

Article

The Factors Affecting Domestic Water Consumption in Portugal: An Econometric Approach [†]

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Abstract

Water is a valuable resource that needs to be managed carefully. Therefore, sustainable water consumption is a critical issue, mainly in urban areas, where tourism activities are of great importance. In mainland Portugal, this has become a crucial matter, particularly because of climate limitations and the recent growth of the tourism sector. To manage water resources effectively, we must analyze the primary factors driving consumption. Therefore, an econometric model to identify the main factors is a relevant tool for policy design. This paper tries to fill this gap. In the first stage, an ordinary least squares (OLS) model was implemented. In a second stage, the autocorrelation is evaluated, and a weighted geographical regression (GWR) model is used to improve the previous results. The models were implemented in the 278 municipalities of continental Portugal, considering the average situation of the last decade. The results were promising since the OLS model presented an R^2 of 0.42 identifying purchasing power, urban green spaces, tourism and education as the main explanatory factors for water consumption. The geographical weight regression presented an R^2 of 0.646 proving the importance of considering spatial context for the identification of these factors' influence on water consumption.

Keywords: domestic water consumption; Portugal; Ordinary least Squares (OLS); Geographically Weighted Regression (GWR); sustainable water management



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1. Introduction

Water is necessary for human survival and ecosystem preservation; nevertheless, climate changes and the resulting droughts, together with an increase in population, have led to a decrease in the availability of this vital resource within numerous urban areas [1], several of them located in the Mediterranean Basin.

The Mediterranean climate presents dry periods, but it is a fact that, in recent years, there have been more frequent and prolonged droughts. The World Resources Institute, in a projection for 2040, classifies Portugal as having a high risk of water stress, i.e., a high risk of having to manage a lack of quality water in response to the needs of the country. This scenario is not homogeneous for the Portuguese territory, with the south being more vulnerable to shortages. This possibility requires thinking in the long term. It is not about reversing the trend of climatic issues that are foreseen, but what is to be discussed, on the

demand side, is how to mitigate waste and question the different uses for this resource that is limited by nature [2].

Water scarcity is a critical issue in Portugal, particularly in the southern region. Silva [3] examines the challenges facing the Algarve's public water network, focusing heavily on the Municipal Water Supply System of the Algarve. This "primary" supply network is managed by Águas do Algarve, and the study explores alternative solutions for the region's public water management. Driven by recent climate trends, identifying the key factors behind water consumption has become essential for managing this resource sustainably. Ultimately, intensifying climate change and growing water demand from sectors like tourism require a strategic shift toward reducing consumption and maximizing the value of this scarce resource.

Recent decades have witnessed a growing urbanization and shifts in sociodemographic composition within the Mediterranean basin, particularly in regions and municipalities specialized in residential tourism. Urban and tourist expansion of these areas has imposed the necessity of water resources to answer to urban hydrological demands. These heavy requirements have led to water scarcity, a condition exacerbated by climatic instability [4].

Water supply systems are experiencing heightened variability in both resource availability and consumer demand. Effective water conservation initiatives necessitate a comprehensive understanding of the underlying determinants of domestic water consumption. However, previous investigations have adopted a reductionist approach, examining isolated factors [5]. Common methodologies tend to simplify the relationship between explanatory variables and water consumption, despite the actual dynamics being more complex, involving potential feedback loops, indirect influences, and counterintuitive outcomes [5]. Water demand management is also a complex issue since it needs to balance environmental, economic, and social sustainability; future research should adopt a holistic perspective on water demand determinants [5]. Moreover, the age of residents has influenced domestic water consumption [6].

Therefore, to identify the main determinant factors that condition water consumption, several studies were carried out [1,4,5,7–12]. However, no model has yet been developed for the whole Portuguese territory considering the main socioeconomic factors.

To identify the main determinants of water consumption, econometric approaches such as ordinary least squares (OLS) offer a consistent approach. Additionally, it is relevant to consider geography, as factors may vary in their influence across geographical areas. There are local differences that need to be accounted for and that are omitted in a OLS model. Geographically weighted regression (GWR) operates on the assumption that non-stationary relationships exist between the response and explanatory variables. Consequently, the model addresses this issue by estimating distinct local parameters for each individual location [13,14]. Tariffs were not considered as an explanatory variable in the regression model, firstly, because water price in Portugal is low and therefore it is not a key decision variable for water consumption. This choice is backed by the empirical literature which consistently demonstrates that residential water demand is highly price-inelastic [4,15,16] particularly within domestic thresholds where water serves non-discretionary essential needs. Additionally, because water expenditures typically constitute a marginal fraction of total household income, price signals exert negligible influence on daily consumption behavior [16]. We also highlight that water pricing structures in Portugal are highly fragmented, as tariffs are determined at the municipal level or by localized private concessions rather than a uniform national standard, and many have a fixed and a variable tariff according to consumption. This decentralized framework introduces substantial variability and may mask the results with an undesirable impact on the global accuracy of the model.

This paper aims to ascertain the influence of these variables on domestic water consumption for continental Portugal. In order to achieve this objective, an ordinary least squares (OLS) regression model and a geographically weighted regression (GWR) are proposed. Therefore, this study will try to answer two research questions:

- Q1.** *What are the main factors explaining domestic water consumption in Portugal?*
- Q2.** *Is there an influence of the spatial context in domestic water consumption?*

The remainder of this article is presented as follows. In Section 2, the materials and methods are presented; in Section 3, the results; Section 4 presents the discussion; and finally, Section 5 presents the concluding remarks.

2. Materials and Methods

2.1. Previous Studies

The main determinants of water consumption are an important issue. Therefore, a screening of previous studies was carried out. In the research, we may find several literature reviews on the factors influencing domestic water consumption, such as [15,17,18].

The factors influencing household water consumption have been investigated since the late 1960s across various spatial scales, ranging from urban centers to individual residences [5]. Initially, economic variables, such as price, and broader socioeconomic conditions were the primary areas of research [4,11], and the physical characteristics of properties, such as lot size, size of outdoor space, housing typology, etc., were also often found in the literature [4,19–21]. Nowadays, technological advancements are increasingly capturing the attention of researchers focused on water conservation [4,5].

The majority of the research was conducted in the United States and Australia by economists, considering the price of water as an independent variable to identify the ideal price to regulate population water demand [18], concluding that water exhibits inelastic demand, meaning that fluctuations in price have minimal impact on water consumption [15]. The role of demographic configurations play in shaping water demand has received far less academic attention. Nonetheless, the limited research addressing these social dynamics indicates that certain population segments have significantly more conservative consumption habits [4]. The existing academic literature yields highly conflicting conclusions, primarily because the populations under analysis do not represent homogeneous socioeconomic groups. Instead, these studies examine cohorts with vastly different income levels and backgrounds, making it difficult to draw uniform assertions [4,22].

In addition, several relevant studies are presented as follows.

Mazzanti and Montini [7] investigate the determinants of residential water consumption within the Emilia-Romagna region of Italy. Employing a municipal panel dataset encompassing five of the region's nine provinces and focusing exclusively on residential water usage, the analysis seeks to identify key factors influencing water demand.

Schleich and Hillenbrand [8], using Germany as a case study, analyze the influence of economic, environmental, and social factors on residential water consumption. The socioeconomic and environmental variables are identified as significant determinants of consumption.

Grafton et al. [9] quantify and assess the effects of monetary and non-monetary significance factors on domestic water consumption. The research investigates the correlation between domestic water-saving habits and the price of water. The authors utilized household survey data from ten nations as their dataset.

Makki et al. [1] proposed a sociodemographic and natural science database comprising 200 households in southeastern Queensland, Australia to identify these determinants. The researchers utilized analysis of variance (ANOVA) and multiple regression analysis.

Fan et al. [10] used conditional inference trees and the random forest algorithm to investigate the determinants influencing water consumption in a case study that included 286 Chinese municipal cities.

Romano et al. [11] examined the variables influencing domestic water consumption in prominent Italian urban centers, collecting information on tariffs, per capita income, meteorological conditions, and geographical and demographic attributes. The findings showed that cities with larger populations exhibited elevated levels of consumption; a tariff exerted a negative impact on domestic water consumption; and domestic water consumption was not affected by per capita income.

Eslamian et al. [23] propose a novel methodology for forecasting daily water consumption, utilizing a function of socioeconomic variables, using, as a case study, a city located in the Montreal metropolitan region, Canada, to validate predictions.

De la Cruz et al. [12] analyze the factors influencing domestic water consumption in Hermosillo, Mexico, proposing a cross-sectional study and a multiple regression analysis approach.

Bich-Ngoc and Telle [5] investigate determinants of water consumption and their relationships. These determinants were divided into the following categories: “(1) Economic; (2) Sociodemographic; (3) Physical properties; (4) Technological; (5) Climatic; and (6) Spatial drivers”.

Villar-Navascués and Pérez-Morales [4] examined the drivers of municipal water consumption along the Spanish Mediterranean coast, analyzing urban land-use, socioeconomic, and sociodemographic variables. To account for spatial autocorrelation present in ordinary least squares (OLS) residuals, the authors utilized both OLS and geographically weighted regression (GWR) models. Their findings reveal that the proportion of second homes and the percentage of residential properties with swimming pools are the key factors driving water consumption.

Research examining the specific factors driving domestic water use throughout Portugal remains remarkably limited. To date, academic efforts have approached the issue from distinct angles, beginning with Martins and Fortunato [24], who developed an empirical equation to map how pricing structures and tariff policies dictate residential consumer habits. Matos et al. [25] investigated how domestic plumbing habits align with demographic profiles, specifically analyzing variables such as overall family size, the presence of dependent minors or elderly relatives, financial brackets, and formal education levels. Cabral et al. [26] leveraged continuous telemetry data from localized monitoring zones across Lisbon and Setúbal regions to isolate the direct impacts of fluctuating weather patterns on municipal water demand. Costa et al. [27] determine the factors associated with residential water consumption in the city of Aveiro, Portugal, using a survey and concluded that household water consumption increases with larger family size, the presence of children, and higher income. However, higher education levels correlate with lower water use. Building age does not affect per capita consumption. Instead, usage is driven by behavior. Barreira and Jacinto [28] presented a study using cluster analysis to evaluate how monthly water use per household across 122 municipalities is affected by regional location and population trajectories and concluded that both growing and shrinking municipalities see higher household water use and lower rates. Barreira and Andraz [16] concluded the factors influencing water consumption differ across various demographic groups and regional areas.

Table 1 synthesizes the main studies and their contributions.

Table 1. Main studies reviewed and their contributions to the body of knowledge.

Author	Main Contribution	Case Study	Main Factors
Mazzanti and Montini [7]	Key determinants of water demand using a municipal panel dataset to analyze factors influencing usage.	Emilia-Romagna, Italy (5 provinces)	Water price; income
Schleich and Hillenbrand [8]	Analyzed the influence of economic, environmental, and social factors; identified socioeconomic and environmental variables as significant.	Germany	Price, income, household size, the share of wells, summer rainfall, age
Grafton et al. [9]	Quantified monetary and non-monetary factors, focusing on the correlation between water-saving habits and pricing.	10 nations (International household survey)	Price; environmental concerns
Makki et al. [1]	Developed a sociodemographic and natural science database using ANOVA and multiple regression to identify usage determinants.	Southeastern Queensland, Australia	Household size and makeup; showerhead efficiency rating
Fan et al. [10]	Utilized conditional inference trees and random forest algorithms to identify determinants of water consumption.	286 Chinese municipal cities	Precipitation, water conservation investment, water heater for showering or bathing per household and gross domestic product per capita; water supply capacity; socioeconomic status, GDP per capita, education
Romano et al. [11]	Examined impacts of tariffs, population size, income, and climate; found tariffs reduce consumption while population increases it.	Italian urban centers	Tariff; population; altitude
Eslamian et al. [23]	Proposed a novel forecasting methodology for daily water consumption based on socioeconomic variables.	Montreal metropolitan region, Canada	Rainfall; socioeconomic factors; weekend effect;
De la Cruz et al. [12]	Analyzed domestic consumption factors via a cross-sectional study and multiple regression analysis.	Hermosillo, Mexico	Low water cost;; number of bathrooms in the household; service supply; use of purified bottled; number of female inhabitants
Villar-Navascués and Pérez-Morales [4]	Used OLS and geographically weighted regression (GWR) to identify water consumption factors.	Spanish Mediterranean coast	Percentage of second homes; percentage of residential properties with swimming pools; income per capita; percentage of low-income pensioner households
Martins and Fortunato [24]	Residential water demand equation is estimated using panel data.	Five Portuguese local communities observed over 72 months	Price presents a weak elasticity

Table 1. *Cont.*

Author	Main Contribution	Case Study	Main Factors
Matos et al. [25]	Correlation analysis (Spearman's correlation test) with the factors.	Porto, Vila Real and Valpaços in Portugal	Population density, income level, existence of children; residence area
Cabral et al. [26]	Cluster analysis; multiple linear regression analysis.	Portuguese water distribution systems	Temperature; billed consumption in the third and fourth tariff levels
Costa et al. [27]	Survey and descriptive statistics.	City of Aveiro, Portugal	Income; family size (Household size); presence of children; water-saving fixtures
Barreira and Jacinto [28]	Kendall correlation coefficient, cluster analysis.	122 Portuguese municipalities	Water prices; minimum and maximum temperatures; average family size; percentage of city inhabitants
Barreira and Andraz [16]	Estimation of panel data models to identify consumption factors.	Urban municipalities in Portugal	Highest block of tariffs; population; tourism; income; number of households; household aging index

From the several references analyzed, we can conclude that the studies for Portugal, considering a spatial approach such as GWR, are missing. This is an approach that has considerable potential and needs to be explored. Also, in Portugal, the previous studies highlighted the importance of several factors, but the socioeconomic reality is different across the country, which suggests that the whole territory approach should be addressed carefully.

2.2. Regression Analysis

2.2.1. The Research Hypothesis

The research hypotheses were defined considering previous studies from the body of knowledge. Therefore, a careful screening of the main factors identified in the literature in Portugal and in other similar areas, namely in Spain, were carried out. We focused on the demographic, socioeconomic, and land-use dynamic factors that affect water consumption. Then an expert analysis was carried out, considering also the available data on the Portuguese municipalities. One important aspect was the available information and its characteristics which may limit the model. An elimination process was carried out excluding variables and hypotheses that were not significant. Initial testing of the data using correlation matrices as well as preliminary regression models were implemented. These research hypotheses should be seen in a combined way, being interconnected among themselves although collinearity is not allowed.

Tourism contributes to an increase in water consumption in Portugal, particularly in the southern Algarve region. While some researchers suggest a positive correlation between tourism and water use [29], others advocate for positive effects [30] under specific conditions. Certain studies [31] have not identified a significant influence of tourism on water demand, although this may be a critical factor primarily in coastal municipalities of southern Portugal, where water resources are more limited. Thus, the following hypothesis was specified:

H1. *There is a positive relationship between tourism activity and water consumption.*

The previous research has verified that one of the primary determinants of domestic water consumption is the prevailing urban land-use pattern related to the impact of external water uses [4,15,21,32]. Therefore, the following hypothesis was considered:

H2. *There is a positive relationship between the urban areas and domestic consumption.*

Populations with higher levels of income may tend to increase water consumption. Elevated income levels can influence housing typology or the selection of water appliances [4,33], which often tend to be more expensive. So, we have formulated the following hypothesis:

H3. *There is a positive relationship between the level of income and domestic water consumption.*

Detached houses tend to have a high water consumption, due to their green gardens and house size [33]. Green irrigated gardens in urban areas often consume considerable quantities of water, which need careful management by the persons responsible in the territory. Therefore, the following hypothesis was formulated:

H4. *There is a positive relationship between irrigated green spaces and domestic water consumption.*

The retired population exhibits lower water consumption, often attributed to reduced income levels and specific consumption patterns [4,34]. In contrast, younger age groups demonstrate higher water consumption [4,35] and distinct consumption habits, with a greater prevalence of shower and washing machine usage [4,36]. Since there is no consensus on how age influences water use, the following hypothesis was formulated:

H5. *There is a positive relationship between young age population groups and domestic water consumption.*

Villar-Navascués and Pérez-Morales [4] state that previous research indicates a positive correlation between educational achievement and level of environmental awareness. This can result, particularly among individuals with higher education levels, in distinct behaviors, such as water use reduction to only the essential and the acquisition of water-saving appliances.

H6. *There is a negative relationship between education level and domestic water consumption.*

The household constitutes a significant factor in water consumption, as relative demand inversely correlates with the number of residents within a household [4,37]. Water authorities actively promote the installation of water-saving devices. This particular phenomenon is related to economies of scale.

H7. *There is a positive relationship between the size of the household and domestic water consumption.*

Analyzing water consumption needs a complex approach integrating several types of factors, such as demographic, socioeconomic, and land-use dynamics, which are interconnected. Water consumption is heavily influenced by land-use patterns and dominant economic activities. Urban areas and population density will have a crucial role on consumption, namely those that have a fluctuating population through the year. The urban land-use pattern itself (H2) dictates the intensity of domestic consumption, as the typology of cities shapes the requirement for external water uses, and it is related to population density. A clear manifestation of this relationship between urban space and water is the

presence of irrigated green spaces (H4) that serve the necessities of the exiting population. An urban area with green spaces is favorable for tourism, which emerges as a critical driver of pressure on water resources (H1), an activity that often materializes through the expansion of urban areas and in many cases determine a fluctuation of the population using the water resources. Within this socioeconomic framework, the level of income (H3) acts as a catalyst, since households with higher purchasing power tend to occupy larger properties and acquire more water appliances, influencing consumption behavior. However, this economic factor is nuanced by demographic and cultural variables, such as age, education, and household structure (H5 and H6). The socioeconomic and demographic characteristics of individuals (H3, H5, H6, H7) dictate their housing and lifestyle choices (H4), which, when integrated into the macro-context of urbanization and tourism (H1, H2), ultimately define water consumption.

2.2.2. The Regression Model

The selected model is a critical aspect of this research, since according to Barreira and Andraz [16] the functional form of domestic water demand is where several different approaches are used, such as: linear OLS [4] log-linear [7] and log-log [38]. According to Villar-Navascués and Pérez-Morales [4] for Spanish Mediterranean areas, OLS offers a valid tool with potential, but it is necessary to consider the spatial context using a spatial regression. A GWR may provide a powerful tool, since all the assumptions of these methodologies exist.

Firstly, it was essential to analyze the data and their relations. After analysis, it was found that OLS provided a valid tool, if all assumptions were respected. Multiple regression models are vulnerable to situations with high correlations among predictor variables which is called multicollinearity [39,40]. To assess this, the following measures were calculated: (1) correlation matrices using the Pearson correlation coefficient; (2) diagnostic indicators such as eigenvalues, condition indices, tolerance, and Variance Inflation Factor (VIF). Homoscedasticity, a fundamental assumption of linear regression, stipulates constant variance of the dependent variable across different values of the independent variables. Moreover, the model's validity hinges on normally distributed residuals [39,41]. The Durbin–Watson test was employed to assess residual independence [40], while graphical methods were used to evaluate the normality of errors.

To explain domestic water consumption per inhabitant, a multiple regression analysis is proposed [4,39] in two steps. By starting with an ordinary least squares baseline, it establishes a clear statistical benchmark before introducing spatial complexity. Applying the Moran's I index directly to the OLS residuals offers an objective, mathematical justification for moving to a geographical model, ensuring that the shift is driven by actual data patterns rather than researcher preference. Then a geographic weighted regression model allows the study to account for natural spatial clustering and localized variations, yielding far more accurate standard errors, reliable *p*-values, and realistic real-world insights than a standard global regression could ever achieve alone.

2.3. Empirical Implementation

2.3.1. Study Area

The study region encompasses the 278 municipalities of continental Portugal (Figure 1). This area, characterized by a substantial coastline, exhibits pronounced tourism activity, namely in the south, in the Algarve Region. These areas have been subjected to significant landscape modifications in recent years [42]. The Portuguese climate is Mediterranean, though it is influenced by diverse geographical factors, leading to regional disparities. The northwest experiences elevated precipitation levels, primarily due to orography [43,44],

and southern Portugal is characterized by hot, arid summers with low relative humidity and precipitation [43,44], with up to six months of dry weather. Climatic conditions exert a substantial influence on water resource availability, with watercourse discharge generally diminishing from north to south and from coastal to inland areas [43,44].

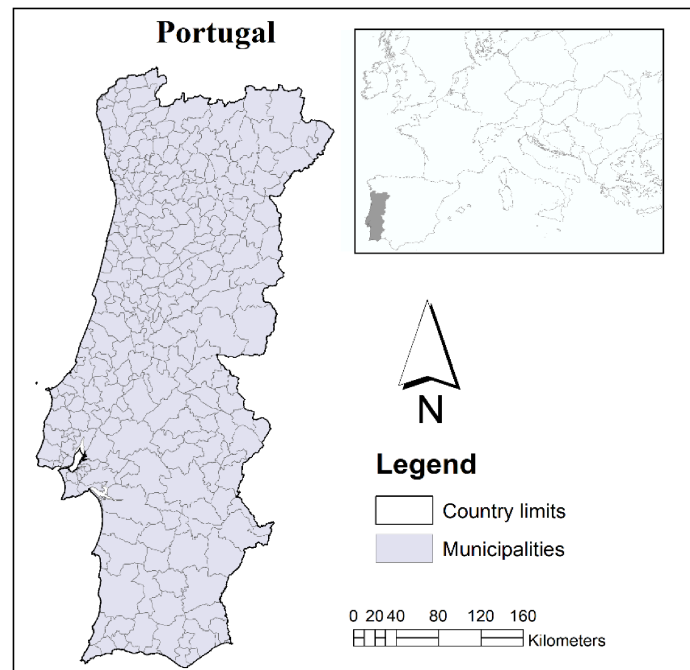


Figure 1. The study area.

The spatial distribution of the water consumption per inhabitant is presented in Figure 2 and shows that several municipalities of south Portugal have a considerable consumption per inhabitant. Nevertheless, there are differences in water availability. Northern regions typically enjoy more abundant rainfall and surface water, while the Algarve and Alentejo regions in the south have a more limited resource. Even in years with high rainfall, the south remains vulnerable because its aquifers and reservoirs are limited and sensitive to human activities. Climate models for 2040 project changes where the southern half of the country faces a high risk of permanent water stress.

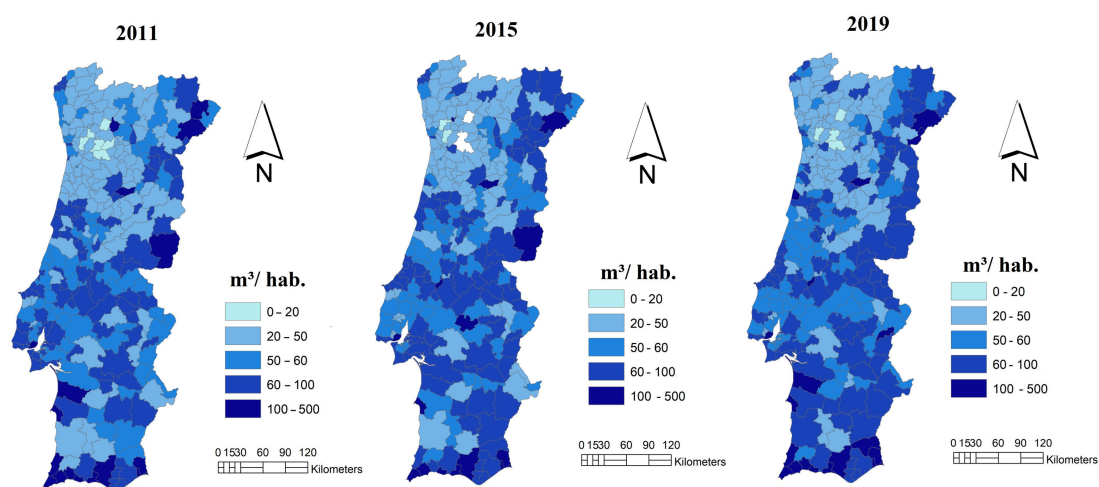


Figure 2. The spatial distribution of water consumption per inhabitant/resident ($\text{m}^3/\text{hab.}$).

2.3.2. The Data

Multiple data sources were utilized to implement the methodology. One source was the National Statistics Institute (INE), which provides a comprehensive dataset of variables at the municipal level. The other source was the soil and land-use occupation mapping of the General Directorate of Territory. The INE comprehensively collects data from various sources and consolidates it into a unified database that is standardized and processed for ease of use.

The selection of variables considered previous studies and were considered in a way to test their explanatory potential for urban water use. To measure water consumption, the variable water distributed by the inhabitant was selected as the dependent variable. This variable shows the average water distributed by the inhabitants of a municipality, which are mainly in urban areas or near them. This concept encompasses the volume of treated water supplied to the supply pipelines or directly to the public distribution system for domestic, commercial, or industrial consumption, which is then divided by the number on inhabitants. It was used as a proxy for domestic consumption as the separated domestic data was not possible to obtain. While this metric includes commercial and industrial use, it effectively captures the entire water footprint required to sustain an inhabitant's lifestyle within that area. Please note that, according to this concept, other areas that are mainly dispersed may be included in public areas.

The data treatment and sources are detailed in the Supplementary Materials. Table 2 presents the variables selected for this study. The water consumption is represented by the variable “water distributed by inhabitant” (ADH). The independent variables are the following: purchasing power (in percentage) (PCOMP); population age represented by the population under 14 years old (POP014); urban areas in meters (AURB); green urban spaces in meters (ESP_VERD); touristic population measured by the number of overnight stays by tourists (DOR); education represented by the amount of population with superior education (PENSUP); and habitation conditions represented by the classic family households of usual residence with 200 m² or more (AREA200m).

Table 2. The variables considered in the regression models.

Variable	Type	Short Description	Abbreviated Names	Source
Water consumption	Dependent	Water distributed by inhabitant	ADH	INE
Purchasing power	Independent	Purchasing power %	PCOMP	INE
Population age	Independent	Population under 14 years old	POP014	INE
Urban areas	Independent	Urban area in meters	AURB	DGETERRITÓRIO (COS)
Green urban spaces	Independent	Urban green spaces in meters	ESP_VERD	DGETERRITÓRIO (COS)
Touristic population	Independent	Number of overnight stays by tourists	DOR	INE
Education	Independent	Number of population with superior education	PENSUP	INE
Habitation conditions	Independent	Houses with 200 m ² or more	AREA200m	INE

The explanatory variables include the following: purchasing power measured in percentage population age by considering the population under 14 years; urban area in meters; urban green spaces; touristic population (represented by the number of overnight

stays by tourists); population with higher education; and habitation conditions (represented by houses with 200 m² or more).

Finally, regarding the GWR, some technical aspects are presented. The kernel type is fixed, which means that a fixed distance was used in the spatial context used to solve each local regression analysis. Choosing a fixed kernel provides a consistent, standardized neighborhood distance that is structurally ideal for continental Portugal's contiguous and evenly distributed municipal boundaries. The extent of the kernel is determined using the Akaike Information Criterion (AICc). A major benefit of using AICc to determine the bandwidth extent is that it outputs a standardized score. This allows a direct comparison of the GWR model against the baseline global OLS model. Regarding the testing we considered for each coefficient a p value of 0.05. The pseudo- t test was calculated using the variables' standard error and their coefficients. The OLS model was implemented in SPSS 22 and ArcGis Pro 3, while the geographical weighted regression model was done using ArcGis Pro 3.

2.3.3. The Regression Models

For the econometric approach, one ordinary least squares (OLS) model was implemented in the first stage. Then, a Moran's I index was applied to residuals to analyze autocorrelation. Therefore, in the second stage a Geographical Regression Model was specified using domestic water consumption as the dependent variable. Based on the previous research mentioned before (see, for instance [4,31,45]), several research hypotheses for factors conditioning sustainable water use were identified. The linear multiple regression model expressing the relationship between the explanatory variables and water use sustainability is presented in the following equation:

$$Y = \beta_0 + \beta_1(X_1) + \beta_2(X_2) + \beta_3(X_3) + \beta_4(X_4) + \beta_5(X_5) + \beta_6(X_6) + \beta_7(X_7) + \varepsilon \quad (1)$$

where Y is the domestic water consumption per inhabitant. The remaining variables on the right-hand side of the equation are the explanatory variables, which include: X_1 —number of hotel stays for measuring the level of tourism activity; X_2 —urban areas; X_3 —purchasing power for measuring the income level; X_4 —area of irrigated green spaces; X_5 —percentage of population aged 14 years or less for assessing the young age population groups; X_6 —number of inhabitants with superior education; and X_7 —size of the household.

Traditional regression models (OLS) determine a stationary relationship between dependent and independent variables across the study area, without considering spatial heterogeneity, and disregarding space [14,45]. However, the geographically weighted regression (GWR) method accommodates spatial non-stationarity by estimating location-specific parameters, thereby capturing the varying relationships between variables across the study area [13,14,46]. The GWR model is calculated as follows [13,14,46]:

$$Y_i = \beta_{0i} + \sum_{n=1}^k \beta_{ni}(u_i, v_i)x_{ni} + \epsilon_i \quad (2)$$

where Y_i is the domestic water consumption at municipality i , (u_i, v_i) represent the coordinates of the centroid of municipality i , β_{0i} , β_{ni} indicates the local estimated intercept and effect of variable n for municipality i , respectively, x_{ni} refers to the values of the i th explanatory variable while ϵ_i denotes a random error term.

3. Results

The descriptive statistics are presented in Table 3. The endogenous variable, Average Domestic Water Consumption (ADH), exhibits a median value of 56.35 m³ and a mean

value of 60.0 m³ with a standard deviation of 27.1 m³, reflecting a notable dispersion in household water demand. The substantial range between the minimum (14.8 m³) and maximum (214.0 m³) values underscores the existence of extreme outliers and suggests that domestic consumption patterns are subject to strong local determinants, like different socioeconomic and climatic conditions across Portuguese territory. Regarding the explanatory variables, the highest average scores are related to the urban area (AURB), population with superior education (PENSUP), and number of overnight stays by tourists (DOR). The lowest minimum values are registered by urban green spaces (ESP VERD) and overnight stays by tourists (DOR). Among the explanatory variables, the highest median values are observed in the number of overnight stays by tourists (DOR) at 23,091.5, followed by the population with higher education (PENSUP) at 1284.0, and urban area (AURB) at 742.5. The high standard deviations of several variables—DOR, AURB, PENSUP, and ESP VERD—highlights the presence of extreme upper outliers.

Table 3. Descriptive statistics of items.

Variable	N	Average	Median	Std. Deviation	Minimum	Maximum
ADH	278	60	56.35	27.1	14.8	214
PCOMP	278	79.78	75.68	19.42	54.00	217.02
POP014	278	12.4	12.44334	2.3	5.6	18
AURB	278	1424.4	742.5347	6032	40.3	100,162.3
ESP VERD	278	12.3	3.443	26.8	0	332.2
PENSUP	278	5245.6	1284	13,574.4	98	173,361
AREA200m	278	1219.5	596.5	1599.1	54	9187
DOR	278	167,255.7	23,091.5	805,947.9	0	10,134,789.7

Note: ADH—water consumption; PCOMP—purchasing power; POP014—population age; AURB—urban areas; ESP_VERD—green urban spaces; DOR—touristic population; PENSUP—education; AREA200m—habitation conditions.

Table 4 outlines the skewness and kurtosis descriptive statistics and allow the evaluation of the normality of the distribution. Following established statistical thresholds, skewness coefficients within the [−1, +1] interval reflect optimal alignment with univariate normality, while values within [−2, +2] are generally deemed acceptable. Conversely, absolute values exceeding 2 indicate severe deviations from normality, signifying substantial non-normality [47]. In this case, all the variables, but the population age (POP014), present skewness values higher than 2. Regarding kurtosis, the same can be verified.

Table 4. Statistics on skewness and kurtosis of major variables.

Variable/Item	N	Skewness		Kurtosis	
		Statistic	Std. Error	Statistic	Std. Error
ADH	278	2.442	0.146	9.171	0.291
POP014	278	−0.200	0.146	−0.222	0.291
PCOMP	278	2.320	0.146	10.555	0.291
AURB	278	15.953	0.146	261.826	0.291
ESP VERD	278	7.045	0.146	74.140	0.291
DOR	278	9.888	0.146	108.893	0.291
AREA200m	278	2.641	0.146	7.723	0.291
PENSUP	278	7.963	0.146	87.324	0.291

Note: ADH—water consumption; PCOMP—purchasing power; POP014—population age; AURB—urban areas; ESP_VERD—green urban spaces; DOR—touristic population; PENSUP—education; AREA200m—habitation conditions.

To determine the magnitude and direction (positive or negative) of the linear associations between the primary variables, a Pearson bivariate correlation analysis was conducted and the resulting correlation matrix is detailed in Table 5. The water distributed by inhabitant (ADH) presents a correlation of 0.52 with the number of overnight stays by tourists (DOR), and the p -value is always less than 0.01 ($p < 0.01$). Regarding the correlations among independent variables, the values range from 0.519 to 0.731. The highest values are recorded among AREA200m and PENSUP, and between POP_ENS_SUP and PCOMP.

Table 5. Correlation matrix of variables.

Variable	1	2	3	4	5	6	7	8
1. ADH	1.000							
2. PCOMP	0.316 **	1.000						
3. POP014	0.047	0.543 **	1.000					
4. AURB	0.011	0.109	0.095	1.000				
5. ESP VERD	0.292 **	0.267 **	0.121 *	0.073	1.000			
6. DOR	0.522 **	0.519 **	0.207 **	0.051	0.182 **	1.000		
7. PENSUP	0.201 **	0.723 **	0.325 **	0.088	0.176 **	0.684 **	1.000	
8. AREA200m	−0.040	0.595 **	0.451 **	0.166 **	0.218 **	0.343 **	0.731 **	1.000

Note: ** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level. ADH—water consumption; PCOMP—purchasing power; POP014—population age; AURB—urban areas; ESP_VERD—green urban spaces; DOR—touristic population; PENSUP—education; AREA200m—habitation conditions.

The regression model serves to quantify the explanatory power of independent variables. Prior to evaluating the regression coefficients, it is imperative to validate the fundamental assumptions of linear regression, specifically linearity, homoscedasticity, and multicollinearity. These diagnostic assumptions pertain to the variables individually and to the structural relationship as a whole [40,41,47,48].

Multicollinearity manifests within a regression model when explanatory variables exhibit strong intercorrelations. Under these conditions, model interpretation becomes ambiguous and statistically unreliable, as isolating the unique effect of each independent variable on the dependent variable becomes problematic. Optimally, explanatory variables remain orthogonal, thereby facilitating valid statistical inference and parameter estimation. Although examining bivariate correlations offers an intuitive diagnostic approach, academic literature establishes no definitive correlation threshold for identifying collinearity [41].

The collinearity diagnostics presented in Table 6 indicate the absence of multicollinearity. The observed tolerance values range from 0.201 to 0.966, remaining well above the critical threshold of 0.1 [49]. The maximum condition index is 17.682, which is safely below the established threshold of 30 [49]. Additionally, the eigenvalues do not approach zero, and the Variance Inflation Factors (VIF) do not exceed 5 [40], confirming the model is free from multicollinearity distortions.

Homoscedasticity mandates that the variance of the dependent variable remains constant across all levels of the independent variables. While the normality of residuals may be evaluated graphically, validating residual independence is imperative. Table 7 displays the Durbin–Watson statistic utilized. The obtained value (1.944) exceeds the upper critical threshold; pursuant to the established decision rule [40], the null hypothesis of correlated errors is rejected, confirming residual independence and the absence of autocorrelation. Because the diagnostic assumptions regarding multicollinearity, homoscedasticity, linearity, and residual independence are satisfied, the linear regression model is appropriate for inferring relationships between the explanatory and dependent variables. Table 7 outlines

the goodness-of-fit metrics: R , R^2 , adjusted R^2 , and the standard error of the estimate. The R^2 and adjusted R^2 values of 0.435 and 0.420, respectively, indicate that approximately 42% of the variance in domestic water consumption is accounted for by the explanatory variables. These metrics suggest the model exhibits moderate predictive limitations regarding domestic water consumption. The Akaike Information Criterion (AIC) is 2519.267.

Table 6. Collinearity statistics.

Model	Eigenvalue	Condition Index	Tolerance	VIF
POP014	4.390	1.000	0.626	1.598
AURB	1.341	1.809	0.966	1.035
ESP VERD	0.916	2.190	0.898	1.113
AREA200m	0.733	2.448	0.355	2.816
PCOMP	0.471	3.052	0.355	2.816
DOR	0.121	6.016	0.465	2.150
PENSUP	0.014	17.682	0.201	4.975

Note: PCOMP—purchasing power; POP014—population age; AURB—urban areas; ESP_VERD—green urban spaces; DOR—touristic population; PENSUP—education; AREA200m—habitation conditions.

Table 7. Model summary indicators.

R	R^2	Adjusted R^2	Standard Error	Durbin–Watson
0.659	0.435	0.42	20.635	1.944

One crucial aspect is the results obtained and the validity of the model when compared to previous research, in similar cases. Villar-Navascués, and Pérez-Morales [4] obtained 72.62% of the explained variance in the OLS model for Spain (which analyzed a more limited number of 99 municipalities). De la Cruz et al. [12], on a set of 403 households, obtained 31.6% of the explained variance in water consumption. Our results are in line with these, as the OLS model explains 42% of the variance in domestic water consumption in 278 municipalities, which presents considerable geographical heterogeneity.

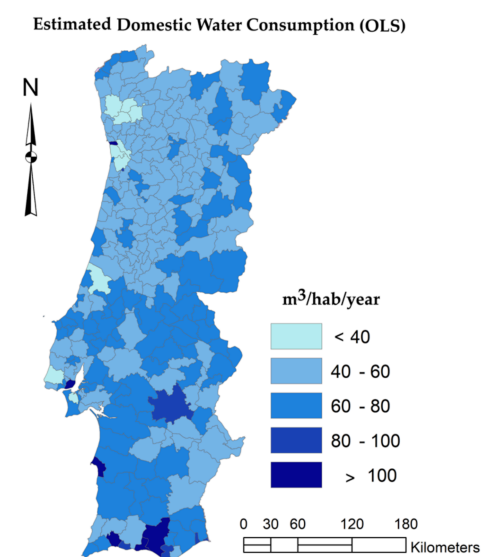
The analysis of variance (ANOVA) for the regression model indicates an F-statistic of 29.689 with 277 degrees of freedom, demonstrating that the overall regression model is statistically significant at the 0.01 level ($p < 0.01$). Consequently, the null hypothesis is rejected, confirming that the regression coefficients are collectively distinct from zero and that the independent variables reliably predict the outcome.

The regression coefficients and the results of hypothesis testing are presented in Table 8, while the estimated domestic water consumption distribution is presented in Figure 3. These results show that the number of overnight stays by tourists (DOR—Touristic population) has a significant and positive effect on domestic water consumption at the 0.01 significance level with a t-statistic of 9.050 and $p = 0.000$ ($p < 0.01$). This empirical evidence allows us to accept Hypothesis 1, which states that there is a positive relationship between tourism activity and water consumption. The standardized regression coefficient is 0.607, meaning that an increase of 100% in the explanatory variable results in an increase of 60.7% in the outcome variable.

Table 8. Regression coefficients.

Model	Non-Standardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
Constant	35.525	8.292		4.284	0.000
POP014	−1.049	0.677	−0.090	−1.549	0.123
AURB	0.000	0.000	0.002	0.051	0.960
ESP VERD	0.205	0.049	0.203	4.206	0.000
AREA200m	−0.004	0.001	−0.248	−3.228	0.001
PCOMP	0.499	0.107	0.358	4.667	0.000
DOR	0.000	0.000	0.607	9.050	0.000
PENSUP	−0.001	0.000	−0.299	−2.930	0.004

Note: PCOMP—purchasing power; POP014—population age; AURB—urban areas; ESP_VERD—green urban spaces; DOR—touristic population; PENSUP—education; AREA200m—habitation conditions.

**Figure 3.** Estimated domestic water consumption per inhabitant (OLS).

The statistical tests show that despite the effect of urban areas (AURB—Urban areas), it is not significant since the t-statistic is 0.051 and $p = 0.960$ ($p > 0.05$). In this case, Hypothesis 2, which states that there is a positive relationship between urban areas and domestic consumption, is rejected. Therefore, the size of the urban area is not relevant to the increase in domestic water consumption, which leads us to consider the characteristics of such areas.

The statistical tests show that the effect of purchasing power (PCOMP—purchasing power) is significant since the t-statistic is 4.667 and $p = 0.000$ ($p < 0.01$). Therefore, we may accept Hypothesis 3—there is a positive relationship between the level of income and domestic water consumption. The standardized regression coefficient is 0.358, meaning that an increase of 100% in the explanatory variable results in an increase of 35.8% in the outcome variable.

These results show that the green urban spaces (ESP_VERD—Green urban spaces) have a significant and positive effect on domestic water consumption at the 0.01 significance level with a t-statistic of 4.206 and $p = 0.000$ ($p < 0.01$). This empirical evidence allows us to accept Hypothesis 4, which states that there is a positive relation between irrigated green spaces and domestic water consumption. The standardized regression coefficient is 0.203, meaning that an increase of 100% in the explanatory variable results in an increase of 20.3% in the outcome variable.

The results reveal that young age population groups (POP014–Population age) do not have a negative effect on domestic water consumption at the 0.01 significance level, with a t-statistic of -1.549 and $p = 0.123$ ($p > 0.05$). Therefore, there is no empirical evidence to accept or reject Hypothesis 5, which states that there is a positive relationship between young age population groups and domestic water consumption.

The results reveal that the population with higher education (PENSUP–Education) has a negative effect on domestic water consumption at the 0.01 significance level, with a t-statistic of -2.930 and $p = 0.004$ ($p < 0.01$). Therefore, there is empirical evidence to accept Hypothesis 6, which states that there is a negative relationship between education level and domestic water consumption. The standardized regression coefficient is -0.299 , meaning that an increase of 100% in the explanatory variable results in an increase of -29.9% in the outcome variable.

The results reveal that the size of the household (habitation conditions, AREA200m) has a negative effect on domestic water consumption at the 0.01 significance level, with a t-statistic of -3.228 and $p = 0.001$ ($p < 0.01$). Therefore, there is empirical evidence to reject Hypothesis 7, which states that there is a positive relationship between the size of the household and domestic water consumption. The standardized regression coefficient is -0.248 , meaning that an increase of 100% in the explanatory variable results in an increase of -24.8% in the outcome variable.

Table 9 shows global Moran's I results indicating significant spatial autocorrelation among model residuals ($Z = 8.228$, $p < 0.01$), which suggests a Geographical Weighted Regression would improve outcomes. Additionally, all independent variables—except urban areas (AURB) and green spaces (ESP_VERD)—demonstrate statistically significant clustering ($p < 0.01$).

Table 9. Moran's I index for independent variables and residuals.

Variable	Moran's I	Expected Index	Z Score	p Value
POP014	0.580	-0.004	15.467	0.000
AURB	0.003	-0.004	0.704	0.481
ESP VERD	0.015	-0.004	0.560	0.576
AREA200m	0.486	-0.004	13.155	0.000
PCOMP	0.412	-0.004	11.232	0.000
DOR	0.097	-0.004	3.394	0.001
PENSUP	0.429	-0.004	13.841	0.000
Model's residuals	0.229	-0.004	8.228	0.000

Note: PCOMP—purchasing power; POP014—population age; AURB—urban areas; ESP_VERD—green urban spaces; DOR—touristic population; PENSUP—education; AREA200m—habitation conditions.

To capture the spatial variation in each predictor's influence, the geographically weighted regression (GWR) model allows the coefficients to vary across municipalities based on the local values of both dependent and independent variables [4,50]. The results of the GWR model are summarized in Table 10. The model achieved an Akaike Information Criterion (AIC) of 2403.650, an R^2 of 0.700, and an adjusted R^2 of 0.646. With a residual sum of squares (RSS) of 62,552.5, these diagnostics demonstrate a clear improvement in model performance over the ordinary least squares (OLS) approach. Compared with the study of Villar-Navascués and Pérez-Morales [4], the GWR results are lower as the authors obtained 88.7% of the explained variance. Nevertheless, we must highlight that their model was limited to a set of 99 coastal Spanish municipalities with a relative homogeneity.

Table 10. Summary results of the Geographical Weighted Regression model.

Indicator	Bandwidth	Residual Squares	Effective Number	Sigma	AICc	R ²	R ² Adjusted
Results	89,799.984	62,552.513	43.577	16.198	2403.65	0.700	0.646

Figure 4 displays the distribution of estimates and standard residuals. Moran's I for the residuals dropped to 0.0448 ($p = 0.09$), reflecting a substantial reduction in spatial autocorrelation. Because this result is not statistically significant ($p > 0.05$), it demonstrates that the GWR model successfully captured spatial patterns that a global model missed.

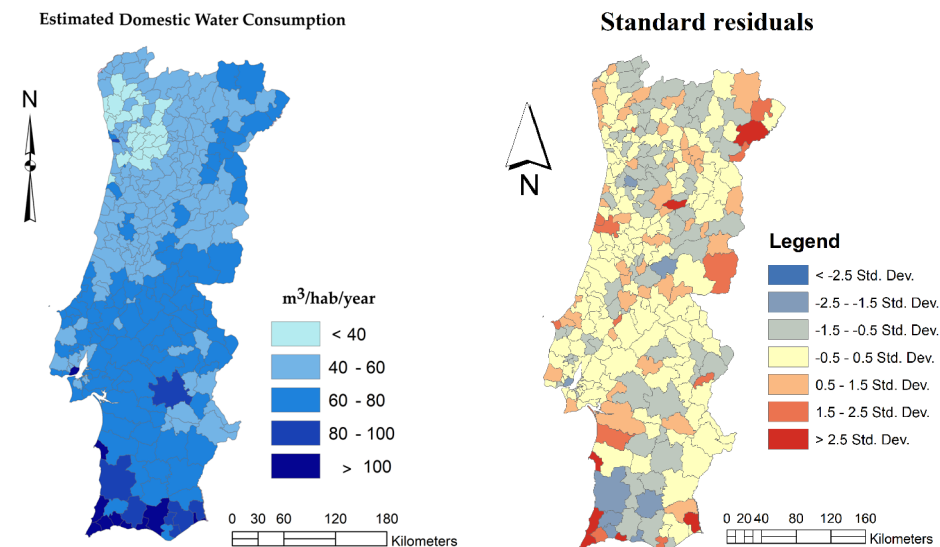
**Figure 4.** The estimated domestic water consumption per inhabitant and the distribution of the standard residuals (GWR).

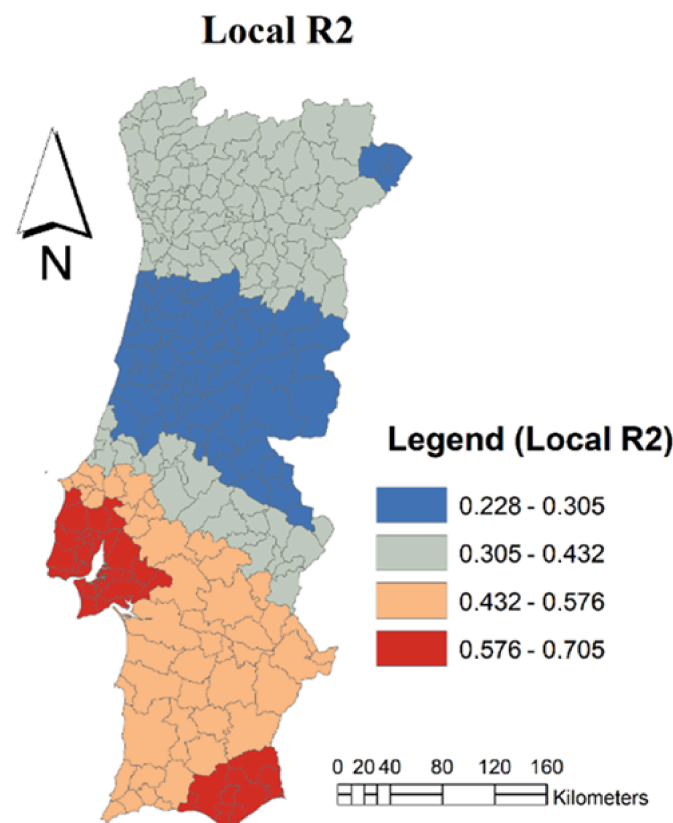
Table 11 presents the coefficients of the GWR. The median values for the regression coefficients of the independent variables differ between both models. The highest positive regression coefficients are of purchasing power (PCOMP) and of urban green spaces (ESP_VER). The wide range between the minimum and maximum values for parameters like the Intercept (12.94 to 76.36) and POP014 (−4.09 to 14.50) confirms that a “one-size-fits-all” global coefficient would be misleading for local policy. Therefore, we may identify some main drivers of water consumption. The first is purchasing power (PCOMP), which is the main primary positive driver, meaning higher wealth generally correlates with higher water use (Median = 0.416). The other is urban green spaces (ESP_VER): Green spaces are (Median = 0.187) likely due to the irrigation requirements of urban vegetation. On the other hand, the factor of youth population (POP014) has a negative influence, meaning that a higher percentage of the population aged 0–14 is associated with lower water consumption in most regions (Median = −2.445).

The distribution of the local R² is presented in Figure 5. The model predicts water consumption best (highest R²) in water-scarce areas like Lisbon, Setubal, and the eastern Algarve, where usage closely aligns with socioeconomic variables like tourism and wealth. Conversely, Central Portugal exhibits the lowest R² values, indicating that additional, unmodeled factors influence water consumption in that region.

Table 11. Results of the geographically weighted regression model—regression coefficients.

Parameter	Minimum	First Quarter	Median	Third Quarter	Maximum
Intercept	12.93789	48.16849	52.47982	55.92080	76.3565
PCOMP	−1.13256	0.37394	0.41607	0.47482	0.5926
POP014	−4.08946	−2.93530	−2.44488	−1.57212	14.4975
AURB	−0.00438	−0.00010	0.00006	0.00040	0.0155
ESP_VER	−0.03898	0.09338	0.18743	0.24597	0.4798
DOR	−0.00006	−0.00001	0.00000	0.00002	0.0000
PENSUP	−0.00101	−0.00027	0.00051	0.00107	0.0036
AREA200m	−0.05083	−0.00638	−0.00522	−0.00252	0.0021

Note: PCOMP—purchasing power; POP014—population age; AURB—urban areas; ESP_VER—urban green spaces; DOR—touristic population; PENSUP—education; AREA200m—habitation conditions.

**Figure 5.** Distribution of the local R².

Finally, examples of the spatial distribution of the individual coefficients are also presented for each variable explaining domestic water consumption in Figure 6, while the pseudo *t* values are presented in Figure 7. If pseudo $t \leq -1.96$ or $t \geq 1.96$ the results are statistically significant if $p \leq 0.05$. A positive result indicates that as the independent variable increases, the dependent variable significantly increases, while the negative one is the inverse. A brief analysis is presented as follows for the statistical significance results.

Regarding purchasing power (PCOMP), this indicator is positively related to water consumption across a considerable number of municipalities in northern, central, and southern Portugal, suggesting that improvements in purchasing power lead to lifestyle changes and higher water consumption. However, in some municipalities within the Algarve, PCOMP is negatively related to water consumption. This can be explained by distinct consumption habits in an area characterized by substantial purchasing power where basic needs are already fulfilled, alongside a considerable proportion of foreign

residents. Furthermore, this region faces critical water availability challenges, which may foster greater environmental context and awareness.

For urban areas (AURB), the statistically significant positive results in the Algarve demonstrate that these urban zones possess water-intensive characteristics. These include extensive green spaces, public swimming pools, a high concentration of tourism activities with heavy water requirements, specific residential traits, and localized economic activities. Similarly, urban green spaces (ESP_VER) display a statistically significant positive relationship in southern Portugal, as well as in parts of the center and north. This validates the research hypothesis across most of the Portuguese territory: there is a positive relationship between irrigated green spaces and domestic water consumption. This effect is particularly remarkable in the south, where the climate features prolonged dry periods.

Regarding tourism (DOR), it impacts Portugal's domestic water consumption differently depending on the region. In southern areas like the Algarve and Alentejo, tourism increases municipal water use. Because per capita metrics only count permanent residents, the uncounted seasonal visitors and second homes cause significant, unmeasured consumption spikes. Conversely, tourism negatively correlates with municipal water consumption in the northeast. This area enjoys better natural water availability, and its traditional accommodations lack water-intensive infrastructure—often relying on private water sources instead. Coupled with much lower and steadier tourist volumes, the regression model assigns tourism a negative weight for municipal water demand in this region.

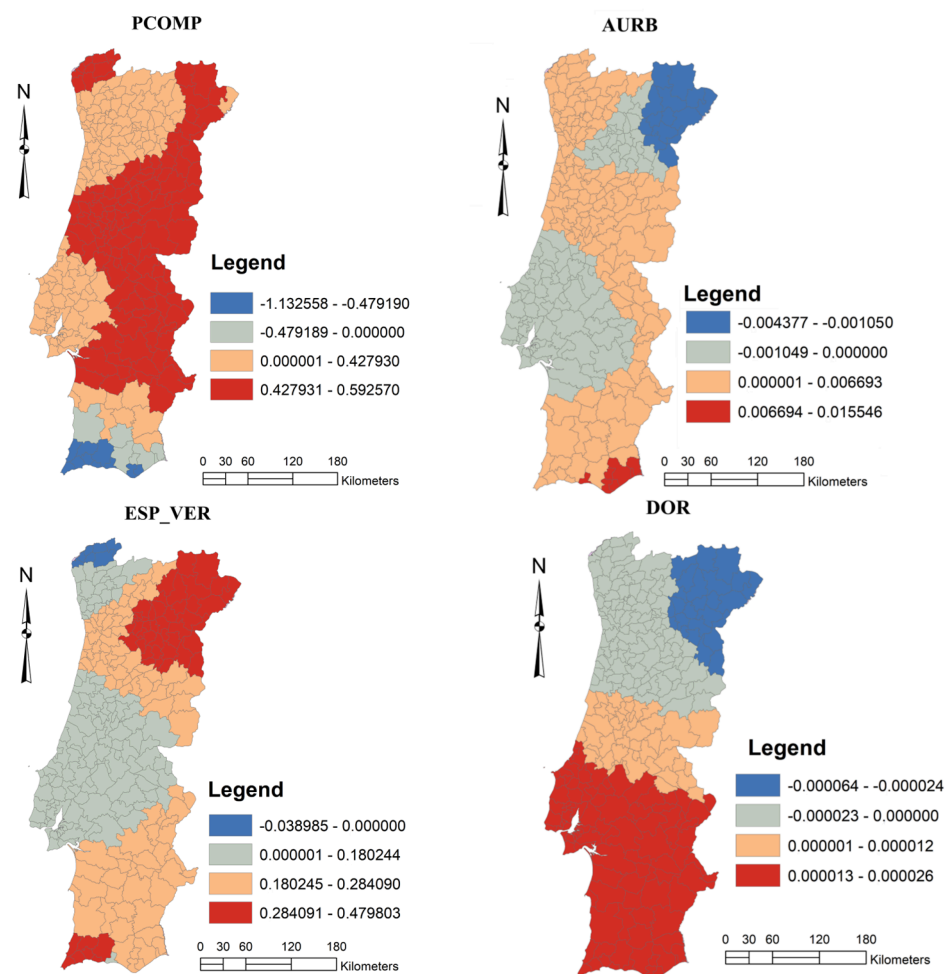


Figure 6. The GWR explaining variable coefficients.

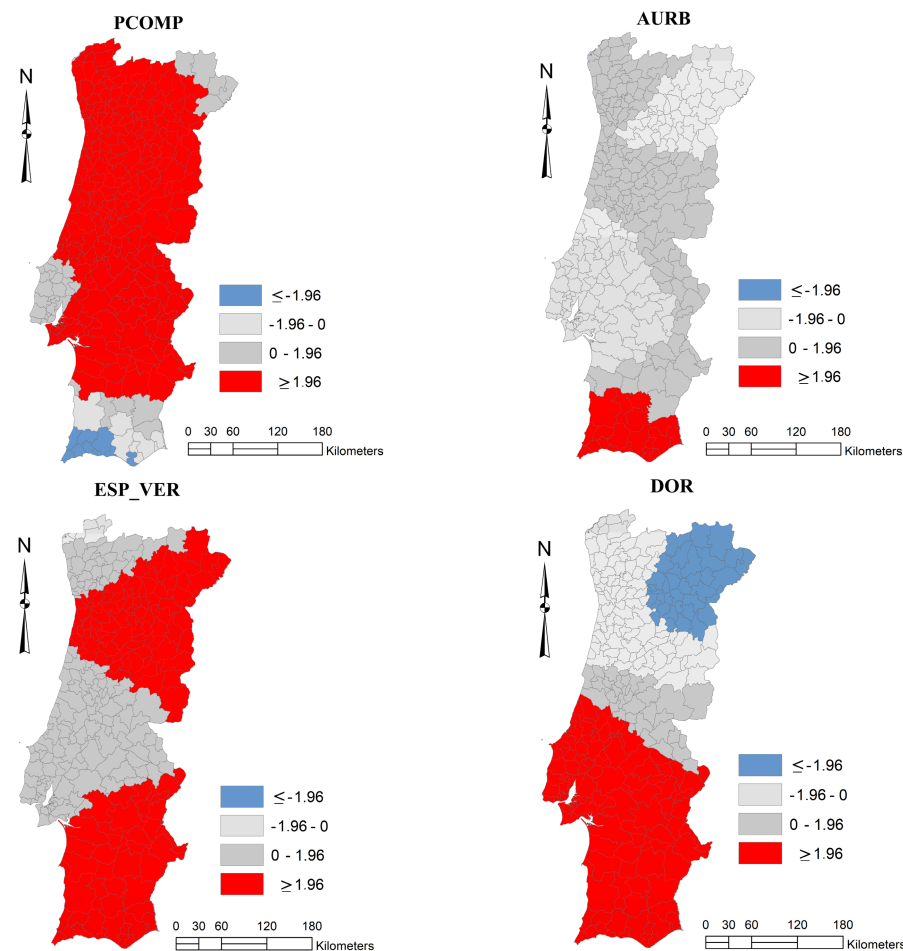


Figure 7. The pseudo t-values.

4. Discussion

Historically, the specification of price in residential water demand estimation has been a subject of debate. An early study by Taylor [51] argues that consumers respond to the marginal price corresponding to their current level of consumption. Conversely, Shin [52] provides empirical evidence favoring an average price specification. For Portugal, we identified the main factors explaining domestic water consumption.

Our static model relies on annual aggregate data. Per capita water distribution is calculated relative to the *de jure* (permanent) population. While this approach omits intra-annual seasonal population fluctuations—potentially confounding initial observations in tourist-heavy regions—the model inherently accounts for specific localized dynamics.

Notably, a significant portion of permanent residents lease secondary residences or rooms during peak seasons. This is underscored by Portugal's short-term rental market, which features over 124,000 predominantly privately owned registered properties.

Consequently, while the model does not explicitly capture temporal seasonality, it isolates tourism-induced impacts on the dependent variable via the proxy “Tourist population” (quantified as total annual overnight stays). Therefore, these results show that the number of overnight stays by tourists has a significant and positive effect on domestic water consumption. This is especially true in the municipalities located in the littoral areas and in the south in the Algarve Region. Therefore, several strategies and public policies area need to overcome this high consumption, which has fluctuations. Urban green spaces also have a significant and positive effect on water demand; municipalities with a larger number of green spaces will tend to have higher water consumption.

The geographically weighted regression (GWR) model reveals that in a considerable number of municipalities, income is positively related to domestic water consumption. This finding aligns with previous studies [7,8,27,53]. Income influences water consumption both directly, by determining a household's purchasing power, and indirectly, by serving as a proxy for overall population wealth.

However, as [4] also verified, this variable is negatively related to consumption in several municipalities, mainly in the Algarve region, which is a region with an average purchasing power of 97.6% and therefore very close to the national average. These results contradict the ones presented by [4], which identified that this situation occurred in municipalities with a lower level of income and may be related to water consumption habits, and show environmental context and awareness of the population.

Regarding the geographically weighted regression (GWR) model, it is critical to emphasize that the extensive presence of urban green spaces—often associated with higher purchasing power—significantly drives domestic water consumption. Furthermore, the prevalence of second homes artificially inflates per capita domestic water consumption. Because data limitations prevented the inclusion of seasonal populations in the per capita calculations, the apparent water use per person is skewed upward in municipalities with a high concentration of secondary residences. Ultimately, these dynamics underscore how geographical factors influence the regression coefficients, variations in local parameters, and the overall impact of different consumption drivers.

The education of the population will result in a reduction in water consumption. It was shown that the population with superior education will contribute negatively to domestic water consumption. The relationship between attitudinal characteristics, environmental concerns, and water consumption carries significant policy relevance, particularly as public awareness campaigns frequently aim to curb demand by fostering conservationist attitudes [9]. Consequently, the precise mechanisms through which these behavioral and psychological factors influence consumption patterns warrant further empirical investigation.

Some areas of the south, such as the Algarve shifted from a state of “unprecedented drought” to a “managed recovery” in recent time, but need to carefully account for the main factors identified. This will contribute to a more resilient territory and to achieve a more sustainable consumption, as our model suggests several relevant socioeconomic factors that, in areas of scarcity, are determinants for domestic water consumption.

The strategy to reduce water consumption should not be national. Instead, it should focus on purchasing power and green area management in the south, while investigating the “missing variables” that are driving consumption in the center. Purchasing power (PCOMP): This is a primary positive driver, meaning higher wealth generally correlates with higher water use (Median = 0.416). Urban green spaces (ESP_VER): Green spaces also drive consumption significantly (Median = 0.187), likely due to the irrigation requirements of urban vegetation. Youth population (POP014): Interestingly, a higher percentage of the population aged 0–14 is associated with lower water consumption in most regions (Median = −2.445).

Finally, regarding policy, National Water Plan (PNA) is the main strategic tool for water resource management in Portugal. It establishes the core guidelines of national water policy, ensuring both the quality and availability of this vital resource. The plan aims to balance public supply, agriculture, and industry demands with environmental sustainability. Furthermore, it outlines crucial measures to mitigate extreme events, such as droughts and floods, in the face of climate change. But as already pointed out [4], the future reduction in water resources because of climate change implies several measures, limited by public administrations due to budget, mainly as regards construction engineering solutions; individual measures to reduce consumption imply lower costs and efficiency.

Our approach provides information on the main factors that condition water consumption. The article provides an econometric and geographically weighted regression (GWR) framework that acts as a vital tool for policy design by mapping out the specific local drivers of domestic water consumption across all 278 municipalities in continental Portugal. This study proves that water reduction strategies should not be uniform at a national level; instead, it highlights the need for regional tailoring. Therefore, the article establishes a solid empirical foundation for designing targeted, climate-resilient water conservation policies. Regarding the water supply system in Portugal, it is divided as the bulk system supplies water to the retail distribution network which delivers it directly to end consumers. The aspects of these recommendations will provide new insights for managing these two parts of the supply system in a more integrated way.

5. Concluding Remarks

This article tried to understand the joint influence of a set of urban, sociodemographic, and socioeconomic factors on domestic water consumption in continental Portugal. We found that factors like tourism (measured by the number of overnight stays by tourists), purchasing power, and urban green spaces have a relevant importance for domestic water consumption. The education (measured by the number of inhabitants with superior education) has a negative role in consumption. Also, the household area seems to have a negative effect, which leads to the necessity of considering not only the area, but also the characteristics. Also, it is relevant to consider the spatial context as the importance of the explaining factors will be different across the territory. Spatial regression models are therefore a useful tool, as they allow us to identify local dynamics and develop locally tailored strategies using the factors identified as a basis.

These findings have a set of practical implications, namely for water management in urban areas.

Nevertheless, this study had several limitations. The first one was the data used. This was limited to a restrictive number of variables due to the statistical data availability in the sources. The lack of data was a direct consequence of the fragmented nature of localized environmental and socioeconomic databases, which often lack the longitudinal depth necessary for a more expansive multivariate analysis. Besides this fact, there was some missing data which had to be complemented with local calculus. While these remedial measures were essential to maintain the structural continuity of the dataset, they introduce a layer of estimated values that must be considered when interpreting the fine-grained local coefficients. These limitations underscore the ongoing need for more robust, harmonized, and high-resolution spatial data infrastructures to support increasingly complex urban metabolism and water resource modeling.

The findings of this study open up a promising set of new research tools. One critical avenue for subsequent research involves the typological stratification of municipalities through the implementation of advanced cluster analysis (e.g., K-means or Hierarchical Clustering). By segmenting territorial units into specific profiles based on shared socioeconomic, climatic, and infrastructural characteristics, researchers can move beyond general spatial trends to identify localized behavioral patterns in domestic water consumption. This approach would allow for a more granular understanding of how consumption “regimes” differ between highly densified metropolitan hubs, tourism-dependent coastal regions, and agrarian rural landscapes. Another promising area of research will be to try to identify other relevant factors that may arise. Future models could benefit from incorporating high-resolution datasets related to micro-climatic variables or water pricing. Including these and other factors would allow the inclusion of these indicators, which would enhance the model’s sensitivity to the nuanced drivers of water demand, providing

a more comprehensive evidence base for the design of targeted, climate-resilient water conservation policies.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/w18151829/s1>.

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References

1. Makki, A.A.; Stewart, R.A.; Panuwatwanich, K.; Beal, C. Revealing the determinants of shower water end use consumption: Enabling better targeted urban water conservation strategies. *J. Clean. Prod.* **2013**, *60*, 129–146. [\[CrossRef\]](#)
2. Dias, F.; Correia, C. *O Uso Da Água Em Portugal Olhar, Compreender e Actuar Com os Protagonistas Chave*; Fundação Calouste Gulbenkian: Lisbon, Portugal, 2020.
3. Silva, C. O Abastecimento Público de Água na Região do Algarve: Caracterização e Perspetivas de Evolução. Master's Thesis, Universidade do Porto, Porto, Portugal, 2009.
4. Villar-Navascués, R.A.; Pérez-Morales, A. Factors Affecting Domestic Water Consumption on the Spanish Mediterranean Coastline. *Prof. Geogr.* **2018**, *70*, 513–525. [\[CrossRef\]](#)
5. Bich-Ngoc, N.; Teller, J. A review of residential water consumption determinants. In *International Conference on Computational Science and Its Applications*; Springer: Cham, Switzerland, 2018; pp. 685–696.
6. Mayer, P.W.; DeOreo, W.B. *Residential End Uses of Water*; Aquacraft, Inc. Water Engineering and Management: Boulder, CO, USA, 1999.
7. Mazzanti, M.; Montini, A. The determinants of residential water demand: Empirical evidence for a panel of Italian municipalities. *Appl. Econ. Lett.* **2006**, *13*, 107–111. [\[CrossRef\]](#)
8. Schleich, J.; Hillenbrand, T. Determinants of residential water demand in Germany. *Ecol. Econ.* **2009**, *68*, 1756–1769. [\[CrossRef\]](#)
9. Grafton, R.Q.; Ward, M.B.; To, H.; Kompas, T. Determinants of residential water consumption: Evidence and analysis from a 10-country household survey. *Water Resour. Res.* **2011**, *47*, W08537. [\[CrossRef\]](#)
10. Fan, L.; Gai, L.; Tong, Y.; Li, R. Urban water consumption and its influencing factors in China: Evidence from 286 cities. *J. Clean. Prod.* **2017**, *166*, 124–133. [\[CrossRef\]](#)
11. Romano, G.; Salvati, N.; Guerrini, A. An empirical analysis of the determinants of water demand in Italy. *J. Clean. Prod.* **2016**, *130*, 74–81. [\[CrossRef\]](#)
12. de la Cruz, A.O.; Alvarez-Chavez, C.R.; Ramos-Corella, M.A.; Soto-Hernandez, F. Determinants of domestic water consumption in Hermosillo, Sonora, Mexico. *J. Clean. Prod.* **2017**, *142*, 1901–1910. [\[CrossRef\]](#)
13. Charlton, M.; Fotheringham, S.; Brunson, C. *Geographically Weighted Regression*; White paper; National University of Ireland Maynooth: County Kildare, Ireland, 2009.
14. Mansour, S.; Al Kindi, A.; Al-Said, A.; Al-Said, A.; Atkinson, P. Sociodemographic determinants of COVID-19 incidence rates in Oman: Geospatial modelling using multiscale geographically weighted regression (MGWR). *Sustain. Cities Soc.* **2021**, *65*, 102627. [\[CrossRef\]](#) [\[PubMed\]](#)
15. House-Peters, L.A.; Chang, H. Urban water demand modeling: Review of concepts, methods, and organizing principles. *Water Resour. Res.* **2011**, *47*, W05401. [\[CrossRef\]](#)

16. Barreira, A.P.; Andraz, J. Water demand of urban Portuguese households by population trajectory and region. *Eur. Plan. Stud.* **2026**, *34*, 63–83. [\[CrossRef\]](#)
17. Arbués, F.M.; García-Valiñas, A.; Martínez-Espiñeira, R. Estimation of residential water demand: A state-of-the-art review. *J. Socio-Econ.* **2003**, *32*, 81–102. [\[CrossRef\]](#)
18. Worthington, A.C.; Hoffman, M. An empirical survey of residential water demand modelling. *J. Econ. Surv.* **2008**, *22*, 842–871. [\[CrossRef\]](#)
19. Syme, G.J.; Shao, Q.; Po, M.; Campbell, E. Predicting and understanding home garden water use. *Landsc. Urban Plan.* **2004**, *68*, 121–128. [\[CrossRef\]](#)
20. Fox, C.; McIntosh, B.S.; Jeffrey, P. Classifying households for water demand forecasting using physical property characteristics. *Land Use Policy* **2009**, *26*, 558–568. [\[CrossRef\]](#)
21. Wentz, E.A.; Gober, P. Determinants of small-area water consumption for the City of Phoenix, Arizona. *Water Resour. Manag.* **2007**, *21*, 1849–1863. [\[CrossRef\]](#)
22. Garcia, X.; Llauas, A.; Ribas, A. Landscaping patterns and sociodemographic profiles in suburban areas: Implications for water conservation along the Mediterranean coast. *Urban Water J.* **2013**, *11*, 31–41. [\[CrossRef\]](#)
23. Eslamian, S.A.; Li, S.S.; Haghighat, F. A new multiple regression model for predictions of urban water use. *Sustain. Cities Soc.* **2016**, *27*, 419–429. [\[CrossRef\]](#)
24. Martins, R.; Fortunato, A. Residential water demand under block rates—A Portuguese case study. *Water Policy* **2007**, *9*, 217–230. [\[CrossRef\]](#)
25. Matos, C.; Teixeira, C.A.; Bento, R.; Varajão, J.; Bentes, I. An Exploratory Study on the Influence of Socio-Demographic Characteristics on Water End Uses Inside Buildings. *Sci. Total Environ.* **2014**, *466–467*, 467–474. [\[CrossRef\]](#) [\[PubMed\]](#)
26. Cabral, M.; Mamade, A.; Loureiro, D.; Amado, C.; Covas, D. Modeling the Effect of Weather Conditions on Urban Water Demand in Multiple Network Areas: A Practical Approach to Improve Monthly and Seasonal Operation. *J. Water Supply Res. Technol. Aqua* **2016**, *65*, 612–625. [\[CrossRef\]](#)
27. Costa, S.; Meireles, I.; Sousa, V. Understanding residential water demand: Insights from a survey in a Mediterranean city. *Urban Water J.* **2024**, *21*, 521–537. [\[CrossRef\]](#)
28. Barreira, A.; Jacinto, G. Clustered Patterns of Household Water Consumption in Portuguese Municipalities: Do Regional Location and Population Trajectory Matter? *Util. Policy* **2025**, *93*, 101887. [\[CrossRef\]](#)
29. Cordero, J.M.; Pedraja-Chaparro, F.; Pisaflores, E.C.; Polo, C. Efficiency assessment of Portuguese municipalities using a conditional nonparametric approach. *J. Prod. Anal.* **2017**, *48*, 1–24. [\[CrossRef\]](#)
30. Le Lannier, A.; Porcher, S. Efficiency in the public and private French water utilities: Prospects for benchmarking. *Appl. Econ.* **2014**, *46*, 556–572. [\[CrossRef\]](#)
31. Benito, B.; Faura, Ú.; Guillamón, M.D.; Ríos, A.M. The efficiency of public services in small municipalities: The case of drinking water supply. *Cities* **2019**, *93*, 95–103. [\[CrossRef\]](#)
32. March, H.; Sauri, D. The suburbanization of water scarcity in the Barcelona metropolitan region: Sociodemographic and urban changes influencing domestic water consumption. *Prof. Geogr.* **2009**, *62*, 32–45.
33. Domene, E.; Sauri, D. Urbanization and water consumption: Influencing factors in the metropolitan region of Barcelona. *Urban Stud.* **2006**, *43*, 1605–1623. [\[CrossRef\]](#)
34. Gregory, G.D.; Di Leo, M. Repeated behaviour and environmental psychology: The role of personal involvement and habit formation in explaining water consumption. *J. Appl. Soc. Psychol.* **2003**, *33*, 1261–1296. [\[CrossRef\]](#)
35. Kim, S.H.; Choi, S.H.; Koo, J.K.; Choi, S.I.; Hyun, I.H. Trend analysis of domestic water consumption depending upon social, cultural, economic parameters. *Water Sci. Technol. Water Supply* **2007**, *7*, 61–68. [\[CrossRef\]](#)
36. Nauges, C.; Thomas, A. Privately operated water utilities, municipal price negotiation, and estimation of residential water demand: The case of France. *Land Econ.* **2000**, *76*, 68–85. [\[CrossRef\]](#)
37. Murdock, S.H.; Albrecht, D.E.; Hamm, R.R.; Backman, K. Role of sociodemographic characteristics in projections of water use. *J. Water Resour. Plan. Manag.* **1991**, *117*, 235–251. [\[CrossRef\]](#)
38. Vallès-Casas, M.; March, H.; Sauri, D. Examining the Reduction in Potable Water Consumption by Households in Catalonia (Spain): Structural and Contingent Factors. *Appl. Geogr.* **2017**, *87*, 234–244. [\[CrossRef\]](#)
39. Voces, R.; Diaz-Balteiro, L.; Romero, C. Characterization and explanation of the sustainability of the European wood manufacturing industries: A quantitative approach. *Expert Syst. Appl.* **2012**, *39*, 6618–6627. [\[CrossRef\]](#)
40. Marôco, J. *Análise Estatística Com a Utilização Do SPSS*; Sílabo: Lisbon, Portugal, 2003; ISBN 9789726184522.
41. Fragoso, R.; Rocha-Junior, W.; Xavier, A. Determinant factors of entrepreneurial intention among university students in Brazil and Portugal. *J. Small Bus. Entrep.* **2020**, *32*, 33–57.
42. Papadimitriou, F. Artificial intelligence in modelling the complexity of Mediterranean landscape transformations. *Comput. Electron. Agric.* **2012**, *81*, 87–96. [\[CrossRef\]](#)

43. Freitas, M.D.B.C.; Xavier, A.; Fragoso, R.; Antunes, C. A composite indicator to measure sustainable water use in Portugal: A compromise programming approach. *J. Environ. Manag.* **2022**, *311*, 114791. [[CrossRef](#)]
44. Medeiros, C.A. *Geografia de Portugal: Ambiente Natural e Ocupação Humana*; Estampa: Lisbon, Portugal, 2000; ISBN 9789723316094.
45. Da Cruz, N.F.; Marques, R.C. Revisiting the determinants of local government performance. *Omega* **2014**, *44*, 91–103. [[CrossRef](#)]
46. Fotheringham, A.S.; Charlton, M.E.; Brunsdon, C. Geographically weighted regression: A natural evolution of the expansion method for spatial data analysis. *Environ. Plan. A* **1998**, *30*, 1905–1927. [[CrossRef](#)]
47. Hair, J.F.; Hult, G.T.M.; Ringle, C.M.; Sarstedt, M. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, 3rd ed.; Sage: Thousand Oaks, CA, USA, 2022.
48. Wooldridge, J.M. *Introductory Econometrics. A Modern Approach*, 3rd ed.; Thomson South-Western: Mason, OH, USA, 2009.
49. Cooper, D.R.; Schindler, P.S. *Business Research Methods*, 8th ed.; McGrawHill Irwin: Boston, MA, USA, 2006.
50. Kontokosta, C.E.; Jain, R.K. Modeling the determinants of large-scale building water use: Implications for data-driven urban sustainability policy. *Sustain. Cities Soc.* **2015**, *18*, 44–55. [[CrossRef](#)]
51. Howe, C.W.; Linaweaver, F.P. The impact of price on residential water demand and its relation to system design and price structure. *Water Resour. Res.* **1967**, *3*, 13–32. [[CrossRef](#)]
52. Foster, H.S.; Beattie, B.R. On the specification of price in studies of consumer demand under block price scheduling. *Land Econ.* **1981**, *57*, 624–629. [[CrossRef](#)]
53. Romano, G.; Salvati, N.; Guerrini, A. Estimating the Determinants of Residential Water Demand in Italy. *Water* **2014**, *6*, 2929–2945. [[CrossRef](#)]

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