over water demand in logarithms. X is a $n \times 6$ vector of explicative variables, the same used in previous models. β is 6×1 parameter vector to be estimated. W_1 and W_2 are the spatial weighted matrixes. u is the random error term in standard normal distribution with mean equal zero and a constant variance. λ is the autoregressive parameter associated to error term. Finally, ρ is the autoregressive parameter associated to the lagged dependent variable. To be the correct specification, it is expected that the parameters λ and ρ are simultaneously statistically different from zero, once if only one of those parameters is different from zero, then we will be either in the SEM model ($\lambda \neq 0$ e $\rho = 0$) or in the SAR model ($\lambda = 0$ e $\rho \neq 0$).

According to Carvalho and Albuquerque (2010), the W_1 and W_2 matrixes do not need to be equal. If these matrixes are equal, the model will not be identified and the estimative of λ and ρ coefficients will be unstable. This will not happen if the X matrix has more than one variable, besides the intercept, which is not our case. Thus, it is possible to use the same W matrix to spatially lag both the dependent variable and the error term. We use a maximum likelihood approach.

The justification for the use of the SARMA model comes from the belief that the spatial effect is in both the error terms and the dependent variable. As to the error terms, the theoretical justification is that there are non observed factors that influence the residential water demand. Such factors would be the climate, biophysical, socioeconomic, geographic location, and the infrastructure of water distribution system. Also, these factors present a spatial association and, because of this, the error terms present spatial dependence. Moreover, it is expected that the residues from the OLS estimated model present spatial autocorrelation.

The theoretical justification for advocating spatial effects running through the dependent variable comes from imitation of consumption in neighboring residences. Some author, as Ramachandran and Johnston (2011), believe that there is imitation of water consumption in neighboring residences, especially to imitate the shape and type of plants used in gardens. Plus, the infrastructure of water distribution system may creates consumption autocorrelation, once the pressure over the distribution system may cause that one's residence consumption affects the consumption from close residences. Moreover, the empirical justification comes from the data exploratory analysis carried out in previous section, where Moran-I index shows spatial dependence in residential water consumption. To decide which from the three specifications capture in a more accurate way the spatial effect over residential water demand, we applied Lagrange multipliers tests.

According to Almeida (2004), the Lagrange multipliers tests (LM) both for lag (LM_ρ) and for spatial error (LM_λ) must be employed with cautious, since under the null hypothesis of lack of spatial dependence the test statistic has a chi-squared distribution with one degree of freedom. In the case of bad local distribution, when there is spatial dependence, the test turns into a non centralized chi-squared. This rejects the null hypothesis very often. In this sense, the robust Lagrange multipliers (RLM) was developed to solve this problem, aggregating a correction factor to take into account the bad local specification, increasing the power of the test.

To detect the correct functional form, Florax, Folmer, and Rey (2003) suggest the use of the "hibridrus identification"strategy, using both the classical and robust tests for spatial autocorrelation. The strategy of identification consists in estimating, first by OLS, the model and then testing the hypothesis of lack of spatial autocorrelation due to either the lag or the error through classical LM_ρ and LM_λ statistics. If these tests are not significant, it is used the OLS model as the most accurate. If both tests are significant, it is used both the RLM_ρ and RLM_λ to decide which model must be estimated. If RLM_ρ is significant and RLM_λ is not, then it is estimated the SAR model. If RLM_ρ is not significant and RLM_λ is, then the most appropriated model must be the SEM model. If both RLM are significant and $RLM_\rho > RLM_\lambda$, it is used the SAR model. However, if $RLM_\rho < RLM_\lambda$, then the SEM model is the most appropriated.

However, if both RLM are significant, it might be that the correct specification for the model is not neither the SAR model nor the SEM model, but the SARMA model. In this sense, we will use the SARMA test ($ML_{\lambda\rho}$) that tests the simultaneous presence of spatial effect over both lagged variable and error. This test follows a chi-squared distribution with two degrees of freedom, what decreases the power of the test. Next section presents the estimations and results.

6. RESULTS

Table 4 presents first the results related to the econometric model for residential water demand function with no spatial effects. According to the results, the estimated coefficients for all variables showed expected signals and are statistically significant.

The negative coefficient for average price confirms the theory that asserts a negative relation between price and quantity demanded. As we know, in this type of specification the estimated coefficient for average price represents elasticity-price for demand. The magnitude of -0,6175 points to a inelastic

Tabela 4: Water Demand (ln) with No Spatial Effect - OLS

Variable	Estimative	Stand. Desv.	t value
(Intercept)	1.4873	0.0344	43.27
ln(PME)	-0.6175	0.0254	-24.28
DIF	-0.0078	0.0002	-42.71
NR	0.0763	0.0056	13.55
R	0.0482	0.0110	4.36
NC	0.0415	0.0046	8.98
F(5,2930)= 619.4	Prob>F= 0	R^2= 0,5138	
$\overline{R}^2$= 0,513	N= 2930		

Source: Elaborated by authors

demand. Comparing the estimated values with other papers, the demand elasticity-price is similar to Agthe, Billings, and Dobra (1986) (0,62), Andrade, Brandão, Lobão, and Silva (1995) (0.16 to 0.60); it is higher than those found by Mattos (1998) (0,19 to 0,25), Rosa, Fontenele, and Nogueira (2006) (0,31); and it is lower than Melo and Neto (2007) (0,95 and 1,0). (See, Table 5)

Tabela 5: Demand Price-elasticity in Some Published Papers

Authors	Place	Estimated value (absolute)
This paper	Fortaleza, CE, Brazil	0,6175
Agthe, Billings, and Dobra (1986)	Arizona, EUA	0,62
Andrade, Brandão, Lobão, and Silva (1995)	Paraná, Brazil	0,16 up to 0,60
Mattos (1998)	Piracicaba, SP, Brazil	0,19 up to 0,25
Rosa, Fontenele, and Nogueira (2006)	Ceará, Brazil	0,31
Melo and Neto (2007)	Northeast Region, Brazil	0,95 and 1,0

Source: Elaborated by authors

When we look at the difference variable, the estimated coefficient of -0,0078 indicates that when there is a increase of R$ 1.00 in the difference between the price that the consumer pays and the price that he/she would pay if all units were charged by the marginal price, consumption decreases by 0.78% on average, once the consumer is paying more than he/she would pay in marginal price.The coefficient estimated of 0.0482 for income means that consumers go from a lower income class to a superior income class, with no changes in his tax status, his consumption increases 4.82%, in average. Finally, the coefficient estimated of 0.0763 and 0.0415 for total of residents and total of rooms, respectively, indicate a increase of 7.63% and 4.15% in the amount of water consumed when there is a new person in the house and there is a new room. The $\overline{R}^2$ equals to 0.513 shows a good level of explanatory power for the water demand estimation in a cross-section microdata regression, once the variables used in the model explains 51% in water consumption variation.

Since there is room for spatial dependence on water consumption, we run the Moran-I test for the residues estimated by OLS. The results are presented in table 6. Table 6 shows that the Moran-I statistic is equal to 0.0231 and it is significant. This means that the probability for the spatial association pattern being random is close to zero, supporting the hypothesis of residues spatially dependent. Moreover, the positive value indicates that the autocorrelation is positive, as expected.

After confirming the presence of spatial autocorrelation in the residues, we run Lagrange multipliers tests in their classic and robust versions to define which model is more appropriate, once

Tabela 6: Moran-I statistic for the residues estimated by OLS

Moran-I statistic	Mean	Variance	p-value
0,0170	-0,0004	6.72e-06	$<$ 7.39e-12

Source: Elaborated by authors
Note: empirical p-value based on randomization method

there is spatial autocorrelation in the dependent variable. Table 7 presents the results from these tests.

Tabela 7: Lagrange multipliers tests

Test	Estimated value	df	p-value
LM_λ	40.6957	1	1.77e-10
LM_ρ	36.9793	1	1.19e-09
RLM_λ	10.8584	1	0.0009
RLM_ρ	7.1419	1	0.0075
SARMA	47.8376	2	4.094e-11

Source: Elaborated by authors

Following the methods proposed by Florax, Folmer, and Rey (2003), we compare the LM_λ and LM_ρ values first. The values of 40.69 and 36.97, both significant, indicates that there is spatial dependence associated both to lag in the dependent variable and to non modeled effects, this last represented by error term. Next, comparing the values for RLM_λ and RLM_ρ we have that both are significant. Also, since RLM_λ > RLM_ρ this indicates that the most appropriate model would be the SEM model.

However, since there is spatial autocorrelation both for residues and for the dependent variable, it is possible that the correct model might be the SARMA model. Thus, analyzing the result from the SARMA test shown in table 7, we can see that the value of 47.83 is statistically significant. This implies that the SARMA model is the most appropriated to model spatial effect over residential water demand in the city of Fortaleza. Based on this, we estimated the SARMA model and its results are presented next[4].

Tabela 8: Water Demand (ln) with Spatial Effect - SARMA

Variable	Estimative	Stand. Desv.	Z value
(Intercept)	0.9445	0.2673	3.5336
ln(PME)	-0.6250	0.0253	-24.6794
DIF	-0.0077	0.0001	-42.6593
NR	0.0778	0.0056	13.7113
R	0.0435	0.0116	3.7343
NC	0.0378	0.0047	7.9275
Rho	0.2185	0.1050	2.0809
Lambda	0.2373	0.1445	1.6418
LR=26.546	p-valor=1.7200e-06		
R^2= 0.5182	AIC=4006.8	N= 2936	

Source: Elaborated by authors

The results presented in Table 8 show that the estimated coefficient of autoregressive parameters linked to both the lagged dependent variable and the error term are statistically significant

[4]The results from estimation of the SEM and the SAR models can be obtained upon request.

and positive, although the coefficient for the autoregressive linked to the error term is significant only at 10%, confirming the presence of positive spatial autocorrelation. Moreover, the likelihood ratio test rejects the null hypothesis of absence of spatial dependence, indicating that the model is correctly specified.

Also, Table 8 shows that the price-elasticity of demand to SARMA model is 0.625 in absolute terms. This means an increase of 1.21% comparing to the model with no spatial effect. Comparing both SEM and SAR models, the elasticity is higher than the one found in SAR model, and it is lower than that one found the in SEM model.

The income variable present a value of 0.0435. This represents a negative variation of 9.75% comparing to the model with no spatial effect. The total of rooms presents a negative variation, 8.92%, with a value of 0.0378. Finally, the total of residents presents a value of 0.0778, which represents an increase of 1.97%. Comparing the SEM and SAR models presented previously, these effects are higher than those found the in SEM model and lower than those found in the SAR model. After this analysis, next section presents the final considerations and a summary about the most important results found in this work.

7. FINAL CONSIDERATIONS

This paper sought to apply a new methodological approach to estimate the residential water demand, including the spatial effects into the analysis. We presented showed that the determinant factors to explain residential water consumption in the city of Fortaleza are: average price, difference, income, total of residents, and total of rooms in a residence.

As expected, the average price and the difference variables had a negative impact over water consumption. Also, water behaves as a normal good. The negative effect appearing in the difference variable shows that the more is the difference between the bill account and the bill account at marginal price the less is the water consumption, since the consumer would be paying more. So, the tendency is that consumption decreases. Income, total of residents, and total of rooms presented a positive effect. Moreover, the results found were similar to those presented in other papers, such as Agthe, Billings, and Dobra (1986) and Andrade, Brandão, Lobão, and Silva (1995). These authors found that price-elasticity of demand is around 0.61 in absolute terms.

The Moran-I statistic confirmed the presence of spatial dependence on water consumption. A possible explanation for this may be the infrastructure of CAGECE's distribution system. Also, local Moran-I indicated a set up of clusters with high water consumption in rich areas and in downtown, and with low water consumption in poor areas. Also, besides the the presence of spatial dependence on water consumption, the Moran-I test showed that exist a positive spatial autocorrelation on error terms estimated by OLS.

Lagrange multipliers and SARMA tests showed, both in classic and robust versions, that the "best specification" to estimate residential water demand is the SARMA model, instead of the SEM. Finally, we have shown that the lack of inclusion of these spatial features underestimates, in absolute terms, the effect of average price, underestimates the effect of the total of residents and overestimates the effect of income and total of rooms. In essence, this paper demonstrates the importance of including spatial effects in order to understand the determinants of water consumption in Fortaleza, suggesting to policy makers that aggregating spatial effect in their analysis and propositions to implement policies is important.

As suggestions to future studies, besides addressing the pressing issue of endogeneity, we believe that both the incorporation of spatial heterogeneity and the inclusion of water quality variables are worth pursuing. As to the first, we must check if the relation between independent and dependent variables varies through space. If this is the case, include that feature accordingly. As to the second, our data base have three questions containing measures of water quality, i.e., how is the quality of the water supplied, how frequent is the water supplied and in what amounts is water supplied. It appears to us that the quality dimension of water demand has been neglected so far.

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This paper aims at estimating a residential water demand function for the city of Fortaleza, Brazil, considering the potential impact of spatial effects on water consumption. The empirical evidence is a micro dataset obtained by means of a household survey of water consumption in 2006. We estimated three econometric models, which had as explanatory variables the average price, the difference, income, number of residents and the number of rooms, under different spatial specifications: the spatial error model (SEM), the spatial autoregressive model (SAR), and finally, the spatial model autoregressive moving average (SARMA). The results show that spatial autocorrelation exists in two forms (error and lag), indicating that the SARMA specification is the "best"as shown by a series of tests. Such results are in contrast to that suggested by Chang et al. (2010), House-Peters et al. (2010), Franczyk and Chang (2008), Ramachandran and Johnston (2011), who favored the use of the SEM model. Our results point out to the necessity of considering spatial effects in the estimation of residential water demand, since the absence of spatial effects is a key misspecification error, underestimating the effect of important variables such as average price and number of residents, while overestimating the effect of other variables such as income and number of rooms.

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